SAFETY IN MINES RESEARCH ADVISORY COMMITTEE

SIMRAC

Final Project Report

Title: THE SAFE USE OF MINE WINDING ROPES

Volume 5: Training Manuals for Incumbent Rope Inspectors

Author/s: E J Wainwright, T C Kuun, M Borello and G F K Hecker

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STUDY GUIDE

FOR

WIRE ROPE INSPECTORS

by

E.J. WAINWRIGHT

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E.J. Wainwright

SUBMITTED TO:

Safety in Mines Research
Advisory Committee
Engineering Advisory Group

E.J. Wainwright

REVIEWED BY:

G.F.K. Hecker

DIVISION OF MATERIALS SCIENCE AND TECHNOLOGY
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PREFACE

This study guide relates to training modules commissioned by a committee constituted by the Chamber of Mines' sub-committee of Consulting Mechanical and Electrical Engineers for investigation into specification and operating parameters for Drum Winders and continued under SIMRAC Project GAP054.

Five Manuals have been completed for this project. They are:-

"The Technology of Wire Rope for Mine Winding" by E.J. Wainwright completed in May 1994 which deals with the design, manufacture and use of wire ropes for the various types of mine winder.

"An Introduction to Mine Winders in South Africa" by E.J. Wainwright completed and circulated for comment in August 1995. Because there is no definitive work on mine winders in general this manual attempts to give a simple explanation of the various winders used in South Africa and a description of the various components. Detailed design information is omitted except for some factors which have a significant effect on wire rope performance.

"Destructive Testing of Wire Ropes" by M. Borello which was completed in July 1992. This module explains the procedure for testing wire rope and gives a comprehensive interpretation for evaluating the test results.

"Practical Aspects of Rope Inspection" by T.C. Kuun completed in January 1996. All aspects of rope inspection are covered, from an evaluation of the most likely areas of rope deterioration to the tools and methods of carrying out the inspection.

"Magnetic Rope Testing Instruments." by T.C. Kuun completed in January 1996. A module on this subject was produced by another author but was rejected on the basis that it needed to be re-written. This new module explains the theory of magnetic testing, describes various systems being used, specifies requirements for suitable instruments and gives guidelines for using them.

In addition this guide gives a list of appropriate regulations applicable to rope inspections and the use of ropes in mining applications. Personal safety and responsibility are stressed.

This guide has been produced by

MINE HOISTING TECHNOLOGY,
A DIVISION OF MATERIALS SCIENCE AND TECHNOLOGY
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FOR
WIRE ROPE INSPECTORS.

1 INTRODUCTION.

The continuing requirement in the South African gold mining industry for hoisting men, material and mineral from ever increasing depths has led to sophisticated winders and the use of the lowest practical design factors for winding ropes.

The safe operation of these winders is vitally important; safeguarding persons who travel in the shafts and maintaining the output from the shaft which ensures the continuing operation of these mines. The component of the winding system which is subjected to the greatest operational wear and fatigue is the winding rope which therefore has a definite operational life. For safe operation the rope must be discarded and replaced before it reaches a dangerous condition. To do this a code of practice is required for guidence and instruction.

A code of practice for the condition assessment of mine winder ropes should at least address the following issues in the order shown:

- Discard criteria
- Condition assessment techniques and procedures
- Equipment specifications
- Selection, training and certification of personnel

Discard criteria and an assessment strategy are defined by the machine component designers, manufacturers and users, as well as by the legislators. Conservatism must prevail where the safety of people or continuity of production is involved. The most important issue for the person involved in condition assessment is the reliability of defect detection and evaluation in terms of the prescribed code. Thorough knowledge and understanding of component behaviour under given service conditions are indispensable to all parties concerned. Reliable feedback is essential for ongoing improvement of the code.

The training of personnel is one of the prime requirements for the safe operation of winder ropes. A series of manuals has been produced to identify important features and to facilitate an understanding of the operation of mine winders as well as to guide inspectors and others in correct procedures.

An objective of this study guide for "wire rope inspectors" is to provide an overview of the training modules and to identify the most important features of winder operation and rope inspection.

2 SYLLABUS.

The sylabus is divided into theoretical and practical parts.

2.1 THEORETICAL

(The examination for a Level 2 student will include Level 1 questions)

Subject	Level 1	Level 2
Legal Knowledge	Procedures in and around the shaft. Responsibility and accountability.	Statutory rope regulations.
Winders	Winder types (e.g. Drum, BMR, Koepe, Stage, ...). Winder components (e.g. sheaves, Blair and Koepe compensators, cheek plates, hawse holes, ...)	Winder performance. Rope deterioration patterns relating to winder type. (i.e. where to look for expected deterioration.)
Rope technology	Rope constructions and terminology. Rope manufacture (including Haggie visit). Installation and maintenance of ropes on winders (basic knowledge). Rope deterioration (basic knowledge).	Deterioration (advanced). Installation and maintenance (advanced). Rope terminations (appropriate terminations and modes of rope and termination deterioration).
Code of Practice	Assessment procedures. Discard criteria (basic) including broken wire counting and distributions. Assessment of combined effects.	Assessment intervals. Discard criteria (including cumulative effects). Record keeping and reporting. Assessment of report on tests done by Level 1 tester.
Instrumentation	Measuring instruments (e.g. diameter tape, lay length rule, straight edge, ...). Calculation of EM trace calibrations.	EM test instruments: Basic understanding, limitations, troubleshooting. Multiplication factor calculations.
Destructive Tests	Familiarity with laboratory testing and test results.	Interpretation of laboratory test results
General	Identify wire failure modes (brittle, fatigue, corrosion) and differentiate between abrasive wear and plastic deformations.	How to test stage ropes, kibble ropes and chairlift ropes.

2.2 PRACTICAL

Subject	Level 1 Rope examination on site	Level 2 Laboratory examination and Rope Assessment
Discard Criteria	Measurement of diameters, lay length etc. Measurement of waves and rope deformation.	Measurement of waves, deformations, identification of broken wires (split, slack, proud ...). Application of all criteria
Preparation for test	History of rope, construction, records of previous tests, examine mine's records.	Perusal of previous tests (including destructive tests) - wire brittleness, nicking, ...
Actual test and inspection.	Application of personal safety. Equipment calibration. EM test. Identification and inspection of anomalies. Sheave groove measurement. Report.	Equipment setup and calibration. EM test. Identification and inspection of anomalies. Evaluation of the rope and recommendations regarding further action by the mine.
Rope technology.	Identification of different rope constructions	Visual inspection of short samples (which are not EM tested).

The laboratory test for level 2 candidates will include an EM test on a rope with known anomalies. The examination will at least cover assessment of broken wires, corrosion, plastic deformation and wear.

3 STUDY TECHNIQUES.

The most important principle in successful study is that one should understand every item. It is not necessary that one should agree with everything that one studies. However with understanding the content becomes clear and easily remembered.

It is the responsibility of the student to gain the necessary understanding. If the written study material is not clear or practical procedures not understood additional guidance must be obtained. This may not always be easy, but for any prescribed course of study there will always be appropriate councillors. If they are not able to help in gaining understanding it is still the student's responsibility to find someone who can give correct explanations. Problems of this nature must be brought to the attention of the relevant authority so that corrective action can be taken with respect to the modules or the prescribed practical aspects of training.

3.1 THEORETICAL KNOWLEDGE.

All the course modules have been prepared to give a clear and overall picture of each subject. For this reason it is important that each module be read completely at the outset. The object of this is to gain an overview of the subject matter so that detailed study gains in relevance. As far as possible a module should be read through in as short a time as practicable. Before attempting detailed study of a particular subject the following three modules should first be read through.

1. An Introduction to Mine Winders in South Africa.
2. The Technology of Wire Rope for Mine Winders.
3. Practical Aspects of Rope Inspection.

The overall view gained from these modules is a sound base on which to build further knowledge of the subject of wire rope inspection and evaluation.

As far as possible the student should follow a systematic and logical path in the detailed study requirements listed in Paragraph 4 of this guide. To a great extent the initial items for study will depend on activities of the student in normal job situations.

Everyone has their own style of study. A well proven approach is as follows:-

> The specific item or items being considered should be carefully read through and a clear understanding of the subject achieved. After a short period of rest the student should then try and paraphrase what he has read and writing it into a note book. Having done this the notes should be compared with the original to confirm correctness of the notes. Having achieved a correct interpretation the student can then proceed to the next item to be studied. It is appropriate to mark off completed topics in the various modules where indicated in the level of knowledge required so that no subject or item is overlooked.

It must be noted that not everything in the various modules is required for study and examination. These items have been included in the modules for general information and to encourage more advanced study or interest.

The preceeding advice does not apply to study of the appropriate laws and government regulations. In the case of the required knowledge an overview can be obtained by firstly reading all the items listed. So much in the regulations is not applicable to hoisting or persons working in and around shafts that it is merely awast of time to read everything contained in the regulations. The items listed are the appropriate ones and must all be known and understood.In many cases the student will find it easier to learn the relevant regulations verbatim. However exact knowledge of wording is not required and it provided all aspects of each regulation are known and understood paraphrased answers are acceptable.

3.2 PRACTICAL EXPERIENCE.

Besides on-the-job experience related to the level of training being undertaken additional experience is required. It is the responsibility of the student to ensure that arrangements for visits and short practical courses related to the various modules as applicable are made by his supervisor or organisation. These visits must be achieved over the period of training and not necessarily all at onr time. If appropriate visits are made relating to theoretical work being studied the knowledge gained is reinforced and more easily remembered.

The following practical visits are recommended for each of the modules.

a. An Introduction to Mine Winders.

Shafts	Vertical Sub-vertical Tertiary Inclined with angle of inclination in excess of 45°. Inclined with angle of inclination less than 20°. Sinking Shafts with fixed guides and rope guides
Drum Winders	Single drum Small double drum Large double drum Blair Multi Rope
Koepe Winders	One or two rope Four rope Six rope Tower mounted Ground mounted
Lifts	Traction Gearless Single and two to one roping
Sinking winders	Kibble winder Blair stage winder Four drum stage winder

b. The Technology of Wire Ropes for Mine Winders.

When visiting the types of winders just mentioned, the ropes being used should be established. The operation of the ropes should be observed and any specific behaviour patterns determined, such as coiling patterns on drum winders, or any other relevant features.

Visits to steel and rolling mills should be arranged and thereafter a detailed visit to a rope factory. If possible a day each should be spent in the wire mill, the ropery and with the quality assurance personnel.

c. The Destructive Testing of Wire Ropes.

One or two days should be spent at the Cottesloe Rope Testing Laboratory of the CSIR. The preparation, test and examination of rope samples must be studied and related back to methods of manufacture identified during the visit to the rope factory. Of particular importance are methods of handling and preparing rope samples for test. In addition the condition of the rope and the types of wire fracture should be identified and related back to the content of the module.

d. Minerals Act and Regulations.

In all the visits outlined above the relevant parts of the regulations must be considered. In particular the safety regulations relating to persons working in and around shafts and moving machinery must be identified and adhered to.

e. Practical Aspects of Rope Inspection

When visiting shafts and various types of winders the various aspects of the arrangements which affect rope performance should be identified noted. In particular the deterioration patterns related to the type of winder should be discussed with operating personnel to confirm the descriptions in the module.

f. Magnetic Rope Testing Instruments.

It is important that experience with the operation of many types of non destructive test instruments be gained. In particular, the response of various types of instrument to the deterioration patterns found in operating ropes should be observed and related to the actual rope condition.

4 OVERVIEW OF MODULES.

In addition to a concise introduction to each of the modules and individual sections, the relevant paragraphs containing the information required for each level of competence are listed and the level indicated, for ease of study.

4.1 AN INTRODUCTION TO MINE WINDERS.

It is obvious that before any useful activity can be achieved in the inspection and monitoring of wire ropes used on mine winders, a basic understanding of shafts, hoisting and winders is required in addition to a detailed knowledge of ropes. Although there is a vast amount of detailed information available in the form of reports, papers etc. it is difficult to obtain appropriate information to give a basic understanding of the requirements and possible solutions of hoisting problems.

This module aims at giving an overall background to mine hoisting practice in South Africa. At the outset it must be explained that developments in hoisting and hoisting systems anywhere in the world have depended very much on local experiences. For this reason winder and hoisting practice in other parts of the world have often developed along different lines with emphasis being given to aspects which are sometimes regarded as being self evident. For this reason publications from other parts of the world must be assessed with these differences in mind.

The module gives a brief resume of shafts and shaft systems and after a chapter on the requirements of hoisting systems describes winding systems and their components. The question of maintenance of ropes and winders has not been addressed although some comments have been made where maintenance affects system design.

2 SHAFTS AND SHAFT LAYOUTS.

To a large extent shafts and shaft layouts have developed from geographical as well as mining constraints. For instance; in hilly or mountainous country it is often possible to use an adit system to gain access to underground workings whereas in flat country with the ore-body at some depth from the surface vertical shafts are appropriate.

The type of guide system used is often determined by the shaft layout requirements. Fixed guide systems are generally used in South Africa except for shaft sinking where the ropes used to support the sinking stage are used as guide ropes.

	Item	Level 1	Level 2
2.1	Shaft Systems.	Yes	Yes
2.2	Compartment Layout.	Yes	Yes
2.2.1	Guides.	Yes	Yes
2.2.2	Services	Yes	Yes
2.4	Headgear and Surface Layout	Yes	Yes

3 REQUIREMENTS FOR HOISTING SYSTEMS.

A short discussion on various aspects for safe operation to be considered when choosing a winder and deciding on operating parameters.

	Item	Level 1	Level 2
3.1	Winder Size.	Yes	Yes
3.2	Rope Speed	Yes	Yes
3.3	Men	Yes	Yes
3.4	Material	Yes	Yes
3.5	Mineral	Yes	Yes
3.6	Regulations	Yes	Yes

4 TYPES OF WINDERS.

The various configurations of the two basic winding systems are discussed.

These systems are:-

a) Drum winding; where the rope is attached to the drum.
b) Friction winding; where there is no fixed connection between the winder drum and the rope.

	Item	Level 1	Level 2
4.1	Drum Winders.	Yes	Yes
4.1.1	Double Drum Winder.	Yes	Yes
4.1.2	Sinking Winders.	Yes	Yes
4.1.3	BMR Winders.	Yes	Yes
4.1.4	Small Hoists.		Yes
4.2	Friction Winders.	Yes	Yes
4.2.1	Koepe Winders.	Yes	Yes
4.2.2	Lifts.	Yes	Yes
4.2.3	Blair Stage Winder.	Yes	Yes
4.3	Other Winders.		Yes
4.3.1	Reel Winder.		Yes
4.3.2	Whiting Hoist.		Yes

5 COMPONENTS OF DRUM WINDERS.

Many components used in winders have to be chosen from a wide range of available systems and designs. Often the choice is easily made, but in some cases there are far reaching consequences which can affect the performance of ropes in the system.

Many of the alternatives are discussed, with comments on performance and guidelines for appropriate design.

	Item	Level 1	Level 2
5.1	Type of Power and Control.	Yes	Yes
5.1.1	DC System.	Yes	Yes
5.1.2	AC System.	Yes	Yes
5.2	Braking.		Yes
5.2.1	Drum Type Brakes.		
5.2.2	Disc Brakes.		
5.3	Drums.	Yes	Yes
5.3.1	Drum Cheeks.	Yes	Yes
5.3.2	Fleet Angles.	Yes	Yes
5.3.3	Drum Barrel and Grooving.	Yes	Yes
5.3.4	Rope Connection to the Drum.	Yes	Yes
5.3.5	Operating Rope Storage.	Yes	Yes
5.3.6	Rope Adjustment. (i.e. Clutching)	Yes	Yes
5.4	Sheaves and Sheave Layout.	Yes	Yes
5.5	Protection Devices.	Yes	Yes
5.5.1	Electrical Protection	Yes	Yes
5.5.2	Mechanical Protection	Yes	Yes
5.5.3	Overwind.	Yes	Yes
5.5.4	Detaching Devices.	Yes	Yes
5.5.5	Additional Protection for Shaft Sinking.		Yes
5.6	Conveyances.		Yes

6 COMPONENTS OF KOEPE WINDERS.

Many components and systems used on drum winders are equally applicable to Koepe winders. However, the friction system requires many specially designed components. These are discussed, with guidelines where appropriate.

	Item	Level 1	Level 2
6.1	Type of Power and Control	Yes	Yes
6.2	Braking		Yes
6.3	Ropes	Yes	Yes
6.3.1	Head-ropes.	Yes	Yes
6.3.2	Tail-ropes.	Yes	Yes
6.4	Drums.	Yes	Yes
6.4.1	Drum Treads.	Yes	Yes
6.4.2	Tread Length Measurement.	Yes	Yes
6.5	Sheaves.		Yes
6.5.1	Fleet Angles.		Yes
6.6	Rope Connections.	Yes	Yes
6.6.1	Rope Adjustment.	Yes	Yes
6.6.2	Force Equalisation.	Yes	Yes
6.6.3	Re-making Terminations.	Yes	Yes
6.7	Protection Devices.	Yes	Yes
6.7.1	Rope Slip.	Yes	Yes
6.7.2	Overwind.		Yes
6.8	Conveyances.		Yes

7 COMPONENTS OF LIFTS.

A lift is a specialised type of friction winder where there is no driver. Control and operation is initiated from within the conveyance and the machine operates automatically until the designated stopping place is reached. Lifts are also designed for operation under conditions of limited inspection and maintenance.

Although lifts are supplied (and often maintained) by specialist companies many of the principles of design and operation should be understood so that appropriate action can be taken by rope inspection technicians in their inspections and recommendations regarding rope discard.

	Item	Level 1	Level 2
7.1	Types of Lift	Yes	Yes
7.1.1	Gearless.	Yes	Yes
7.1.2	Traction.	Yes	Yes
7.1.3	Two to One Roping.	Yes	Yes

	Item	Level 1	Level 2
7.2	Ropes.	Yes	Yes
7.2.1	Hoist Ropes.	Yes	Yes
7.2.2	Governor Rope.	Yes	Yes
7.2.3	Compensating Ropes.	Yes	Yes
7.3	Guides.		Yes
7.4	Control.	Yes	Yes
7.5	Safety Devices.	Yes	Yes

8 COMPONENTS OF STAGE WINDERS.

Shaft sinking requires specialised equipment, especially with respect to winders and other related components. The stage winder is one such device. It can consist of a winder with multiple drums or an arrangement for ensuring excellent operation of friction type interconnected drums.

	Item	Level 1	Level 2
8.1	Blair Stage Winder.	Yes	Yes
8.1.1	Rope Equalisation.		Yes
8.1.2	Main Winder.		Yes
8.1.3	Take-up Winder.		Yes
8.1.4	Compensating Tower.		Yes
8.2	Multi Drum Winder.		Yes
8.2.1	Rope Equalisation.		Yes
8.2.2	Clutching.		Yes
8.2.3	Brakes.		Yes
8.2.4	Control.		Yes
8.3	Stage.		Yes

4.2 THE TECHNOLOGY OF WIRE ROPE FOR MINE WINDERS.

This module is a comprehensive document designed to acquaint rope users and inspectors with all the various types of wire rope used on mine winders in South Africa.

Rope constructions and properties are described in sufficient detail to enable an understanding of design constraints which affect rope performance and recommendations are made for appropriate constructions for various applications.

The manufacture of the input wire of a wire rope is described, as well as the ropemaking processes which are used for manufacturing the many types of wire rope product. An understanding of these processes with their limitations and constraints is an essential requirement for correctly assessing rope condition in the field.

Finally, the characteristics of many hoisting systems are described and the appropriate rope constructions recommended for satisfactory rope performance. The reasoning behind these choices will assist in anticipating the mode of rope deterioration to be expected for various types of winder. An understanding of these factors will ensure that critical areas of rope deterioration will not be overlooked.

Chapter 1 INTRODUCTION TO ROPE AND ROPE TECHNOLOGY.

This chapter starts with a short history of wire rope. The various parts of a wire rope are described as well as various constructions and methods of laying a rope up. Many of the properties of the input wire are described as well as the properties of the rope itself.

	Item	Level 1	Level 2
1.2	PARTS OF A STEEL WIRE ROPE.		
1.2.1	Strands.	Yes	Yes
	Wires.	Yes	Yes
	Strand Core - Wire or Fibre.	Yes	Yes
1.2.2	Rope Core.	Yes	Yes
	Fibre Core.	Yes	Yes
	Wire Strand Core.	Yes	Yes
	Independent Wire Rope Core.	Yes	Yes
1.2.3	Wire.		Yes
	Steel.		Yes
	Tensile Strength.	Yes	Yes
	Ductility.		Yes
	Modulus of Elasticity.		Yes

Item		Level 1	Level 2
1.3	TYPES OF STEEL WIRE ROPE.		
1.3.1	Single Strand.		Yes
	Bridge Strand.		Yes
	Locked Coil.		Yes
	Other.		Yes
1.3.2	Round Strand Rope.	Yes	Yes
	Single Layer Round Strand Rope.	Yes	Yes
	Multi-strand Round Strand Rope (Non-spin).	Yes	Yes
1.3.3	Shaped Strand Ropes.	Yes	Yes
	Single Layer Shaped Strand Ropes.	Yes	Yes
	Multi-strand Shaped Strand Ropes (Non-spin).	Yes	Yes
1.4	ROPE PROPERTIES.		
1.4.1	Breaking Strength.	Yes	Yes
	Calculated Aggregate.	Yes	Yes
	Actual Aggregate.	Yes	Yes
	Estimated or Minimum (or Guaranteed).	Yes	Yes
	Actual.	Yes	Yes
	Tolerance.	Yes	Yes
1.4.2	Mass.	Yes	Yes
	Calculated or Estimated.	Yes	Yes
	Actual.	Yes	Yes
	Tolerance.	Yes	Yes
	Steel Mass.	Yes	Yes
	Grease Mass.	Yes	Yes
1.4.3	Elongation.		Yes
	Elastic.		Yes
	Permanent.		Yes
	Ductility.		Yes
	Work Done to Failure.		Yes
	Plastic Portion of Elongation.		Yes
1.4.4	Moduli.		Yes
	Elastic Modulus.		Yes
	Coefficient of Thermal Expansion.		Yes
	Other Moduli.		Yes
1.4.5	Rope Lay.	Yes	Yes
	Lang's.	Yes	Yes
	Ordinary (or Regular).	Yes	Yes

	Item	Level 1	Level 2
1.4.6	Spinning Characteristics.		Yes
	Torque.		Yes
	Non-spin Properties.		Yes
1.4.7	Special Properties.		Yes
	High Strength.	Yes	Yes
	Strength to Mass Ratio.	Yes	Yes
	Flexibility.		Yes
	Can transmit a force over very long distances.		Yes
	Fatigue Resistance.		Yes

Chapter 2 MANUFACTURE OF HIGH TENSILE WIRE FOR USE IN WIRE ROPES.

A steel wire is one of the highest strength materials used today. It is so ubiquitous that its properties are taken for granted. However many of its properties make the manufacture and use of wire rope possible and satisfactory.

A simple description of wire drawing practice and the metallurgical processes required for producing good wire is intended to assist in identifying wire related problems. The practical limits to strength and size are discussed as well as the various test methods for determining the required wire properties.

	Item	Level 1	Level 2
2.1	STEEL.		
2.1.1	Processes.		Yes
	Steel Manufacture.		Yes
	Production of Billets.		Yes
2.1.2	Rod.	Yes	Yes
	Hot Rolled.	Yes	Yes
	Controlled Cooled.	Yes	Yes
2.1.3	Steel Making And Rolling Problems.	Yes	Yes
2.2	WIRE.		
2.2.1	Processes.	Yes	Yes
	Heat Treatment.	Yes	Yes
	Cleaning and Coating.	Yes	Yes
	Drawing.	Yes	Yes
	Corrosion Protection.	Yes	Yes
	Testing.	Yes	Yes

	Item	Level 1	Level 2
2.2.2	Properties.	Yes	Yes
	Size.	Yes	Yes
	Strength.	Yes	Yes
	Ductility.		Yes

Chapter 3 ROPE MANUFACTURE

The theory of ropemaking is stated and the types of ropemaking machines described. Rope design is mentioned and a few simple formulae given and discussed.

The ropemaking processes are discussed and the inspection procedures required for good consistent rope quality described. Rejection and concession procedures are discussed.

	Item	Level 1	Level 2
3.1	THEORY OF ROPEMAKING.		
3.1.1	Explanation Of Ropemaking Terms.	Yes	Yes
3.1.2	Lay Blocks	Yes	Yes
3.1.3	Machinery.	Yes	Yes
	Sun and Planet Machines.		Yes
	Tubular Machines.		Yes
	Bunchers.		Yes
3.1.4	Rope Design.		Yes
	Basic Concepts.		Yes
	Selection of Wire Diameters.		
	Tensile Strength of Wire.	Yes	Yes
	Rope Core.	Yes	Yes
3.2	ROPE-MAKING PROCESSES		
3.2.1	Stranding		Yes
	Wire Winding		Yes
	Joining of Wires		Yes
	Lay Plate		Yes
	Round Strand		Yes
	Postforming		Yes
	Shaped Strands		Yes
3.2.2	Closing		Yes
	Tubular Closers		Yes
	Sun and Planet Closers		Yes
	Preforming		Yes
	Postforming		
	Maximum Length or Mass		

	Item	Level 1	Level 2
3.3	INSPECTION AND TESTING	Yes	Yes
	Wire	Yes	Yes
	Strand	Yes	Yes
	Rope	Yes	Yes
	Rejection and Concessions	Yes	Yes

Chapter 4 RECOMMENDATIONS FOR USE OF ROPES IN VARIOUS HOISTING APPLICATIONS.

In choosing a rope for any application there are several factors which must be considered. Fatigue, wear and flexibility are properties which often have to be considered for a particular application. In some cases requirements for good wear properties conflict with concurrent requirements for flexibility and / or good fatigue performance and a choice has to be made resulting in a compromise.

Various hoisting applications are described and appropriate rope constructions recommended. In some cases recommendations are made regarding important winder design parameters to ensure satisfactory rope performance.

	Item	Level 1	Level 2
4.1	BASIC CONSIDERATIONS.		
4.1.1	Strength.	Yes	Yes
	Tensile Grade of Steel.		
	Breaking Strength of Rope.		
4.1.2	Flexibility.		
4.1.3	Wear Resistance.		
	Abrasive Wear.		
	Plastic Deformation.		
4.1.4	Fatigue Performance.		
	Tension-Tension Fatigue.		
	Bending Fatigue.		
	Corrosion Fatigue		
	Splitting Fatigue		
4.1.5	Lay.		
4.1.6	Torque.		
4.1.7	Resistance To Crushing.		
4.1.8	Corrosion Resistance.		
4.1.9	Stability.		
4.1.10	Reserve Strength		
4.1.11	Generalised Aspects Of Choice.		

	Item	Level 1	Level 2
4.2	ROPES FOR MINE HOISTING.		
4.2.1	Drum Winding.	Yes	Yes
	Vertical Shafts.	Yes	Yes
	Incline Shafts.	Yes	Yes
	Type of Guides.	Yes	Yes
	Depth of Wind.	Yes	Yes
	Rope Speed.	Yes	Yes
	Drums.	Yes	Yes
	Kibble Ropes.	Yes	Yes
	Small Hoists.	Yes	Yes
4.2.2	Friction Hoisting.	Yes	Yes
	Koepe Winding.	Yes	Yes
	Koepe Tail-ropes.	Yes	Yes
	Blair Stage Winder Ropes.	Yes	Yes
	Elevators.	Yes	Yes
4.2.3	Sinking Ropes.		Yes
4.2.4	Condensed Recommendations For Winders.	Yes	Yes

APPENDICES

Various appendices are listed which are useful for reference purposes.

REFERENCES
LIST OF SYMBOLS USED IN FORMULAE
GLOSSARY
LIST OF RELEVANT STANDARDS

4.3 THE DESTRUCTIVE TESTING OF WIRE ROPES.

All wire ropes for mine winding have to be tested after manufacture to confirm the quality and strength of the rope. In addition, ropes operating on most winders (the exception is Koepe winders) have to have a sample from the conveyance end tested to destruction every six months. These tests are prescribed in order to monitor the condition of the rope as far as possible by an independent authority.

This module describes the test procedures, including preparation required to achieve representative results. The results of the tests are discussed and guidelines given for interpreting the results supplied on the test certificate.

Item	Level 1	Level 2
2. SPECIMEN PREPARATION IN THE FIELD	Yes	Yes
3. APPLICATIONS FOR TEST	Yes	Yes
3.1 General	Yes	Yes
3.2 Ultra High Tensile Winding Ropes	Yes	Yes
4. TEST PROCEDURE		Yes
4.1 Specimen Preparation		Yes
4.2 Testing of the Specimens		Yes
4.3 Specimen Inspection after Test		Yes
4.4 The Test Certificate		Yes
5. INTERPRETATION OF TEST RESULTS	Yes	Yes
5.1 Breaking Strength	Yes	Yes
5.2 Gauge Length		Yes
5.3 Least Diameter of Outer Wire		Yes
5.4 Lay Length		Yes
5.5 Diameter		Yes
5.6 Corrosion	Yes	Yes
5.7 Condition of Lubricant	Yes	Yes
5.8 Appearance of Wires at Fracture	Yes	Yes
5.9 Number of Strands Broken		Yes
5.10 Position of Fracture		Yes
5.11 Remarks		Yes
6. THE LOAD-ELONGATION DIAGRAM		Yes
6.1 General		Yes
6.2 Description of Testing Parameters		Yes
APPENDICES		
Appendix A: Degree of corrosion	Yes	Yes
Appendix B: Condition of lubricant	Yes	Yes
Appendix C: Modes of wire failures	Yes	Yes

4.4 MINERALS ACT (ACT 50 OF 1991) AND REGULATIONS.

LEGAL KNOWLEDGE

Introduction

The Minerals Act and regulations are aimed at promoting the safety and health of all persons employed at mines and works irrespective of their job category.

In the field of non-destructive testing there are also sections of the Minerals Act and regulations pertaining to the safety of, and responsibilities, of the RCA technician himself and persons working under his control.

Before the regulations are discussed there are certain sections of the Minerals Act (Act 50 of 1991) that should be studied as they are of importance.

Chapter 1.	Definitions
(ii)	"certificated"
(vii)	"employee"
(x)	"investigating officer"
(xii)	"manager"
(xiii)	"officer"
(xxv)	"peace officer"
(xxvi)	"person"
(xxvii)	"prescribed''
(xxxi)	"record"
(xxxii)	"regional director"

	Item	Level 1	Level 2
Section 37.	Negligent act or omission offence under certain circumstances.		
Chapter 8.	General and Miscellaneous provisions.	Yes	Yes
Section 51.	Power of entering upon any land or place and perform other acts.	Yes	Yes
Section 52.	Producing of documents at request of regional director or authorised person.	Yes	Yes
Section 53.	Proof of certain facts.	Yes	Yes
Section 55.	State not liable for claims.	Yes	Yes
Section 56.	Serving of documents and validity.	Yes	Yes
Section 57.	Right of appeal.	Yes	Yes
Section 58.	Prohibition of Victimization.	Yes	Yes
Section 59.	Prohibition or obstruction of officer or person.	Yes	Yes
Section 60.	Offenses.	Yes	Yes
Section 61.	Penalties.	Yes	Yes
Section 52.	Delegation of Power.	Yes	Yes
Section 63.	Regulations.	Yes	Yes
Section 67.	Machinery and Occupational Safety Act, 1983, not applicable.	Yes	Yes

Together with the promulgation of the Minerals Act, the Republic of South Africa has been divided into nine (9) regions which replaces the fourteen (14) inspectorates as follows:

Region	Office
1 . Western Cape	Cape Town
2. Northern Cape	Kimberley
3. Orange Free State	Welkom
4. Eastern Cape	Port Elizabeth
5. Natal	Dundee
6. Eastern Transvaal	Witbank
7. Northern Transvaal	Pietersburg
B. P.W.V	Johannesburg
9. Western Transvaal	Klerksdorp

Each region is headed by a "regional director" under whose direction the "regional mining engineers" will operate. The regional directors have replaced the Chief Inspectors of Mines and Machinery and the inspectors of mines and machinery are now known as "regional mining engineers".

Regulations.
Regulations pertaining to the responsibility of the RCA technicians are listed first.

	Item	Level 1	Level 2
Chapter 1.	Definitions.		
(4)	"certificated"	Yes	Yes
(4B)	"competent person" - This definition will be applicable to the RCA technician because under (a) (i) is qualified by virtue of his knowledge, training, skills and experience to organise the work and its performance, (ii) is familiar with the provisions of the Act and the regulations which apply to the work to be performed: and (iii) has been trained to recognise any potential or actual danger to health or safety in the performance of the work.	Yes	Yes
(6B)	"engineer"	Yes	Yes
(11A)	"hazardous area"	Yes	Yes
(14A)	"light metal"	Yes	Yes
(45A)	"flameproof apparatus"	Yes	Yes
(45B)	"flexible cable"	Yes	Yes
(46A)	"increased safety apparatus"	Yes	Yes
(46C)	"intrinsically safe apparatus"	Yes	Yes
(50B)	"portable electric apparatus"	Yes	Yes
Chapter 3. General provisions.			
3.1.1	No unauthorised admittance.	Yes	Yes
3.11	Responsibility for contravention.	Yes	Yes
3.12	Disobedience	Yes	Yes
3.13	Deputing of work	Yes	Yes
3.14	Safety precautions not to be damaged or removed.	Yes	Yes

	Item	Level 1	Level 2
Chapter 4. Workmen.			
4.7.2	No intoxicating liquor at any place	Yes	Yes
4.14.1	Not more than 48 hours of work in 7 consecutive days.		Yes
Chapter 5. Personal safety.			
5.8.1	Life-line used where danger of falling or slipping.	Yes	Yes
5.8.3	Hard hat worn where danger of falling objects.	Yes	Yes
Chapter 11. Fire prevention.			
11.3.1	Leaving naked light or flame.	Yes	Yes
11.3.4	No welding	Yes	Yes
11.3.6	No smoking	Yes	Yes
Chapter 15. Lighting.			
15.1	No travel or work in dark place without a light.	Yes	Yes
15.9.1	No smoking in fiery mines.	Yes	Yes
Chapter 16. Winding Plant.			
16.4	Weight of persons.		Yes
16.25	Breaking strength test of new rope.	Yes	Yes
16.27	Examination of newly installed rope.	Yes	Yes
16.30.1 & 16.30.2	Definition of terms for calculation.		Yes
16.31	Ratio of man load to mineral load.	Yes	
16.32	Multiple ropes.		Yes

	Item	Level 1	Level 2
16.33	Factors of safety winding ropes.		Yes
16.34.1	ditto		Yes
16.34.2	ditto		Yes
16.34.3	ditto		Yes
16.34.4	ditto		Yes
16.35.1	ditto		Yes
16.35.2	ditto		Yes
16.36	ditto		Yes
16.36.1	ditto		Yes
16.36.2	ditto		Yes
16.37	ditto		Yes
16.38	ditto		Yes
15.39	Factor of safety, balance rope.		Yes
16.40	Factor of safety, guide rope.		Yes
16.41.1	Cutting, recapping and test.	Yes	Yes
16.52	Entering winding compartments.	Yes	Yes
16.55	Driver to be warned.	Yes	Yes
15.65	Persons authorised to travel with material.	Yes	Yes
15.67	Restricted travel outside conveyance.	Yes	Yes
16.72	Trial run after stoppage.	Yes	Yes
16.77	Defects reported to manager.	Yes	Yes
16.79	Rope record book.	Yes	Yes
16.81	Drivers log book for each winder.	Yes	Yes
16.81.3	Special instruction to driver.	Yes	Yes
16.81.4	Warnings given in terms of 16.55.	Yes	Yes

	Item	Level 1	Level 2
16.85	Driver not to be distracted.	Yes	Yes
16.86.1	When driver may start engine.		Yes
16.87	Signalling by authorised person only.	Yes	Yes
16.89.1	Who may give signals.	Yes	Yes
16.89.2	Signalling by banksman and onsetter - authorization.	Yes	Yes
16.91.10	Persons to be safe before signalling.		Yes

Lifting machines and lifting tackle

16.98.1	Construction and strength.	Yes	Yes
16.98.2	Safety of persons not endangered.	Yes	Yes
16.98.3	No run-back.	Yes	Yes
16.98.4	Automatic power cut-off.	Yes	Yes
16.98.5	Maximum safe loads.	Yes	Yes
16.99	Factors of safety of ropes.	Yes	Yes
16.100	Steel rope construction	Yes	Yes

Chairlifts

16.110	Regional mining engineer may lay down rules for use.		Yes
16.112	Rope suited to pulley size.		Yes
16.112.1	Traction chain approved type.		Yes
16.112.2	Not more than 10% less in strength.	Yes	Yes
16.112.3	Safety rope to prevent run back.		Yes
16.112.4	Minimum factor of rope strength.		Yes
16.112.5	70 kg/person		Yes
16.112.6	Rope splices and clamps.	Yes	Yes
16.112.7	Restriction of and no. of splices and spacing.	Yes	Yes
16.118	Emergency brake.		Yes

	Item	Level 1	Level 2
Chapter 17. Elevators.			
17.3.4	Elevator record book.	Yes	Yes
17.4.1	Details of elevator.	Yes	Yes
17.5.1	Persons appointed for weekly examination of ropes.		Yes
17.5.2	Monthly inspection of engineer.		Yes
17.5.3	Dangerous defects to be reported.	Yes	Yes
17.5.4	No persons conveyed during examination/servicing.	Yes	Yes
17.27.1	Ropes of steel wire, adequate, no defects.	Yes	Yes
17.27.2	Wire and rope size limitations.		Yes
17.27.3	At least two ropes, equal size and strength.	Yes	Yes
17.27.4.1	Minimum factor of safety.	Yes	Yes
17.27.4.2	Force in Newtons - mass in kg times 9,8.	Yes	Yes
17.27.6	Rope breaking strength from actual test.		
17.30	No slipping of rope not attached to drum.		Yes
Chapter 20. Machinery safety measures.			
20.1.1	Competent person in charge of machinery.	Yes	Yes
20.1.2	Supervision continuous: 10 hour man shifts.		Yes
20.2	No trespassing within safety guards/fences.	Yes	Yes
20.3.1	Dangerous places to be fenced off.		Yes
20.3.2	No unauthorised entrance to machinery locations.	Yes	Yes
20.4	No loose outer clothing close to moving machinery.	Yes	Yes
20.5	Dangerous machinery fenced, guards fitted.		Yes
20.6	No unauthorised servicing/repairing moving machinery.	Yes	Yes
20.7.3	All reasonable measure before starting machinery.	Yes	Yes
20.8	Every reasonable precaution taken in use of machinery.	Yes	Yes
20.9.1	All safety devices in good order; properly used.	Yes	Yes
20.9.2	Unsafe machines immediately stopped.	Yes	Yes
20.9.3.1	Power switched off and remains off during servicing.	Yes	Yes
20.9.3.2	No servicing unless machines/parts are safe.	Yes	Yes

	Item	Level 1	Level 2
Chapter 21. Electricity.			
21.1.1.1	Electrical apparatus, selected, maintained, placed and protected not to cause danger to persons.		Yes
21.4	Not interfere or render ineffective electric apparatus.	Yes	Yes
21.17.1	Manager to identify hazardous areas and record on a plan.		Yes
21.17.2	Only explosion proof apparatus in hazardous areas.		Yes
21.17.3.1	Identification of explosion proof apparatus.		Yes
21.17.3.2	Explosion proof apparatus to be clearly and indelibly marked.		Yes
Chapter 25. Reporting of accidents by Manager.			
25.1 (a)	death of any person.	Yes	Yes
(b)	injury likely to be fatal.	Yes	Yes
(c)	unconsciousness.	Yes	Yes
(d)	incapacitation.	Yes	Yes
(e)	incapacitation period.	Yes	Yes
Notice in respect of (a), (b) and (c) shall be immediate by the quickest means available.		Yes	Yes
25.4	Place of accident to be left undisturbed.	Yes	Yes
25.5	Right to attend inspection.	Yes	Yes
25.6	Reporting of non-casualty accidents	Yes	Yes
	(a) winding plant	Yes	Yes
	(b) elevators	Yes	Yes
	(c) chairlifts	Yes	Yes

4.5 Practical Aspects of Rope Inspection.

For a long time, people tried to control the risk of rope failure on mine winders by selecting certain factors of safety for the new rope and by relying on rope inspection strategies that were poorly defined and of uncertain quality. About ten years ago it was finally realized that rope safety cannot be controlled properly in this way. It is now accepted that, even at high factors of safety (now more correctly called rope design factors), no rope can be used safely unless the following objectives are met:

a) normal deterioration of the rope is controlled by means of regular and efficient rope inspection;

b) abnormal damage to the rope is avoided, and where it does occur it is detected early;

c) the normal and the maximum forces acting on a rope are controlled within specified limits.

This training module deals with the practical requirements of rope inspection, in order to assist with achieving objectives a and b above: i.e. the proper assessment of normal as well as of abnormal deterioration of winding ropes. The causes of the different types of defects that occur in winding ropes, equipment used for rope inspection, detailed inspection procedures, analysis of inspection results, application of discard criteria, and inspection reports and records are considered. Detailed discard criteria, with background information, are given in the Appendix.

Item	Level 1	Level 2
2. ROPE DEFECTS	Yes	Yes
2.1 Defects in a new rope	Yes	Yes
2.2 Abnormal damage	Yes	Yes
2.3 Normal deterioration	Yes	Yes
2.4 Summary of rope defects	Yes	Yes
3. INSPECTION EQUIPMENT	Yes	Yes
3.1 Types of equipment	Yes	Yes
3.2 Approval, testing and certification	Yes	Yes
3.3 Care and maintenance	Yes	Yes
4. PLANNING OF ROPE INSPECTIONS		Yes
4.1 Inspection intervals		Yes
4.2 Rope sections to be inspected		Yes
4.3 Inspection locations and preparations		Yes
4.4 Safety considerations	Yes	Yes
4.5 Arrangements for inspection		Yes

Item	Level 1	Level 2
5. MAGNETIC TESTS	Yes	Yes
5.1 Instrument characteristics	Yes	Yes
5.2 Calibration and sensitivity	Yes	Yes
5.3 Testing procedures	Yes	Yes
5.4 Trace analysis	Yes	Yes
6. PHYSICAL INSPECTIONS	Yes	Yes
6.1 Positions in rope	Yes	Yes
6.2 Detailed examination	Yes	Yes
6.3 Other inspections	Yes	Yes
7. EVALUATION OF RESULTS	Yes	Yes
7.1 Discard criteria	Yes	Yes
7.2 Examples of calculations	Yes	Yes
8. REPORTS AND RECORDS		Yes
8.1 Inspection log		Yes
8.2 Site report		Yes
8.3 Assessment report		Yes
8.4 MD 208 forms		Yes
8.5 Maintenance reports		Yes
8.6 Rope destructive testing test reports		Yes
8.7 Rope record file		Yes

APPENDIX.
DISCARD CRITERIA FOR WINDING ROPES.

1. CHANGE IN ROPE DIAMETER	Yes	Yes
2. CHANGE IN LAY LENGTH	Yes	Yes
3. BROKEN WIRES	Yes	Yes
4. CORROSION	Yes	Yes
5. DISTORTION OF ROPE	Yes	Yes
6. ROPE CORE FAILURE		Yes
7. HEAT DAMAGE	Yes	Yes
8. MECHANICAL PROPERTIES		Yes
9. SHORT ROPE		Yes
10. COMBINED EFFECTS		Yes
11. RATE OF DETERIORATION		Yes
12. OTHER CONSIDERATIONS		Yes
SUMMARY OF DISCARD CRITERIA	Yes	Yes

4.6 MAGNETIC ROPE TESTING INSTRUMENTS.

A wire rope in service can have a mixture of manufacturing defects, damage experienced during handling and storage, normal defects and abnormal defects.

The law requires that every winding rope must be examined visually every working day. However, well maintained drum winding ropes are covered in rope dressing and many defects are not visible unless the complete rope is properly cleaned. This is not possible in practice and only short lengths of critical portions of a rope are cleaned and examined thoroughly on a regular basis. In addition, some defects are not visible from the outside such as internal corrosion and wire, core and strand failures inside the rope.

Rope wires can be magnetised. Many of the defects listed above have some effect on the magnetic fields in the rope and in the air around the rope. In order to assist with visual examination of the rope, instruments based on magnetising the rope and then detecting changes in the magnetic fields were developed. The first design was produced in South Africa in about 1906. Further work was also done in England, Germany, Canada and later in various other countries as well. Good instruments have been made and used in South Africa since 1950. Many different types of magnetic rope testing instrument are now available from local and overseas suppliers. These instruments have different characteristics. To use any one of them properly, it is necessary to know how it works and how to set it up. These matters are explained in this training module. Analysis and application of the test results are covered in the training module "Practical Aspects of Rope Inspection".

Item	Level 1	Level 2
2. DEFINITION OF SYMBOLS AND TERMS		Yes
3. BASIC PRINCIPLES		Yes
3.1 Magnetism		Yes
3.2 Magnetisation of ropes		Yes
3.3 Signal generation devices (sensors)		Yes
3.3.1 Coils		Yes
3.3.2 Hall sensors		Yes
3.3.3 Flux gate sensors		Yes
3.3.4 Magnetoresistors		Yes
4. INSTRUMENT CHARACTERISTICS	Yes	Yes
4.1 AC electromagnetic instruments	Yes	Yes
4.2 DC electromagnetic instruments	Yes	Yes
4.3 Permanent magnet instruments	Yes	Yes
4.3.1 Rope steel area	Yes	Yes
4.3.2 Local defects	Yes	Yes
4.3.3 Summary of instrument characteristics	Yes	Yes

5. REQUIREMENTS FOR INSTRUMENTS		Yes
5.1 Specification		Yes
5.1.1 Physical requirements		Yes
5.1.2 Performance requirements		Yes
5.2 Evaluation		Yes
5.3 Certification		Yes
5.4 Maintenance		Yes
6. USE OF MRT INSTRUMENTS	Yes	Yes
6.1 Magnetic conditioning of ropes	Yes	Yes
6.2 Setting up of instruments	Yes	Yes
6.3 Operation of instruments	Yes	Yes

5 GENERAL INDEX

This is a combined index relating to all the training modules described in this study guide.

The indexed items refer to paragraph numbers in the relevant documents preceded by a letter identifying the particular module. These letters are as follows:-

A An Introduction to Mine Winders.
B The Technology of Wire Rope for Mine Winding.
C The Destructive Testing of Wire Ropes.
D Practical Aspects of Rope Inspection.
E Magnetic Rope Testing Instruments.

Not included in the index.
Minerals Act (Act 50 of 1991) and Regulations.

AN INTRODUCTION

TO

MINE WINDERS

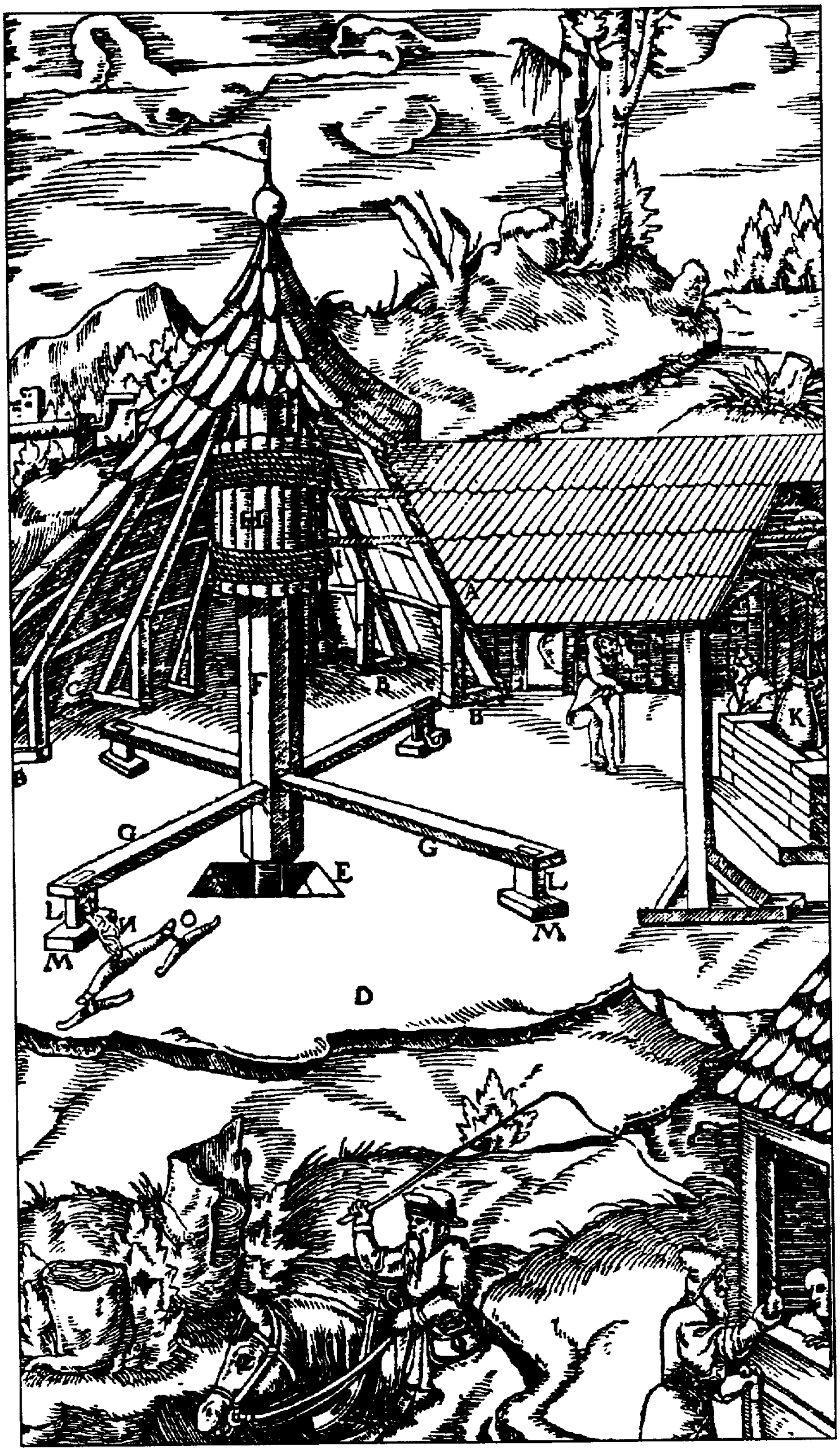
by

E.J. WAINWRIGHT

CONTENTS

LIST OF FIGURES

LIST OF TABLES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An Introduction to Mine Winders

1 INTRODUCTION.

"The hoisting of ore to the surface is a problem that is as old as mining itself. Agricola stated in 1550 that hoisting was one of the great difficulties of mining."[1]

The mine winder is the single most important machine on any deep underground mining operation. Men, material and mineral (ore) are transported to and from the underground workings in an effective and efficient operation.

When the depth of mining is greater than 100 m, an open pit operation becomes impractical and underground workings are more economical. Shallow operations operate satisfactorily with an incline haulage or conveyor belt installation for transportation. If the ore zone is more than 300 m below surface and the required production rate is over 1000 tons per day, a man and ore hoisting shaft becomes appropriate.

There are many arrangements for the hoisting of men, rock and materials, each of which requires its own approach to ensure safe and satisfactory operation.

2 SHAFTS AND SHAFT LAYOUTS.

Definition:- Given in the South African Mining Regulations[2].

Shaft means any tunnel having a cross-sectional dimension of 3,7 m or over and -
(a) having an inclination of 15° or over; or
(b) having an inclination of less than 15° but more than 10° where the speed of traction may exceed 2 m/sec .

This definition of a shaft indicates that it is not only for the transportation of persons, material etc., but can have other uses. In addition to its use for transportation it is essential for providing ventilation to underground workings. Exhaust air is usually carried in upcast shafts which are not used for any other purpose. Fresh air is provided in shafts which are used for hoisting and other purposes. However, in some cases a brattice wall provides means for both upcast and downcast ventilation.[3]

2.1 SHAFT SYSTEMS.

Figure 1 is a schematic illustration of a selection of shaft arrangements which can currently be found in South Africa. Incline shafts are convenient for following an inclined ore body in a cost effective way. Sometimes the incline is a continuation of a vertical shaft or an incline shaft at a different angle. These combinations are termed compound shafts. They are not favoured for new developments because of problems in operation and in maintaining the shaft and equipment.

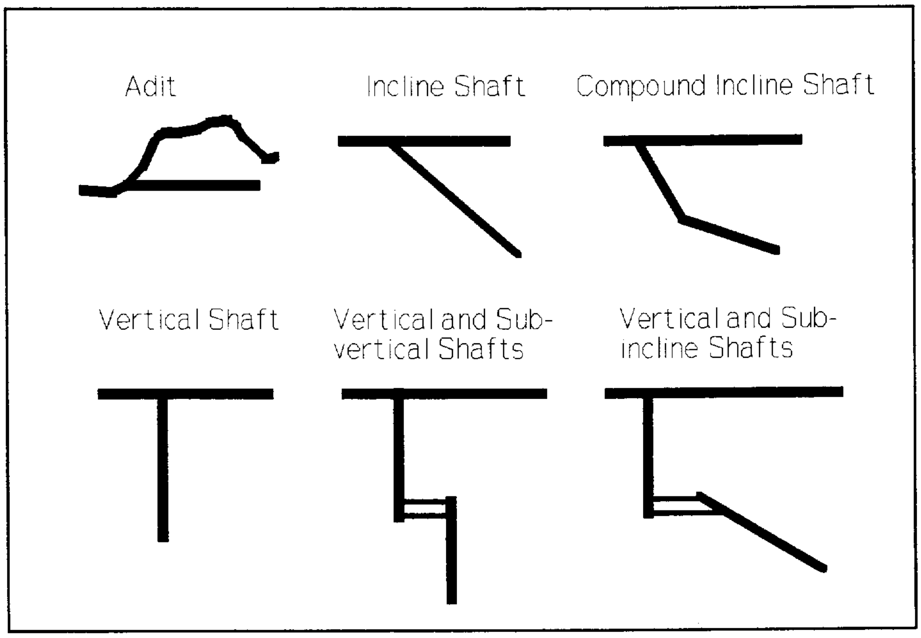

Figure 1 Schematic Diagram of Some Shaft Layouts

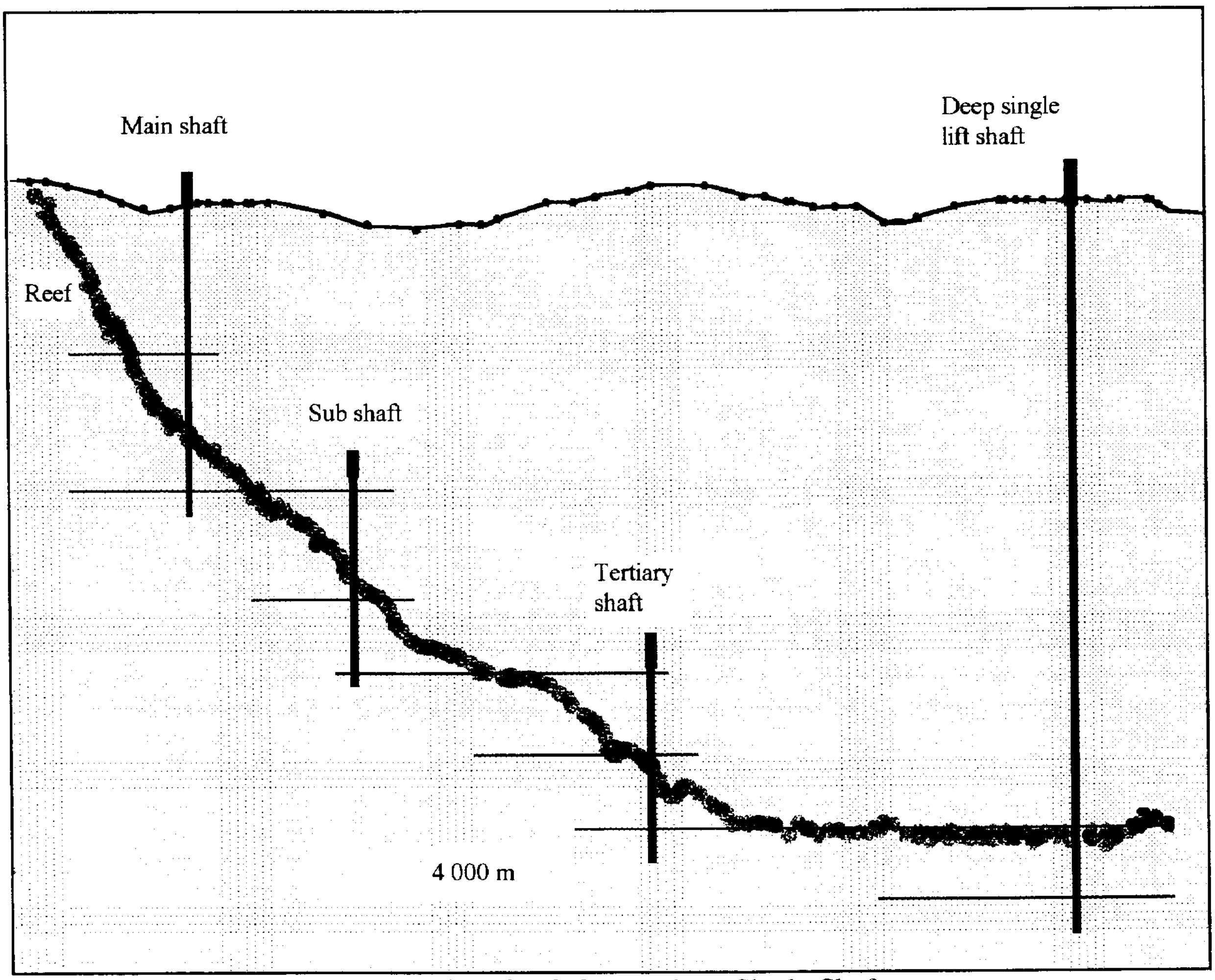

Figure 2 Replacement of a Tertiary Shaft System by a Single Shaft

As mining depths become greater, incline shafts are no longer attractive solutions because shafts become excessively long and maintenance and safe operation of the shaft become more difficult. Vertical shafts are therefore the preferred option for deep mining operations.

In addition, as mining depths increased, so did shaft depth within the technical capabilities of the time. Consequently with ever increasing mining depths it became necessary to provide secondary and then tertiary shafts. The disadvantage of this system was the additional capital required to install winders and transfer arrangements underground and also the time taken to transport men from surface to the lowest working places.

Improved technology and proposals for changes in the mining regulations have made it possible to consider replacing secondary or even tertiary shaft systems by a single deep shaft. See Figure 2. Winding depths being considered are from in excess of the current maximum depth of 2500 m to as deep as 4000 m.

2.2 COMPARTMENT LAYOUT.

Because of the requirement for a second outlet from a mine, two shafts may be required where other outlets do not exist. This allows for some flexibility in deciding on shaft layout. A production and a service shaft can be chosen or as is most common in South Africa a production/service shaft and a pure upcast ventilation shaft can be used. Common shaft layouts are illustrated in Figure 3 to Figure 5.

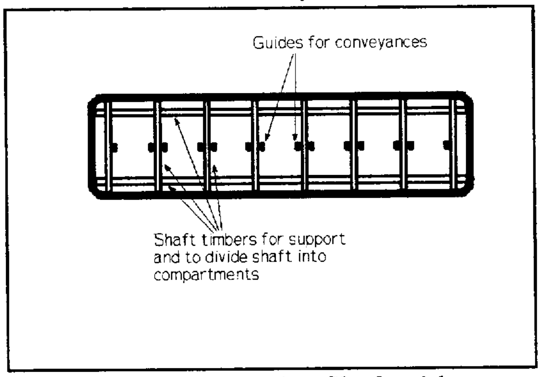

Figure 3 Rectangular Shaft with 7 Compartments

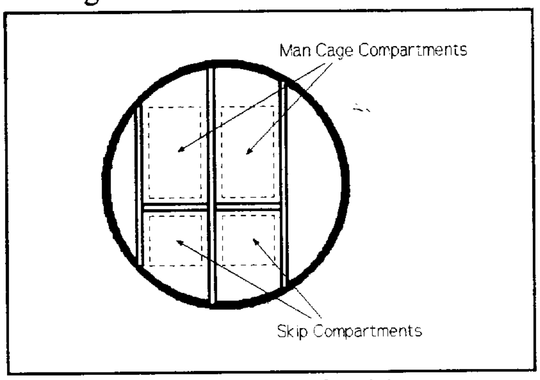

Figure 4 Circular Shaft with 4 Compartments

o In the past rectangular shafts were the rule. Support was provided by timber sets, built as the shaft was being sunk, and guides for the conveyances were fixed to this timber framework. Figure 3 illustrates a 7 compartment shaft which provides for a service compartment and 6 compartments to accommodate the conveyances for 3 winders. A disadvantage of the use of timber in the shaft was the necessity of keeping the timber wet to avoid the development of dry rot. To do this water sprays were set up at the surface and provided a continual spray of water in the shaft. This continual flow of water promoted excessive corrosion of all metal used in the shaft, especially the hoisting ropes.

o Round section, elliptical (or quasi-elliptical) shafts became attractive due to improvements in shaft sinking techniques and with the use of reinforced concrete to provide support produced stronger shafts with lower maintenance requirements. Buntons and dividers were no longer required to support the shaft and were used to position fixed guides in the shaft. These concrete lined shafts could be kept dry, so corrosion was no longer such a problem.

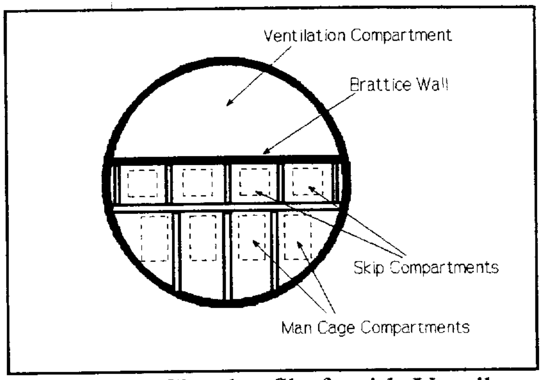

Figure 5 Circular Shaft with Ventilation Compartment and Compartments for 4 Winders

2.2.1 Guides.

In South Africa most vertical shafts are equipped with fixed guides, which are fixed to the shaft buntons or the shaft side-wall. These guides resist the torque developed by the hoist rope and provide a secure and positive means of controlling the conveyance.

2.2.1.1 Timber Guides. Timber guides are still used in older shafts. A feature of timber guides is that arresters (or dogs) can be used to control a free falling cage and for this reason timber guides are still used in such countries as Canada and the USA for man riding conveyances.

In a well maintained shaft, timber guides provide a stable guiding system and seldom cause excessive oscillation of the conveyance. The most serious problems arise when excessively worn guides are replaced and inadequate arrangements made for the transition from an adjacent worn guide to the new guide. In this case the conveyance is subjected to impulses which can adversely affect the entire winding system.

2.2.1.2 Steel Guides. All major shafts in South Africa sunk since 1960 are equipped with steel guides of various designs supported by steel buntons and dividers. These shafts are all maintained to be as dry as possible so corrosion does not present an important problem. A factor which is related to the steel support of shaft guides is an occasional occurrence of severe vibration which can affect either the conveyance or the rope.

2.2.1.3 Rope Guides. The use of ropes for guiding conveyances in shafts is a common practice. All sinking shafts in South Africa use ropes to guide the kibbles. These ropes are also provided to support the sinking stage. Rope guides in permanent shaft arrangements are less usual in spite of some obvious advantages such as:-
- o Provide a very smooth guiding system.
- o Can accommodate very high conveyance speeds which are only limited by aerodynamic effects.
- o Has reduced resistance to the flow of ventilation air.
- o Can be quickly installed.

The disadvantages, however, have limited the usefulness of the system;-
- o Non-spin or locked coil hoisting ropes must be used. Non-spin ropes do not give good life and locked coil ropes are expensive and not necessarily cost effective.
- o The perceived danger of using 6 or 8 conveyances in a shaft, limit the shaft output which can be achieved.
- o Extra spacing of conveyances required to avoid contact with other conveyances or the shaft wall reduces possible shaft output.

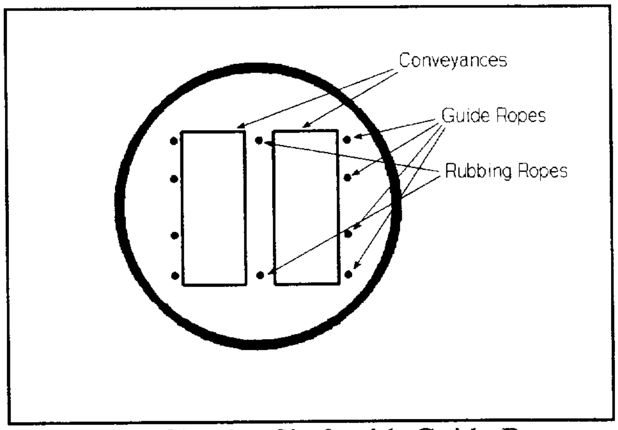

Figure 6 Circular Shaft with Guide Ropes

- In deep shafts rope guides could be more expensive than conventional fixed guides due to increased strength requirements in the shaft collar and head-frame.
- Adequate guiding capability reduces with depth. Although resistance to impulse loading remains high due to inertia effects, the resistance to constantly applied forces, such as the torque in the winding rope, reduces rapidly with depth. A useful rule of thumb for designing rope guides, or evaluating an existing installation, is:- "that the constantly applied force required to deflect the guide rope by 150 mm at the centre of the shaft should be at least 90 N."

The regulations[2] for these ropes are:

16.40 A guide rope shall not be used in a winding system if the breaking strength at any point in such ropes is less than five times the effective combined weight of the rope and its tensioning weight. This provision shall not apply to any guide rope which is also used as a winding rope to raise or lower a stage, in which case the breaking force at any point in the rope shall not be less than 4,5 times the effective combined weight of the length of winding rope, and its share of the combined weight of the stage and attachments, the maximum permitted number of persons and the load of material.

2.2.2 Services

Most shafts are arranged to accommodate various services. These services usually take the form of electrical cables, pump columns, backfill columns and pipes and cables for other underground activities. In incline or circular (or elliptical) vertical shafts services can be placed in operating compartments without interfering with normal operation of conveyances and winders. Rectangular, timbered, vertical shafts have a compartment dedicated to services and in some shafts a ladder-way is also provided.

Where a separate compartment is reserved for services it is usual to provide a winder to handle installation and maintenance of these services. This winder is usually a simple single drum hoist (often called a Mary Ann) and is only used in attending to the services.

2.3 SHAFT SIZE.

Once it has been decided to establish a mine, and a decision has been made on the most appropriate output, decisions must be made on shaft size and layout to access the ore-body, bearing in mind that once constructed it cannot readily be modified with regard to depth or capacity[4 5].

Hoisting capacity and the quantity of ventilation air required are the two major requirements that dictate the cross-sectional area of shaft systems. For a deep level mine it is economically desirable that a shaft complex be designed to serve an area that will have a life span equivalent to that of the mine as a whole. Small shafts will serve a comparatively small area and so multiple systems may be required, whereas a very large shaft will have to provide for the whole area of the mine over its life span. Both these approaches have been used and experience seems to indicate that the optimum is between these two extremes.

2.4 HEADGEAR AND SURFACE LAYOUT

Whatever system of hoisting is chosen for transport in a shaft, arrangements have to be made to place the winder in the most convenient and cost effective position and to lead the ropes into the shaft in an efficient manner.

Most winders are positioned at some distance from the shaft to give adequate access to the shaft and conveyances. In this case the primary purpose of the headgear is to provide support for sheave wheels at the correct elevations and attitudes.

In the case of Koepe winders, it has often been found convenient to position the winder directly over the shaft and allow the ropes to hang directly from the winder down the shaft. In some cases deflecting sheaves are provided to align ropes on one side of the winder with an appropriate compartment. An extremely strong and rigid headgear is required for this application.

Further fundamental requirements are listed as follows:-

1. There must be provision for handling men, rock and material.
2. Adequate arrangements for disposing of ore and waste and subsequent storage for treatment or discard must be made.
3. There must be adequate space for marshalling men, equipment and material for transport in the shaft.
4. Important secondary items must be provided for, such as limit switches and other safety devices, rope detaching devices for drum winders or arresters for friction winders and catches for holding detached conveyances.

The height of the headgear is determined by other aspects of the winding system design and layout. The following are some of the factors which influence the height requirement:-

a. The legal requirements for over-run space above the highest stopping positions of man cage or skips.
b. The length of skip and the influence of tip length combined with the designed allowance for taking up rope stretch.
c. Any allowance which must be made for bin capacity and for tipping directly into the bin.
d. The arrangement of sheave wheels in the case of more than one winder operating in the shaft.
e. Any allowance which must be made for handling long material in the shaft, such as slinging pipes etc.

3 REQUIREMENTS FOR HOISTING SYSTEMS.

Any hoisting system must be safe and efficient. Many requirements for safety are perceived to have adverse effects on efficiency so all factors must be carefully considered. There is nothing less efficient than an accident, so in the long run the prime requirement is for safe operation.

Unless some method of balancing is used, the load on a winder is a very fluctuating one; heavy at the beginning of the wind, when raising the load, and light in the same direction at the end of the wind, requiring sensitive control of retardation and braking. When lowering the conveyance, heavy braking is required at the end of the wind. Some form of balancing is usually desirable and the choice of hoisting system is influenced by this consideration with respect to the power or "maximum demand" required to operate the winder.

3.1 WINDER SIZE.

Winder type and size are determined from the following, either individually or in combination:-

- Required depth of wind.
  For shallow winds most winder types can be used. However Koepe winders (see page 16) are not usually a satisfactory option at depths greater than 1800 m and the BMR winder (see page 14) then provides the capability for heavier end loads.
- Required output from shaft.
  Sometimes the required output is in excess of the capabilities of a single winder so the use of additional winders must be investigated.
- Maximum end load required.
  In many cases heavy loads are required to be transported in the shaft. It is most appropriate for these to be carried in a conveyance, so for transporting heavy machines such as trackless mining equipment, a cage and counterweight system is often used to provide for a cage with sufficient cross-sectional area.
- Available time for hoisting.
  The hoisting of men always takes precedence, but material and rock hoisting must also be properly scheduled. Due to power constraints it is often appropriate to schedule the hoisting of rock for periods of low power consumption. The time available for rock hoisting is then reduced to, say, 16 hours a day and six days a week.
- Specialised requirements.
  These include any other requirements such as are appropriate for kibble and stage winders for shaft sinking or for any other application.

3.2 ROPE SPEED.

Although there have been winders licensed in South Africa to operate at speeds of up to 24 m/s, there are none currently in use which operate at such high speeds. The highest winding speed at present is 19 m/s, but most winders operate at either 12, 15 or 18 m/s.

For a shallow winds, high acceleration and deceleration at the start and end of a wind are more important for high output than high maximum speed. This tends to increase rope loads and causes some increase in fatigue loading in ropes and other winder components. Deep shafts, on the other hand benefit from high winding speed and initial acceleration is not so important. The most important factor in limiting speed is the stiffness of guide and bunton arrangements. For this reason it is not expected that winding speeds will exceed current licensed values to any great extent.

3.3 MEN.

In South Africa, large numbers of men are transported to and from underground every day. Safety of these persons is the first consideration. Secondly is the ability to transport these people in a reasonable time. For instance on a large mine it may be required that 5000 men be transported underground, at a particular shaft, in a period of 2 hours and raised to surface again in the same time after a working shift.

Factors which need to be considered can be listed as follows:-

- The time for a single person to travel from surface to his working place must be as short as possible. i.e. There must be a minimum time spent in waiting when travelling in multiple shaft systems. Good organisation and a matching of winder capacities are therefore required.
- Loading and unloading of conveyances must be safe and quick.
- There must be no possibility of the winder moving before persons are loaded, or unloaded, and the conveyance doors closed and secured.
- As persons are loaded or alight from the conveyance there must be no dangerous movement of the conveyance due to rope stretch. The maximum movement of the cage due to this factor should not exceed 0,5 m. In deep shafts rope stretch may exceed this and suitable arrangements must be made to avoid this problem.
- In an emergency the conveyance must be stopped in a safe manner. Excessive deceleration causes injuries to persons in the conveyance.
- Ventilation in conveyances must be adequate for all persons travelling, especially for prolonged stoppages due to some cause such as a power failure or breakdown.
- There must be no possibility of conveyance doors opening inadvertently while travelling in the shaft.
- Persons must be protected from coming into inadvertent contact with anything in the shaft while travelling.

3.4 MATERIAL.

Material comprises such things as timber for underground support, explosives, all types of equipment and stores for use underground. Most material is transported in cars but sometimes large equipment needs to be slung under the conveyance because of size considerations.

The most important factors relating to transport of materials are similar to requirements for persons:-

- Loading and unloading of conveyances must be safe and quick.
- There must be no possibility of the winder moving before material is loaded or unloaded and the conveyance doors closed and secured.
- There must be no dangerous movement of the conveyance, due to rope stretch, while material is being loaded or unloaded from the conveyance.

- In an emergency the conveyance must be stopped in a safe manner. Excessive deceleration can cause material to move dangerously in the conveyance.
- There must be no possibility of material falling or being dislodged from the conveyance while travelling in the shaft.
- If equipment is slung under the conveyance there must be no possibility of it coming into contact with anything in the shaft. If there is any danger of the equipment moving due to aerodynamic effects the speed must be limited to avoid this.

3.5 MINERAL.

The time taken to hoist mineral is usually not of prime importance, provided throughput is maintained: It is not usually necessary for ore which has been broken to be transported within a short time span. In most mines there is sufficient flexibility in the transport system to stockpile a certain amount of mineral to allow for variations in mining and also to allow for hoisting of mineral at times of reduced electrical demand.

Factors which must be considered when hoisting ore are:-

- Loading must be smooth and without shock loads even when it is rapidly done.
- The conveyance must not be overfilled and there must not be any spillage from the conveyance during the wind.
- The amount of ore must be accurately measured to ensure that there is no overloading. This measurement can be either volumetric or by load monitoring.
- Discharge of the mineral must also be uniform and without introducing shock loads into the system.

3.6 REGULATIONS

The following government regulations[2] give some of the legal requirements for mine winders. Of course all of Chapter 16 of the regulations relates to mine winding, but some appropriate regulations related to the design and layout of winders are quoted.

16.4 In calculating the total mass of persons for the purpose of regulation 16.6 and regulations 16.29.1 to 16.33 inclusive, 75 kilograms shall be allowed for each person.

16.5 The winder shall be such that:-

(a) When running at various speeds with light or heavy loads it can be readily slowed and stopped and after being stopped, except after a tripout, can be restarted in either direction; and

(b) Can lift from the bottom to the top of the shaft the maximum unbalanced load on one drum. This provision shall not apply where other means exist enabling persons employed underground to reach the top of the shaft.

16.6.1 Each winding drum or winding sheave shall be provided with an adequate brake(s) which shall be kept in proper working order and shall be capable of:-

(a) Holding without slipping the conveyance loaded with the maximum load in the maximum out-of-balance position as allowed in the prescribed permit together with an applied torque in the direction of gravity equivalent to the torque required to lift the maximum allowable out-of-balance load; and

(b) Stopping the winder from its permitted speed with its maximum allowable load descending, at a rate such that in conjunction with the safety devices, required in terms of regulation 16.9.1, an approved degree of protection can be maintained.

16.6.2 Every winding drum shall have flanges or horns, and if the drum is conical or spiral, such other appliances to prevent the rope from slipping off or coiling unevenly.

16.6.3 Except for friction drive or sheave type of winders, there shall not be less than 3 turns of rope upon the drum when the conveyance is at the lowest point in the shaft from which hoisting can be effected. The end of the rope where applicable shall be fastened securely.

16.6.5 Every winder drum at the right hand side of the winder facing the shaft shall have an overlay rope; where only one drum is used it shall have an overlay rope.

4 TYPES OF WINDERS.

The different types of winder installations are discussed in this section together with their relevant terminology.

The following definitions taken from the statutory regulations[2] distinguish winders from lifts:

"Automatic winder" means any winder, hoist or other appliance used or intended to be used for the conveyance of persons, material, explosives or minerals by means of a conveyance in any shaft where the driving machinery is operated automatically without a driver in attendance, but shall not include any lift or construed to have such meaning during such times such winder is operated manually.

"Manually driven winder" means any winder, hoist or other appliance used or intended to be used for the conveyance of persons, material, explosives or minerals by means of a conveyance in any shaft where the control system of the driving machinery is normally operated manually but excluding any lifting machine or lift.

"Lift" means any installation used or intended to be used for the conveyance of persons, material, explosives or minerals by means of a car fitted with safety catches running in a hatchway on fixed solid guides serving defined landing levels, where the control system of the driving machinery is not normally operated manually from the motor or engine room.

"Winder" means any automatic or manually operated winder.

There are two basic hoisting systems:-
a. A system involving the use of drums to which the rope is attached and
b. A system in which friction is used as the means of driving the rope.
Each system has several sub-types and those in use in South Africa will be considered.

4.1 DRUM WINDERS.

A drum winder is one where the rope is securely connected to the drum and is wound onto the drum when the conveyance, which is attached to the other end of the rope, is hoisted up the shaft. When lowering the rope is unwound from the drum. It should be noted that, although a reel winder using a flat rope fits this description, this type will not be discussed as there are none of this type operating in South Africa. (Note: They are still common in Europe.)

There are many arrangements and types of drum. The simplest is a single drum with only one rope on the drum. The drum has a plain parallel barrel and the rope is wound onto this without any form of guidance. This type is used for small installations and is not much different from a large winch installation.

The power requirement for a winder operating with only one conveyance becomes excessive as size and depth of wind increases. Consequently two conveyances are used, each connected to ropes which are wound onto the drum in opposite directions and providing some measure of balance. An option is to connect both ropes to the same drum, but at opposite ends of the drum. With this arrangement as one rope is being wound onto the drum the other is unwinding. See Figure 7. This is an apparently simple arrangement, but is very difficult to operate satisfactorily due to the difficulty of adjusting rope lengths, both on installation

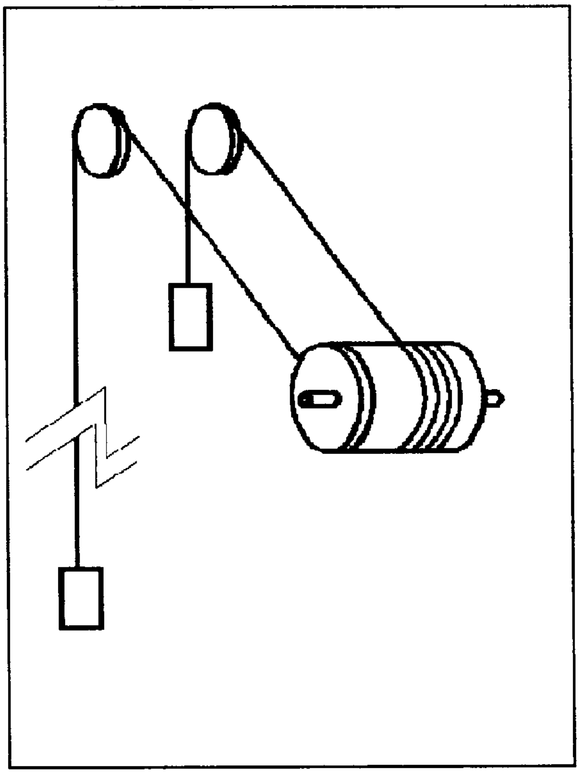

Figure 7 Parallel-drum Winder

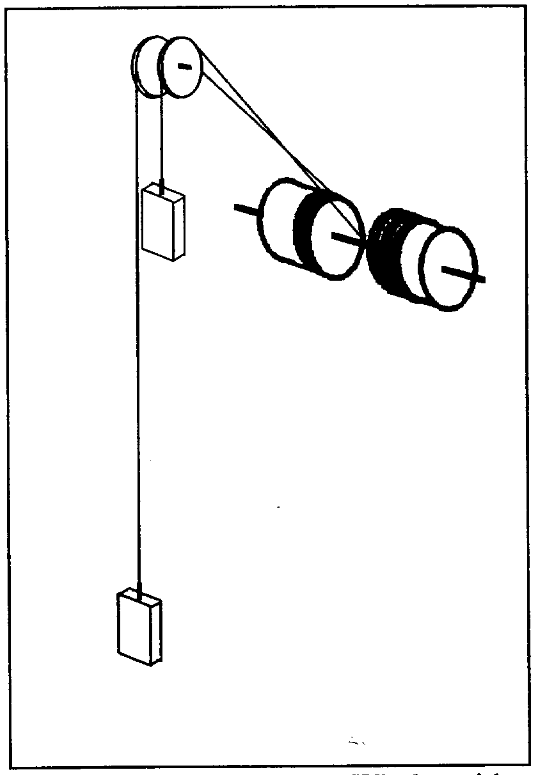

Figure 8 Double Drum Winder with Parallel Barrel

and in maintenance. The logical answer to this is to have two separate drums on the same drum shaft but connected by means of clutches. This is the double drum winder. See Figure 8.

4.1.1 Double Drum Winder.

The rationale behind the double drum winder has just been explained. This is a very flexible arrangement, particularly if both drums are fitted with clutches. By clutching it is possible to operate both conveyances from any intermediate level in the mine shaft.

Before the advent of a large electrical power grid there was a practical limitation on the maximum torque which could be used for hoisting from the bottom of the shaft even though the winder was operated with two conveyances. With deeper shafts the relative effect of rope mass became significant and various methods were tried to reduce the maximum torque required. The most obvious was to use a balance, or tail, rope. Many drum winders were fitted with tail ropes and operated satisfactorily. Of course the use of tail ropes reduced the flexibility of the drum winders to which they were fitted because operating from multiple levels became more complicated, if not impossible.

Other methods of reducing starting torque were used which involved redesign of the winder drums. Conical drums were introduced and as depths became greater parallel sections were added to both the small diameter and the large diameter of the drum. These were known as bi-cylindro-conical drums, Figure 9, and many successful installations were the result. This design resulted in extremely large winder drums which posed problems in manufacture and transport. All these winders were manufactured overseas by casting.
The last bi-cylindro-conical drum to be installed in South Africa was prior to 1940. The high cost of manufacture and the possibility of using higher starting torques due to developments in electrical power distribution have made further use of this type of winder unlikely. Since 1950 new drum winders commissioned in South Africa have parallel drum barrels.

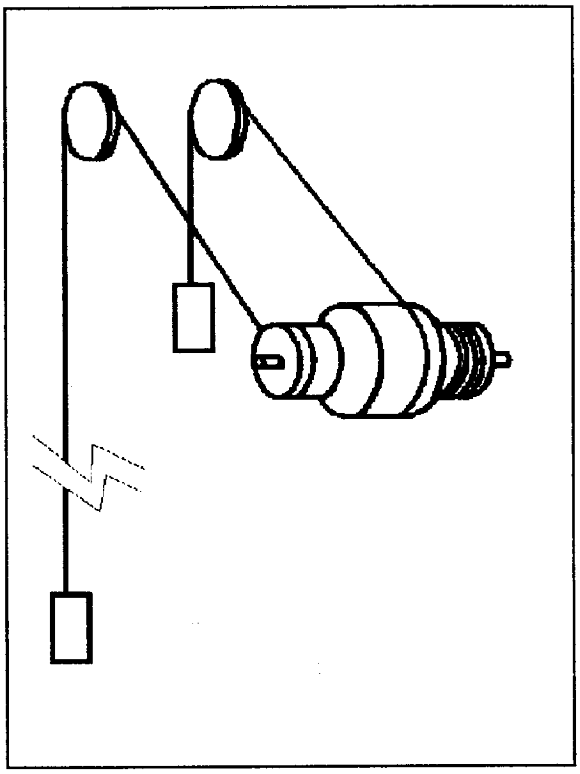

Figure 9 Bi-cylindro-conical Drum Winder

4.1.2 Sinking Winders.

A sinking winder must be able to hoist its maximum load from the maximum winding depth under the most adverse conditions. Because of blasting in the shaft bottom all equipment must be moved a safe distance away from the blast. This means that a conveyance operating in balance can not approach the shaft bottom where it can be damaged. In consequence the winder must be capable of hoisting the maxim unbalanced load in one conveyance.

o **Kibble Winders.** The above mentioned requirement coupled with the fact that the use of balance ropes is impractical eliminates the use of simple friction winders for hoisting men, materials and rock in a sinking shaft, so drum winders are always used. Double drum winders with parallel barrels are used because conical or bi-cylindro-conical drums are unsuited to this type of application, where the depth of wind is continually changing. Special arrangements used to be required to ensure that the winder could hoist from the shaft bottom in the event of a power failure. This requirement is no longer applied subsequent to the introduction of electric blasting from the surface when all persons have been raised out of the sinking shaft. In all other respects kibble winders have similar requirements to normal drum winders.

o **Stage winders.** The sinking stage is required to support several diverse functions. Its primary function is to provide adequate cover to protect personnel working on the shaft bottom from falling rocks or material. Other functions are to provide a platform (or platforms) to enable workmen to erect shaft support work or to erect shuttering for concreting a shaft lining. In addition the stage also provides a base from which a mechanical grab can assist in loading broken rock from the shaft bottom. To support a stage for these functions multiple falls of rope are required. Both drum and friction type winders (see page 18) have been developed for this duty. Drum winders are usually arranged with multiple drums, each driven from a lay-shaft through a clutch and gearing. Each drum is provided with its own brake which is suitably interlocked with the clutch to ensure positive control at all times. Four drums are usually used and the ropes may operate in either one or two falls. Occasionally a double drum type winder is used and the ropes reeved in multiple falls.

4.1.3 BMR Winders.

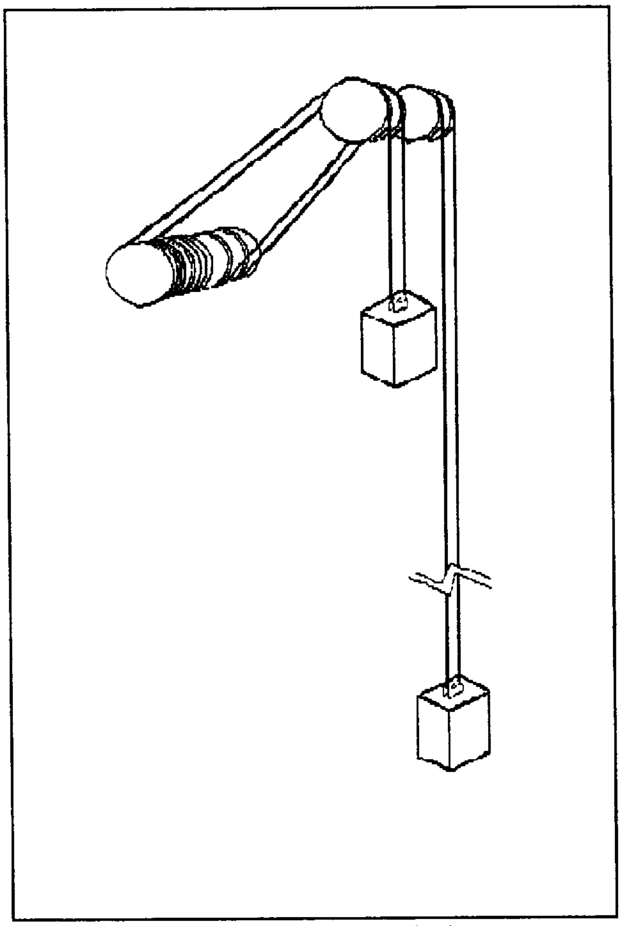

Figure 10 Blair Multi-rope Winder

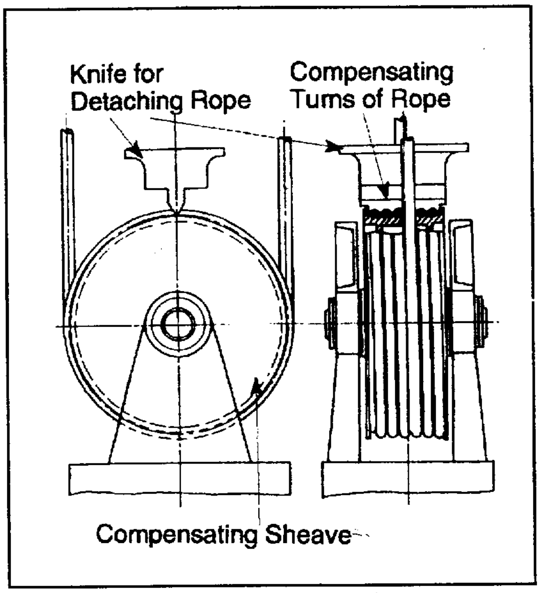

Figure 11 Sheave Type Blair Compensator

The Blair Multi-rope winder[6 7] is a development of a drum winder which allows the use of more than one rope to support the conveyance, see Figure 10. Each drum is divided into two compartments. Each rope coils in its own compartment and is monitored by a device which ensures uniform coiling. The advent of the Lebus coiling system (see paragraph 5.3.3) ensured the success of this type of winder.

Because of inherent differences between different ropes and the machining tolerances which must be catered for, some form of tension compensation must be provided. The original BMR design incorporates an equalising sheave (drum) mounted on the conveyance to which each rope is connected. The sheave is free to rotate on a shaft and each rope is coiled for up to three turns in an opposite direction in grooves on the sheave. Compensation is achieved by the higher tensioned rope being payed out and the lower tensioned rope being coiled onto the sheave. Figure 11 is a schematic diagram of the arrangement.

An alternative arrangement for rope compensation is shown in Figure 12 where the headgear sheaves are mounted on interconnected hydraulic cylinders which allow movement of the sheaves to achieve compensation.

This design of compensator has made the use of more than two ropes per drum feasible. Designs have been produced for a BMR winder with three ropes per drum but have not been implemented due to capital constraints.

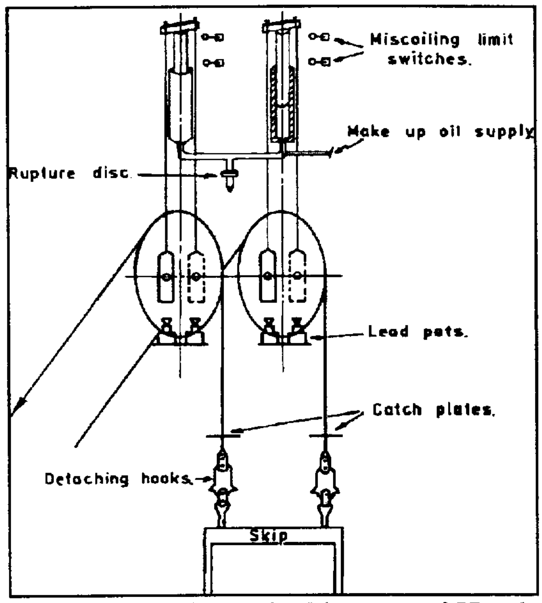

Figure 12 Schematic Diagram of Headgear Sheave Compensator

4.1.4 Small Hoists.

These are small winders driven by a motor of less than 250 kW and which do not carry persons. They are exempt from many of the requirements of the regulations.

4.2 FRICTION WINDERS.

Friction winders comprise all the various arrangements of Koepe winder as well as lifts and other arrangements which use fleeting wheels or double drum capstans.

4.2.1 Koepe Winders.

Koepe winders are the simplest of the friction winding systems. The rope makes approximately half a turn round the driving drum and is driven (supported) by an insert made of friction material which provides the required force to drive the system. The rope arrangement comprises a head-rope, a tail (or balance) rope and either two conveyances or a conveyance and a counterweight. More than one head-rope may be used and there are systems in the world which have as many as 10 head-ropes, however four or six head-ropes are most common in South Africa. The tail-ropes are required to balance the system. There is no necessity to have an equal number of tail-ropes as head-ropes, as long as the total mass per unit length of all the tail-ropes is the same or slightly heavier than the total of all the head-ropes.

Two alternative arrangements are used. A tower mounted system or a ground mounted system.

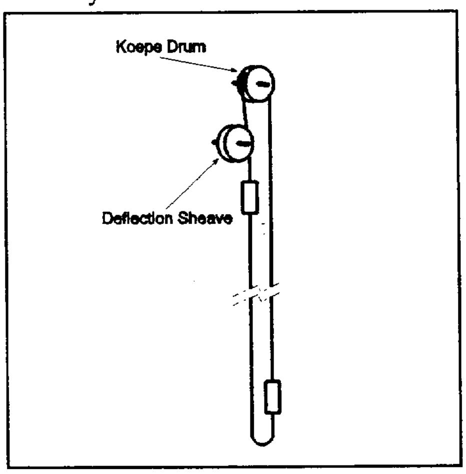

Figure 13 Tower Mounted Koepe Winder

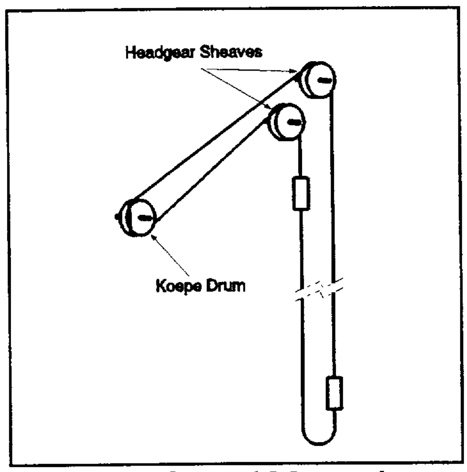

Figure 14 Ground Mounted Koepe Winder

4.2.1.1 Tower Mounted. The tower mounted system, Figure 13, often incorporates a deflection sheave to align the ropes with the centre-lines of the shaft compartments. This obviously introduces additional bending of the ropes which affects rope performance. It has been found that winders with no deflection sheaves give better rope performance and so are preferred.

4.2.1.2 Ground Mounted. The ground mounted system also has two arrangements; one in which the headgear sheaves are in line with drum and the ropes and are mounted one above the other, Figure 14, and the other where the headgear sheaves are mounted side by side at the same level. The latter arrangement, having the sheaves side by side, is not favoured as it introduces the complication of a permanent fleet angle which can affect rope performance. In spite of the extra bending introduced by the headgear sheaves, ground mounted Koepe winders have one definite advantage over the tower mounted ones. The layout ensures that the conveyances do not approach too closely to the winder drum and so the effect of discrepancies in winder drum tread lengths are not as critical to rope performance and tread wear.

4.2.1.3 Tail-rope Arrangements. The Koepe system necessitates the use of balance ropes to reduce the requirement for frictional force at the Koepe drum. This balance is necessary in shallow winders and becomes more important as the depth of wind becomes greater. However, in a balanced system the available frictional force for hoisting a payload is least for shallow winders and increases with depth as the total mass of the system increases. It is usual to arrange for the mass per metre of the tail-ropes to match that of the head-ropes or to be slightly heavier. A difference in mass of up to 5% can be beneficial from the power consumption and braking point of view if the tail-ropes are the heavier.

4.2.2 Lifts.

Lifts are devices used for hoisting men and material under automatic control initiated by a person desiring to travel and, as such, are equivalent to mine winders. A lift comprises a conveyance and counterweight supported by ropes and travelling in fixed guides. The conveyance usually has a trailing cable to provide power for lights and the electric circuits for control. Figure 15 illustrates the general arrangement for a friction driven lift.

The lift is operated from the conveyance by anyone wishing to travel, or an operator, and does not have a driver. Because there is only one conveyance the control circuits allow for travel to any predetermined stopping place (or landing) which is equipped with interlocked doors which make it impossible for the lift to move until the doors have been closed.

This flexibility is counterbalanced by stringent regulations[2] which makes it possible to operate safely within the operating parameters of:

a) control from the conveyance and
b) less frequent inspection and maintenance requirements than for winders.

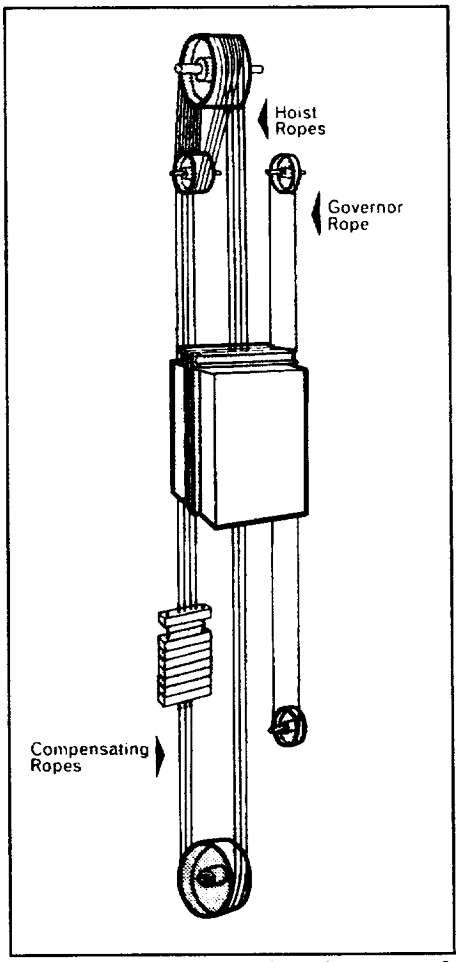

Figure 15 Schematic Diagram of Lift Arrangement

4.2.3 Blair Stage Winder.

The Blair stage winder[8] [9](see Figure 16) has simplified the sinking of vertical shafts. The use of only two ropes in multiple falls has enabled full use of the available rope strength because the layout is easily arranged to ensure equal tensions in both ropes. In addition multiple falls of high strength rope enable the use of large sinking stages designed for many operations.

The winder comprises two friction type winches driven from the same drive shaft suitably connected by means of clutches. Each winch is equipped either with a fleeting wheel designed for operation in both directions or a double drum capstan. Because of problems with snatching, especially when lowering the stage, the use of a double drum capstan is now universal. Each winch has its own brake, operated as a unit, but interlocked with the clutch gear. The clutches are only required for small adjustments in the ropes due to slight inequalities in rope diameter or capstan diameter. As with any friction drive a back tension is required to generate the required operating tension. This is provided by means of a tensioning device incorporated in the rope storage system. Each stage rope is coiled on its own storage drum and tensioned by means of a weight operating in a compensating tower. As the winder raises or lowers the rope connected to the stage, the counterweight is either raised or lowered in its tower. At the top and bottom of the tower limit switches are provided to start and stop the storage drum as required. This arrangement provides a simple means of maintaining a constant tension on the low tension side of the winder capstan.

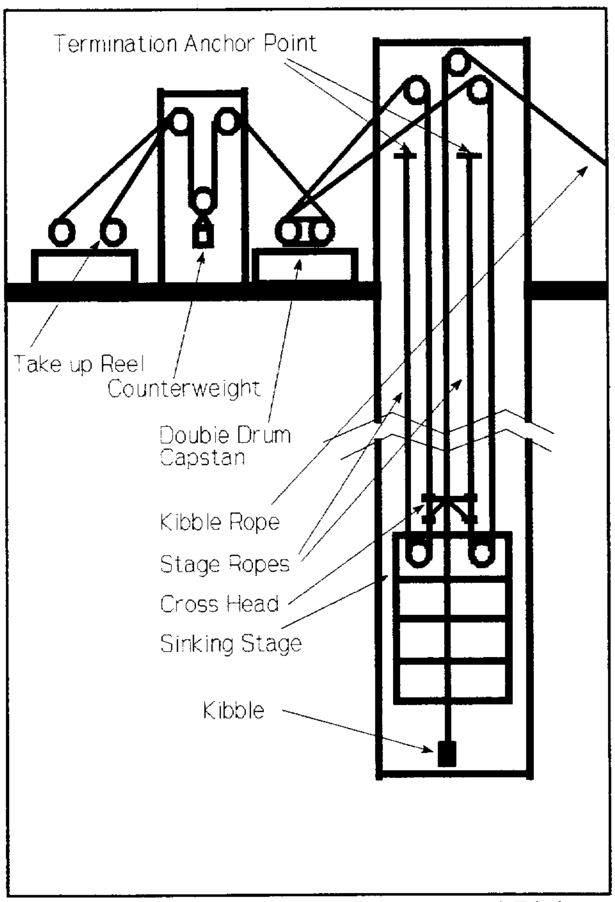

Figure 16 Schematic Arrangement of Blair Stage Winder

Each rope is usually reeved in four parts, which means that the stage is supported by eight times the strength of the rope. Of course more, or less, falls can be used depending on requirements. Six falls have been used on occasion.

Because of the large number of supporting lengths of rope it is easily arranged for these ropes to be used for guiding the conveyances. The use of such guides for four kibbles is commonplace.

4.3 Other Winders.

There are other winders which have been used in South Africa, which due to operating difficulties or other performance problems are no longer used.

4.3.1 Reel Winder.

A reel winder operates with a flat rope. The rope is attached to the reel and winds upon itself in hoisting the conveyance up the shaft. See Figure 17. This arrangement provides a measure of automatic torque compensation in that lower torque is required when starting from the bottom of the shaft compared to the high torque at the top of the shaft when all the rope is wound onto the drum. The disadvantage of this system is the high cost of the flat rope, which is still hand made to a large extent, as well as the severe wear and corrosion problems encountered.

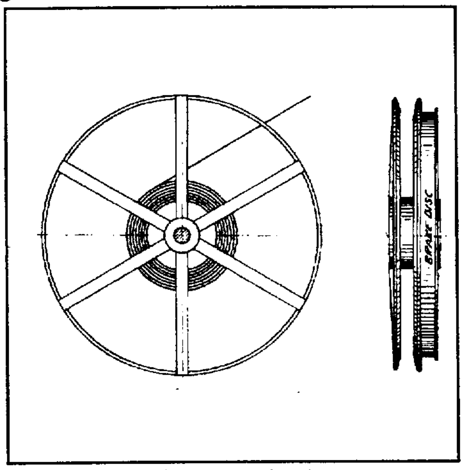

Figure 17 Schematic Arrangement of a Reel Winder

4.3.2 Whiting Hoist.

This type of winder, see Figure 18 for schematic diagram, is essentially a double drum friction type winder. Both drums are driven and the single host rope makes two or three turns around both drums. A tail arrangement provides adjustment for rope stretch or for the regular cutting of the rope for statutory testing. Practical machining tolerances make it impossible for tread lengths to be kept within the requirements for successful operation and so loose rings, called "Walker rings", are used to provide means for a limited amount of slip and so maintain appropriate tension between the turns of rope on the drums. A balance rope is also required.

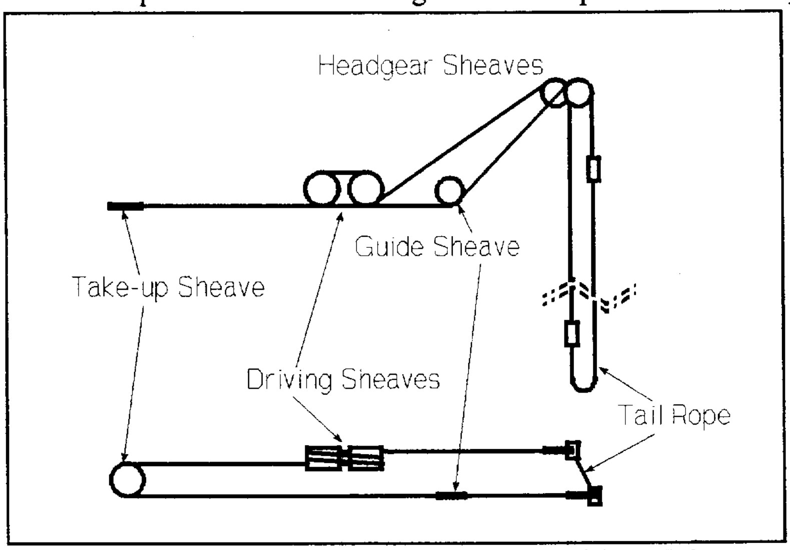

Figure 18 Schematic Arrangement of a Whiting Hoist

In addition to the high maintenance requirement of the "Walker rings" coupled with the very high internal stresses in the system, particularly bearings, this arrangement has all the problems and disadvantages of the Koepe system.

5 COMPONENTS OF DRUM WINDERS.

The safe operation of any winder is dependent on every item which makes up a winding system. Many of these directly influence stress levels in the system and some are specifically related to rope performance.

5.1 TYPE OF POWER AND CONTROL.

The motive power for driving a winder is either provided mechanically or electrically. Mechanical devices range from water wheels to steam engines. In South Africa all major winders are electrically driven. However, on small remote properties where electrical power is not readily available petrol or diesel engines are used.

The electrical power and control systems used are either AC or DC. Each type of power system used is essentially a compromise between cost and effectiveness of control. Besides being able to operate the winder at the normal operating speed, control systems must be flexible enough to allow for operation at slow and creep speeds for rope and shaft inspection as well as shaft maintenance. The control system must also be able to safely move a fully laden conveyance in any direction, even in an unbalanced single drum operation.

5.1.1 DC System.

The shunt wound DC motor provides the basis for a system which gives precise and excellent speed control. The motor is usually direct coupled to the winder drum. This limits mechanical complication but results in a large and expensive motor to operate at the low rotational speeds required. The direct current required for this system is provided by thyristors which have now superseded the motor generator set used in older installations. However many winders with motor generator sets are still in service.

5.1.2 AC System.

In its simplest form a squirrelcage motor is used which usually runs at 3000 rpm. In more sophisticated systems control is provided by means of a liquid controller and special circuitry to provide a measure of electrical braking at the ends of the wind. Final control of the winder is by means of mechanical brakes. Because motor speed under full speed conditions is strictly limited by motor design and frequency of power supply, gears are required to drive the winder drum at the correct speed.

The attractive financial implications of the lower capital requirements for AC control have resulted in specialised control systems which attempt to provide the same measure of control available in DC systems. A recent development, a large cycloconverter fed vector controlled AC induction motor[10], is reputed to give the excellent and sensitive control necessary for winders which will be operated under the reduced design factors of the regulations promulgated in 1995.

5.2 BRAKING.

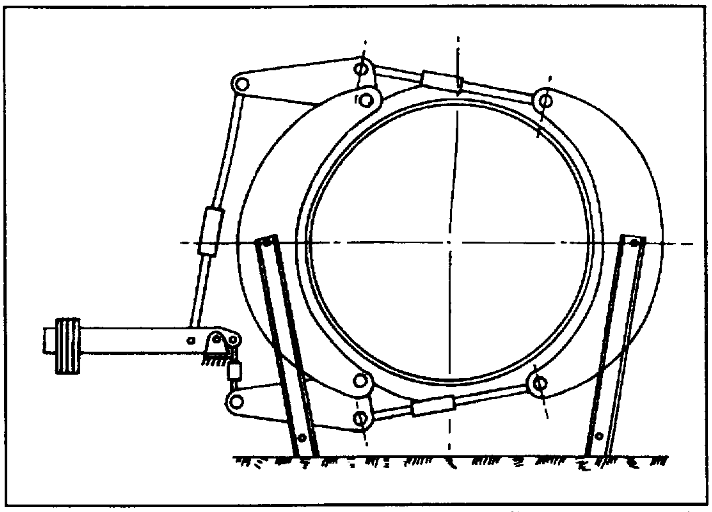

Figure 19 Floating Shoe Type Brake System - Dead-weight Applied

Of all the systems which make up a winder the control and operation of braking are the most important for the safe use of the winder. The regulations only specify the maximum braking force which must be available, however the braking force required is dependant on the speed and type of operation being undertaken as well as the position of the conveyances in the shaft. For example when a double drum winder is being clutched it is effectively being operated as a single drum winder. Although primarily designed to control the winder in balanced operation the brakes must be so arranged that sufficient braking force is available to control a down-going conveyance (or counterweight) and on the other hand if the conveyance is being raised the brakes must be applied suitably gently until the conveyance has stopped (see paragraph 5.5.2 on page 31). This requirement is of particular importance on single drum winders and double drum systems where the drums are only electrically coupled and not mechanically.

Furthermore the brakes must be "fail-safe". This means that in the event of a power failure or other untoward happening the brakes must be applied automatically and without external power. This is achieved by using an external force to remove braking effort and allowing the brakes to be applied by gravity or the force of compressed springs when required.

Two alternative brake arrangement are the drum type and the disc type.

5.2.1 Drum Type Brakes.

Although band brakes are still used on winches and small hoists they are not suitable for mine winders. Post type brakes of various designs are generally used, the most common being the suspended type with a floating shoe. Figure 19 shows a common arrangement.

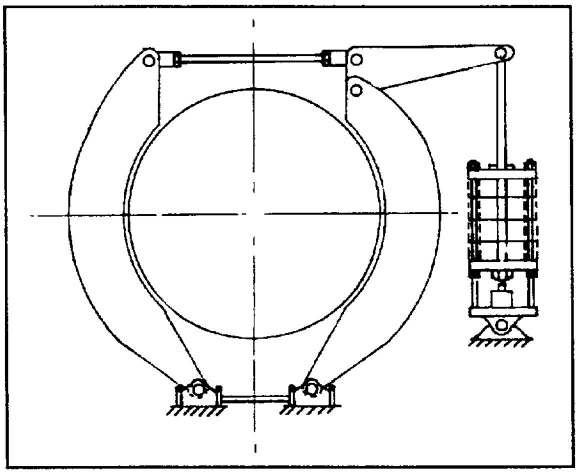

Figure 20 Calliper Brakes - Spring Activated

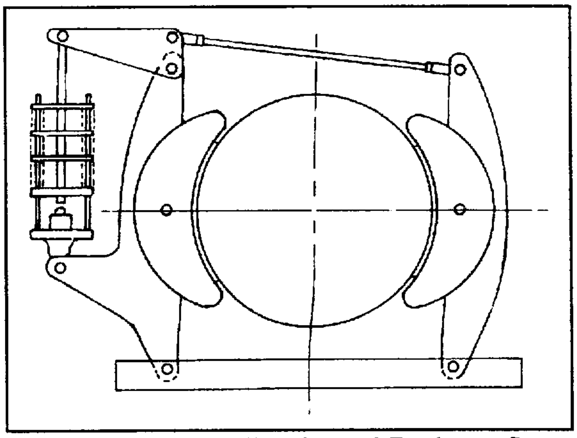

Figure 21 Centrally Pivoted Brakes - Spring Applied

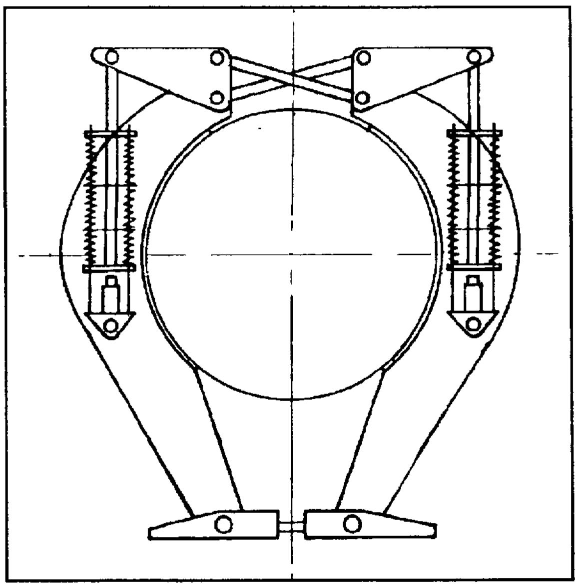

Figure 22 "Black's" Type Brake System

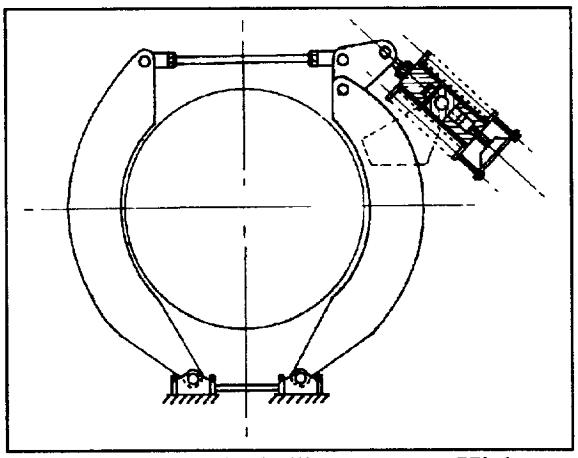

Figure 23 G.E.C. Calliper Type - High Pressure Oil Activated

Other arrangements which can be found in South Africa are shown in Figure 20, Figure 21, Figure 22 and Figure 23.

Considerable research has gone into the composition of the brake friction material which is fastened to the brake shoes with a suitable backing material such as timber.

5.2.2 Disc Brakes.

The success of disc brakes on motor vehicles obviously led to the use of this type of brake in other applications. They have been used on mine winders with considerable success.[11]

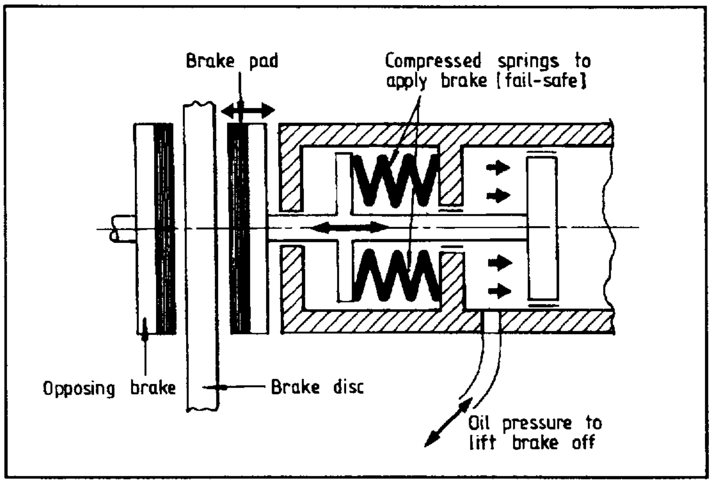

Figure 24 Principal of Disc Brake

Figure 24 is a schematic diagram which illustrates how a disc brake works. The brake pads are forced against the disc with a force equal to the difference between the compressive force in the springs and the hydraulic cylinder force which is controlled by the brake control system. Details of a disc brake unit are shown in Figure 25.

Some of the main advantages of disc brakes on mine winders are as follows:

o **Contact Pressure.** The contact pressure distribution between the disc pad and the flat surface of the disc is more uniform than that obtainable on the curved surfaces of drum type brakes.

o **Heat Input.** As disc pads are mounted in pairs heat input during braking is uniform on both sides of the disc which reduces heat distortion.

o **Multiple Units.** Two to four pairs of disc pads can be installed to operate on a single disc. The braking force available is proportional to the number of units installed.

o **Standardisation.** Commercially available proprietary disc brake units are normally used. This results in standardisation of the brake units for more than one winder on a shaft or mine.

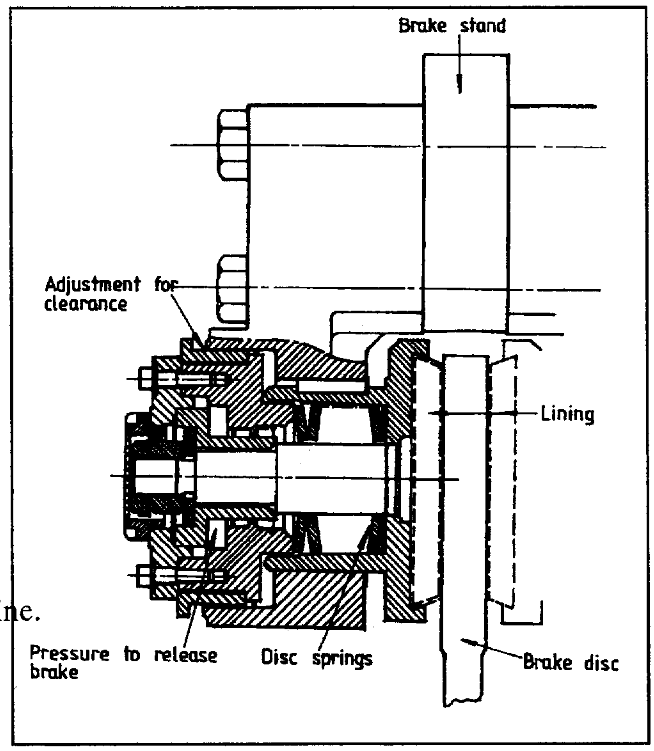

Figure 25 Details of Disc Brake Unit

5.3 DRUMS.

The design of winder drums is a subject for study in its own right. There are several concepts relating to rope usage which must be incorporated in the design if adequate rope performance is to be achieved[12]. These are listed as follows:-

- The drum barrel must be a circular cylinder or cone. If the barrel runs out of true, vibrations and stresses will be set up which will result in poor performance.
- The drum barrel must be stiff enough to ensure that the hoop stresses caused by the rope coiling on the drum do not cause sufficient deflection of the drum for some of the rope turns to become slack.
- Drum flanges must be perpendicular to the axis of rotation of the drum, especially in the case of multi-layer coiling.
- Drum flanges must be stiff enough to resist dishing due to rope forces in the case of multi-layer coiling.

5.3.1 Drum Cheeks.

For multi-layer coiling the drum cheek (or flange) of a parallel drum provides an essential part of the control mechanism for successful operation. The cheeks must be located at the correct distance apart, taking rope diameter tolerances into account, and be perpendicular to the axis of rotation of the drum. The cheek must be maintained in a smooth and true condition. Any wear which occurs on the cheek where the rope contacts it must be kept within very close limits.

5.3.2 Fleet Angles.

The angle formed between the rope and the perpendicular to the drum axis is termed the fleet angle. When the rope is in contact with the flange at either extremity of the drum the angle between the rope and the flange itself is called either the maximum or minimum fleet angle. Figure 26 illustrates this concept.

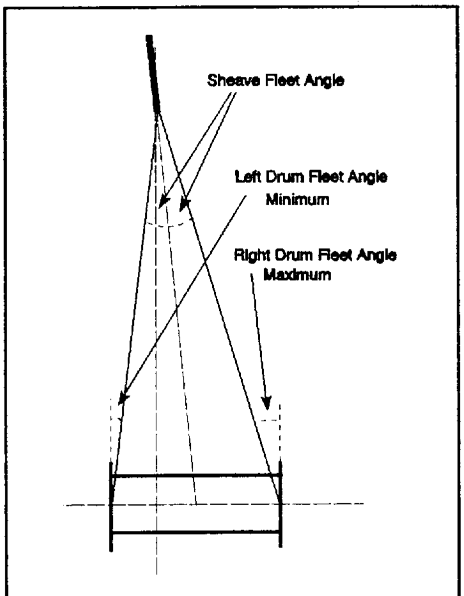

Figure 26 Fleet Angles

For high speed mine hoisting, the maximum fleet angle at a drum flange should not be more than 1° 30'. The minimum fleet angle at a drum flange should not be less than 0° 15' with 0° 30' being the preferred figure. The danger of too small a fleet angle at the flange, when operating with more than layer of rope, is the possibility of the rope climbing on itself for part of a drum turn and then falling off with a resultant bang and impulse in the rope. Too large a fleet angle can give problems with miscoiling especially if there is considerable catenary oscillation.

5.3.3 Drum Barrel and Grooving.

Although most of the following comments apply to other drum types they are specifically intended for applications with parallel drums.

o **Barrel.** Multi-layer coiling compresses the drum elastically during every winding cycle. The compression of the drum reduces the rope stresses in the underlying rope layers and dead coils. During uncoiling the rope stresses are restored again. The drum barrel must be designed to limit the change in stress in the rope, due to this factor, to acceptable limits. The drum barrel must not deform permanently under normal rope loading, as any dishing or hogging of the drum surface can have unacceptable consequences for the rope.

If grooves are machined into the drum barrel, sufficient metal must be provided to allow for wear of the grooves. Many winders have a plain drum to which wrapper plates are fastened by bolting. It is most important that these wrapper plates are securely fixed so that there is no movement of the wrapper plate relative to the drum surface.

o **Grooving.** The simplest arrangement, and one which is often used, is to operate the rope on a plain drum. This involves careful planning of fleet angles (see Figure 26) to allow for correct coiling. If the rope is coiled from the incorrect flange with respect to the sheave wheel (i.e. from the flange with the greater fleet angle), the rope will tend to open coil until the relative angle between the rope and the drum centre line reaches 90°.

If there is only one layer of rope, it can be coiled spirally. However, for multi-layer coiling, when the rope is coiled onto a parallel plain drum to form the first layer, the coiling pattern must be parallel to the flanges, with the shortest cross-over length that will form naturally. The first and last turns of rope must fit snugly against the flanges for good coiling and to avoid damage at layer cross-overs. i.e the rope must just fill the bottom layer on the drum.

The most positive method of controlling the coiling of rope onto the drum is by the use of grooved drums. One of the oldest methods of grooving a drum was to merely provide parallel grooves on the drum, spaced at the appropriate pitch. The depth of groove was only about 10% of the rope diameter and the rope had to climb over the ridge at each turn cross-over. The recommended dimensions for groove pitch and groove diameter are shown in Figure 26

P = Nominal rope diameter + 5%

R = Nominal rope radius + 7,5%

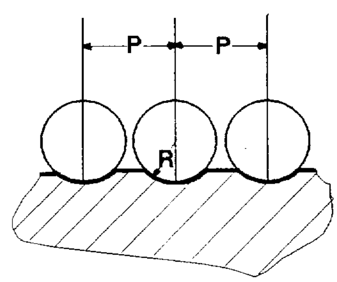

Figure 27 Dimensions of Parallel Grooving

This method works extremely well up to four layers of rope, after which coiling tends to be somewhat erratic.

Because the actual point of turn crossover is not precisely controlled, but is dependent on the actual rope diameter, the coiling pattern changes as the rope beds down and wears. This feature tends to spread the localised wear at turn and layer cross-overs with positive effects on rope performance. However, a disadvantage of this system is the tendency for the drum grooves to wear at the cross-over points which in time become so irregular that the rope is often damaged at these places. To obviate the irregular wear and damage to the grooves at the cross-over points, the area where the rope is expected to cross over from turn to turn can be machined smooth to remove the groove shoulders. Correctly done, this has proved to give satisfactory results.

Where more than four layers of rope are to be used on the drum, or where perfect coiling is required as on a Blair multi-rope winder, one of the patterned coiling systems should be used. The best known in South Africa is the Lebus system, which can provide perfect coiling for as many layers as are required. In this system the rope is guided in grooves to operate with two half cross-overs on every turn. This pattern repeats on every layer resulting in perfect coiling. Figure 28 is a schematic diagram which illustrates the pattern of the grooves and the positioning of wedges, spacers and risers. Advantages and disadvantages of the system are listed in Table I:-

As is often the case the advantages outweigh the disadvantages and consequently this system is commonly used on South African winders, especially those operating at great depth. This system of coiling has greatly simplified the operation of BMR winders, where the exact matching of rope coiling on each drum is of great importance.

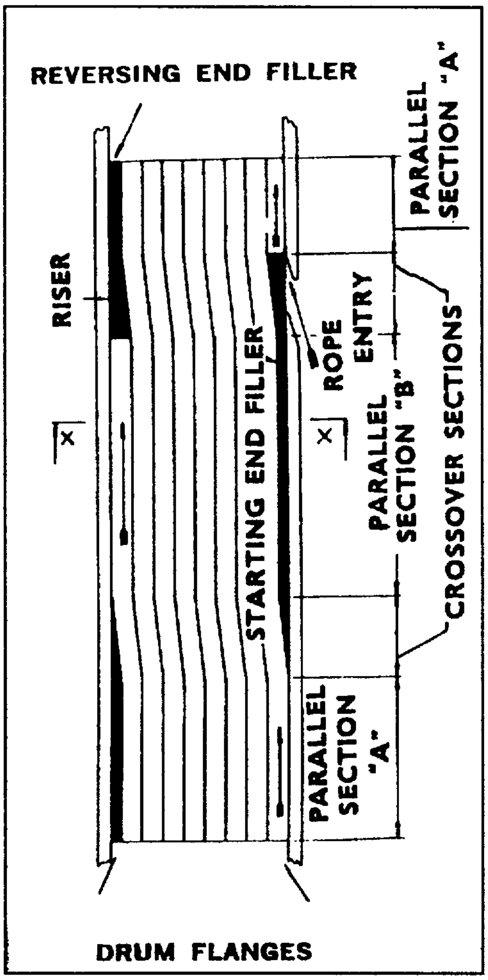

Figure 28 Schematic Diagram of Lebus Pattern

5.3.4 Rope Connection to the Drum.

To comply with the regulations there must always be at least three turns of rope on the drum when the conveyance is at its lowest position in the shaft. Due to friction between the rope and drum these three turns effectively reduce the rope force at the drum termination. Nevertheless, the rope connection to the drum should be capable of sustaining a force of at least 80 % of the rope breaking strength. There are several methods for making the termination at the drum.

o **Thimble Splice or Socket.** The types of rope termination used for connecting the rope to the conveyance can be used, with an anchor pin mounted in a suitable position inside the drum.

o **Clamps.** Two or four bolt clamps, arranged to fasten the rope onto one of the drum spokes, make a satisfactory termination. This is a commonly used system in many

Table I Advantages and Disadvantages of Lebus Coiling

Advantages	Disadvantages
Perfect repeatable coiling. Can operate on as many layers as are required. Multiple ropes can be made to coil in unison. The rope is subjected to a lower transverse impulse at the turn crossovers which can reduce rope oscillation in the catenary between the drum and the head-gear sheave.	The perfect coiling means more localised wear which can result in shorter rope life. To spread the wear there is additional maintenance required such as more frequent pulling in the rope on the drum to move the parts which have been subjected to localised wear. Rope dimensions and changes in diameter due to wear or operating conditions are more critical. Usually supplied as grooved wrapper plates which have to be fitted to the drum. This system often results in loose fixing bolts which can damage the rope or the possibility of the wrapper plate becoming slack and allowing the rope to loosen on the drum which can lead to premature rope deterioration and discard.

parts of the world. In some cases the rope is clamped in an undulating path, to achieve the maximum frictional effect.

o **Clove Hitch and Rope Clips.** A secure method is to thread the rope round the drum shaft, inside the drum, in the form of a clove hitch. The free end of the rope is clamped to the main part of the rope by means of two or three rope clips. This arrangement has an efficiency of about 80 %, but has the advantage that the rope is secured round the basic support of the winder. This method of terminating the rope at the drum is the most commonly used in South Africa. The chief disadvantage is the difficulty of making the clove hitch and also making adjustments when pulling in the rope for maintenance purposes. This is particularly the case on winders operating at great depths, where large diameter ropes have significantly increased the difficulty.

5.3.5 Operating Rope Storage.

If a rope on a drum winder remains in service for more than six months, an additional length of rope is required to allow for the statutory cutting of the rope for testing and also for remaking the termination at the front end. There is also a requirement for additional rope to allow for the maintenance procedure of moving the rope on the drum, by cutting the back end. The additional length of rope required is a multiple of the lengths to be cut off and the expected number of operations. In other words, a greater length of extra rope is required for a rope that remains in service for 8 years than for a rope which is discarded after only 1 year in service.
It is most usual to accommodate this extra length of rope on the drum and operate with additional dead turns. In most cases this is a satisfactory arrangement. Wear on the drum

is spread over a greater area as a result of the regular shortening of the rope. There are limits to the amount of extra rope which can be accommodated in this way because it is unwise to operate with more than a full layer of dead rope. The rope becomes trapped at the layer cross-over and the first layer quickly becomes slack with its attendant problems.

There are also some drum designs which make this practice impractical, such as a winder with conical drums.

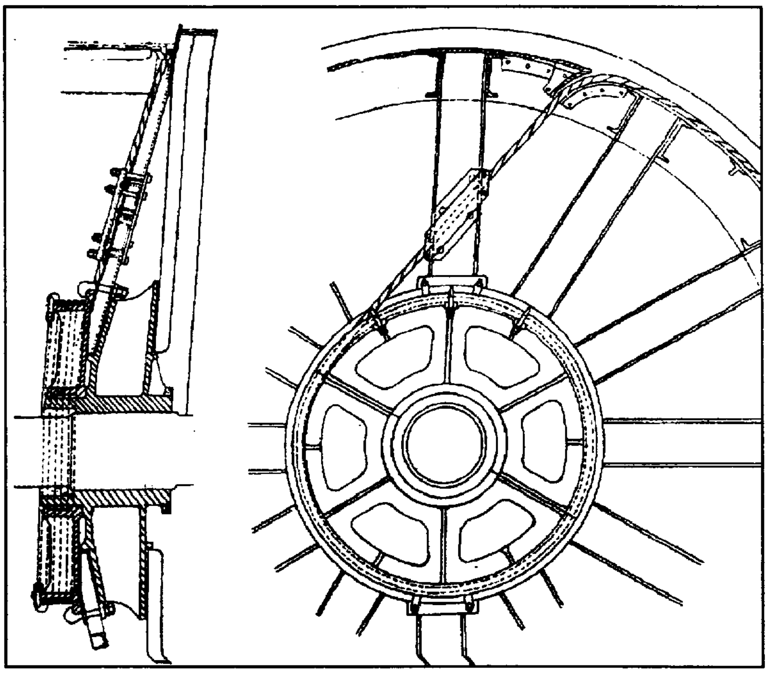

Figure 29 An Alternative Rope Storage System

The alternative arrangement illustrated in Figure 29 can be used to avoid these problems. A small storage drum is mounted inside each winder drum, from which rope can be payed out as required. The rope is secured by means of suitable clamps which must be designed to avoid damaging the rope. Care must be taken to ensure that the rope in the statutory three dead turns does not deteriorate excessively before the next time the rope is payed out. In this case instead of removing deteriorated rope from the operating length it is possible to introduce badly deteriorated rope into the most highly loaded part.

5.3.6 Rope Adjustment. (i.e. Clutching)

All ropes will stretch permanently to some extent, the amount depending on the rope construction. This means that on a drum winder operating with two conveyances in balance, the alignment of the conveyances at the end of wind positions is affected. At some stage the misalignment becomes so great that the winder operation is adversely affected and ropes must be adjusted. If both ropes are mounted on a single drum or if the drums are both fixed to the drum shaft, adjustment can only be achieved by removing the ropes from the drum and pulling them in by the required amount.

To avoid this problem, and also to make it possible to hoist in balance from varying levels in the shaft, it is usual to arrange for the drums to be connected to each other and to the driving arrangement by means of clutches. Although friction type clutches have been used the use of positive arrangements such as dog clutches is nowadays almost universal. In most cases the drums are free to rotate on the drum shafts and are each provided with a clutch attached to the drum shaft. Because of this arrangement, brakes have to be provided on each drum with sufficient restraining force to hold the total out of balance load (rope, conveyance and payload). In addition, conveyance position indicators must be provided for each drum. An interlocking system to sprag the unclutched drum is also used, in addition to the automatic application of the brake of that drum, before the clutch is actually released.

The clutching procedure entails a certain amount of danger, so it is usually limited to adjustments with unloaded conveyances. By regulation persons are not permitted in conveyances during clutching operations.

5.4 SHEAVES AND SHEAVE LAYOUT.

Large drum winders cannot be mounted in such a way that the rope can be directly connected to the conveyance, as can be done with Koepe winders. Consequently the winder is mounted on the ground and the ropes deflected into the shaft by means of suitable sheaves mounted on a headgear.

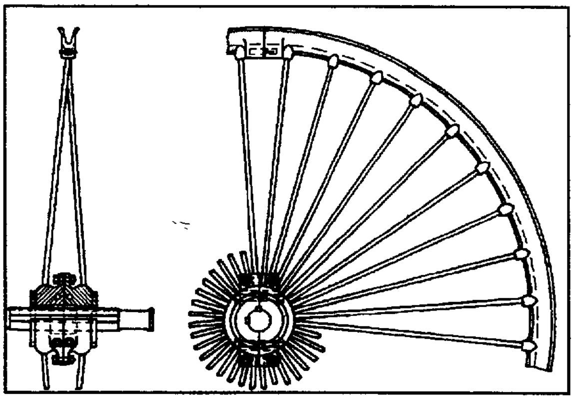

Figure 30 Headgear Sheave with Cast Iron Rim

Requirements for headgear sheaves may be simply stated, but are not so easily achieved:-

a. Sheave diameter must be in accordance with the rope manufacturer's recommendations.
b. The strength of the sheave must be sufficient to cope with an overload that will break the winding rope. Under this extreme loading the sheave must not distort of fail.
c. The sheave must not distort or deflect excessively when the rope is fully loaded and at its maximum fleet angle.
d. The sheave must have a low inertia.
e. It must run freely.
f. The sheave groove and flanges must run truly, with no out of round or throw.
g. The material of the sheave groove must resist wear, but nevertheless be easily re-grooved.
h. Bearings and other parts of the sheave must be designed for ease of inspection and maintenance.

Sheaves must be set up with the centre-line of the rope in the shaft within the area projected by the drum flanges. The sheave must point to approximately the centre of the drum and should be sufficiently far from the drum so that the maximum and minimum fleet angles are within the recommended values. Figure 26 illustrates these requirements.

5.5 PROTECTION DEVICES.

Protection devices can be divided into two groups; mechanical and electrical.

5.5.1 Electrical Protection

Electrical protection is designed to eliminate or restrict damage due to overload and the occurrence of electrical faults.

o **Current Overload.** Protection is required in AC and DC power circuits as well as fault protection in the mechanical protection circuits. In all cases the winder should be brought to a controlled and safe stop.

o **No-start Device.** Peak electrical loads of two to two and a half times the RMS rating of the winder are common when starting the winder. The heating effect of this on winder motors which are not rotating can lead to rapid destruction of the motor and associated circuits. No-start devices should be installed to protect against current being applied for too long a period without the winder moving.

o **Fault Detectors.** Devices for detecting other electrical faults, such as earth fault detectors, should be installed and set to stop the winder in the event of faults. An important feature of all fault detectors should be the provision of automatic indicators which identify faulty circuits.

5.5.2 Mechanical Protection

Mechanical protection, which includes electrical devices, is provided to protect the winder against overspeeding, overwinding and the possibility of operating in the wrong direction.

o **Overspeed.** A winder is required to operate within a clearly defined envelope of speed and distance. A tolerance of about 10 % to 15 % is usually allowed and the winder is tripped out if this tolerance is exceeded.

The monitoring of the winder speed with respect to the required speed of each conveyance relative to the ends of wind is the function of such devices as the Lilly controller. The required speed profile of each conveyance as it approaches each end of the wind is set by means of specially profiled cams adjusted to trip the winder if the speed at any particular position is excessive. In addition cams are provided to trip the winder at preset limits of travel. These limit switches give the initial protection against overwinding and can be automatically adjusted for dual purpose winders.

Alternatively, specially adapted computer systems monitor winder speed and position continuously. Any deviation outside the required envelope initiates appropriate signals and stopping of the winder.

o **Acceleration and Deceleration.** The acceleration of a winder from rest to full speed is generally controlled in the design of the control circuits. It is important to note that smooth acceleration of the winder is desirable. Systems which introduce impulses into the system can add significantly to fatigue damage of ropes, especially in high fatigue systems.

In normal operation deceleration of a winder is carefully controlled to avoid excessive loads and impulses. The deceleration control is electrical and the mechanical brakes are only used in the final stages and to hold the winder at rest. Under tripout circumstances the mechanical brakes have to control the winder under all conditions. The out of balance torque on a deep level drum winder varies considerably between the shaft bottom and the bank. If a constant braking torque is applied, the deceleration will vary, depending on the winding conditions and the position in the shaft. Various types of deceleration governor have been designed and used. The most successful is the ESCORT[13] [14] device. The word "ESCORT" stands for Electrical Sensing and Control of Retardation. This device senses and controls retardation to make the winder come to rest at the same rate for all winding conditions anywhere in the shaft.

o **Locked Bell (Brake) System.** To ensure the safety of persons and also to avoid the possibility of other accidents an interlock is provided between the brakes and bell signalling system that ensures that the brakes cannot be released by the driver until a signal has been given by either (or both) the onsetter and the banksman. In this system the driver is required to signal when he has stopped and when access to the conveyance is given for loading and unloading men or material. When the driver gives a signal on either of the two bell systems, i.e. to the onsetter or the banksman, the brakes are automatically locked in the on position. In addition signal lights at the stations indicate that the brakes have been locked on. The brake lock is only released by a signal from the appropriate position. These requirements are clearly specified in regulation 16.36 of the Minerals Act[2]

o **Brake Clutch Interlock.** A mechanical interlock must be provided to make it impossible to unclutch a winder drum unless the brake on that drum is fully applied. It is also usual to provide electrically operated signals to indicate if the clutch is engaged or not.

o **Overwind Prevention Device.** Besides the protection afforded by the controller in the winder house switches are mounted in the headgear and at the shaft bottom to trip the winder if a conveyance should pass a predetermined position. The switches are either magnetic type proximity switches or cam operated mechanical switches.

o **Slack Rope Device.** In any shaft there is always the possibility of a conveyance becoming stuck or jammed at any point in the shaft. The most usual places are at the ends of the wind. Skips can become jammed at the tip and cages where they are stopped for considerable times at the bank and bottom station. Keps are often the cause of slack rope on cages.

Although tight rope, caused by jammed conveyances, leads to overload it is slack rope which causes the most dangerous conditions. The effect of slack rope depends on the position of the conveyance in the shaft.

a. Slack rope caused when the conveyance is at the top of the shaft is the most dangerous. Due to catenary tension the rope in the catenary sags to the extent that loose coiling and kinking of the rope can occur at the drum. Also, if the conveyance suddenly becomes free, its subsequent drop and sudden tightening of the rope can cause rope, connection or conveyance failure in deep shafts where the rope stiffness is high due to a very high capacity factor.
b. When the conveyance is at a position in the shaft where the rope mass below the headsheave is sufficient to maintain the tension in the catenary and it becomes jammed the rope will become slack at the connection to the conveyance and usually forms a kink. With no indication at the winder, it is possible that sufficient rope is payed out onto the top of the conveyance to overcome the jamming force and the conveyance then falls away, with the possibility of a broken rope etc. In any event the formation of a kink is a dangerous occurrence, especially if it is not immediately identified.

In older winder systems slack rope is usually detected by means of trip wires stretched across the rope opening in the winder house. This is usually sufficient to detect slack rope as described in a. above but does not give any indication of the second condition. Following a serious accident which resulted in many fatalities, more sensitive slack rope devices are now used. These devices monitor the tension in the connection of the rope to the conveyance and trip the winder if the tension reduces below a certain minimum. In this way the winder is stopped before a seriously dangerous condition develops.

5.5.3 Overwind.

In spite of the presence of overwind prevention devices, overwinds do occur. To avoid excessive damage to shaft and headgear and to avoid injury to persons a means of detaching the rope is provided.

5.5.4 Detaching Devices.

Figure 31 illustrates a common design of detaching hook. The device forms the connection between the rope termination and the conveyance. It is designed so that it cannot accidentally detach. In the event of an overwind, the detaching hook is pulled into a catch plate, commonly called a "spectacle plate". The scissors mechanism is forced to open and release the rope termination. At the same time the opened scissors plates form a catch mechanism which holds the hook and conveyance securely in the headframe. In addition, it is common to provide additional catches in the headframe which become engaged before the detaching hook enters the catch plate.

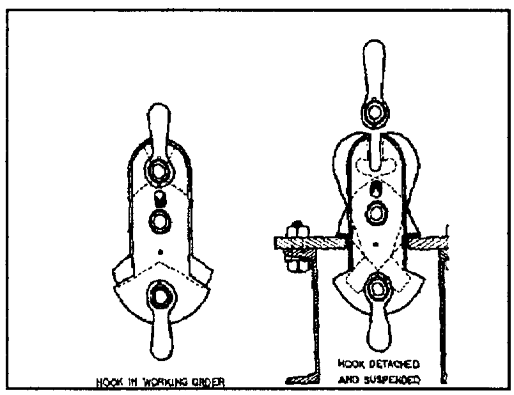

Figure 31 Detaching Hook

5.5.5 Additional Protection for Shaft Sinking.

All the preceding protection devices, except for detaching hooks, are also used with some specialised modification in shaft sinking. In addition there are important devices related specifically to shaft sinking.

o **Bank Doors.** Doors which close off the top of the shaft are provided at bank level with the objective of minimising the chance of anything falling down the shaft and to facilitate the safe loading and unloading of the kibble, (men, material or rock). These doors are normally kept closed but are opened to allow the kibble or other conveyance to pass through. Interlocks are provided to ensure that the doors are open before the kibble can pass through and to also ensure that the doors are closed when the kibble is being tipped or brought to the loading position for men or material.

o **Crosshead Monitoring.** The separation of a crosshead while a kibble is being lowered down the shaft is potentially the most dangerous condition that can occur during winding in a sinking shaft. Electronic monitoring devices are used to warn the driver and stop the winder if separation does occur while winding in the shaft. Suitable switches allow for separation of the kibble and crosshead at the stage and in the headgear and limit the speed at which the winder can operate.

o **Signal Interlocks Between Kibble and Stage Winders.** To ensure that the kibble winder does not operate while the stage is being moved there are interlocks between the kibble winder and stage winder signalling systems which prevent one system from operation while the other is in motion.

o **Stage Position.** Because stage position varies continuously as the shaft gets deeper arrangements are made to superimpose the stage position on the kibble winder depth indicator. This is usually done by providing another pointer which is interconnected with the stage depth indicator.

5.6 CONVEYANCES.

The objective of all winding systems is to hoist a conveyance from underground to surface. Conveyances are designed to accommodate men and/or material and to handle the ore or broken rock. There are also specialised conveyances used for shaft maintenance, installing pipes and cables and other applications.

o **Man and Material Cages.** The dimensions of cages are usually determined by the available shaft compartment size and the type of material which is to be transported. If large trackless mining machines are to be handled, it is common for the cage to be a suitable size for driving the machine in at the surface, lowering it and driving it out at the required level. This generally requires a suitably large floor area, so only one or two decks are provided for handling men. Because shaft size is always limited, floor area of cages is designed as economically as possible and it is usual to provide three or even four decks to accommodate the required payload.

When multiple decks are used, specialised loading arrangements are required for controlling access of persons to or from the conveyance. The loading stations are provided with multi-deck loading platforms so that each deck can be loaded simultaneously.

Some of the safety requirements for man cages are as follows:
- Persons must be protected from water and any falling material in the shaft.
- Persons must be fully enclosed in the cage, with no possibility of them coming into contact with shaft steelwork while being transported.
- Doors must be arranged so that they cannot inadvertently open and allow persons to fall out.
- There must be sufficient ventilation to prevent asphyxia while the conveyance is stationary in the shaft (even for several hours).

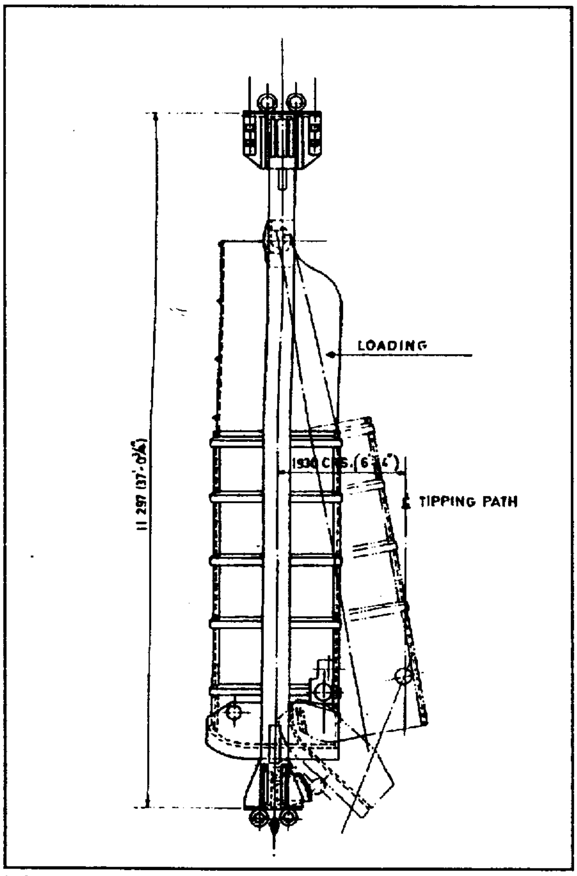

Figure 32 Typical Bottom Discharge Skip

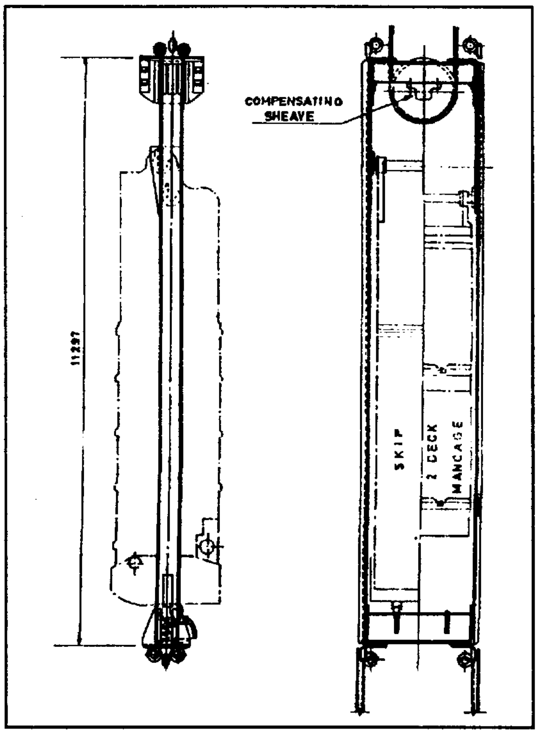

Figure 33 Bridle Arrangement for BMR Winder

- **Skips.** A skip comprises a bridle which is attached to the winding rope and provided with suitable arrangements for engaging the guiding system in the shaft. A pan or flask arrangement is mounted in the bridle in such a way as to allow broken rock to be loaded into it and to be discharged automatically at the end of the wind. There are many designs of skip which relate to the type of material to be transported.

Until about 50 years ago skips having a capacity of up to 5 tons were adequate.[15] Overturning skips were used where the pan of the skip was hinged to the bridle at the bottom of the pan at an off centre position. The rock was dumped out of the ship at the surface using rollers on the pan to force it from its stable position and to discharge its contents by overturning around the hinge in the bridle. These skips worked satisfactorily with pay loads up to 12 tons, but then became too cumbersome and inefficient when higher payloads were required. Skip to payload ratios (ratio of the mass of the skip bridle and attachments to the payload) were as high as 0,8 but could only be reduced to about 0,65 with improved designs and material.

Bottom discharge skips have proved to be satisfactory for payloads in excess of 6 tons and are currently used up to payloads in excess of 25 tons. There are several designs of bottom discharge skip in use and designs have been improved to the extent that skip payload ratios of 0,45 are common.

Figure 32 illustrates a common design where the pan is attached to the bridle by means of a hinge at the top and the payload is supported on a well fitting discharge door attached to the bottom of the bridle Tipping is achieved by a roller on the skip body engaging in a tipping path which forces the pan into the open position and allows the rock to discharge, guided by the discharge door.

The arrangement of the bridle for use on a BMR winder is illustrated in Figure 33.

o **Kibbles for Shaft Sinking.** The conveyances used for shaft sinking are not guided while passing through the sinking stage and down to the shaft bottom. A circular section is appropriate so that there are no problems with the conveyance (or kibble) snagging on the stage while passing through. After being hoisted through the stage the kibble engages with a crosshead which is guided by two stage rope falls. A general arrangement of a kibble and crosshead is shown in Figure 34.

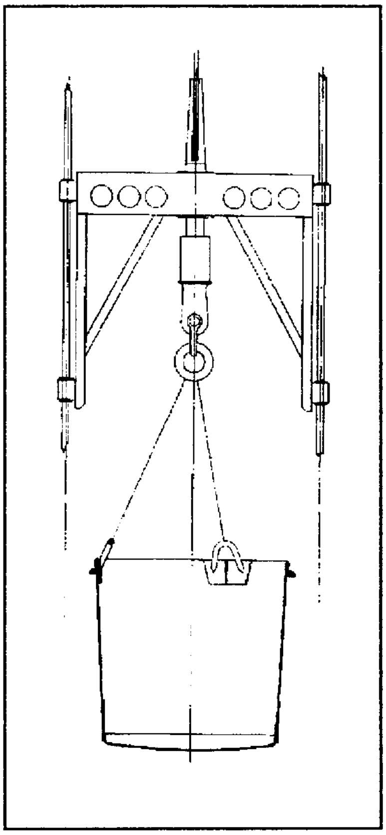

Figure 34 Kibble and Crosshead

o **Other Types of Conveyance.** Many other types of conveyance are used for specialised purposes. Skeleton type conveyances are used for shaft maintenance and for installing pipes in the shaft. Conveyances fitted with reel handling devices are used for installing electrical cables in the shaft. Purpose designed bridles are also used for handling and securing large components which have to be slung into the shaft and ensure that they are safely transported, either up or down the shaft.

o **Guide Systems.** All conveyances must be equipped with the means for achieving the guidance provided by the guides. In the case of fixed guides an arrangement of slippers is used for timber and a combination of rollers and slippers for steel guides. In the case of rope guides suitably designed bushes are mounted on the conveyance.

The use of slippers only, for fixed guides, was phased out many years ago and a combination of rollers and slippers is in general use. The rollers are mounted at the top and bottom of the bridle (or conveyance) in suitable position to engage each shaft guide. Rollers are generally sprung with a progressive resistance to deflection so that the conveyance travels smoothly in the shaft. The resistance is so arranged that excessive shocks are transmitted to slippers which are also provided.

In the case of guide ropes, bushes are used to guide the conveyance in the shaft. However at each end of the wind fixed guides are provided which engage an arrangement of slippers on the conveyance which ensure that the conveyance is correctly positioned for loading and discharge. This arrangement also ensures that impulses are not applied to the guide ropes which could set up vibrations and adversely affect travel in the shaft.

6 COMPONENTS OF KOEPE WINDERS.

Some of the components of Koepe winders are specifically related to the requirements dictated by friction driven rope systems. On the other hand many components and systems which have been developed and proved on drum winders are used where possible.

6.1 TYPE OF POWER AND CONTROL

Both AC and DC systems are used as for drum winders and discussed in paragraph 5.1 on page 20. Because the Koepe system subjects the ropes to a higher fatigue loading than drum winders, care must be taken to avoid excessive impulses to the system caused by the type or method of control.

6.2 BRAKING

Brake systems mentioned in paragraph 5.2, page 21 can be used for Koepe winders. It must be noted that, although there is only one drum in the Koepe system, two separate brakes and systems must be used to provide appropriate redundancy for safety.

6.3 ROPES

Specialised ropes, rope installation and maintenance procedures are required in deep level Koepe winder systems.

6.3.1 Head-ropes.

In a friction winder system each end of the head-rope is attached to a conveyance so that the rope is end for ended on every wind. The effects of this must be taken into account when choosing a rope construction[12 16]. Six strand head-ropes can be used successfully for depths of 500 m. However non-spin ropes are required for depths greater than this. It is not advisable to use the Koepe system for depths greater than 2000 m due to the adverse effects of depth on the rope performance.

One of the benefits of the Koepe system is that multiple head-ropes can be used to enable hoisting of very heavy payloads. The original Koepe system was based on the use of only one head-rope and one tail-rope. However it was soon found that instead of using large diameter ropes for hoisting heavy loads it was possible to use more than one head-rope. Two rope systems were introduced and soon after, systems with four or more ropes were introduced.

6.3.2 Tail-ropes.

As mentioned in paragraph 4.2.1.3, an integral feature of a Koepe winder is the use of balance (or tail) ropes. Non-spin ropes are also used for this application, the type being determined by the method of controlling the tail-rope loop at the shaft bottom.

In choosing a tail-rope it is advantageous to operate with as few ropes as possible. Shaft layout, the centre to centre distance between compartments and the capability for handling heavy ropes are factors which affect the choice and can be limiting factors. In addition the type of loop control chosen determines the rope construction and rope properties required.

o **Free Loops.** The satisfactory operation of free looping tail-ropes is completely dependent on swivels except for relatively short winds in shafts which operate without any abrasive spillage or corrosive conditions. In the latter case ropes can be provided which are completely spin-free and which can remain in this condition provided there is no external or internal wear or deterioration to affect the torque characteristics. In South Africa where shafts can have corrosive conditions and where abrasive particles are a common feature of water in the shaft this type of rope cannot be used satisfactorily.

o **Swivels.** The behaviour of a tail rope loop is dependent on the relative reaction between the rope and the swivels. It is extremely important that the swivels should be as free as possible. It is recommended that the swivel design characteristics should provide a starting torque less than 27,12 Nm under 89 kN load and less than 2,7 Nm under 2,1 kN load. (i.e. Starting torque (Nm) $\leq$ 0,281 $\times$ load (kN) + 2,11). These figures are obtainable and should be maintained during the life of the swivel.

Because of this interaction between the rope and swivel the tail-rope loop will be seen to move in the compartment in a regular manner. Multiple ropes do not necessarily move in unison and may cross or touch each other at the loop.

o **Loop Control.** The movements of the tail-rope loops and the possibility of sticking swivels necessitate some type of loop control. It is recommended that the rope be protected from the shaft steelwork by timber beams lined with a low friction material so that the loop can move freely and is only restrained at the perimeters of the compartments as illustrated in Figure 35. In any free loop system there is always the possibility that the reaction between the rope and swivels could cause the rope to "figure eight" at the loop. This is a condition which could cause considerable damage to the rope and also possibly the shaft. To reduce this possibility a timber baulk should be placed at the centre of curvature of the loop and a trip wire mounted beneath it to stop the winder in the case of serious interference.

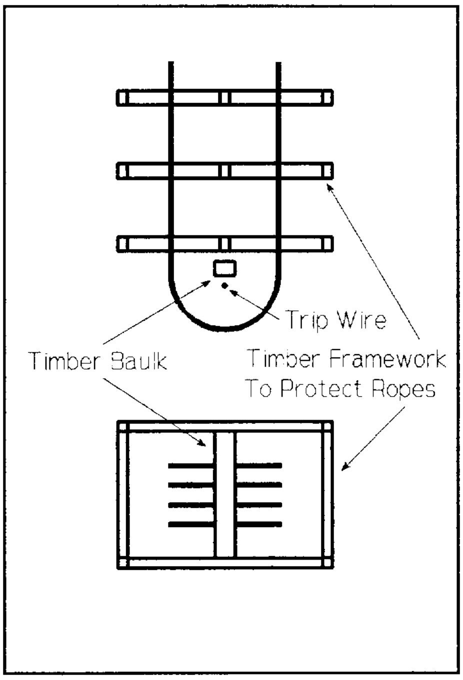

Figure 35 Control of Tail-rope Loop

In deep shafts or when the ropes are mounted close to each other there is the possibility of the tail ropes wrapping around each other. This is particularly noticeable if a sticky rope dressing is used. Because of this the bottoms of each tail-rope loop should be maintained within a range of 150 mm of each other to ensure that if ropes do wrap around each other there is no damage to the ropes. For this reason it is also recommended that the ropes should not be separated from each other by dividers or other arrangements.

o **Tail Sheaves.** Because the starting torque of swivels is proportional to the load on the swivel the control of tail-rope loops and maintenance of swivels on deep winds becomes more critical than for shallow winds. It is possible that there is an optimum loop diameter related to depth, for satisfactory operation. The deepest wind, in South Africa, on which free looping tail-ropes are used is 1500 m and in this case the centre to centre distance of the winder compartments is 118 times the tail-rope diameter. The tail-rope loops are stable in this case but there is some doubt as to what the minimum ratio should be at this depth.

When the depth of wind is very deep there is an increased expectation of problems in operating with free loops due to the starting torque characteristics of swivels. The solution has been to use tail sheaves to control the tail-rope loop. The use of sheaves in this position is a different proposition to the use of sheaves in other applications. The rope is bent round the sheave at a minimum load so any misalignment is of significant importance. The tread pressure between the rope and sheave is very low but in spite of this and due to slip between rope and sheave during acceleration and deceleration, wear of the sheave can be extremely rapid so that groove profiles can quickly become unacceptable.

The solution to rapid groove wear has been the use of low friction plastic inserts in the sheave grooves. These inserts must be of sufficient size to avoid contact of the rope with sheave groove flanges. The method of fixing the inserts in the groove must also be such as to ensure that the rope does not come into contact with keep plates or the like.

6.4 DRUMS.

For single rope Koepe winders the drum is not much more than a sheave designed with suitable brake path arrangements. (It is often referred to as the Koepe drive sheave). However with multiple ropes drum design is more critical. Drum deflection under load must be maintained at a minimum so that each rope maintains its share of the total load during the winding cycle. Because the ropes are driven by friction and the angle of wrap is seldom much more than 180° and sometimes less, friction treads are provided.

6.4.1 Drum Treads.

The friction tread material is mounted on the drum in specially provided grooves and secured by means of clamps. Wood, leather, rubber, plastic or composite materials are common materials used for treads. A common shape of the tread insert is illustrated in Figure 36. In South Africa, where stranded ropes are used, wood and leather have proved to be unsuitable. Both plastic and rubber tread materials are satisfactory. Propriety brands of high friction plastic material are now generally used.

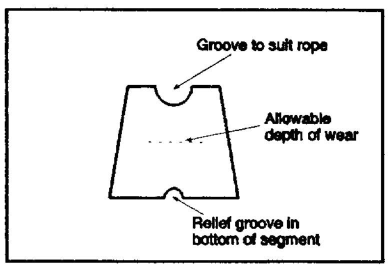

Figure 36 Shape of Rubber Tread Insert

6.4.2 Tread Length Measurement.

The treads on the Koepe drum have to be accurately machined to ensure that equal lengths of rope are transferred over the drum during the wind. Initially the tread diameters can be physically measured by means of tape or callipers. However, as soon as the head-ropes are installed, measurement becomes more complicated. Many methods of establishing the relative measurements of drum treads have been tried. The most successful method was developed in Canada and called the 'Bank to Bank' method[17]. This method automatically compensates for the small differences in rope diameter found in a set of head-ropes as well as variations in the compressive deflection of the tread and drum.

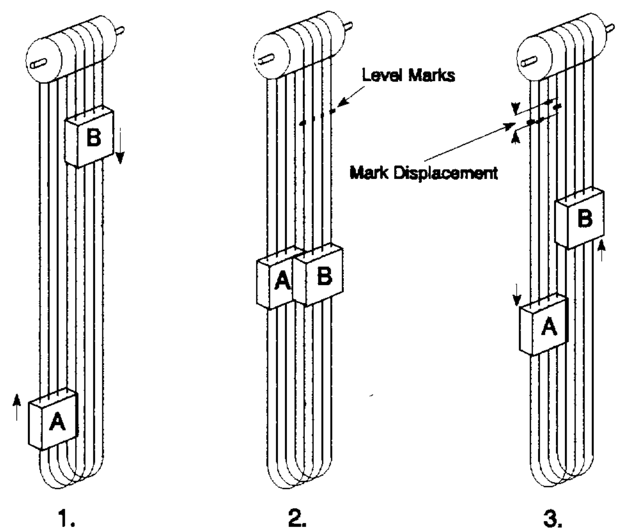

Figure 37 Bank to Bank Measurement

Before starting this test, rope lengths should be checked with the conveyance chaired at the bottom of the shaft. Any discrepancies should be corrected. The winder should then be operated normally for about half an hour. Any dirt or build up of grease etc. on the treads should be cleaned off at this stage. The procedure is as follows (see Figure 37):

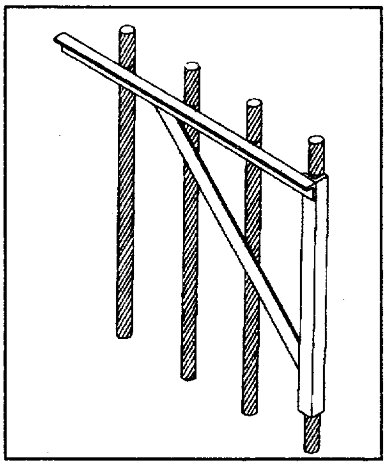

Figure 38 Aluminium Square for Marking Ropes

1. Conveyance "A" is hoisted from the bottom of the shaft to the mid-shaft position.
2. At the bank, or suitable position in the headgear, each rope in conveyance "B" compartment is marked with a level mark. (A convenient device for doing this is illustrated in Figure 38).
3. The winder is reversed and the marks moved to the same level in the other compartment (conveyance "A" lowered), without stopping the winder until the marks are in the correct position. The number of drum turns to move the marks from the one side to the other must be counted,

4. The displacement of the marks is observed and measured.

If for any reason the winder is stopped before the test is completed the results should not be used and the test should be repeated.

The lowest mark indicates the rope running in the tread with the largest diameter and the highest mark is on the rope operating in the groove with the smallest circumference. The difference in tread circumference between the grooves can be calculated from the position of the marks in this test and is given in the following formula:

$$\chi = \frac{\Delta L}{R}$$

Where

χ = difference in tread circumference between drum grooves. (mm)
ΔL = measured distance between marks in bank to bank test. (mm)
R = number of revolutions made by Koepe drum in moving marks from bank to bank.

If this distance exceeds the maximum allowable difference in tread length, the treads with the greatest diameter will need to be machined. After machining the bank to bank test should be repeated to confirm that the treads have been correctly adjusted.

The maximum allowable difference in tread length is based on the premise that the accumulated difference in tread circumference during one winding trip should be less than the stretch in the head-rope between the conveyance and the drum when the conveyance is in the highest operating position and the winder is operating with no payload. This difference in tread lengths can be calculated from the following formula:

$$\chi = 1000 \left(\frac{\pi D L'}{L} \; \frac{T}{0{,}495 d^2 E} \right)$$

Where

χ = maximum allowable difference in tread circumference between grooves. (mm)
L = depth of wind. (m)
L' = distance from highest operating position to Koepe drum. (m)
D = diameter of Koepe drum. (m)
d = diameter of head-rope. (m)
T = maximum static tension in rope. (N)
E = Modulus of Elasticity of head-rope. (Pa)
(110 GPa for non-spin rope)

6.5 SHEAVES.

Tower mounted winders can be arranged so that the head-ropes lead directly from the winder to the conveyances without having to be deflected. This is an ideal arrangement which should be used if possible. However, it is not usually feasible to arrange for this type of layout and so sheaves are used to deflect the ropes.

Sheaves should be the same diameter as the Koepe winder drum and are usually provided with an insert tread material, similar to that used on the drum.

o **Deflection Sheaves.** These are used in tower mounted systems to position the head-ropes with respect to the shaft compartments. The rope is usually deflected by an angle of less than 15°. In positioning the deflection sheave care must be taken to ensure that it is not too close to the Koepe drum. The time taken for the rope to travel from the drum to the sheave should not be less than 0.5 s for high speed winders. When used for only low speed operation the rope distance between sheave and drum should follow this rule but must never be less than twenty times the rope diameter.

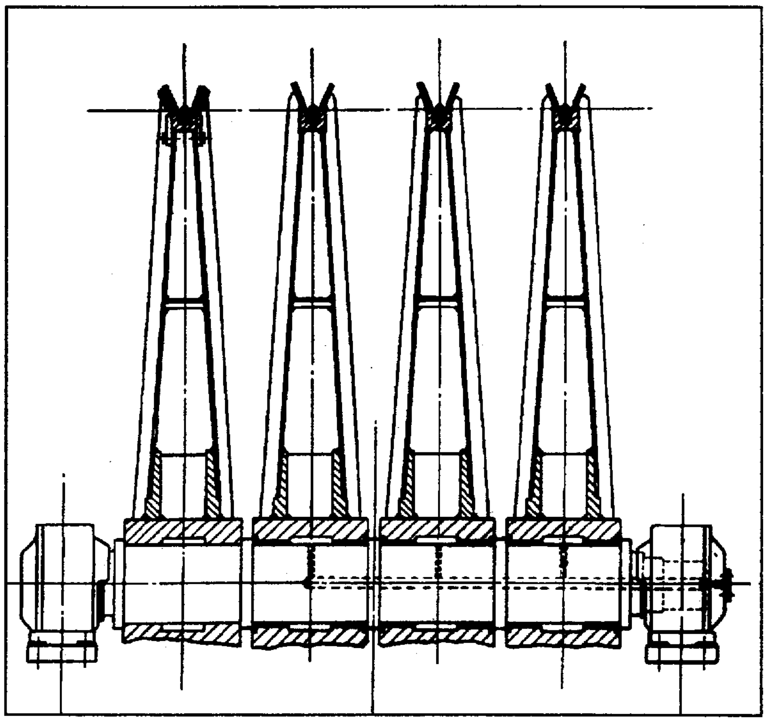

Figure 39 Arrangement of Multiple Deflection Sheaves

Because of the small angle of deflection, rope loads exerted onto deflection sheaves are relatively low. Deflection sheaves can therefore be fairly lightly constructed with a low moment of inertia. Multiple sheaves can be mounted on a single shaft. It is usual to key one of the sheaves to the shaft, mounted in plummer blocks, and to allow the other sheaves to rotate separately by mounting them on the shaft with bronze bearing bushes.

o **Headgear Sheaves.** Ground mounted Koepe winders are provided with headgear sheaves similar to those used on drum winders. These are subjected to the full rope and conveyance load at all times, the variable load being due to the payload. On multi-rope winders sheaves are mounted close together. The practical spacing of the sheaves determines the required rope spacing on the drum.

6.5.1 Fleet Angles.

As far as possible, Koepe winders should be designed and operated without fleet angles. Because of the nature of non-spin ropes even a small permanent fleet angle will cause rotation of the rope and this continuous alternating rotation often causes distortion of the rope in the form of either bird-caging or the formation of corkscrews. One arrangement which can cause problems is the fleet angle introduced on ground mounted winders by having the headgear sheaves on the same level.

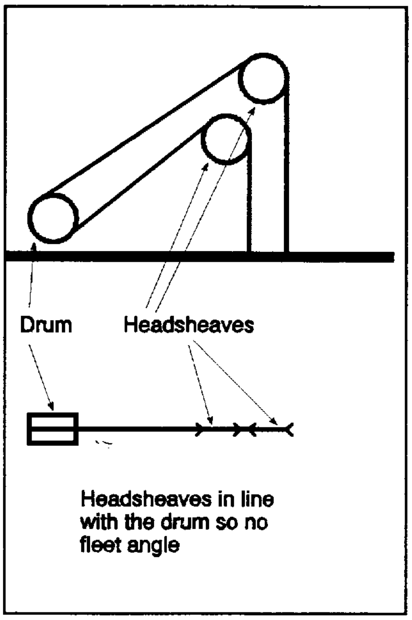

Figure 40 Ground Mounted Koepe with Sheaves In-line

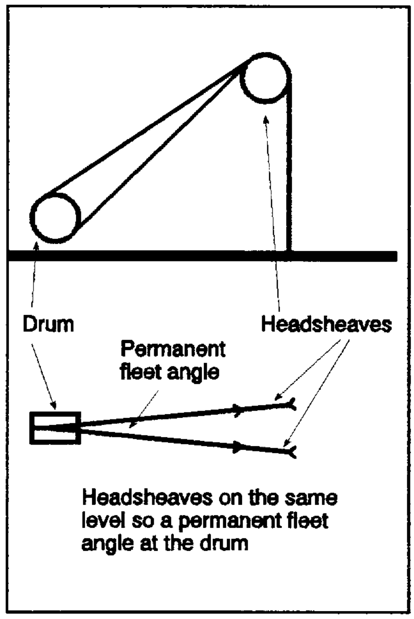

Figure 41 Ground Mounted Koepe with Sheaves on Same Level

Figure 40 and Figure 41 illustrate the differences between the two arrangements, one with the sheaves in line and mounted on different levels and the other where the sheaves are side by side and on the same level. The effect on the fleet angle can be seen, where a permanent fleet angle is introduced when the sheaves are mounted side by side.

On tower mounted Koepe winders with lever type tension compensators there is a fairly common practice of securing the ropes to the conveyance at different centres to the drum grooves or deflection sheaves. As can be seen in Figure 42, which gives a schematic diagram of the arrangement, a fleet angle is introduced which is a maximum when the conveyance is at the top of the shaft and reduces as the conveyance travels down the shaft. Round strand head-ropes are not much affected by this arrangement, but the performance of non-spin ropes and locked coil ropes is often severely reduced.

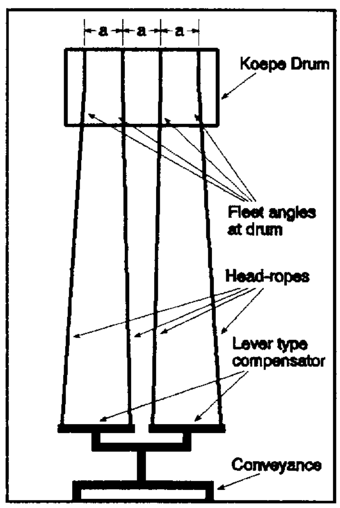

Figure 42 Unequal Rope Spacing on Drum and End Terminations

It should be noted that arrangements with differing centres are not only confined to systems with compensators. In some ground mounted multi-rope winders, headgear sheaves have been mounted in such a way that different centres have been created. It is also possible that space considerations at the conveyance can affect the arrangement of end connections leading to the same effect.

6.6 ROPE CONNECTIONS.

A feature of the Koepe system is that it does not permit the regular cutting of the head-ropes for testing. However ropes do fatigue at the connections so it is important that suitable end terminations are chosen.

6.6.1 Rope Adjustment.

In any Koepe system the head-ropes must be connected to the conveyances in such a way that the conveyances are always in the correct positions at the ends of the wind. There is some tolerance normally allowed, but the end termination must be designed to allow for simple adjustment.

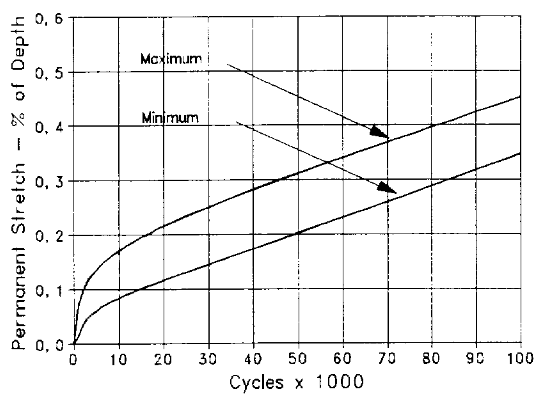

Figure 43 Expected Permanent Rope Stretch for 15 strand "Fishback" Non-spin Koepe Head-rope

o **Stranded Ropes.** In addition, when Koepe winders operate with two conveyances, the effect of permanent rope stretch needs to be considered. Permanent stretch characteristics of stranded non-spin ropes are illustrated in Figure 43. The curves indicate the tolerance as maximum and minimum stretch which can be expected. This stretch has to be taken up by moving the rope in the end connections. Adequate design of skip loading arrangements or over-run space at the top of the wind will ensure that, in the initial stages of rope operation, length adjustment can be done at convenient intervals. As can be seen, the rope continues to stretch progressively throughout its life. This feature makes it possible to regularly move the rope in the end connection and so avoid localised fatigue occurring at the connection. The fact that there is a requirement to take up rope stretch fairly often in the first few days of the rope's life makes it sensible to choose an end connection which is relatively quick and easy to adjust. The thimble type capel, Figure 44, fills this requirement admirably.

When there is a conveyance and a counterweight, the amount of stretch which can be tolerated is increased considerably. However it is still necessary to change the position of the rope in the capel at regular intervals.

These comments apply equally to six strand Koepe head-ropes.

o **Locked Coil Ropes.** The amount of stretch experienced when Full Locked Coil head-ropes are used is considerably less than that experienced with stranded ropes. In view of this it is not so important to use an end connection which can quickly be attached to the rope. Because of its relative bending stiffness, locked coil ropes are not suitable for use with normal size thimbles. The preferred attachments are either sockets or wedge capels. In view of the reduced stretch of these ropes, it is usual to also provide chase blocks to allow for adjustment of conveyances and so that the rope can be moved in the terminations at regular intervals.

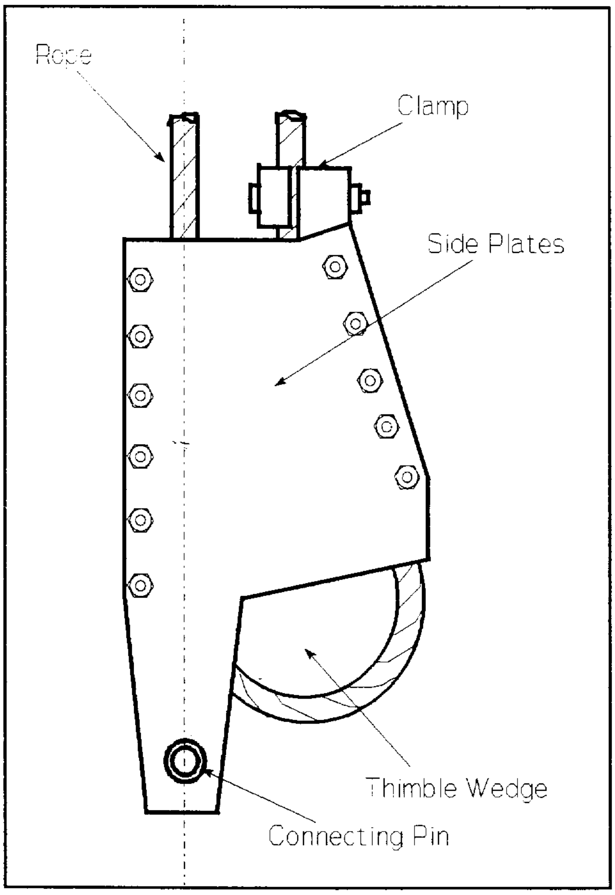

Figure 44 Thimble Type Capel

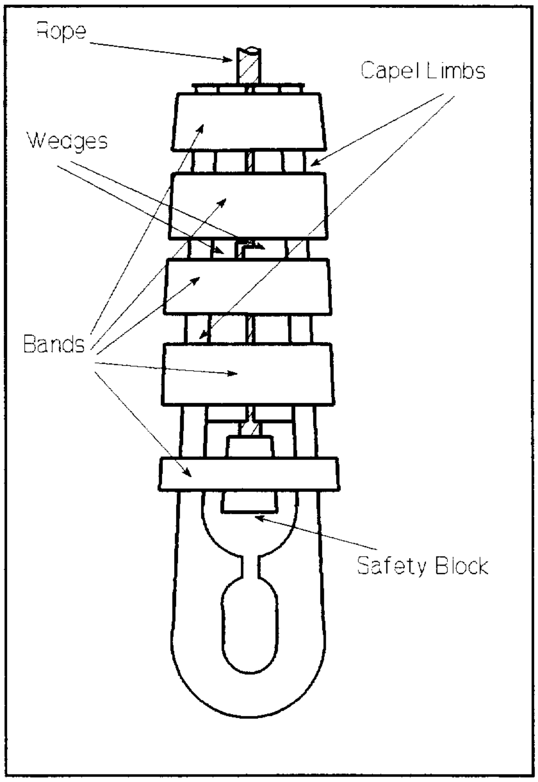

Figure 45 Wedge Capel

6.6.2 Force Equalisation.

In any multi-rope Koepe system the equal loading of head-ropes throughout the winding cycle is important. Conventional wisdom suggests that overloading of one or more ropes is of prime concern. However most damage usually occurs to ropes which become unloaded during the winding cycle. These ropes usually distort forming cork-screws, birdcages or "popped cores" which necessitates removal of the affected rope.

The regulations state that some form of load equalisation device must be installed. However none of the systems which are intended to automatically adjust rope tensions are satisfactory for very long. Because of limited movement, bearings and other components tend to seize-up thus making the device ineffective. The most effective way to achieve the required force equalisation is by the correct design of winder layout and subsequent attention to system maintenance. See paragraph 6.4.2 on page 40 in connection with tread length measurement.

6.6.3 Re-making Terminations.

As required in the regulations[2] (Regulation 16.16) the rope terminations must be taken off, stripped, thoroughly cleaned and examined in accordance with an approved safety standard. Usually it is not possible to cut off a significant length of head-rope, however, when the termination is reassembled the rope should be pulled through the connection slightly to move it with respect to the mouth of the termination. In the case of stranded ropes the accumulation of permanent stretch is usually sufficient to allow for a slight shortening of the rope. End terminations for locked coil ropes are arranged for the insertion of chase blocks to allow for the shortening of the rope.

6.7 Protection Devices.

Electrical protection for the winder is basically similar to that described for drum winders on page 30. In addition mechanical protection devices for overspeed, acceleration and deceleration, locked bell system and overwind prevention devices are similar to those described for drum winders on pages 30 to 31. Besides these there are devices specifically required because of inherent properties of friction systems.

6.7.1 Rope Slip.

Rope slip can occur at any time, especially during loading and acceleration of the conveyance or when braking at the end of the wind. Rope slip is also a possibility in the event of severe braking in trip-outs.

The two basic consequences of rope slip are as follows. Firstly, that indicator devices become ineffective with the resulting possibility of overwinds. The other is the effect of slip on rope treads which can be severely worn in extreme cases.

To indicate the occurrence of rope slip, (or the less severe condition of creep) it is usual to arrange for a tacho-generator to be driven by a wheel in contact with a rope. The output of this device is compared with the rotation of the drum and any severe discrepancies either trip the winder or warn the driver of the problem. The normal creep experienced during every wind is allowed for by automatically resetting the device when the winder stops at the end of every cycle.

Severe cases of rope slip can cause the rope to wear the rope treads completely. In this case the winder must be tripped without fail. A means of achieving this is to position trip wires in the rope treads such that when the tread has been worn to a predetermined depth the rope contacts these wires and trips the winder.

6.7.2 Overwind.

In spite of the safety devices provided to prevent overwinds, these sometimes occur. It is not appropriate to arrange for rope detaching devices because the detached rope and the other conveyance will fall down the shaft in the other compartment. Other means must be provided to prevent injuries or excessive damage to the winder and headframe. The usual solution is to install some type of arrester.

6.7.2.1 Arresters. There are several considerations in the design of arresters[18] that must be addressed for safe and appropriate operation.

a. Limit of effectiveness of an arrester. The limiting factor is that the deceleration on the conveyances must not exceed the acceleration due to gravity (g) and for practical purposes, to avoid injury to persons or damage to equipment, should not exceed a quarter of this.
b. Distance available for arrest. Because of limited distance available for arresting a conveyance in the event of an overwind there is always a compromise to be established. The deceleration must either be allowed to approach g, or the maximum speed of conveyance which can safely be arrested will be much less than the maximum winding speed.
c. Ability of headframe to withstand upward load. Since the retarding force required is in the upward direction adequate allowance for this must be made in the design of headframe.
d. Absorption of energy. The kinetic energy of the moving system must be absorbed and not merely stored so the use of springs or pneumatic systems is inappropriate.
e. Shock at entry. The decelerating force should be progressively applied and not as a sudden shock load.
f. Slip of rope on driving wheel. This is not of great consequence and is in fact encouraged in some systems.

A common means for arresting the conveyances in the event of an overwind was the provision of tapered fixed guides at the top and bottom of the shaft. The conveyance bridle entered the tapered guides and was retarded by the wedging action. It was usual to arrange that the downgoing conveyance entered the arrester first and so-doing reduce the T_2 tension in the head-ropes, possibly allowing the ropes to slip on the winder drum.

This system has serious disadvantages. In order to arrest the conveyances in an appropriate distance, the taper in the guides must of necessity be small and consequently forces are applied which cause severe distortion, or even failure, of the bridle. Under these circumstances the retarding force is lost and the arrester becomes ineffective.

Several alternative systems have been designed which have proved to be effective in the case of deep Koepe winders. These systems involve either friction, the work done in deforming materials or the discharge of fluid through an orifice.

o **Friction Devices.** The most usual type of friction device is a pair of clamps mounted on each side of the compartment which operate on strips of steel secured in the headgear. In the event of an overwind the conveyance engages these clamps, which are then forced along the metal strips providing a retarding force. Multiple strips are usually mounted with the clamp interleaved with each strip.

This is an effective arrangement, but suffers from the disadvantage that there is no progressive increase in retarding force. On the contrary, there is a tendency for the frictional force to reduce due to overheating.

o **Deformation of Materials.** One form of this device is to mount wire drawing dies onto suitably sized steel rods secured in the headgear, on each side of the compartment. When an overwinding conveyance engages the device, the rods are drawn through the dies and so provide a predetermined retarding force. Multiple rods and dies can be used to provide the required force.

A disadvantage of this system is that the rods have to be discarded after an overwind. There is also the possibility that dirt or possible corrosion of the rods could alter the expected retarding force significantly.

Another device which uses deformation is the patented "Selda" device which deforms a strip of steel by means of rollers offset from each other. This is a device which gives significantly constant retardation and also has the benefit that the steel strip is re-usable.

o **Discharge of Fluid Through an Orifice.** Several designs of this type of arrester are in use in South Africa. The principle of the device is a piston operating in a cylinder which is provided with a series of discharge nozzles along its length so that as the piston is forced along the cylinder discharging fluid through the orifices, the effective orifice area is reduced as the piston passes each nozzle thus providing an increasing retarding force as the piston travels through the cylinder. The fluid is discharged into a holding tank and so can be reused many times. The piston is moved by means of a guided piston rod attached to suitably sized wire ropes which traverse the compartment and are secured to a similar device on the other side of the compartment.

This type of arrester has operated satisfactorily on several occasions, although in one case it was unable to stop a conveyance overwinding at a speed in excess of the permitted winder speed.

6.8 CONVEYANCES.

Conveyances used on Koepe winders are very similar to those used for drum winding, except that overturning skips are never used.

The major consideration for Koepe winders is the strength of the bridle. Because the tail-ropes are connected to the bottom of the bridle the normal stresses due to payload and skip or cage body are increased by the additional mass of the tail rope and tail sheaves (if used). In deep winds this can be a doubling of the loads and load range acting on the bridle. Figure 46 shows a Koepe skip at the loading box. The connections of both head-ropes and tail-ropes can be seen.

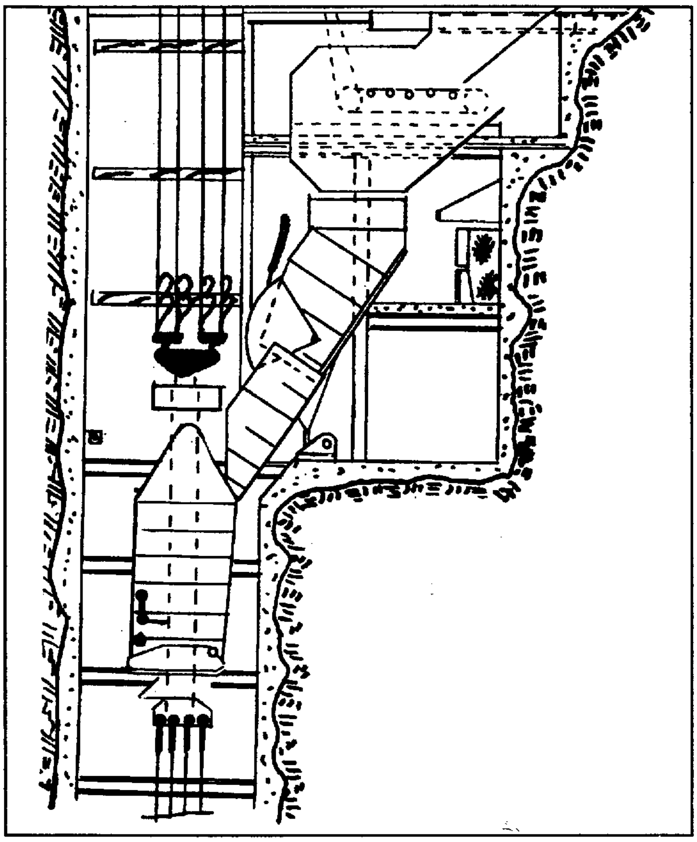

Figure 46 Conveyance at Loading Box

7 COMPONENTS OF LIFTS.

Besides the definition of a lift, given in the regulations and quoted on page 11, there are many further regulations which clarify the differences between Lifts and Winders. In addition, specific requirements are included which tend to make lifts "fail-safe", but which are impractical for high speed deep level mine hoisting.

7.1 TYPES OF LIFT

Although there is no regulatory restriction on the type of machine, drum type lifts are unusual. Traditionally, lifts are friction type machines which are arranged to be operated by the passenger by means of push buttons. Because there is no driver and because inspections and maintenance are done at greater intervals than for normal mine winders the operation must be "fail-safe". One of the penalties for these arrangements are the high design factors (factors of safety) specified in the regulations.

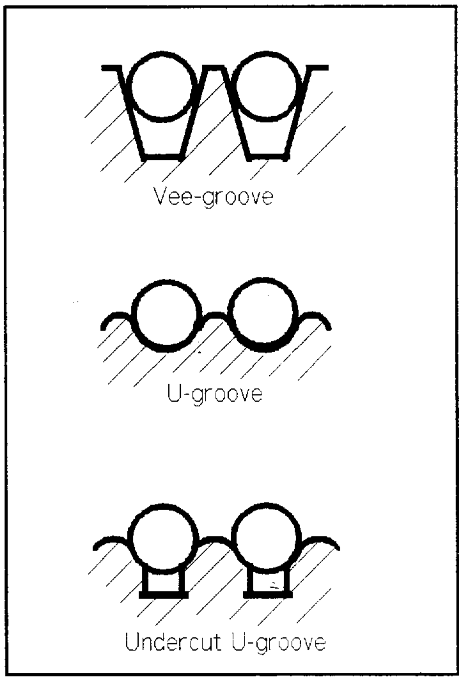

Figure 47 Types of Grooving for Elevator Drums

An important difference between lifts and friction winders is the arrangement of the friction drum grooving which is designed for metal to metal contact, usually with cast iron driving drums. Figure 47 illustrates various arrangements of drum grooving for enhancing the tractive force which the drum can apply. This is necessary due to the short winds for which lifts are commonly used as well as the lower coefficient of friction expected between the rope and the metal drum surface.

Koepe type friction drums with high friction inserts have become common for lifts in mines where heavy loads are handled. In fact one of the lift manufacturers has recently incorporated plastic tread material into the drum design for normal passenger lifts.

The various lift (elevator) systems operate with different types of grooving which are designed to suit the particular system.

7.1.1 Gearless.

This machine is noted for rope speeds (up to 10 m/s) which are high for the drum diameters used and also with respect to traditional speeds of operation. U-grooves are used and adequate traction is achieved by using a double wrap system, see Figure 15 and Figure 48.

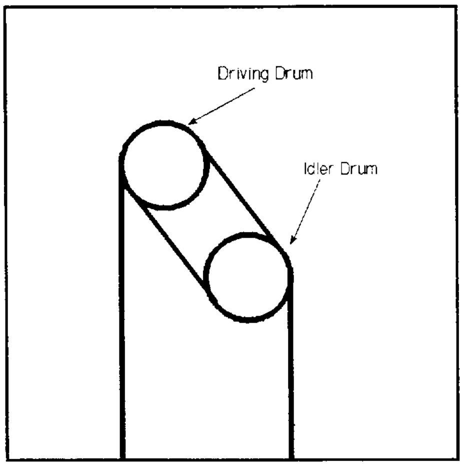

Figure 48 Arrangement of Gearless Elevator Drum

In this arrangement the double wrap is achieved by means of an idler drum. Both drums are grooved but only one drum provides the driving and braking force. The extra frictional force is achieved by the doubling of the arc of contact of the rope on the drum. This arrangement is often used when the ropes support the conveyance on two parts (Figure 50). It is also usually used for high speed lifts operating at hoisting depths in excess of 100 m.

7.1.2 Traction.

With the short winds associated with elevators in buildings or in mines it is difficult to achieve adequate pay-loads when the rope is merely hung over the driving drum as in the single wrap system (see Figure 49). The means adopted to improve the traction of the elevator is the use of specially shaped grooves. The vee-groove (see Figure 47) is not usually used for passenger elevators. The undercut u-groove is the groove of choice and the traction provided can be modified by changing the width of the undercut with respect to the groove diameter.

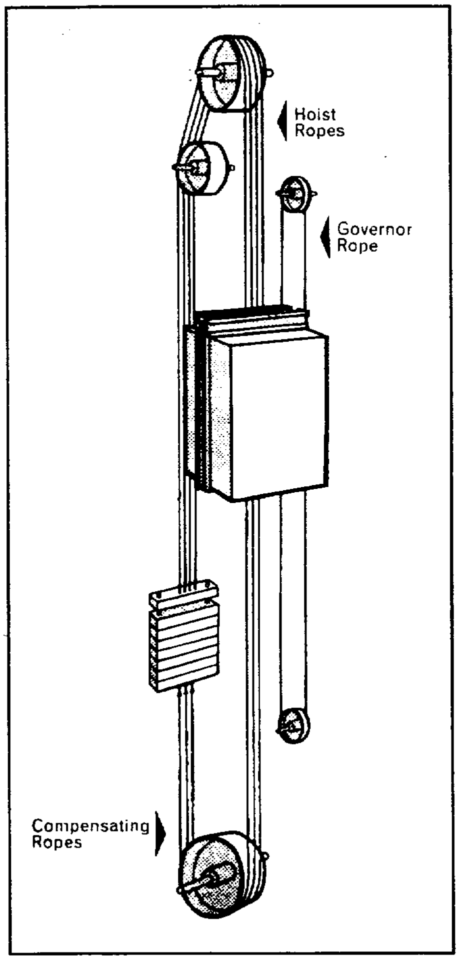

Figure 49 Schematic Layout of Traction Lift

7.1.3 Two to One Roping.

In order to reduce the size of the lift machinery and increase the drum speed two to one roping is sometimes used. In many cases this arrangement avoids the use of compensating ropes (see Figure 50). Alternatively this system is used to enable higher pay-loads without a significant increase in rope or machine size.

7.2 ROPES.

Besides the hoist ropes there are other systems in lift arrangements in which ropes are used. These are compensator ropes (which are equivalent to tail ropes in the Koepe system), governor ropes and in some designs selector ropes for positioning the conveyance at the correct landing places. In all cases good fatigue performance is required as wear is not usually a consideration due to design factors and rope operating conditions.

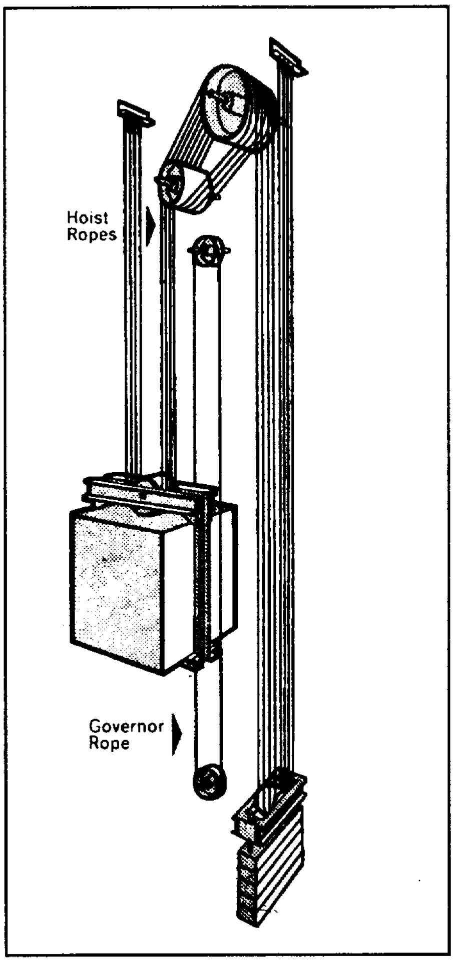

Figure 50 Two to One Roping

7.2.1 Hoist Ropes.

Round strand ropes are usually used, having either six or eight strands. 19 wire Seale strands are usual and fibre cores are preferred, although in some cases steel cores in the form of an independent wire rope are used.

o **Factors of Safety.** Lifts are operated with rope factors of safety in excess of 10. The chief consideration is not primarily related to rope size but to achieve minimum stretch with change in load, so that there is minimal movement of the elevator car at loading stations. Because stretch is inversely proportional to steel area and directly proportional to stress in the rope, the use of high tensile steel merely increases the operating factor of safety if stretch characteristics are maintained. In view of this the criterion for the grade of steel is the requirement for limited stretch with change in load. This matches the use of low carbon steel which is needed to avoid excessive wear of the elevator drum grooves. However, high tensile grades are sometimes used, such as on mines where there are not such critical requirements for limiting rope stretch. In some cases ropes with an IWRC are used to reduce the stretch.

7.2.2 Governor Rope.

The governor rope is a rope which is connected to the conveyance at both ends. It passes round sheaves at the top and bottom of the lift shaft and through a clamping device activated when necessary by a speed governor. In the event of overspeed for any reason the governor prevents this rope from moving, which then activates a device on the conveyance and applies clamp brakes to the fixed guides. The conveyance is then stopped safely in the shaft.

7.2.3 Compensating Ropes.

Because of the friction drive, lifts require balancing force to prevent slip. In small installations the electrical trailing cable for control attached to the underside of the conveyance is sufficient. However most installations require the use of balance ropes which are termed compensating ropes. Similar ropes to the hoist ropes are mostly used but sometimes on large installations non-spin tail ropes are used. Some large slow installations on mines have been equipped with chain compensators.

7.3 GUIDES.

Because of the safety device which applies a clamping force to the guides, fixed solid guides are required. These are usually tee shaped with machined faces where the clamps would be applied. The conveyance are equipped with guide rollers to ensure smooth travel.

7.4 CONTROL.

Lifts are automatically controlled by signals from either inside the conveyance or from push buttons on the stations. DC systems are usually used the design being proprietary to the specific lift manufacturer.

7.5 SAFETY DEVICES.

Lifts are equipped with most of the safety devices used on Koepe winders with the addition of a device which will hold the conveyance in the shaft in the event of rope failure or any other catastrophic event. It is also usual to fit a device which monitors loading and which will prevent the lift from moving if it is overloaded.

8 COMPONENTS OF STAGE WINDERS.

Stage winders provide multi-purpose facilities for shaft sinking. Although drum winders are used the most common type being used in South Africa is the Blair stage winder. Shaft components are the same for both types and are discussed separately.

8.1 BLAIR STAGE WINDER.

This winder[7, 8] comprises three items of equipment which interact to give the desired performance. See Figure 16.

a. The main winder which provides the required force to operate the ropes.
b. The take-up winder which provides back tension and storage for the ropes.
c. The compensating tower which provides back tension control of the ropes and also compensated for differences in speed between the main winder and the take-up winder.

8.1.1 Rope Equalisation.

Because there are only two ropes which operate in multiple falls, the anchoring and sheave arrangements on the stage are arranged to provide perfect balance between the ropes for a limited difference in rope length. This simplifies winder design and allows for efficient use of available rope strength.

8.1.2 Main Winder.

The main winder comprises a friction drive for the ropes in a double drum arrangement. Each friction drive is clutched to the main drive shaft in a similar manner used for double drum winders. Each drive is provided with a separate brake arrangement also interlocked with the clutch arrangement.

The main drive motor drives through a gearbox and is usually AC driven, with suitable speed controls. Rope speed is relatively low. A maximum speed of 5 m/s is normal and depending on the number of falls of rope could be lower.

8.1.2.1 Fleeting Wheel. In the original design of friction drive a reversing type of fleeting wheel was used. Four to six turns of rope were coiled on the wheel to provide sufficiently high T_1/T_2 ratio to provide the required frictional force for moving the stage with a relatively low back tension. The low back tension was desirable because of the large number of rope layers on the take-up winder.

The profile of the fleeting wheel was arranged with different angles as illustrated in Figure 51. The low angle was arranged for hoisting the stage where the high tension of the incoming rope maintained the rope position with the low tension side at the smallest diameter. When operating in the other direction the oncoming rope was the low tension side and the higher angle was designed to ensure that the rope did not climb off the profile.

This design of friction drive has been superseded by the double drum capstan because of an occasional problem with snatching of the rope on the wheel[19]. Excessive loads were placed on the rope and stage which were undesirable due to the high rope tensions being used.

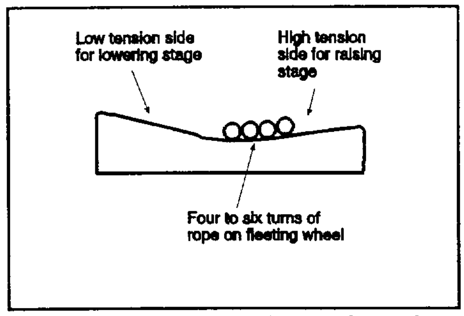

Figure 51 Schematic Profile of Blair Fleeting-wheel

8.1.2.2 Double Drum Capstan. Both the fleeting wheel and the double drum capstan are commonly used on rope making machines. The double drum capstan is choice for large rope diameters and high tensions.

Parallel grooved drums are provided where either one or both of the drums are driven. Four to six turns of rope are wound round the two grooved drums to provide the required frictional force. For satisfactory trouble free operation there are two features of major importance:

a. Grooves must be smooth and machined to suit the rope diameter. The material of the grooves must be either steel or cast iron as either rubber or plastic materials distort sufficiently to cause rope problems.
b. The incoming rope (in either direction) must be arranged to enter the first groove without any fleet angle. If possible it is recommended that the two grooved drums be angled slightly with respect to each other to ensure that there is no fleet angle at any of the grooves.

It must be noted that loads on bearings supporting the drums are high, because of the multiple turns of rope. Adequate bearings and lubrication must be provided.

8.1.3 Take-up Winder.

Two independent single drum take-up winders are provided, one for each rope of the system. The rope storage drum, or take-up winder, must be able to accommodate the full length of rope. (The longest rope supplied to date was 14 600 m long with a mass of 110 tons.) The use of heavier or longer ropes is also probable in the future.

8.1.3.1 Speed and Control. A simple AC drive is usually provided and the winder is provided with an automatic brake which is applied and released as the winder is stopped or started. The unit is designed to run at a constant rotational speed and the rope speed on the bottom layer is arranged to be slightly higher than the maximum rope speed of the main winder. This means that the rope speed when the drum is full will be considerably higher.

The take-up winder is started and stopped purely by automatic control operated by limit switches which are provided in the compensating tower, see Figure 52. The direction of the winder is controlled by a reversing switch connected to the directional control mechanism of the main winder.

8.1.3.2 Drum Coiling. To ensure a reasonable size of drum for the take-up winder it is designed for multiple layers of rope. 30 to 40 layers are common. Because of this large number of layers coiling on this drum is of great importance. Parallel coiling is often used, but can result in uneven coiling. The Lebus or similar pattern system is recommended.

8.1.4 Compensating Tower.

The compensating tower, Figure 52, is provided to compensate for the rope speed difference between the main winder and the take-up winder. It also provides a suspended weight which determines the tension on the take-up winder at all times and the T_2 tension at the friction drive.

If, when lowering the stage, the take-up winder is stationary, the tensioning weight is lifted until it operates the top limit switch. This starts the take-up winder in the appropriate direction. Because the take-up winder rope speed is higher than that of the main friction winder, the tensioning weight is lowered in the tower until it operates the lower limit switch. This stops the take-up winder. This sequence is repeated until the main winder stops. When hoisting, the operation of the compensating tower is similar. The length of travel of the tensioning weight is determined by the rope speed at the main winder and the relative difference in rope speed between this and the take--up winder.

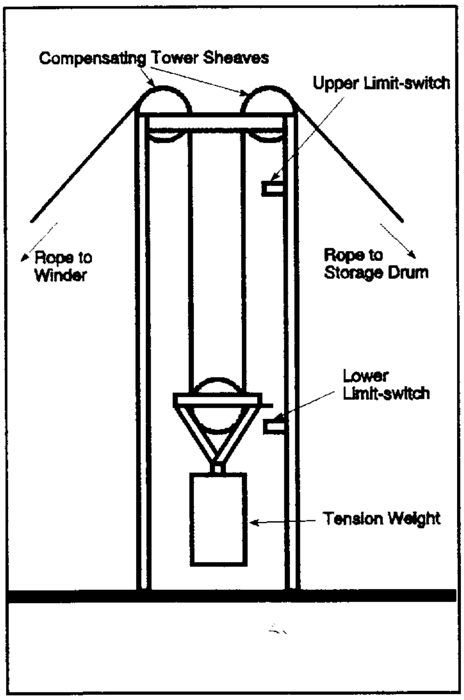

Figure 52 Blair Stage Winder Compensating Tower

Because operating rope speed is relatively low, this on-off action controlling the take-up winder does not give rise to problems and consistent operation can be expected.

In addition to the operating limit switches in the compensating tower, back-up limit switches are provided to trip the whole system in the event of some fault in the normal limit switches or take-up winder control. The complete system will be safely stopped automatically.

8.2 MULTI DRUM WINDER.

Four drums are usually used, each equipped with its own rope. Care must be exercised in coiling the ropes on the drum so that the ropes operate uniformly. There is some latitude for adjustment of rope lengths by clutching.

Because of the slow speed of operation gearing is required, especially if an AC drive system is used. Spur gears and pinions are often used with a spur gear attached to each drum. Pinions are attached to a single shaft driven by the motor, often through a suitable gearbox.

8.2.1 Rope Equalisation.

Because it is normal to use four ropes, symmetrically arranged, to support the stage it is not possible to arrange for adequate equalisation of rope forces. There is a distinct possibility that the stage will only be supported by two ropes due to inherent differences in the ropes and machining tolerances of the winder drums. Consequently, in calculating the required rope size, it is assumed that the stage is only supported by two ropes, even if four ropes are used. Of course, if three ropes are used and arranged symmetrically, equal loads are carried on each rope. The disadvantage of this arrangement is that alternative guiding arrangements must be made for the kibbles, because kibble winders are usually operated with two conveyances and there is only one pair of ropes for use as guides.

8.2.2 Clutching.

Simple dog clutches are usually provided for each drum with suitable clutch and brake interlocks. This arrangement makes it cumbersome to adjust for discrepancies in rope tension and it is seldom that rope tensions can be equalised. The clutch arrangement is usually attached to the pinion on the drive shaft. When open gears are used it is sometimes arranged for the pinion to slide out of mesh with the spur gear instead of providing a separate dog clutch.

8.2.3 Brakes.

Each drum is provided with its own brake. Simple post type brakes are used with similar arrangements to those described for double drum winders. See paragraph 5.2.1 on page 22.

8.2.4 Control.

Because of the slow rope speed of the winder sophisticated control systems are not required. Simple AC systems give safe and adequate control.

8.3 STAGE.

"From the simple single deck 'Galloway Stage' whose main function was to provide protective cover, the modern sinking platform has become a sinking machine in its own right and the nerve centre of the combined sinking/lining operation. In principle, the platforms used during the last 15 years are similar but vary in detail, particularly in respect of method of suspension, number of decks and types of lashing gear."[9] Not very much has changed in the 20 years since this quotation was written. The chief development has been in the total mass of the stage and lashing gear. The heaviest stage to date being 130 tons.

Figure 53 illustrates a typical stage with 10 decks. A mechanical "cactus" grab is mounted on the underside of the stage. The stage is steadied by means of jacks against the side of the shaft while the grab is in operation. Four conveyances operate in this shaft and access holes can be seen in the figure which allow the conveyances to be lowered to the shaft bottom. The kibble crosshead is supported on stops at the top of the stage and the freely suspended kibbles are lowered carefully through the stage.

The top deck is generally the protective cover for operations in the shaft bottom and the stage itself. Stage rope sheaves are mounted on the second deck. Access to the stage from kibbles is generally only on the third deck and the main deck, the other decks being bratticed off from the kibble access holes. The remaining decks provide for workmen required for stripping and installing shuttering for the concrete lining.

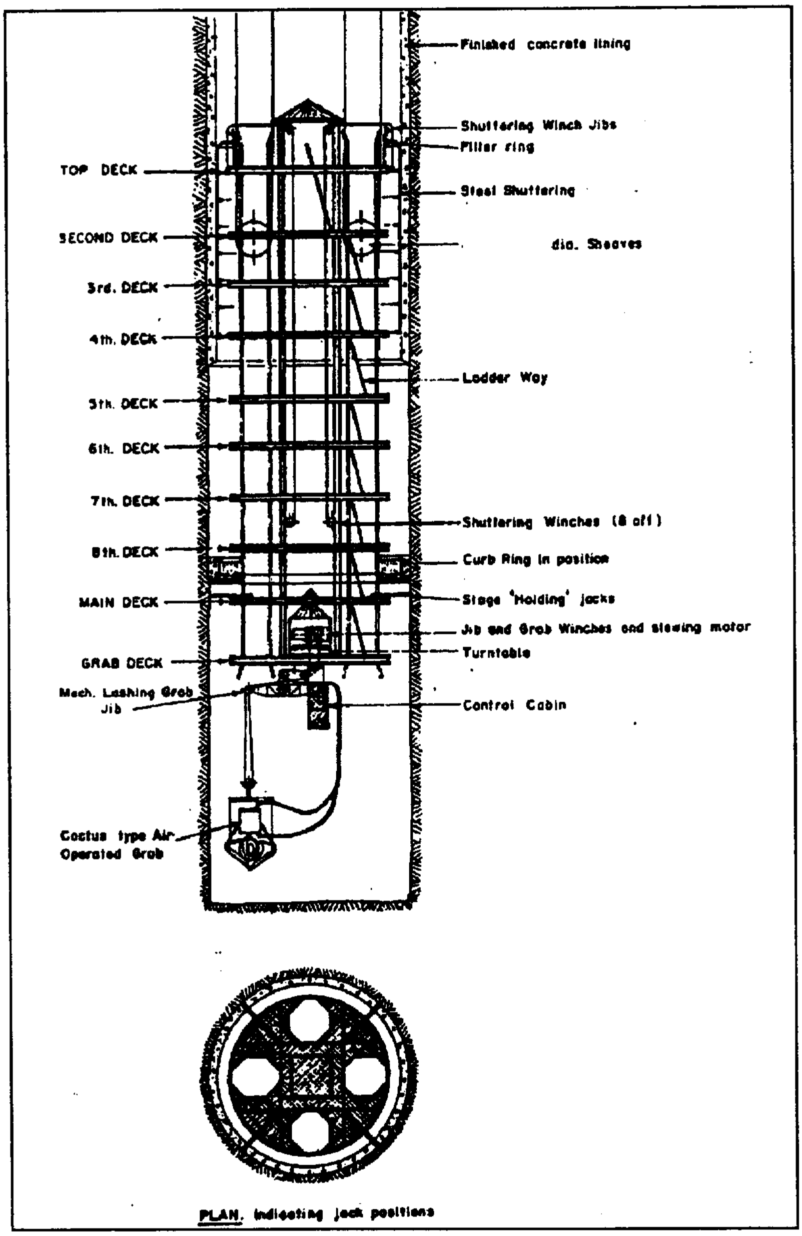

Figure 53 Sinking Stage - Supported on Eight Falls of Rope

9 FURTHER COMMENTS.

This document is intended to be a simple introduction to many of the hoisting systems and winder types used in South Africa. The information is not sufficient for detailed design of a mine winder.

Unfortunately there are no generally accepted manuals relating to the detailed design of a mine winder. Many of the references given will help in designing specific winder components and should be referred to for more detailed information.

Finally it is acknowledged that winder practice in other parts of the world can be significantly different and is usually the result of experience emanating from the requirements for hoisting differing materials. As an example; when coal had to be maintained in discrete large lumps and coal dust was just a waste material it was appropriate to load the coal in tubs and hoist the loaded tubs to surface in cages. The use of skips for hoisting coal has developed along with technology for using the product that was formally waste. In view of this, all parameters must be taken into account when comparing hoisting systems and winders in different mining fields.

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The

TECHNOLOGY

OF WIRE ROPE FOR MINE WINDING

IN SOUTH AFRICA

E.J. WAINWRIGHT

This manual is dedicated to Haggie Rand Ltd and to colleagues, past and present, who have always given unstinting help and advice regarding all aspects of rope usage and manufacture.

Permission from Haggie Rand Ltd for the use of information, text and diagrams from various publications is gratefully acknowledged.

PREFACE

This manual was commissioned by a committee constituted by the Chamber of Mines' sub-committee of Consulting Mechanical and Electrical Engineers for investigation into specification and operating parameters for Drum Winders.

It is intended that this manual should provide the basic knowledge related to the design, manufacture and operation of wire ropes for mine winders. It would therefore provide the basis for the training of all persons involved in the use of winding ropes with special emphasis for persons who will be appointed to undertake the condition assessment of winding ropes.

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Chapter 1

INTRODUCTION TO ROPE AND ROPE TECHNOLOGY

1.1 HISTORY.[1 2]

The art of ropemaking dates back to the earliest recordings of history. Ropemaking scenes are depicted on wall paintings in tombs of the ancient Egyptians. The ancient craft involved either man power or animal power and it was only at the end of the 18th century with the advent of the steam engine that machinery was invented to harness the power which had become available and so improve the speed and range of rope manufacture.

1.1.1 FIBRE ROPE.

The earliest ropes were made from vegetable fibres. Hemp seems to have been the most widely used material. However, any fibrous material ranging from the coir of coconuts to the soft fibre of flax or cotton was used. In more modern times Manila and Sisal fibres have been the materials used.

Large quantities of fibre rope were required in the shipping industry. This requirement increased in the 17th and 18th centuries and provided the demand which stimulated manufacturers to develop improved ropemaking machinery.

In the mining sphere fibre ropes were used for hoisting but gave short lives and often failed in service. Chain suffered the same problems. The demand for safer means for hoisting provided the impetus for rapid development of rope technology.

1.1.2 WIRE ROPE.

Parallel developments in Europe and the United States of America resulted in the use of iron and later steel wire for the making of ropes for somewhat different purposes.

(1) Selvagee Ropes.

In the eastern United States rivers and canals provided an available and cheap means of transport. The use of locks where steep inclines created rapids or waterfalls does not seem to have been widespread and in many places boats were transferred from one level to another on an inclined plane. The fibre ropes used suffered the same disadvantages as mining ropes in Europe. The first attempt to develop an improved rope resulted in the production of a rope made from a bundle of iron wires laid parallel and held together by a wire wrapping. This type of construction is now known as a selvagee rope. Although the first ropes of this type were damaged and had to be replaced (sabotage was suspected) they were sufficiently successful to prompt further development. This construction of parallel wires was not ideal for running ropes but proved to be eminently suitable for static applications such as the main cables of suspension bridges. Many famous bridges were built using this construction rope.

(2) Stranded Ropes.

In the 1830's a mining official of Clausthal in the Hartz Mountains, Wilhelm Albert, experimented with iron wire in various configurations. His first rope, a 3×4 (i.e. 3 strands of 4 wires each) with the wires and strands spun or laid in the same direction was installed at the Caroline Pit at Clausthal in 1834. This rope was successful and it was found that this type of rope was a quarter the price of a fibre rope for the same application and lasted twice as long. At about the same time development work was being undertaken in the United Kingdom.

For the rest of the 19th Century continued developments in UK, USA and Europe resulted in the types of ropes commonly used today. In 1885 the "Seale" construction was patented in America and in 1889 the "Filler Wire" construction was patented. In the 1880's all shaped strand types of mine hoist rope used in South Africa today, were invented by Telford Clarence Batchelor in Great Britain.[3]

Technical developments in the 20th Century have mostly been in the metallurgy and manufacture of High Tensile Wire and in improvements to manufacturing machinery and techniques for producing both wire and rope. Hand in hand with these developments have been new applications and improvements in knowledge relating to rope usage. Improvements in the control of machinery using wire rope have been spectacular.

1.2 PARTS OF A STEEL WIRE ROPE.[4 5]

A wire rope is as much a machine as the implements on which it is used. In its simplest form it is merely a bundle of wires, but many applications require constructions of great complexity. Figure 1 illustrates the basic components of a wire rope.

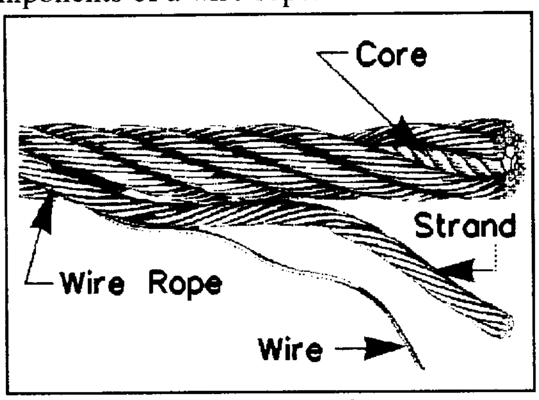

Figure 1 Components of a Rope

It can be seen that this rope is a fairly complicated piece of equipment. In this case six strands are helically formed around a core of fibre. Each strand is made up of several wires which are themselves formed round a strand core.

It should be noted that the strand which is shown unwrapped from the rope and the wire shown unwrapped from the strand both exhibit a helical set. The creation of these helices* in manufacture ensures that the rope, in the as manufactured condition, is easy to handle and will not unlay if the seizing is removed from the end of the rope.

1.2.1 STRANDS.

A strand is basically a bundle of wires which have been helically formed into a coherent unit. It can either be used in this condition or further formed and combined to make up a rope.

(1) Wires.

Wires, yarns or filaments are the basic units used to make rope. Wires can of course be made from any metallic material. The use of metallic wires leads to special constraints in the manufacture of rope and although wire ropes are sometimes made of copper, aluminium, iron or other material, steel wire ropes are the subject of this discussion.

The simplest types of construction would be made from only one or two wire sizes.See Figure 2 and Figure 3 which illustrate strands with only two wire sizes. In both cases the central wire, called the core (or king) wire is a different size to the other wires in the strand. The more complex constructions with good fatigue or wear performance would have three to five different wire sizes in each strand.

* **Unequal Lay Strands.** Constructions having layers of wires formed in separate operations are termed unequal lay strands. In these strands there may be one, two or more layers of wires over a core. Figure 3 shows the cross-section of a 37 wire unequal lay strand.

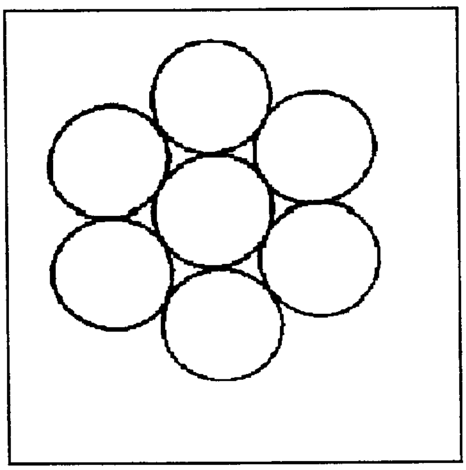

Figure 2 7 wire strand.

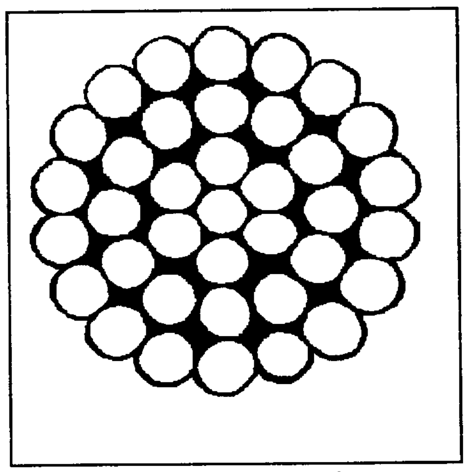

Figure 3 37 wire strand

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* See Chapter 3 for a discussion of rope-making methods and terminology. Concepts such as preforming, lay, lay length etc. are described in detail. The glossary at the end of Chapter 4 should also be consulted for the definition of many rope and rope-making terms.

The lay length of each layer of wires in the strand is arranged so that the lengths of wire in each strand are all the same (except for the core wire). In this case it is found that the lay angle of each layer of wires is the same. Figure 4 illustrates the relationship of strand lay length and pitch circle circumference to the lay angle for unequal lay strands. Because of the difference in lay length between successive layers, the wires covering a particular layer cross over the underlying wires. Therefore the strand size is determined by the sum of the layers of wire in the strand. Figure 5 gives an idealised conception of the way wires in an unequal lay strand cross over each other.

A feature of unequal lay strands and one which has ensured the continued manufacture of this type is the fact that the numbers of wires in each layer in a strand can be arranged so that only one size wire is necessary except for the core wire. It is found that for a uniform size wire the number of wires in a layer should be 6 more than the layer beneath it.

Typical strands would be:-
12 wires laid up 9 over 3
19 wires laid up 12 over 6 over 1
24 wires laid up 15 over 9 over fibre
27 wires laid up 15 over 9 over 3
37 wires laid up 18 over 12 over 6 over 1 and
61 wires laid up 24 over 18 over 12 over 6 over 1

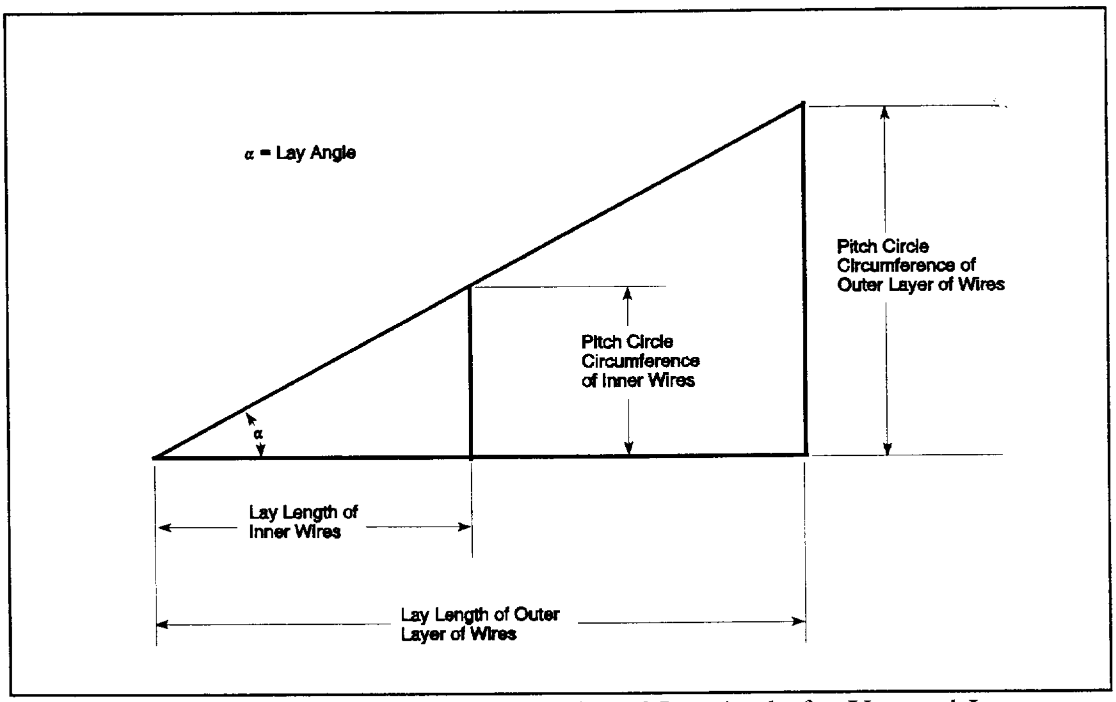

Figure 4 Relationship between Lay Length and Lay Angle for Unequal Lay Strands

Of these strand constructions the 37 wire, 24 wire and 19 wire types have been the most popular and still have many applications in which they are the most suitable product. The 24 wire strand is commonly used in those sling applications where a soft flexible rope is required. In sizes of 3,5 mm and below the 19 wire strand is used almost exclusively in the manufacture of aero-cable.

* **Equal Lay Strands.** Strands that are manufactured in one operation are termed equal lay. All wires are formed into the strand at the same time and therefore of necessity all have the same lay length and so lie parallel to each other either in the gussets formed by the underlying wires or sometimes along the crown of an underlying wire. The difference between this and unequal lay strands is illustrated in Figure 5. Because of this each layer of wires has to have the geometrically correct size wire for it's position in the strand. In addition the number of wires per layer must either be the same or half the number of the covering layer. These constraints result in strands with differing wire sizes in each layer of wires. As an example a 19 wire strand would be made with 9 outer wires over 9 smaller inner wires over a core wire which is bigger than any of the other wires. A strand of this construction is illustrated in Figure 6 and is termed a "Seale" construction.

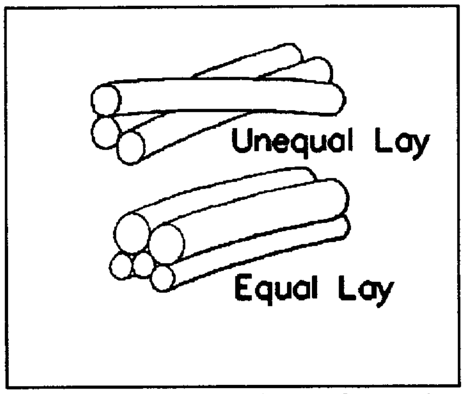

Figure 5 Comparison of Equal and Unequal Lay

The "Filler Wire" construction is a variation of the 12 over 6 over 1 unequal lay construction. In order to stabilise the strand when made equal lay, filler wires are introduced resulting in a strand of great versatility. Initially this construction had been termed a 19 wire filler construction but this terminology has changed to the more logical 25 wire construction. See Figure 7 for a comparison with the 19 wire "Seale" construction.

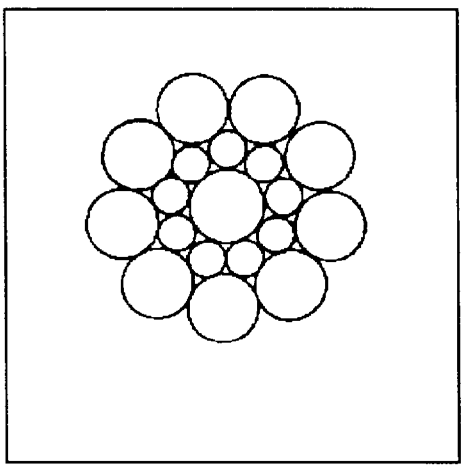

Figure 6 19 Wire "Seale" Strand

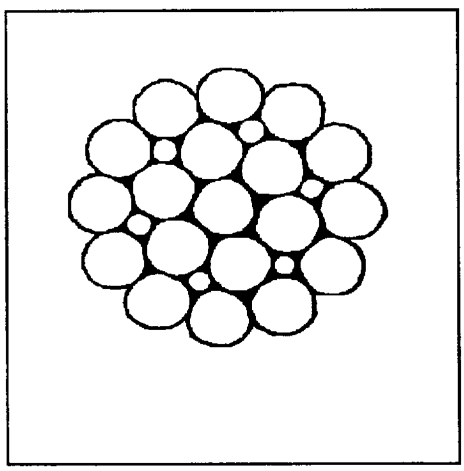

Figure 7 25 Wire (Filler) Strand

There are a large number of possible equal lay constructions but relatively few are in general use. A list of the most commonly used constructions follows:-

17 wires laid up 8 over 8 over 1
19 wires laid up 9 over 9 over 1
25 wires laid up 12 over 6 fillers over 6 over 1
36 wires laid up 14 over 7 plus 7 over 7 over 1
41 wires laid up 16 over 8 plus 8 over 8 over 1
43 wires laid up 14 over 14 over 7 plus 7 over 7 over 1
49 wires laid up 16 over 8 plus 8 over 8 over 8 over 1

It should be noted that the maximum number of outer wires listed is 16. Sometimes for very large ropes 18 or 20 outer wires are used. However performance with these constructions is seldom good as the outer wires often become slack, so such constructions are usually avoided.

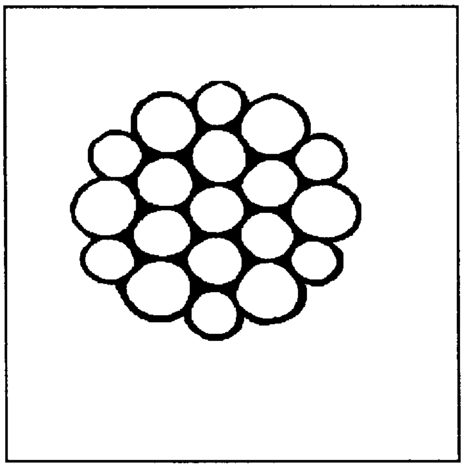

Figure 8 19 Wire Warrington Strand

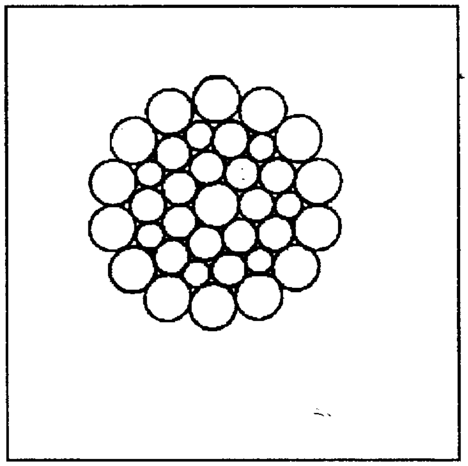

Figure 9 36 Wire Seale-Warrington Strand

The list of constructions also contains a geometrical arrangement which has not yet been mentioned. The 19 wire "Seale" and "Filler wire" constructions were both patented in Europe and the USA, so to avoid the patent and gain the benefits of the equal lay concept the so called "Warrington" design was developed. In this design the outer wires of the strand are not the same size, large and smaller wires are used. The 6 larger wires lie in the interstices of the 6 inner wires and the smaller outer wires lie on the crowns of the 6 inner wires. This 19 wire design is not much used today, however in combination with a cover of wires laid in a "Seale" arrangement it forms the basis for some of the most widely used constructions such as the 36 wire and the 49 wire listed. Figure 8 and Figure 9 illustrate these arrangements.

As the name implies the lay lengths of all the wires in an equal lay strand are the same. This is achieved by forming all the wires in one operation. Because all the lay lengths are the same and each layer of wires has a different pitch circle circumference, the lay angle of each layer is different. The lay angle is smaller the closer a layer is to the core. Figure 10 illustrates this for a strand having two layers of wires over the core.

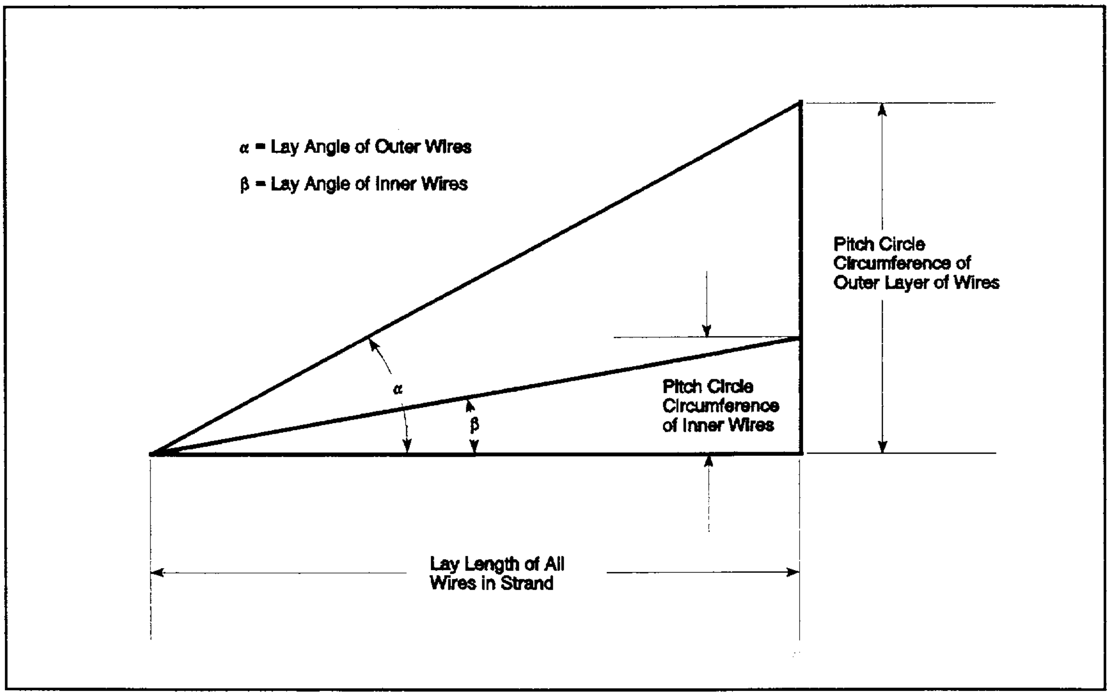

Figure 10 Relationship between Lay Length and Lay Angle for Equal Lay Strands

* **Shaped Strands.** Besides strands which are round in cross-section there are many strand designs having a geometrical shape, many of these having been invented by T.C. Batchelor of Birmingham, England in the 1880's. Shapes vary in cross-section from triangular to elliptical or even ribbon shaped. These three shapes are common in ropes used for mine hoisting.

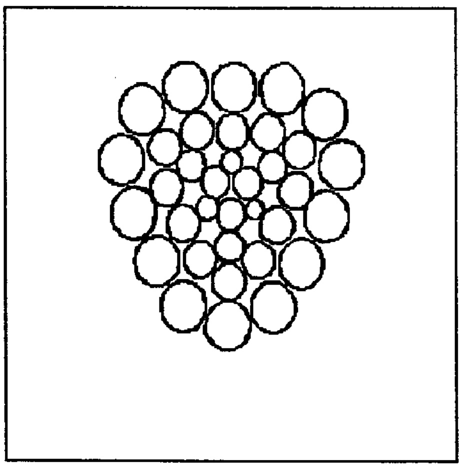

Figure 11 Triangular Strand

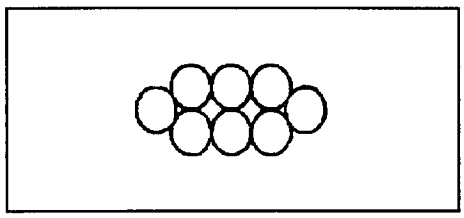

Figure 12 8 wire Ribbon Strand

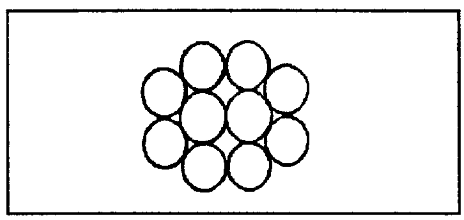

Figure 13 10 wire "Fishback" Strand

The most common shape is the triangular strand which can have one or two layers of wires over a shaped core. A strand with only one layer of wires over the triangular core is termed a simple strand whereas strands with two layers of wires are termed compound. Compound triangular strands are made unequal lay and commonly have between 7 and 16 outer wires formed over 12 inner wires which are formed over a triangular shaped core. Figure 11 illustrates a 32 wire strand laid up 14 over 12 over (6 + 3) triangular core.

The ribbon type strand is made from 6, 8 or 10 wires and has proved to be an excellent shape for use in non-spin ropes. See Figure 12.

In South Africa elliptical strands have only one layer of wires over suitable core wires. Figure 13 shows the cross-section of an elliptical strand which is called a "Fishback" strand to differentiate it from other oval or flat strands. In other parts of the world elliptical strands sometimes have 2 or even 3 layers of wires. These are also made unequal lay.

(2) Strand Core - Wire or Fibre.

Most strands are manufactured with a single steel wire as the core. This is often termed the king wire as it is the basic support for the covering wires in the strand. To achieve extra flexibility or a soft feel a non-metallic core is sometimes used. This is usually some fibrous material such as Jute, Sisal or one of the man made fibres. This type of core is usually made from several yarns twisted into a strand but in some cases may just be a bundle of yarns.

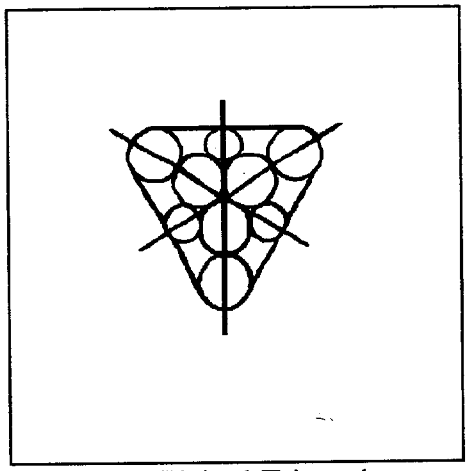

Figure 14 Plaited Triangular Core

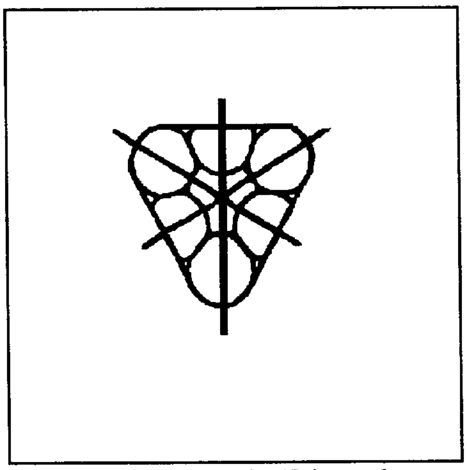

Figure 15 BRangle Triangular Core

The core of shaped strands has the additional function of providing the basis for the shape of the strand.
Ribbon strands have no core, elliptical or "Fishback" strands have either 2 or 3 parallel wires or an elliptically shaped extrusion of plastic or aluminium. In the case of triangular strands the core is usually a specially made rope having three strands of two wires with strand and rope lay lengths arranged to form the triangular shape naturally. This type of core is termed a plaited core. See Figure 14. Where the size of the core allows and extra rope mass is not a problem the triangular core is sometimes made from a round strand, of 6 wires over a low carbon steel core wire, which has been rolled into a triangular shape. This type of core is known as a "BRangle" core and behaves very well in the rope. It also has the advantage of being cheap to make and provides a solid and stable support for the strand. Larger cores of this type are made of 9 wires over 3 low carbon steel wires and are not favoured as there is a strength to

mass penalty, especially for the larger size strands. These two most favoured triangular strand cores are illustrated in Figure 14 and Figure 15.

1.2.2 ROPE CORE.

All ropes having more than three strands require a core to support the strands and prevent distortion.Three strand ropes are often made without a core as the geometry is inherently stable. However where this construction is used as an operating rope a core is usually required to ensure constructional stability and provide sufficient support to avoid severe inter-strand nicking.

Rope cores are chosen to suit the applications for which the ropes are to be used.

(1) Fibre Core.

The most usual core is made of fibre. Vegetable fibres such as Sisal, Manila and Jute are the most common and a sisal fibre core would be supplied as standard if specific requirements are not stated. Cores of synthetic fibre are fairly common but in spite of their advantage of low moisture absorption do not give as good a support to the covering strands as sisal or manila.

Fibre cores are generally in the form of a three or four strand rope. The yarns are pre-lubricated during manufacture and cores for wire ropes are made somewhat harder than an equivalent cordage rope.

(2) Wire Strand Core.

A wire strand core (often called a wire main core, WMC) is the core of choice when extremely long life is expected from a standing rope* and core deterioration must be avoided. These cores are used for applications such as ships rigging, bridge droppers etc. A WMC is not usually found to be satisfactory for running ropes although it is commonly used in rope sizes smaller than 4 mm diameter where good performance is achieved.

The construction of a wire strand core is generally the same as the strands of the rope itself.

(3) Independent Wire Rope Core.

Where round strand ropes are subjected to high pressures such as on machines operating at low design factors and with small drum to rope diameter ratios the support offered by a fibre core is not enough and a steel core is used. In a running rope it is essential that the rope is not prone to birdcaging or premature deterioration of the core due to fatigue. A core made of a steel wire rope satisfies

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* A standing rope is one which does not run over sheaves. The following are considered standing ropes:- Guy ropes, Boom suspension ropes, Cableway track ropes, Guide ropes, Suspension bridge ropes etc. A running rope is one which moves over sheaves.

these requirements and is usually referred to as an IWRC. For six strand ropes the most common core construction is a 6×7(6/1)/1×7(6/1) wire rope. The core is made the same hand of lay as the rope itself and the type of lay is usually the opposite. ie. a Lang's lay core in an ordinary lay rope and vice versa. Note:- Rope lays are discussed in paragraph 1.4.5 on page 25.

1.2.3 WIRE.

Rope wires are generally made from medium to high carbon steel. The basic raw material is hot rolled rod which is drawn to the desired finished size in a wire-drawing machine. This is a cold work process. The work put into the wire to reduce its size results in a fibrous metallurgical structure and an increase in tensile strength. The technology of wire-drawing enables the strength as well as the size to be controlled within the limits required by the rope-maker. See Chapter 2 for further information on the manufacture of wire.

(1) Steel.

The steel required for wire-drawing is supplied in the form of hot-rolled rod. It is controlled cooled after rolling so that it is economical to draw wire directly after cleaning the rod to remove the scale. However in order to achieve the best possible properties in wire for mine hoisting ropes and other sensitive applications the hot-rolled rod may require a heat treatment process called patenting before cleaning. The objective of this is to achieve a desirable grain size and formation in the steel.

In drawing, the diameter of the wire is reduced and the tensile strength increases. It is usual to draw the wire so that the cross-sectional area is reduced by between 70% and 90%. Depending on the carbon content of the steel the tensile strength achieved can vary from 400 MPa to as high as 2300 MPa or higher depending on the final wire size and the parameters of the drawing process. It is possible to achieve extremely high tensile strengths in fine wire with diameter less than 1 mm.

* **Ungalvanised.** The use of ungalvanised wire in ropes is common. Most applications involve operating conditions where the rope must be lubricated and this is usually sufficient to protect the rope from corrosion.

* **Galvanised.** Many ropes are made from galvanised wire. Mine winding ropes that are galvanised are made from wire which has been galvanised before drawing. Although this results in a thin zinc coating the wire properties are not much affected by the galvanising processs. However the tensile strength which can be achieved is lower than an ungalvanised wire. Where corrosive conditions are severe, wire which has been galvanised after drawing is used. In this case there is a much heavier weight of coat, but the disadvantage is that the heat of the galvanising process affects the mechanical properties adversely.

(2) Tensile Strength.

Hard drawn high carbon steel wire is one of the strongest common materials known to man. Because steel wire ropes are universally used in everyday life this strength is taken for granted. The standard strength for most wire ropes is 1800 MPa (or 1770 MPa in European Specifications where the figure is a conversion from 180 kgf/mm^2). Most other steel products such as constructional steel are usually of the order of 400 MPa to 800 MPa.

When a wire is drawn slight variations in the properties of the rod such as diameter and chemical composition make it impossible to achieve an exact tensile strength. There must always be a tolerance range. The permitted range[6] for wire to be used in winding ropes is 200 MPa for a 3,00 mm wire with a nominal tensile strength of 1800 MPa. This increases to 250 MPa for a tensile strength of 2100 MPa.

The nominal tensile strength of a wire is known as the tensile grade and is the minimum strength of the range specified.

(3) Ductility.

The ductility of a wire is measured in three different ways:- tensile testing, torsion testing and bend testing. Good ductility from an engineering point of view means the ability of the wire to deform evenly when subjected to these tests. The engineer's interest in ductility is to ensure that the wire or rope is not brittle (in an engineering sense) and so avoid premature failure at points of local stress concentration.

* **Tensile Ductility.** This consists of two components - the uniform ductility which is homogeneous throughout the material and the rupture ductility which is associated with local plastic flow at the point of failure. The total elongation of a wire at failure is a measure of the total ductility of that wire. Some rope-makers insist on minimum total elongation values for wire to be used in their ropes on the assumption that good ductility will ensure a good rope.

* **Torsional Ductility.** This property is assessed in the torsion test. In this test the wire is physically twisted about it's axis until fracture occurs. Because the maximum strain occurs at the surface of the wire this test is also influenced by the surface condition of the wire. Two factors are taken into account in this test - the number of torsions per unit length and both the appearance of the deformed sample and the fractured end. Most wire specifications only require a minimum number of torsions over 100 times the wire diameter and do not specify the appearance of the fracture or the surface of the specimen.

* **Bend Ductility.** The bend test which is used to assess this property is not a well regarded test as the results are often a measure of the test machine or the method of carrying out the test. Requirements for the bend test results are to be found in most wire specifications but are not often called for.

(4) Modulus of Elasticity.

When a hard drawn roping wire is loaded it stretches or elongates, the amount dependent on the magnitude of the load. Part of this elongation is elastic, however on release of the load a small amount of permanent elongation is evident which is an indication of some plasticity in the wire. Besides this feature the load / elongation diagram of a wire tested to failure does not have a definite yield point[7] but gradually exhibits increasing plastic elongation until failure. See Figure 16.

This behaviour makes it very difficult to assess the amount of stretch which will occur at a given load. In the normal operating range the load elongation curve approximates to a straight line up to about 60% of the breaking strength of the wire. The slope of this part of the curve is described by a number termed "the modulus of elasticity". The number is calculated by dividing a unit of the load by the elongation per unit length attributable to that load and then dividing this number by the area of the wire. The elastic modulus of a wire is found from the following expression:

$$E = \frac{(F \times L)}{(A \times \Delta L)}$$

Where
ΔL = Elongation (m)
F = Tension in wire (N)
L = Length of wire under load (m)
A = Area of wire (m^2)
E = Apparent Modulus of Elasticity of wire (Pa)

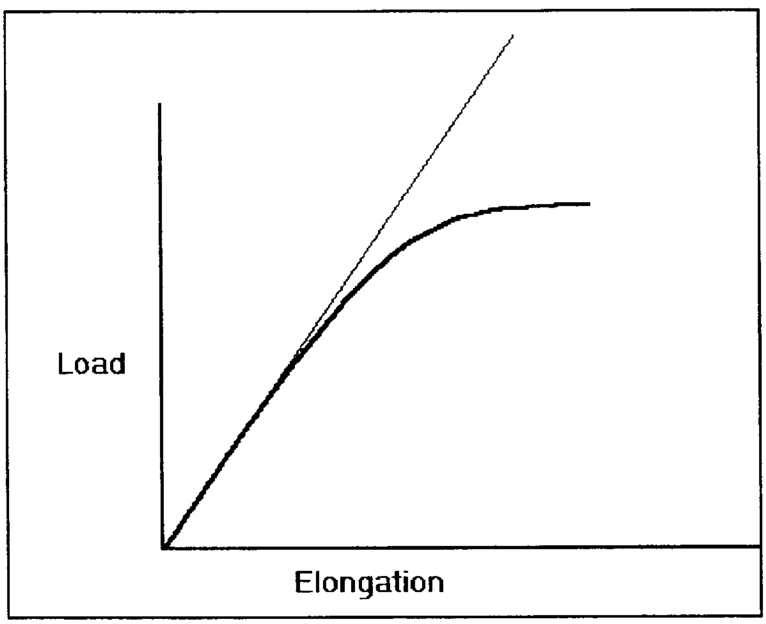


Figure 16 Load Elongation Diagram for Roping Wire

1.3 TYPES OF STEEL WIRE ROPE.

In the foregoing paragraphs the various parts of a steel wire rope have been described. These parts are combined in various ways to produce the type of rope which is judged most suitable for a particular application. It should be noted that there are often differing opinions as to the best arrangement and in most cases it is the users preferences and experience which determines the rope to be used.

1.3.1 SINGLE STRAND.

The simplest of all ropes is the single strand. In sizes below 10 mm it is commonly used for control cables of all types and would be made from 7, 19 or 37 wires laid up unequal lay. See Figure 2 and Figure 3. On the other hand large single strands are difficult to make especially those for static applications where relatively long lay lengths are used. Full Locked Coil and Half Locked Coil ropes are also single strands made with specially shaped wires in the outer layers.

(1) Bridge Strand.

Single strand in excess of 30 mm diameter is often termed bridge strand. Bridge strands are always unequal lay, sometimes with an equal lay core strand. They are laid up with the layers of wires formed in opposite directions to reduce the torque characteristics and any rotation which might occur. In very large sizes there could be as many as 90 to 100 outer wires.

In the largest sizes these strands are used for bridges or as tension members on off-shore oil-rigs or production platforms. Smaller sizes are commonly used as mast guys or boom suspension cables for large earth-moving machines. In all cases except control cables these ropes are used on static applications where their good properties are particularly appropriate and poorer attributes can easily be handled in the design stage. viz.

- High strength to diameter ratio with a relatively low spinning loss. (This is the strength efficiency of the completed rope compared to the strength of the input wire. See paragraph 1.4.1 for discussion of spinning loss.).
- High modulus of elasticity and a low permanent extension. The construction is easily bedded in by pre-stretching.
- Good fatigue performance in tension-tension loading.
- Low torque characteristics.
- Rope is relatively stiff and should only be bent round a radius 20 times the diameter of the strand.
- Due to large wire sizes the maximum tensile grade is limited to about 1600 MPa.
- Special terminations required.
- Bend fatigue performance is such that special care must be taken at terminations to ensure that local bending does not occur and cause premature deterioration.

(2) Locked Coil.

Single strands for static applications are made with relatively long lay lengths. For running ropes however the lay length needs to be much shorter. In spite of a short lay there would still be danger in using a single strand as a running rope, as if a wire were to fail due to fatigue or damage, the wire would loosen and slough (like a snake shedding its skin) with the danger of becoming jammed and breaking. To obviate this the Locked coil rope is used.

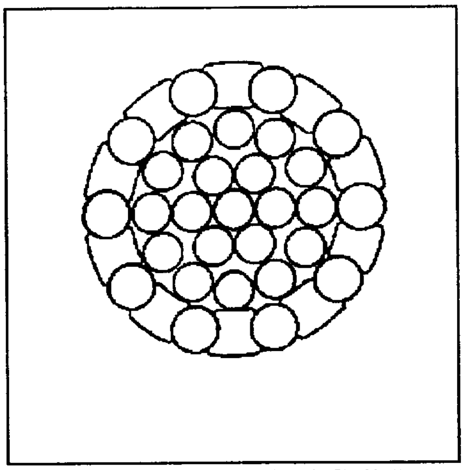


Figure 17 Half Locked Coil Rope

In this rope one to three layers of wires on the outside of the rope are of a shaped cross-section. The shapes of the wires and the tolerances used ensure that if a wire breaks it will usually remain in place and not protrude from the rope. One of the designs incorporates alternate round and shaped wires in the outer layer. See Figure 17. Because the shaped wires alternate with round wires this is known as a Half Locked Coil rope. The most common uses for this type of rope are shaft guide ropes and also track ropes for aerial ropeways.

The other type is the Full Locked Coil rope where the outer wires are of a Z cross-section. There are often one or two half locked layers beneath the outer layer. See Figure 18. The Full Locked Coil rope is used for mine hoisting in Canada and the United Kingdom. It is also extensively used in to-and-fro type aerial cableways as a track rope.

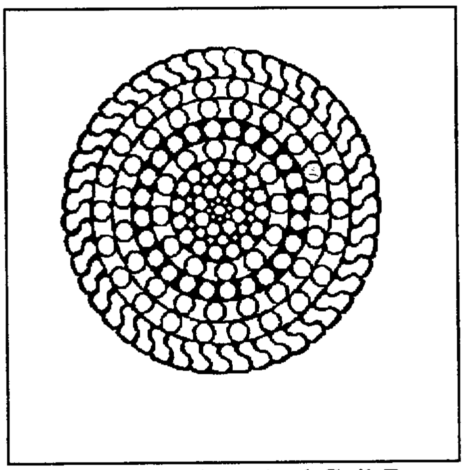


Figure 18 Full Locked Coil Rope

(3) Other.

Small diameter single strands are the basis of most bowden cables. 19 wire strands are most usual as when cross-laid they exhibit lower torque characteristics. These ropes are used in all walks of life and are perhaps the most well known application as their use ranges from the brake control of bicycles to more sophisticated applications in aircraft and motor vehicles.

1.3.2 ROUND STRAND ROPE.

The most widely used type of rope is one made from one of the many round strand constructions. The majority are made of one layer of strands over a core but sometimes more than one layer of strands is required.

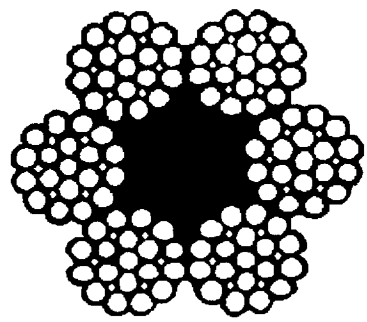


Figure 19 6×25 "Filler" Round Strand Rope

(1) Single Layer Round Strand Rope.

A round strand rope with a single layer of strands over a core can be made with as few as 3 strands and sometimes as many as 9 strands. If more than 9 strands are used with a fibre core the rope is excessively unstable and if a WMC or IWRC are used the rope becomes in effect one made with more than one layer of strands.

The most commonly used number of strands is 6 as this gives the best combination of stability, flexibility and strength. 3 and 4 strand ropes have sometimes been used on cranes as, if laid up Ordinary lay, they have slightly reduced torque factors. At the other end of the scale the 8 strand rope is commonly used on elevators as well as the 9 strand with an IWRC. Recently the use of 8 strand ropes for earth moving machines has become popular.

Figure 19 illustrates one of the commonly used 6 strand ropes, a 6×25(12/6F+6/1)/F. This shows a rope with a fibre core, however it is often made with an IWRC when greater resistance to crushing is required or in hot conditions, as in foundries, where the fibre core would tend to degrade due to the high temperatures.

(2) Multi-strand Round Strand Rope (Non-spin).

When ropes have more than one layer of strands they are termed multi-strand ropes and if they are made with the different layers in opposite directions exhibit non-rotating properties. The 18 strand non-spin is a common rope often used on cranes and sometimes on small drum winders. They can also be used as Koepe winder head-ropes. See Figure 20 for an illustration of one of the simplest a 18×7(6/1)/F laid up with 12 outer strands over 6 inner strands with a fibre core.

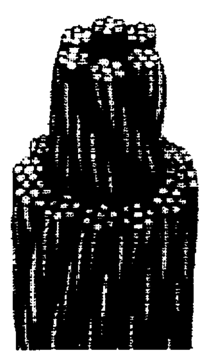


Figure 20 Round Strand 18×7 Non-spin, Ord / Ord

If improved non-spinning characteristics are required a three layer rope is used. The most common is the 34×7(6/1)/F, where 17 outer strands are laid over 11 inner strands which in turn cover 6 strands over a fibre core. The two layers of inner strands are commonly laid in the same direction with the outer strands laid in the opposite direction.

1.3.3 SHAPED STRAND ROPES.

There are certain disadvantages inherent in round strand rope designs such as:-

- o Because of the round shape of the strand, wear is localised and fairly rapid due to relatively high pressures between the wires and sheave or drum surface.
- o The rope is prone to distortion when subjected to high pressures.
- o Multi-strand ropes do not have very favourable torque characteristics.

Because of this, ropes having shaped strands are used in specific applications such as drum winder ropes, shaft sinking ropes and other applications.

(1) Single Layer Shaped Strand Ropes.

As for round strand ropes those with shaped strands can be single or multi-layer with varying number of strands. Single layer ropes with oval strands are often made with less than 6 strands. However these ropes are not common in South Africa. The triangular strand rope on the other hand is commonly used for drum winders. See Figure 21.

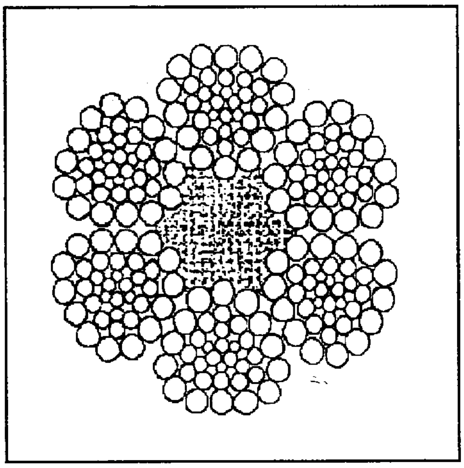


Figure 21 6×32(14/12/6▵)/F Triangular Strand Rope

* **Triangular Strand Ropes.** These ropes are always made with 6 strands and Langs lay. The features which make this rope so successful are as follows:-

- o The external wearing surface of the rope is greater than a round strand rope due to the shape of the strands. This reduces the absolute pressure applied to the wires.
- o The rope is able to take greater pressure in multi-layer applications without distortion.
- o The strength for a given rope diameter is greater than for a round strand rope and the strength to mass factor is higher due to a lower spinning loss.
- o The rope is inherently stable and will accept a large induced lay-length variation without distortion.

The main disadvantage of the triangular strand rope is its poorer resistance to tension-tension and bending fatigue. Because of the varying radii that the wires follow in the strand coupled with the fact that the strands are unequal lay these ropes have a lower fatigue resistance than round strand ropes. However since the applications for which triangular strand ropes are commonly used require good wear and crush resistance the fatigue performance of the rope is of lesser importance.

Other disadvantages are as follows:-
- o Triangular strand ropes are difficult to make.
- o Because they are generally made on slow speed sun and planet machines they are more expensive than round strand ropes.

* **Other.** Ropes with elliptical strands are sometimes used as crane ropes. The strand construction is usually a two layer one with a fibre core. A 5 strand rope of this type made Ordinary lay has improved spinning characteristics compared with a round strand rope and is more stable than a non-spin rope. Due to its construction however it is more expensive to make than the simple 18x7(6/1)/F non-spin rope.

(2) Multi-strand Shaped Strand Ropes (Non-spin).

The most stable non-spin ropes are those with only two layers of strands. These ropes are less prone to birdcaging or distortion than ropes having 3 or more layers. The use of shaped strands for both outer and inner strands makes it possible to design ropes with excellent non-spinning properties. The use of thin ribbon strands over triangular strand inners makes it possible to design a rope that will have minimum torque when placed under load and which will hardly rotate when allowed to hang free. Figure 22 illustrates one of these ropes. These ropes are ideal for shaft sinking purposes where ropes are allowed to hang free on every trip.

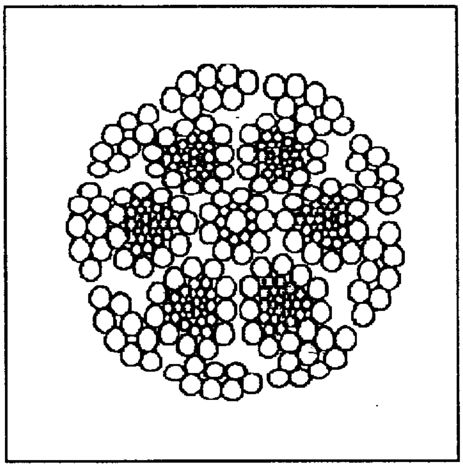


Figure 22 15 Strand Non-spin with Ribbon Outer Strands

The ribbon strand gives the best wear performance but is prone to fatigue of the wires at the edges of the strands due to difficulties in forming the wires into the correct shape, without leaving a slight void in the centre of the strand, and the combination of tension and torsional fatigue in this position. It is found that elliptical strands such as the "Fishback" strand have better fatigue performance at the expense of a smaller wire size, which affect the wear properties of the rope.

In spite of previous comments, there are successful designs of non-spin rope having three layers of strands. One of these designs incorporates two layers of ribbon strands over a round strand inner rope. This rope has been successful when used as a tail rope with a free loop. Another design incorporates two layers of elliptical strands over a layer of ribbon strands in a design which has proved successful in Germany as a Koepe winder head-rope.

1.4 ROPE PROPERTIES.

A wire rope is essentially a bundle of high tensile wires which have been formed together to make a coherent unit. It is the unique properties of this unit that make it an engineering machine of great versatility and usefulness.

1.4.1 BREAKING STRENGTH.

The strength of a wire rope is described in many ways. The different Standard Specifications such as British Standards, Deutsche Industrie Norm and others have varying ways of assessing and specifying the strength of a wire rope.

(1) Calculated Aggregate.

The first step in assessing the strength of a wire rope is to calculate the aggregate strength. This is the simple arithmetic sum of the strengths of all the wires in the rope. It is found by multiplying the cross-sectional area of each wire by the nominal tensile strength of the wire and adding these together. Some Standard Specifications use the calculated aggregate breaking force for establishing the correct size of rope for a particular application. The assessment procedures in the Specification make the necessary allowances for the efficiency of construction of the rope. This is a simplistic approach as the effectiveness of the rope-maker is taken for granted. There is also the possibility that inadequate rope-making practices are encouraged to enable the achieving of other requirements of the specification.

(2) Actual Aggregate.

This is a measure of the actual strength of the wires which make up the rope. After the rope is made all the wires are tested in tension and the sum of these strengths is termed the actual aggregate breaking strength. Comparing this figure with the calculated (or estimated) aggregate gives a measure of how closely the strength tolerance of the wires has been maintained.

(3) Estimated or Minimum (or Guaranteed).

In order to ensure that the manufacturer maintains consistent rope-making practice and to make the use of design factors more meaningful, many specifications require a minimum strength for a particular rope. This is an estimate of the minimum force at which the rope will actually break when tested to destruction in a suitable tensile test machine. Customers often ask for this figure to be guaranteed before placing an order.

In arriving at this figure the manufacturer must take the efficiency of the rope construction into account. When wires are formed into the helical shapes to make up a rope they are not loaded in a uniform axial direction along the rope. The axial force applied along the rope results in a combination of geometrical, axial, torsional and radial stresses which produce a lower breaking force than the aggregate of all the wires. This loss is generally termed the spinning loss of the rope and varies from construction to construction. Representative spinning losses are shown in Table I for several rope constructions.

Although various national and international specifications list breaking strengths for most ropes, rope-makers usually quote their own figures which may differ from the specifications. In South Africa the critical effect of the great depth of operation of drum winders has encouraged the approach that the catalogue figures for breaking strength of mine winding ropes are as close to the actual as practicable.

Table I Spinning Loss for various Rope Constructions

Rope Construction	Approximate Spinning Loss %
6×7(6/1)/F	10
6×25(12/6F+6/1)/F	17,5
6×25(12/6F+6/1)/IWRC	22,5
6×49(16/8+8/8/8/1)/IWRC	22,5
18×7(6/1)/F Non-spin	25
6×30(12/12/6▵)/F and other triangular strand ropes	13
15 strand Non-spin with ribbon strands	17,5
18 strand "Fishback" Non-spin	17,5

(4) Actual.

The actual breaking strength is obtained by testing a suitable sample of a length of rope to destruction in a tensile testing machine. In many cases it is only required to demonstrate that the rope strength exceeds the quoted figure and in this case the rope is held in wedge type grips for the tensile test. Because of the nature of the gripping mechanism the strength so obtained is not necessarily as high as that possible. However this is not suitable for mine hoisting purposes as it is necessary for the rope strength to be established with some accuracy and care must be taken to see that the end connections do not influence the result. This is generally done by using a white metal, zinc or resin capping to connect the rope sample to the machine.

It must be noted that the test done in this way is considered to be representative of the full length of a newly manufactured rope. Tests have been done to verify this assumption by testing a long length or rope at regular intervals along its length[8]. In this test it was shown that the variation was within the limits of accuracy of the tensile test machine. Conversely the test of a used sample of rope is not necessarily representative of the whole length as the presence of wear, corrosion and other localised defects would tend to vary along the length of the rope.[9]

(5) Tolerance.

All engineering products are subject to some form of tolerance. In the case of a wire rope the tolerance on the breaking strength is predicated on the fact that the estimated (or minimum) breaking force is the lower acceptable limit and the maximum breaking force should not be significantly higher than expected from the tensile tolerance of the wire. The normal maximum tolerance in the tensile strength of wire is about +11% to +14% of the nominal so that variations of this magnitude are possible.

1.4.2 MASS.

Wire ropes are no longer sold by mass. However the mass of a rope is important for transport purposes as well as for the determination of design factors for various systems.

(1) Calculated or Estimated.

There are various methods for calculating or estimating the mass per metre of a wire rope. One method merely assesses the mass of each wire and sums these figures to obtain an aggregate mass. An empirical factor is applied as well as additional estimated figures for the fibre core and any rope dressing used. This is generally the method adopted in the various standard specifications.

Another method is to calculate the mass of each wire based on its maximum oversize tolerance, apply a "take-up" factor dependent on the design of the rope and the position of the wire in the rope and then sum these figures. As can be seen in Figure 4 and Figure 10 the length of wire (or strand) in a rope is longer than the rope itself due to the helical formation of the wires. The factor which expresses this is called the take-up factor and is the secant of the lay angle of the wire or strand. Grease and fibre core mass would be assessed as before. In the South African context the benefit of this approach is that the rope will never weigh more than the estimated figure and so design factors for mine hoisting ropes will always err on the safe side.

(2) Actual.

The determination of the actual mass per metre of a rope is a difficult undertaking. One method is to cut a representative sample of the rope from one end, measure it accurately and then weigh the sample. Another method is to measure the length of the rope being manufactured, weigh the completed rope and reel (having weighed the reel) and so establish the rope mass per metre. In both cases measuring the length to the required accuracy is the greatest problem.

(3) Tolerance.

In South Africa due to the method of calculating the mass per metre of a rope the tolerance is quoted as +0% to -7%. However the tolerance accepted overseas is +4% to -4%.

(4) Steel Mass.

As its name implies steel mass is the mass of steel in the rope. Any lubricant, fibre or other material such as plastic or aluminium strand cores is ignored.

(5) Grease Mass.

The amount of grease or dressing in a rope is dependent on the application and to some extent on the finish of wire in the rope.

* **Fully Lubricated.** Unless otherwise requested all drum winder ropes and other ungalvanised ropes are supplied fully lubricated with a heavy grade of bituminous dressing. This normally amounts to about 3,75% of the steel mass of the rope. Galvanised ropes are often required with extremely light dressing or sometimes completely dry. As rope mass is not normally an issue for these ropes the lower mass of lubricant is ignored.

* **Lubricated for Koepe Head-ropes.** As mentioned before the mass of mine winding ropes is important for the evaluation of design factors. Koepe head-ropes operate on a drum provided with an insert to support the rope and are driven by friction. In view of this, special dressings are applied to the outer strands, or outer wires, to ensure that the required coefficient of friction is maintained. The amount of dressing is also reduced and in this case the mass of dressing amounts to about 2% of the steel mass.

1.4.3 ELONGATION.

As for individual wires, a wire rope when loaded will elongate, or stretch. The amount of elongation is dependent on the load and the characteristics of the rope and is composed of both elastic and permanent elongation.

(1) Elastic.

When a rope has been in operation for a short time it beds down and its elongation characteristics become elastic, to a large extent, in the normal operating range of tensions. However bending the rope tends to restore some of its plastic condition. This phenomenon is also influenced by resting the rope for a period of time.

(2) Permanent.

A feature of a wire rope and possibly one which is necessary for good performance is the continuing permanent elongation which accumulates with the operation of the rope. It is well known that a winding rope continually lengthens during its working life and that it needs to be shortened periodically to adjust it back to its correct operating length. In some applications such as Koepe winder ropes this permanent elongation is measured and plotted against number of cycles to give an indication of its continued life expectancy.

(3) Ductility.

The concept of ductility does not strictly apply to a rope as a whole and engineers are generally concerned with what can be considered the engineering ductility of the wire in the rope. Although the steel remains ductile in a metallurgical sense the wire may appear to become brittle due to surface nicks, fatigue cracks or corrosion pits which develop in service.

(4) Work Done to Failure.

When a rope is tested to failure in a tensile test machine a load / elongation diagram is normally provided from which the work done to failure can be determined. This is done by measuring the area under the load / elongation curve and applying a suitable factor to the result depending on the scale of the diagram. Curves produced by the CSIR test laboratory at Cottesloe, Johannesburg have this information provided by computer measurement of the diagram. See Figure 23.

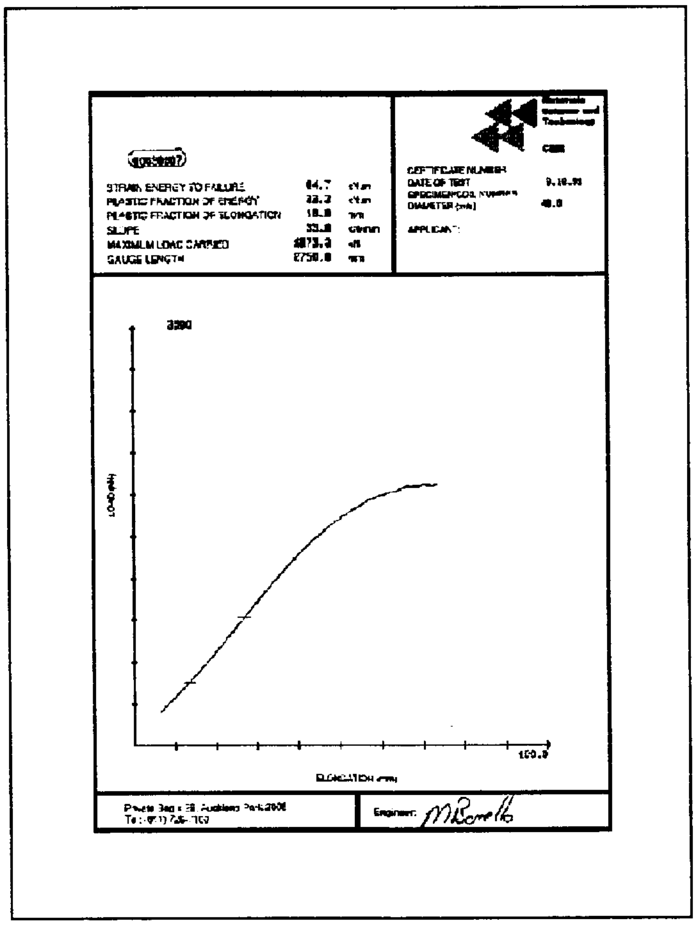


Figure 23 Example of Load Elongation Curve Provided by the CSIR.

The work done to failure gives a convenient means for the assessment of the manufacturing parameters of a new rope when compared with results obtained on other ropes of the same size and construction. This figure is particularly sensitive to ageing of the wire in the rope and can be one of the parameters used for assessing the condition of a rope in service.

(5) Plastic Portion of Elongation.

The load / elongation diagram of a tensile test of a rope will also give information on the non-elastic portion of the elongation characteristic. It is this portion of the curve which is most sensitive to ageing of the wire and any signs of brittleness or damage. These should be confirmed by inspecting wires fractured in the test.

1.4.4 MODULI.

A useful way of expressing relationships is by means of various moduli, the most important of which is the elastic modulus.

(1) Elastic Modulus.

This modulus expresses the relationship between stress and strain by means of a constant. Stress is the force in a rope per unit area and strain is the change in length per unit length of rope for the appropriate change in stress. For a bedded in rope the modulus approximates to a constant but in fact increases slightly as the rope is loaded up to about 50% of its breaking force. At higher loads this concept becomes irrelevant as the rope starts to plastically deform. However in the working range of stress the modulus is sufficiently accurate for practical purposes in assessing elastic elongation. See Table II for representative moduli of various ropes.

* **Young's Modulus.** Ordinary mild steel behaves in a different way to hard drawn wire or wire rope. For this steel the relationship between stress and strain up to the yield point is completely linear and the coefficient is termed Young's Modulus. It is incorrect to refer to the elastic modulus of wire or rope by this term.

* **Area of Steel.** For any rope the stress on which the elastic modulus is determined is based on the steel area. For ease of use the nominal steel area of all the wires in the rope is determined and this is accurate enough in view of the errors which relate to the use of the elastic modulus. If fairly accurate results are required when assessing elastic stretch actual wire sizes for a particular rope should be used in determining the steel area. However the area calculated on the basis of an empirical formula is usually satisfactory. Table II gives formulae for the approximate metallic area of various ropes.

* **Calculation of Elongation.** The amount of elastic elongation can be predicted fairly accurately from the following formula:-

$$\Delta L = \frac{F \times L}{A \times E}$$

Where
ΔL = Elongation (m)
F = Tension in rope (N)
L = Length of rope under load (m)
A = Metallic Area of rope (m^2)
E = Apparent Modulus of Elasticity of rope (Pa)

The table below (Table II) gives approximate metallic areas, in terms of nominal rope diameter (d) and practical values for modulus of elasticity of ropes of various constructions.

It should be noted that calculations based on these modulus values will only give elastic elongation and not total elongation.
Severe loading as in prestressing will result in very rapid "settling down" but even under normal operating conditions most of the inelastic elongation will occur early on in the life of a running rope.

Table II Steel Area and Modulus Figures for various Rope Constructions

Construction	Metallic Area	Modulus of Elasticity GPa
6×7(6/1)/F	0,405d^2	110
6×19(9/9/1)/F, 6×25(12/6F+6/1)/F	0,405d^2	100
6×19(9/9/1)/IWRC	0,475d^2	110
8×19(9/9/1)/F	0,355d^2	86
6×36(14/7+7/7/1)/F	0,410d^2	96
6×14 Triangular strand rope	0,465d^2	103
6×26 to 6×29 Triangular Strand rope	0,450d^2	103
6×30 to 6×33 Triangular Strand rope	0,457d^2	110
Non-spin winding ropes	0,500d^2	110
34 LR UHP	0,493d^2	115
18×7 Non-spin UHP	0,500d^2	115
Half Locked Coil Rope	0,640d^2	138

Note:- The moduli given apply to the normal operating range of loads to which the rope is subjected.

(2) Coefficient of Thermal Expansion.

Steel wire ropes behave in a similar manner to mild steel with respect to the effect of temperature on length and other dimensional parameters. The coefficient of linear expansion of steel of 0,0000114 per °C is the figure used.

(3) Other Moduli.

There is not much call for the use of other moduli such as Bulk Modulus, Poisson's Ratio, Transverse Modulus and Compression Modulus. Special study and possibly research are required for the use of these concepts.

1.4.5 ROPE LAY.

Rope Lay is a combination of the lay length, the direction and the type of lay. Lay length is defined as the length or longitudinal pitch of the helix formed in the wires or strands of a wire rope. In rope manufacture it is the length of rope which passes through the lay block in one revolution of the rope-making machine and similarly in the case of strand .

The direction of lay is either left-hand or right-hand with the latter being the standard direction for most ropes.

(1) Lang's.

A rope is a combination of strands which are formed round a core. When the direction of lay of the strand matches that of the rope the lay is termed Lang's Lay or in Europe, sometimes, parallel lay. Figure 24 illustrates a Lang's lay rope.

Figure 24 Right hand Lang's Lay Rope

A feature of this lay is that a relatively long length of each outer wire is exposed on the surface of the rope. When the rope wears the wear tends to be evenly spread along the wire with beneficial results on performance. Lang's lay ropes also tend to oscillate torsionally in service and this helps maintain a uniform wear pattern around the rope.

Because no counter torque is produced when a Lang's lay rope is loaded it should always be operated with both ends fixed. On no account should this type of rope be operated with a free end as the rope will rapidly unlay.

Ropes made with shaped strands are usually made Lang's lay for ease of manufacture and because this type of lay gives the best fatigue performance.

(2) **Ordinary (or Regular).**

Ordinary lay is the most usual configuration. The rope is laid up in the opposite direction to the strands, so for example the rope will be right hand and the strands left hand. This arrangement gives a most stable rope which is able to operate with one end free without distortion. Of course the rope end will rotate with any change in load if it is free to do so. Figure 25 illustrates an ordinary lay rope.

Ordinary lay ropes can be used in most applications but they do have the disadvantage of slightly inferior fatigue properties compared with Lang's lay ropes.

Figure 25 Right hand Ordinary Lay Rope

1.4.6 SPINNING CHARACTERISTICS.

All ropes have properties related to the geometrical formation of the rope. Some of these properties relate to the torque produced when a rope is subjected to a tension force. Also the amount a rope end will spin when it is free and allowed to rotate when the rope is loaded.

(1) **Torque.**

Because the wires in the strands and the strands in the rope are helically formed in one direction or another, each wire and strand produces a reaction in the form of torque when it is loaded. The resultant is the sum of all these individual contributions. In Lang's lay ropes the torque in the wires and the strands both act in the same direction so this type of six strand rope will develop the greatest torque in relation to its size. Ordinary lay ropes on the other hand have the wires acting in the opposite direction to the strands which reduces the resultant torque. In a single strand the torque is only the resultant of the wire torques and if wire layers are formed in opposite directions the torque will be considerably reduced. The same applies to multi-strand ropes where the strand layers are formed in different directions and so tend to balance the torque

If a rope is in its as-manufactured condition the torque developed is directly proportional to the tension in the rope. This proportionality is described by a coefficient called the C factor. This factor can be calculated from the geometry of the rope. The calculation is a tedious one so this is done at the time of rope design and the manufacturers can supply the calculated factor on request. This factor relates to the design parameters and will change once the rope has been put into service.

(2) **Non-spin Properties.**

A feature of wire ropes is the fact that it is possible to make certain designs in a way that a free rope end will not rotate, or only move a small amount, when there is a change in load in the rope. Of course this is relative to the change in load and for many rope constructions the change in working load is sufficiently small that rotation of the rope is negligible.

There are two alternatives in designing a rope for non-spinning properties. One is to make the rope so torsionally stiff that even if there is a significant C factor there will be minimal rotation of the rope with change in load. This approach is often used for single strands to be used in static applications. For dynamic applications it has the disadvantage that the rope easily distorts and forms either bird-cages or corkscrews depending on details of the design.

The other alternative is to balance the rope as far as possible, but always ensuring that the outer strands have control of the torque. In this mode the rope is only expected to rotate slightly when first installed in a way that balances the torque by changing the stress distribution in the rope. This increases the stresses in the inner strands so it is imperative that it is understood that the rope may deteriorate internally due to fatigue of the inner strands before broken wires occur on the exterior of the rope. This is particularly a feature of the 18 strand non-spin 12×7(6/1)/6×7(6/1)/F. In the USA reaction to this has been such that the authorities try to discourage the use of this construction wherever possible. More torque balanced constructions are favoured therefore. A disadvantage of this low C factor approach to non-spin ropes is the fact that turn can easily be put into the rope by external forces generated by such things as misaligned sheaves or the rubbing of the rope against some obstruction.

1.4.7 SPECIAL PROPERTIES.

Wire rope is noted for its versatility and the fact that it is found in applications related to most industries is confirmation of its usefulness. In some industries it has been displaced by other developments, such as the use of hydraulics in earth moving machinery, but nevertheless its properties are such as to ensure continuing use and development in a wide range of applications.

(1) High Strength.

There is no common engineering material that is of such high tensile strength, coupled with good ductility, resistance to abrasion etc., as hard drawn high carbon wire and it is this that provides the high strength of wire ropes made of this material. The lowest tensile grade used for wire ropes is 1150 MPa ,typically used for elevator ropes in South Africa. On the other hand tensile grades of up to 2150 MPa are used in many mine winding applications. 1800 MPa is considered the standard tensile grade for most ungalvanised (and drawn galvanised) ropes as it provides the optimum compromise between strength and cost for most applications. It is more difficult to achieve high strength with adequate mechanical properties in hot dipped galvanised finish and 1600 MPa is the norm for this type of wire.

(2) Strength to Mass Ratio.

In a mine winding application the high strength of the rope must be accompanied by a reasonable mass per metre if the system is to be economically viable. . A concept which illustrates this feature is the breaking length of a rope. This is the maximum length of rope which can be suspended without breaking. For a typical triangular strand rope with 1800 MPa wire this length is 17 380 m and 19 570 m for a rope made with 2100 MPa wire. Comparative figures for ropes made of other materials are 11 700 m for manila rope, 18 100 m for polyester rope, 26 100 m for polypropylene rope, 28 000 m for nylon rope and 70 000 m for a Kevlar rope. The high figures for nylon and polypropylene indicate the usefulness of these materials, however these ropes elongate very much more than steel wire ropes and also creep to some extent under load. The figure for Kevlar ropes has generated considerable interest. Trials have been carried out to assess the suitability of this material for mine hoisting applications. The ropes elongate about three to five times more than steel wire ropes at similar operating factors and have the additional disadvantage of creep under load. There are also severe problems related to crush resistance as well as the difficulty in assessing rope condition which make them unsuitable for use as mine winding ropes. All these alternative ropes also lack the toughness which is necessary for mine winding and other applications for which steel wire rope is used.

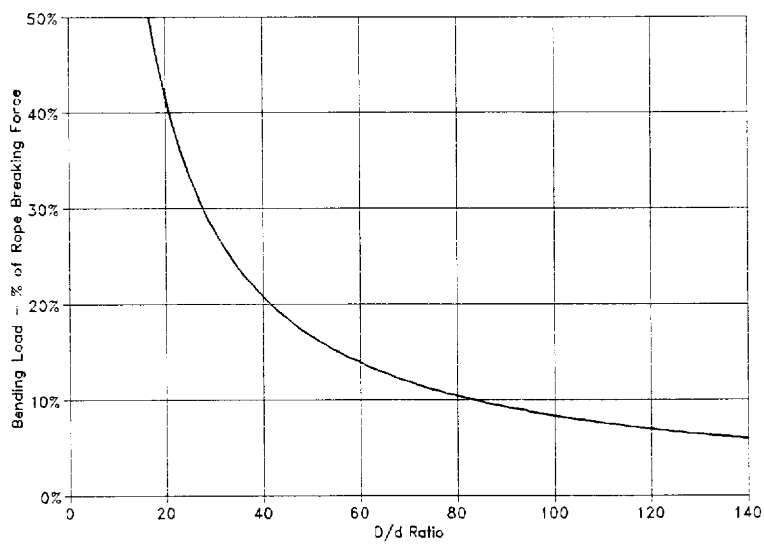


Figure 26 Load due to Bending of 6×30(12/12/6▵)/F 1800 MPa Triangular Strand Rope

(3) Flexibility.

One of the essential properties of a wire rope is its flexibility. In spite of large diameter wires, type of lay, rope construction etc., all wire ropes exhibit a certain amount of flexibility. This flexibility is proportional to some extent to the size and number of wires in the rope and inversely proportional to the lay length. This is one of the features of a rope which is considered by rope designers and when specifying a rope for a particular application. Aspects of flexibility are discussed as follows:-

Table III Recommended Minimum Drum and Sheave to Rope Diameter Ratios

Rope Construction	Recommended Minimum Drum and Sheave to Rope Diameter Ratios
6×7(6/1)/F	38,5
6×19(9/9/1)/F	28
6×25(12/6F+6/1)/F	23
6×36(14/7+7/7/1)/F	19
Triangular Strand ropes	42
Non-spin Winding ropes:-	
15 Strand Non-spin	
9×8/6×29(11/12/6▵)/WMC	42
18 Strand "Fishback" Non-spin	
12×10(8/2)/6×29(11/12/6▵)/WMC	42

* **Can transmit a force round a bend.** This feature of flexibility enables a rope to transmit a force round a bend. This is true even of the large selvagee ropes used for suspension bridges where the curvature of the catenary is obvious. The flexibility of certain ropes makes for extremely compact arrangements which is important for such things as control arrangements in aircraft.

* **Can transmit a force while moving round a sheave.** The unique property of wire rope besides flexibility is the ability to move over a sheave or drum while under load and transmit the force in the rope with minimum loss. Of course there are limits to the diameter over which a rope can be bent while in motion. Table III gives the recommended minimum sheave (or drum) to rope diameter ratios (D/d) for various constructions.

Figure 26 illustrates the effect of bending on a 6×30(12/12/6▵)/F triangular strand rope. In this case it should be noted that there is an effective increase in load in the rope when it is bent and this increase is inversely proportional to the D/d ratio. This additional load imposed upon the rope by bending is dependent upon rope construction, internal lubrication, speed of rope travel and shape of sheave groove, and is therefore difficult to calculate with accuracy. Nevertheless, tests show that a reasonable indication of the increased load due to bending can be obtained from the following empirical formula, provided the sheave diameter is not less than the recommended minimum diameter for the particular rope construction.

$$\sigma = \frac{\delta}{D} E_s$$

Where
- σ = Bending stress (Pa)
- E_s = Modulus of Elasticity of steel (Pa)
- δ = Diameter of outer wire (m)
- D = Diameter of bend (m)

(4) Can transmit a force over very long distances.

Another important feature of a wire rope is the fact that it can be made in extremely long lengths. Even if transport difficulties limit the lengths which can be handled it is possible to join lengths of 6 strand rope together by long splicing to make the required final length. Although this is not permissable for mine winding it is commonly done for aerial ropeways and cable-belt conveyors. Successful ropeways up to 32 km long and cable-belt conveyors of 22 km are operating in various parts of the world. In South Africa the operation of deep shafts hauling from up to 2500 m in a single lift is made possible by the ability of a wire rope to transmit a force over long distances as well as round sheaves.

(5) Fatigue Resistance.

The subject of rope fatigue is a study in itself. Wire rope has an amazing ability to resist fatigue when the conditions under which it operates are considered. No other materials are able to withstand the repeated bending, alternating tension and compressive forces to which wire rope is subjected without adequate warning of the possibility of failure. Because of its unique construction a wire rope does give adequate warning of deterioration so that safe operation of wire ropes has become an accepted norm.

There are various factors which effect the fatigue behaviour of wire rope and although many are listed here the interactions are not fully understood. The major factors are listed as follows:-
- Load range
- Mean load
- D/d ratio
- Speed of operation over sheaves
- Reverse bends
- Repeated bending
- Bending-tension
- Environment ie. saline or corrosive conditions
- Rope construction
- Wire tensile strength

- Method of wire manufacture
- Rope manufacturing methods
- Rope and machine maintenance

Because of this variety of factors which affect rope performance, experience and some theoretical work have evolved practical empirical rules for the design and operation of rope systems. These rules attempt to achieve safe operation without an economic penalty. An illustration of one of these rules is the concept that if a rope is operated above its fatigue limit it will have a life which is dependent on the factors mentioned. This limit is accepted as being about 33,3 % of the breaking strength of the wire or 25 % of the breaking strength of the rope. Of course the life is an engineering concept and is determined by discard at a safe amount of deterioration. Figure 27 illustrates a typical fatigue type curve for the performance of a rope in repeated bending at a constant D/d of 18 to 1.

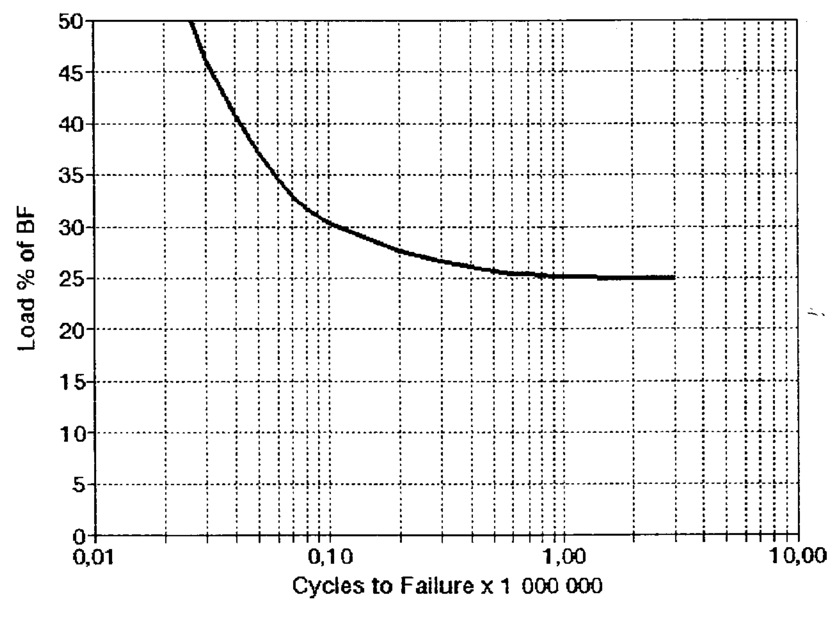
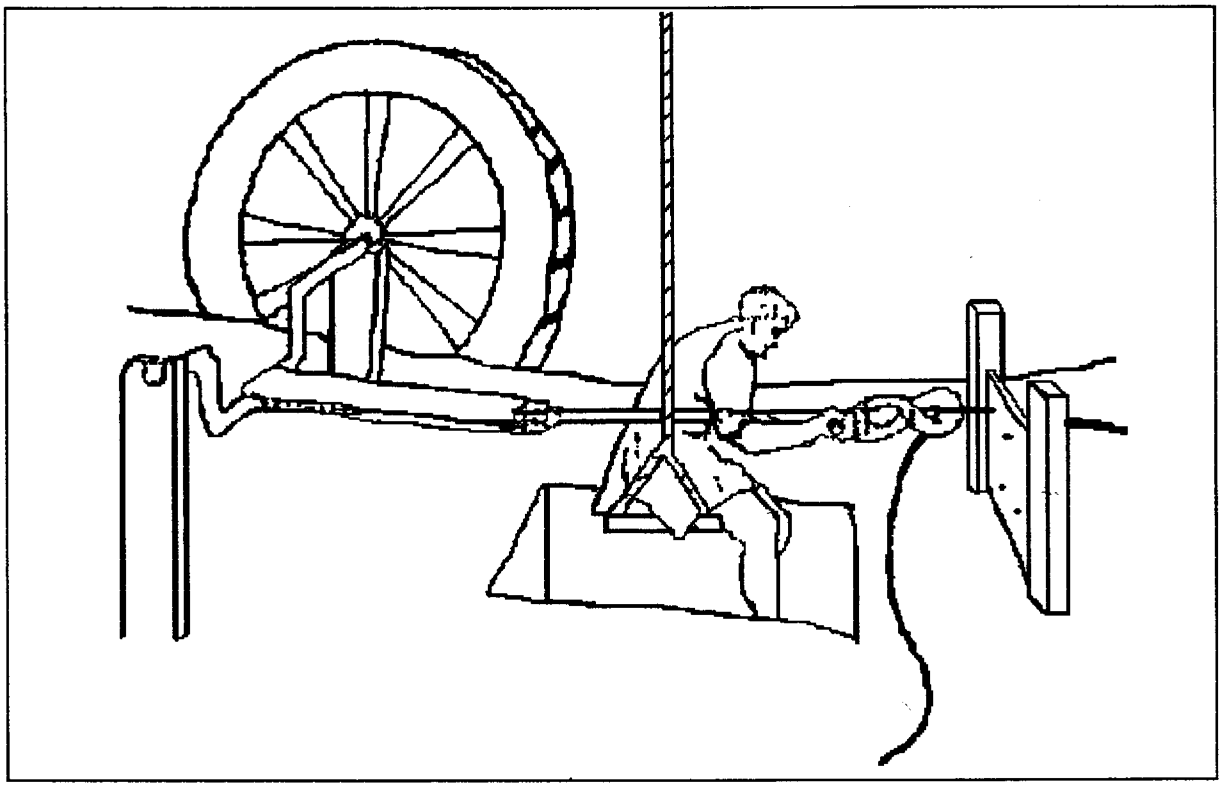


Figure 27 Bending Fatigue Curve to Failure for Wire Rope



Chapter 2

MANUFACTURE OF HIGH TENSILE WIRE FOR USE IN WIRE ROPES

2.1 STEEL.

The required steel product used as a raw material in the production of wire for ropes and other purposes is a hot-rolled rod which is produced in various sizes and compositions. Most steel rod used in South Africa is produced locally [10] but certain specialised products are purchased from overseas producers.

Steel is essentially an alloy of the elements carbon and iron, the carbon ranging in proportion from a few hundredths of one percent to about 1,6 percent. All steels contain varying amounts of the elements manganese and silicon, also small quantities of phosphorus and sulphur. It may contain varying amounts of other elements such as tungsten, cobalt, vanadium and chromium which are added to obtain specific properties in the steel.

The required composition for steel for wire ropes for mine hoisting is shown in Table IV.

Table IV Steel Specification for Wire for Winding Ropes

C	Mn	P	S	Si
0,80% to 0,84%	0,60% to 0,90%	0,04% max.	0,04% max.	0,35% max.
0,78% to 0,82%	0,60% to 0,90%	0,04% max.	0,04% max.	0,35% max.
0,75% to 0,79%	0,60% to 0,90%	0,04% max.	0,04% max.	0,35% max.
0,70% to 0,74%	0,60% to 0,90%	0,04% max.	0,04% max.	0,35% max.
0,65% to 0,69%	0,60% to 0,90%	0,04% max.	0,04% max.	0,35% max.

Considerable quantities of steel wire are made from lower carbon steel. Steel with carbon content from 0,25% and higher is commonly used for wire ropes, springs, prestressed concrete tendons etc. Low carbon steel wire with carbon content below 0,25% is often termed mild wire and is used for such applications as fencing but not for wire ropes.

2.1.1 PROCESSES.

Steel making is a very large subject and it is not appropriate to describe the processes in this manual, even sketchily. The objective is to describe those processes and procedures which have a direct effect on wire manufacture and the quality of wire produced.

(1) Steel Manufacture.

Steel is produced from molten iron by reducing the carbon content of the iron to the required level and also removing undesirable elements and impurities. Various methods in the making of steel are:-

- Bessemer converter process
- Open Hearth process
- Basic oxygen process
- Electric furnace process
- Electric furnace with ladle metallurgy adjustments

These processes are divided according to the furnace lining used, into acid or basic processes. For the acid process an acid refractory material such as silica brick is used and for the basic process a material such as magnesite or dolomite.

The acid process was generally regarded as the best and many specifications required this type of steel for roping wire. In South Africa a common method was a combination of both processes termed the duplex method and supplied as 'Special Basic Steel'.

These processes are now obsolete and improvements in the basic process have been made to such an extent that BS 2763:1982 [5] specifies basic steel for the production of wires.
In the last few years these developments in the production of steel, relate particularly to output and cost. The use of electric furnaces and ladle metallurgy adjustment promises to become a most economical means of producing the required product. However the basic oxygen process is used to produce more than 50% of the steel used in South Africa.

(2) Production of Billets.

A billet is the term used for the steel section which is the input material for rolling to the final rod. A billet for the rod mill is typically 112,5 mm square and about 17 m long and has a mass of between one and one and a half tons. This mass is a function of the arrangements for coiling the rod after rolling.

- **Ingot Cast.** From the wire drawer's point of view the preferred method of obtaining billets for rolling into rod is the use of ingot cast steel. The ingots are cast with the wide end up and with bottom teeming. The top third of the ingot is removed and a small portion at the bottom of the ingot, in order to remove pipe, excessive segregation and inclusions. The ingot is then rolled into blooms about 315 mm square having a mass from 7 to 10 tons and then finally rolled into billets which are cut to the required length and mass. It must be noted that about

40% of the ingot is discarded and then remelted so the efficiency of this process leaves much to be desired.

* **Continuous Cast.** To reduce costs and improve efficiencies an alternative process has been developed. This is termed the continuous casting process. Ladles of steel are tapped into a casting dish which is mounted above vertical curved, square section casting moulds having a radius of about 12,5 m . The steel solidifies in the first few metres and finally becomes a solid bloom or billet which is gradually withdrawn from the mould as the molten steel is poured into the casting dish. This is a continuous process and the bloom or billet is cut into the required lengths and removed for further processing. The disadvantage of this process is the fact that it is not possible to cut off any material which has become segregated and also, the small cross section of the casting limits the amount of hot work which is done to the steel subsequently. Developments in the process to avoid the problem of segregation involve a method of stirring the molten steel as it is solidifying by an electro-magnetic stirring technique. This has produced steel blooms or billets which can be as satisfactory as ingot cast material. See Table V.

If a bloom, typically 315 mm square is produced, this has then to be rolled down to about 110 - 120 mm square suitable for acceptance by the rod mill. In South Africa, ISCOR produces blooms 315 mm square from their continuous casting machines which are then rolled into the required size billets for the rod mill. The quality of this material is highly regarded.

Table V Comparison of Ingot Cast and Continuous Cast Steel

	Advantages	Disadvantages
Ingot Cast	Segregation can be controlled to negligible levels. Hot working advantageous to quality of steel.	Wide end up ingots required for best quality. Large amount of material needs to be remelted. Seams can be formed from blow-holes in the ingot. If there is any splash if the ingot is teemed from the top blisters or scabs form which cause surface problems.
Continuous Cast	More efficient process. Good surface condition of bloom or billet. Less chance of gross non-metallic inclusions or other impurities.	Segregation can be a problem which needs special attention. Reduced amount of hot work can lead to inferior product.

2.1.2 ROD.

Steel rod is the raw material for wire drawing. It is supplied in many sizes and chemical compositions.

(1) Hot Rolled.

In the rod rolling process the shape is changed from roll to roll in a manner which progressively reduces its cross-section until it reaches its final size and circular cross-section. Modern rod mills roll the rod at extremely high speeds and finishing speeds can be as high as 60 m/s . Extremely careful size and temperature control are required throughout the rolling cycle to avoid producing rod with defects such as laps or in-rolled debris.

(2) Controlled Cooled.

When a rod has been rolled to size it is necessary to cool the coils before they can be prepared for despatch to the customer. In the past, this cooling was merely a matter of allowing the rod to cool while being transferred to the despatch department. A more recent development is the controlled cooling of the rods to ensure suitable metallurgical structure of the steel for subsequent drawing. This is termed the Stelmor process. The red hot rod emerging from the last rolling stand is spread in layered coils on a conveyor which is provided with suitable air blast facilities to cool the rod at the required rate and so produce rod which can be drawn directly after cleaning.

This method of cooling produces a micro-structure which may not be entirely suitable for wire for winding ropes or other ultra high tensile requirements.

2.1.3 STEEL MAKING AND ROLLING PROBLEMS.

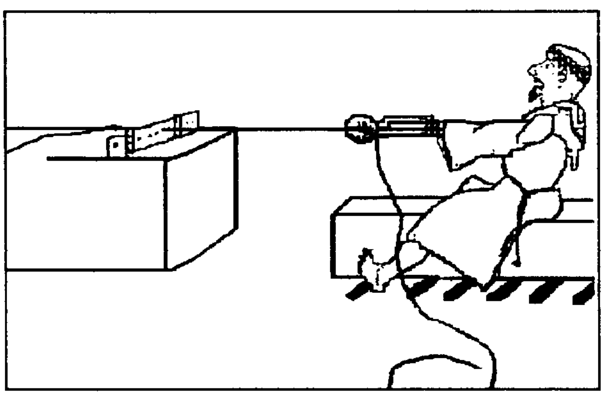
The production of rod, suitable for drawing, from the basic raw materials is a complicated business and it is a credit to the steel makers that relatively few defects occur in rod supplied to the wire drawer. However there are occasional problems and it is appropriate to evaluate these in relation to the effect on either wire production or quality of the drawn wire.

* **Steel Making and Ingot, Bloom or Billet Casting.** Problems relating to these stages are as follows:-
  - o Incorrect carbon, manganese or excessive amounts of phosphorus or sulphur. This may be reason for reject of a cast and would normally occur in the steel plant and not be a problem for the wire drawer. Incorrect carbon or manganese can usually be used for alternative products but incorrect sulphur or phosphorus is always a cause for rejection. Nevertheless the chemical composition of all rod received is checked by the wire drawer.
  - o Non metallic inclusions and non-deformable particles in the steel can cause problems in drawing or later when the wire is used in a rope. Checks are always done but inclusions can be intermittent and so be missed in inspection.
  - o Blow holes are cavities caused by entrapped gasses in the solidification process. Good deoxidation, care during casting and careful cooling can avoid this

problem. The usual result is uneven flow of material in the wire drawing process which can lead to splits in drawing or later in service in a rope.

- o Pipe, caused by uneven solidification of the molten steel at the centre of the section, can lead to hollow wire or cuppy breaks during drawing or even internal fissures which get through the drawing process and remain in the finished wire.
- o Segregation is one of the most common defects and is the subject of continual research and effort by the steel maker. This defect can cause problems throughout the rod making and wire-drawing processes. All rod is checked for segregation as an excessive amount is cause for rejection of a complete batch of rod. Unfortunately segregation is not always uniformly distributed along a rod and can often be overlooked. Problems in wire-drawing and in performance of wire used in ropes are often the result of segregation.
- o Cracks, slivers and seams can be caused by blow holes on the surface of an ingot but are sometimes the result of imperfect moulds, scabs or dirt in the mould which if overlooked can result in these defects. Severe defects of this type usually give problems in rolling or in later wire-drawing. If these survive these arduous operations the defects are usually identified in the final testing of the wire. However any of these defects which are not identified are not likely to give much trouble in ropes in service.

* **Rolling.** Rolling defects mostly give problems in wire-drawing but sometimes can be seen in wire ropes in service.
  - o Out of round rod or rod which varies in diameter along its length is a consequence of poor rolling practice or an inadequate rolling mill. This is not usually a problem today but the usual result is an excessive number of wire breaks in drawing or in less severe cases an excessive variation in the tensility of the wire along its length.
  - o Laps are caused by poor rolling practice where overfill occurs at one or more of the rolling passes and the resulting protuberance is forced over and rolled into the surface of the rod causing a discontinuity. This type of defect is often irregular and not always present at the beginning or end of a coil of rod. In severe cases wire breaks occur in drawing but a mild occurrence would not be detected and does not often cause problems in the operation of ropes.
  - o In-rolled slag, scale or surface damage to the rod usually gives problems in wire -drawing in the form of wire breaks in the machines, the chipping or excessive wear of dies.



2.2 WIRE.

The manufacture of wire is a fairly complicated business. Wire properties can often be critical for particular applications and are influenced by all the treatments and processes used in producing the wire as well as the size and chemical composition of the rod used as the raw material.

The strength of cold drawn wire is derived from three factors:-

- o Chemical composition.
- o Heat treatment.
- o Cold working by means of drawing.

The major strength producing constituent of the steel is carbon with manganese having a secondary effect. Assuming a constant heat treatment, the relationship between carbon content, manganese content and strength of a hot rolled steel rod in the heat treated condition is illustrated in Figure 28.

2.2.1 PROCESSES.[11]

In order to produce quality wire the rod used must be circular in cross-section and be uniform in diameter with no external mechanical damage or contaminants. The steel must be clean and have a consistent chemical composition along the length of the rod. There must be a very low level of segregation and non-deformable inclusions. The surface must be free of cracks, laps or seams from the rolling of the rod.

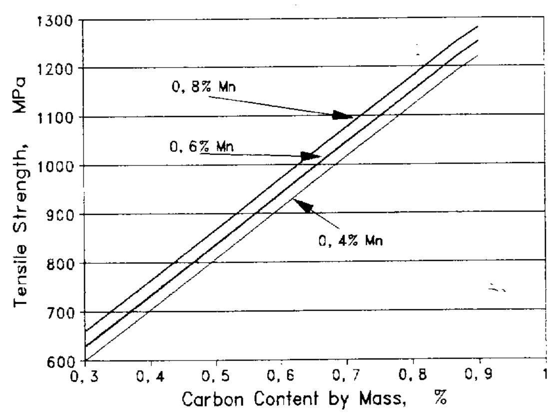


Figure 28 Correlation of Mean Tensile Strength of Rod in Heat Treated Condition with Carbon and Manganese Content

The following processes have specific objectives to enable the production of wire with the desired properties.

(1) Heat Treatment.

Most rod supplied today is controlled cooled. This makes it suitable for drawing into wire directly after cleaning. However the metallurgical structure of the steel is not entirely appropriate for the production of wire for mine hoist ropes even though it is completely suitable for most other rope applications.

For mine hoisting and other applications where resistance to crushing is required it is still appropriate to heat treat the rod under closely controlled conditions. The process is called "Patenting" and involves continuously heating a moving rod in a furnace and then cooling it in a controlled manner. A general view of a patenting furnace is shown in Figure 29. The rod is heated in a neutral atmosphere to a temperature of between 900 °C and 1000 °C and then maintained at that temperature for sufficient time for suitable homogenisation to occur (up to 60 seconds). The rod is then cooled (or quenched) to a temperature between 520 °C and 620 °C, depending on rod size, and maintained at this temperature until the further required transformation is complete (again up to about 60 seconds). Depending on the properties required the cooling may be done in still air, with an air blast or in a bath of molten lead maintained at an appropriate temperature. In some factories molten salt is used as the cooling medium. The process using lead has proved to be the most satisfactory and consistent method and is used in South Africa for wire for winding ropes.

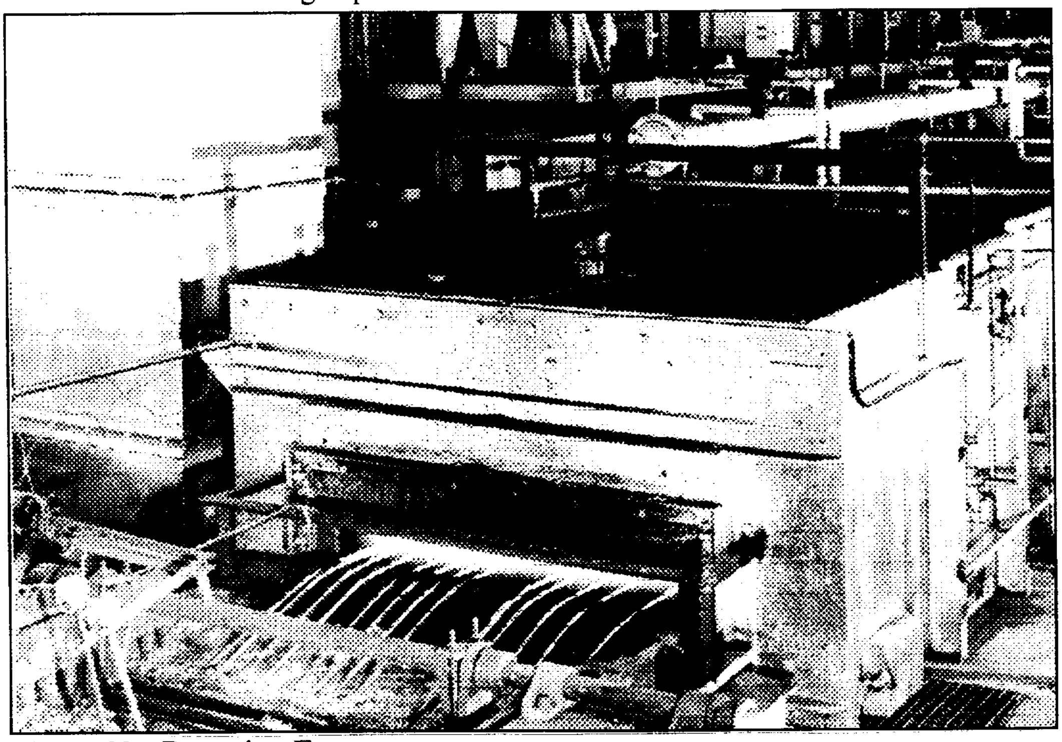


Figure 29 Patenting Furnace

The effect of this heat treatment is to change the micro-structure of the steel in such a way that makes it suitable for drawing. The grain size is changed and the amount of resolvable pearlite* is reduced from about 50 % (Figure 30) to between 5 % and 10 % (Figure 31).

Other mechanical properties are changed as illustrated in Figure 32.

* Pearlite is the name given to the laminated structure of ferrite and cementite. The fineness of the laminations determines the resolvability of the structure under the microscope at a particular magnification. The usual magnification used when assessing resolvability is × 500.

Figure 30 Photomicrograph of 0,8 % Carbon Steel Rod in As Rolled Condition (not controlled cooled). Magnification × 500

Figure 31 Photomicrograph of 0,8 % Carbon Steel Rod as Patented. Magnification × 500

Problems related to the patenting process mostly affect the subsequent drawing operation, but can affect wire quality in certain aspects. The following list gives so me of these problems with comments on the effect on wire production etc.:-

- Too low a patenting temperature. This results in difficulty in achieving the required tensile strength of the drawn wire.
- Too high a patenting temperature. This does not often affect the tensile strength of the wire but can have a detrimental effect on the resistance of the wire to splitting fatigue. If the temperature is much too high the microstructure changes adversely and wire breaks occur in drawing.
- Furnace stoppages which result in coarse pearlite in the affected areas.

- o Uneven or jerky movement of the rod through the furnace. In this case the crystalline structure of the rod is uneven and excessively variable tensile strength and other properties in the finished wire occur which is cause for rejection.
- o Excessive cooling of the rod after the heating stage. This often results in brittleness or low ductility.
- o Insufficient time at the quench temperature which results in incomplete transformation of the steel structure. Unacceptable mechanical properties of the wire are often caused by this.
- o Cabling or crossing of the rod in the furnace or the lead bath. Excessive variability of wire properties cause frequent wire breaks in the drawing process resulting in poor output from the drawing machines and also the probable rejection of the finished wire due to excessively variable properties.
- o Inadequate temperature control of the furnace which results in variability of the structure of the steel. Wire breaks are the usual result but the wire is often rejected due to unacceptable variation of the mechanical properties.
- o Incorrect atmosphere in the furnace which causes excessive decarburization. If local decarburization occurs uneven flow of the steel in the drawing die may result in wire breaks.
- o Inadequate identification of the rods being processed in the patenting furnace. If rods of incorrect size or chemical composition are used the resulting wire will be outside the required specification and so be rejected.

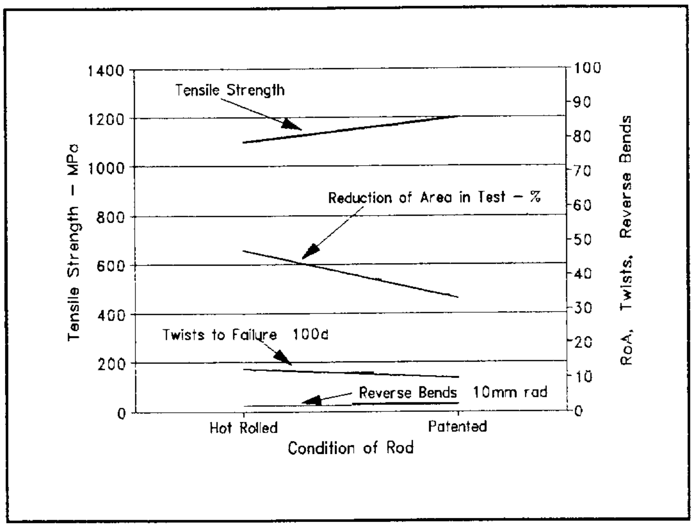


Figure 32 Change in Rod Properties Due to Patenting

(2) Cleaning and Coating.

Pickling is the name given to the cleaning of rods or wire by means of acid, to remove scale or rust and prepare the surface of the rod or wire for drawing. A hot rolled rod or a patented rod or wire has a fairly heavy surface covering of scale. Scale is a mixture of the oxides of iron and is extremely abrasive. Any attempt to draw a high carbon rod or wire with scale would be unsuccessful due to wire breaks caused by uneven drawing. Even if it was possible to draw the wire the scale would chip or abrade the dies making it impossible to continue drawing.

In order to remove the scale the rod is spread on horizontal poles and immersed in acid, containing an inhibitor, for a predefined period. Scale consists of many chemical compounds of which there are three major ones, ferric oxide, magnetite and ferrous oxide. It has an uneven and broken surface so the acid penetrates to the metal of the rod. The iron in the rod is attacked liberating hydrogen which bursts the scale off. The ferrous oxide is also dissolved so the cleaning process is both chemical and mechanical in nature. The acid used is either hot sulphuric acid or hydrochloric acid. Hydrochloric acid is generally used in plants where the wire or rod might subsequently be galvanised as this is the preferred cleaning agent in the galvanising process.

After the rod is removed from the acid in a clean condition it must be thoroughly washed to remove all traces of acid. It is then immersed in a bath of a coating material such as lime, borax or phosphate which coats the steel with a suitable material to assist in the application and transport of soap which is the lubricant used in drawing. Subsequent to this,in the case of a lime coating, the rod is heated to about 200 °C in a flash baker to dry the coating and to drive off any occluded hydrogen which might have been formed while the rod was in the acid bath. For phosphate and/or borax the coating is allowed to dry naturally after immersion in the hot solutions. The rod is now ready to be drawn.

(3) Drawing.

Wire drawing is the process of reducing the cross-section of a wire or rod during its passage through the die by means of the pulling force acting along the axis combined with forces acting perpendicular to the walls of the drawing taper in reaction to the pulling force. The forces relating to the drawing taper exert the most influence.

The deformation of rod or wire by drawing produces changes in the mechanical properties:-

- o Tensile strength is increased.
- o Elastic properties are increased.
- o Hardness is increased.
- o Percentage elongation is reduced.

These properties will be discussed later but the effect of drawing on the mechanical properties of wire is illustrated in Figure 33. These changes in mechanical properties are brought about by the deformation of the crystalline structure of the steel. As the cross-sectional area of the rod or wire is reduced the crystals are elongated and form a fibrous structure. This structure becomes very much stronger in the longitudinal direction with a significant change in the transverse direction. The effect can be compared to a bundle of sticks or grass which has good longitudinal strength but much poorer transverse strength. The micrograph shown in Figure 34 illustrates this feature.

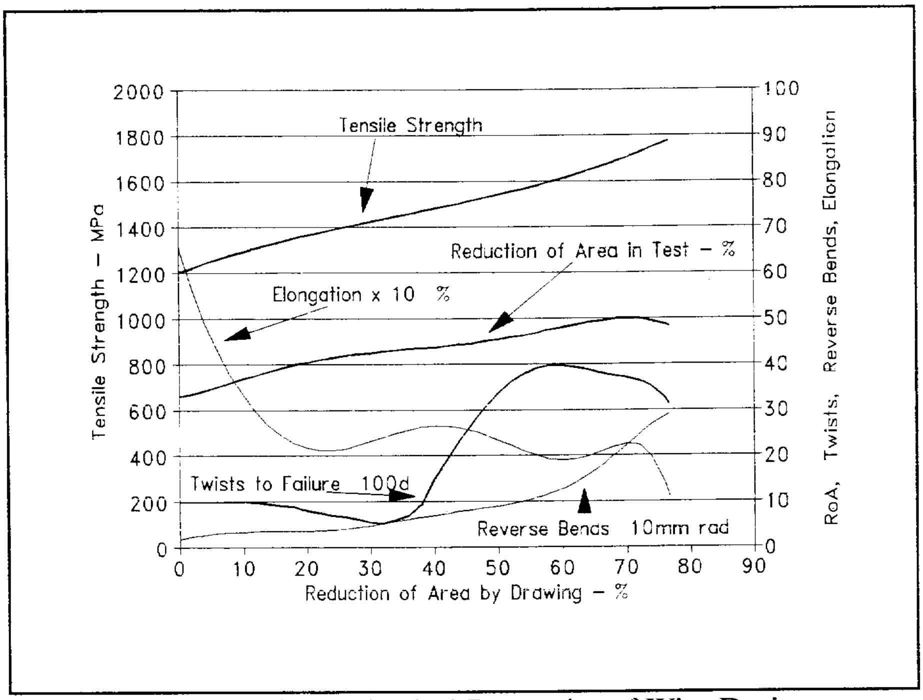


Figure 33 Changes in Mechanical Properties of Wire During Drawing

Figure 34 Photomicrograph of 0,80 % Carbon Wire Drawn to a Reduction of Area of 85 %. Magnification × 500.

* **Wire Drawing Dies.** The use of some sort of die for the drawing of wire dates back to between the first and fourth centuries AD. Until the development of tungsten carbide for use in dies hardened steel plates were used, with holes drilled and shaped by punching the surface in the proximity of the hole. These drawing plates wore very rapidly and would only draw a single coil of wire before having to be re-shaped. Consequently wire drawing machines were all of the single hole type where the wire was drawn through a hole and accumulated on a rotating block. The advent of tungsten carbide dies changed this by reducing the wear to small proportions and making it possible to draw many tons of wire through a die without having to reshape it. Figure 35 illustrates the parts of a tungsten carbide wire drawing die. A pellet (or nib) of tungsten carbide is formed as a circular cylinder with a slightly shaped circular bore. This nib is inserted into a suitable sized case which is shrunk on and provides the strength and compressive force to support the tungsten carbide. The bore of the nib is first ground to the required shape in specialised machines and then polished to a mirror like finish by means of diamond paste.

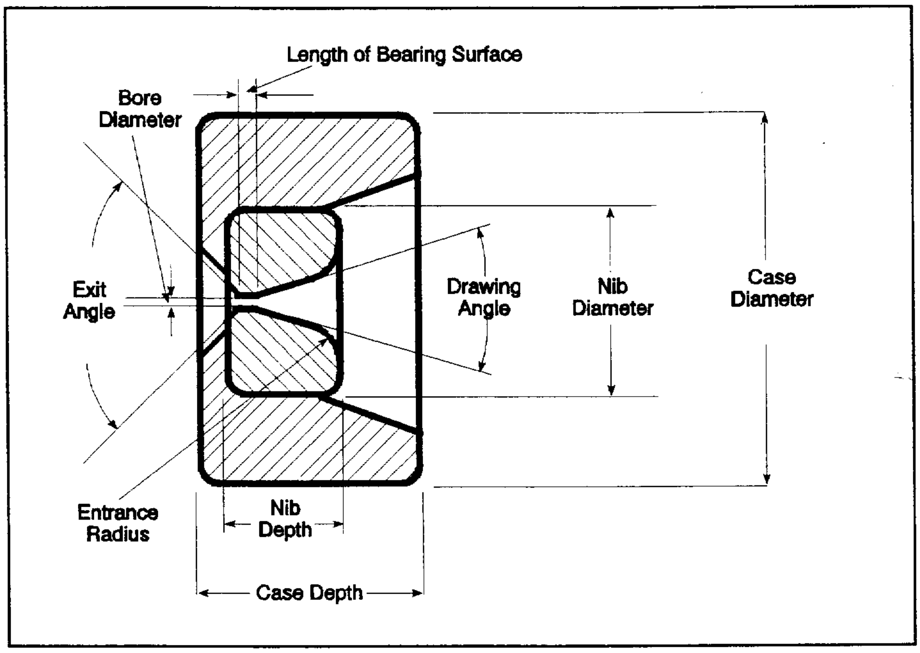


Figure 35 Tungsten Carbide Drawing Die Nomenclature

The main parts of the shape are:-

- The entrance radius which ensures that there is an adequate supply of soap which is the lubricant. This is compressed and taken into the next section with the wire. The shape of this section is important as it governs the amount of soap which can enter the die along with the wire.
- The entrance or drawing angle, which is the part of the die which is the most important in producing the required deformation. This angle is generally of the order of 12° but can be varied somewhat to suit a particular wire requirement. If the angle is too great the wearing surface becomes too small and rapid die wear results. If the angle is too small, friction increases excessively with a resultant increase in die pull.

- The bearing surface which controls the size, finish and surface condition of the wire. The length of this section must be long enough to avoid excessive wear which will rapidly increase the die size to an unacceptable level so that a die change becomes necessary to keep the wire within the size tolerance.
- The exit angle which must be sufficiently large to facilitate the exit of used drawing soap. This angle is also designed to avoid sudden changes in the stress in the tungsten carbide pellet which could cause chipping or flaking of the surface.

A modern theory of wear in a die is that when the lubricant or coat breaks down the surfaces of the wire and the die come into contact. Due to the heat evolved when this occurs welding takes place on a microscopic scale and as a result the wire removes part of the die surface and carries it through the die. This is the cause of ringing and scoring and naturally influences the rate of wear in the parallel portion. Another mode of failure in service is the crazing or scouring of the surface due to thermal shock. Tungsten carbide will work over a wide range of temperature but is very susceptible to rapid changes in temperature which can cause cracking. It is also susceptible to mechanical shock and so must be kept properly supported and uniformly cooled during operation.

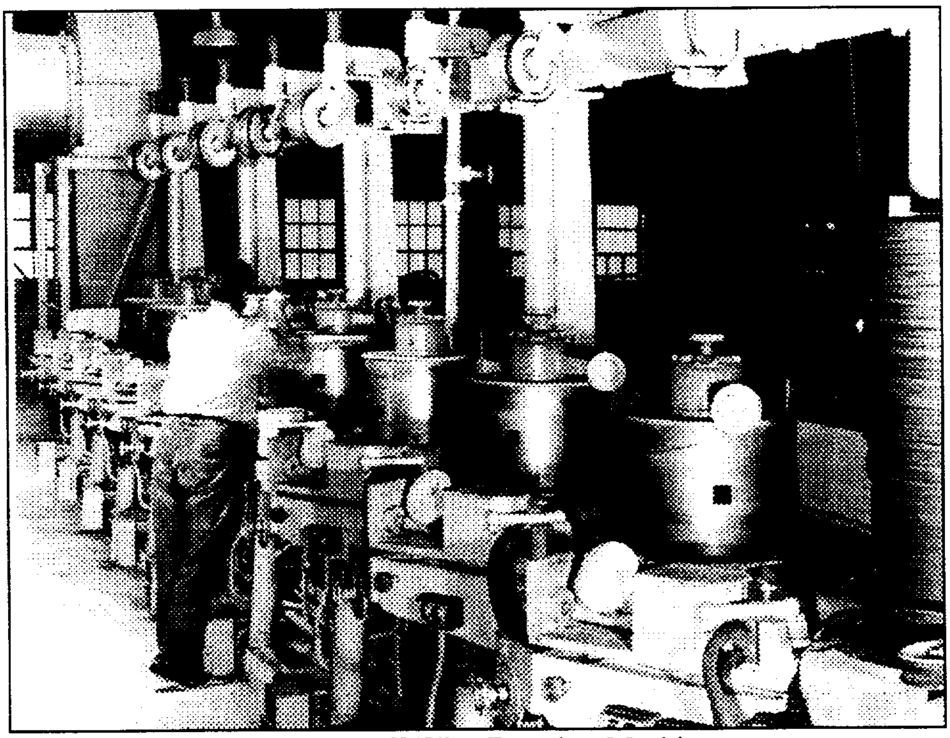


Figure 36 Overhead Take-off Wire Drawing Machine

* **Drawing Machines.** The advent of tungsten carbide dies had a significant effect on the design and operation of wire drawing machines. It was possible to increase drawing speeds considerably and also to combine several drawing passes in series on a single machine.

  Since the wire is increased in length in proportion to the reduction in area the speed of drawing must increase at each die to ensure continuous operation. Small discrepancies in speed can be accommodated in some types of machine but must be accurately controlled for other machines. Because of the high speeds the heat which is developed by the work being done on the wire must be properly dissipated and various machine designs are available to cater for these requirements:-

  - o Overhead take-off high speed accumulating type machine which is ideal for general purpose roping wire. This machine has the advantage of the wire being stored for a time and cooled by air blowing onto the wire and water circulation in the block between dies. See Figure 36 for a general view of one of these machines.

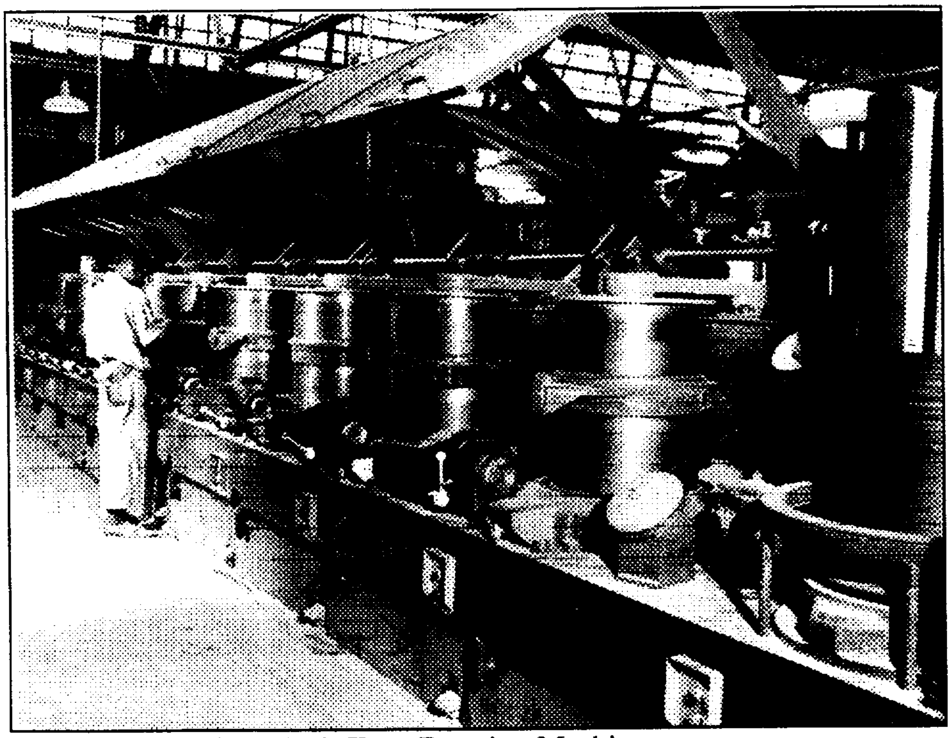


Figure 37 Double Block Type Drawing Machine

  - o Double block type machine. Similar to the over-the-top machine in that the wire is stored for a time for cooling. The arrangement of the accumulating device ensures that no turn or torsion is put into the wire. This makes it an ideal machine for spring wire and certain high quality roping wire. Figure 37 clearly illustrates the difference between this machine and the previous type.
  - o Straight through machine. This type of machine is more difficult to operate as wire speed must be accurately matched to the amount of drawing at each die. Adequate cooling of the wire can be a problem so wire produced on this type of machine is not usually used for roping wire.

- o Wet drawing cone slip type machine. This type of machine is widely used for producing wire of 0,90 mm diameter and finer. The speeds are lower than on a dry drawing type of machine but an excellent quality wire with superior surface finish is produced.
- o Vee-track machine. This machine has been developed to enable excellent cooling of the wire to be achieved without the penalty of reduced speed. It is a straight through machine and the wire is water cooled. To cope with this a vee groove drum (or capstan) is used to provide the required pull through the die. Special air wipes are used to ensure that the water does not interfere with the lubrication in subsequent dies in the machine. This machine produces excellent quality wire with a minimum amount of ageing and is used for the production of the ultra high tensile grades of wire used in mine hoisting ropes.

* **Defects Which Occur in Drawing.** As previously mentioned, in a long and complicated manufacturing process the occurrence of occasional defects cannot be avoided. Most of these are eliminated in the post drawing inspection and testing of the finished wire, but in the case of intermittent defects are sometimes not identified. The causes of these defects are of interest, especially in the evaluation of occasional defects which might be identified in a wire rope in service.

- o Incorrect diameter. When a wire drawing machine is set up to draw wire of a certain size and tensile strength the wire diameter is carefully checked to confirm the correct size. It sometimes happens that the wire drawing die in the last stage wears (or pulls out) to the extent that there is a significant increase in the diameter of the wire being produced. Regular inspection checks are made during the running of a job so this change in size is usually identified before much incorrect wire is produced. The diameter of wire being used in a wire rope is checked so many times in the manufacturing process that it is most unusual to find an incorrect wire in a wire rope. The chief concern with the problem of change in wire diameter during wire drawing is the amount of unusable product which is produced. If other properties are satisfactory the incorrect wire size can be used for an alternative application or if the strength has been affected the wire will be reprocessed and drawn to a smaller size.
- o Out of round. The tolerance for out of round wire is of the same order as the size tolerance laid down in the relevant specification. There are two main causes for out of round, one being the dimensional accuracy of the wire drawing die itself and the other is the alignment of the die in the wire drawing machine. Out of round is a defect which is uncommon in wire ropes and unless it is extremely severe would have very little affect on the quality of the rope.
- o Badly cast. When a wire is drawn it is formed into a coil for handling and transport. A permanent set must be imparted to the wire dimensionally related to the coil size to ensure that the coil will not unravel or become unmanageable. This permanent set is called the cast. Except for very fine wire, cast is not a factor in the performance of wire ropes. However in the rope making factory ease of handling is of prime importance for efficient operation.

- Embrittlement due to ageing. Strain ageing is the name given to the phenomenon of change in mechanical properties of wire after the drawing process. It is affected by various drawing parameters as well as by post drawing conditions such as temperature, stress and time. When a wire ages its tensile strength increases and properties such as tensile and torsional ductility reduce. The amount of ageing which will occur in a wire is dependent on drawing conditions. For some applications it is appropriate to draw wire in a way that will increase its strain ageing properties. However, for mine hoisting applications it is important that the wire should maintain good ductility properties. To achieve this the wire is drawn as cool as possible and the reduction of area due to drawing at each wire drawing die is generally limited to a maximum of 25% in the last few passes.
- Friction cracking. If the lubrication within a die breaks down for any reason metallic contact between the die surface and the wire leads to a rapid rise in temperature. If there is sufficient lubricant to avoid localised welding between the surfaces the temperature can increase to the extent that microscopic transformation of the steel occurs and martensite, an extremely hard and brittle phase of the steel carbon alloy, is formed. On bending the martensite cracks, permanently damaging the surface of the wire with transverse cracks. This type of crack can even occur without the formation of martensite and is characterised by a shiny surface. If there is insufficient lubricant to avoid localised welding cracks can form on the surface of the wire in an intermittent fashion of alternate welding and lubricated flow in the die. In severe cases the wire will immediately break in the wire drawing machine, but occasionally the cracking is not severe enough to cause wire breaks in manufacture and this defect can be found in wire in a rope in service. The lack of lubrication is often of an intermittent nature so friction cracking is not always continuous along a wire. The lubrication problem in drawing either disappears or develops in severity so that wire breaks occur and the problem is corrected. In consequence it is unusual to find more than one or two wires in a rope which have this defect.
- Broken back. A similar defect to the previous one, broken back is the result of uneven drawing of the surface of the wire due to such things as cracked or chipped dies, break down of lubrication, inadequate cleaning of the rod or surface damage to the rod. Broken back generally shows a vee shaped crack on the surface of the wire and is usually a continuous defect which is identified when the wire is tested, if it should not be so severe as to cause a wire break in the drawing machine. If the defect is due to such things as damaged rod or inadequate cleaning the occurrence can be intermittent with the consequent difficulty in identifying affected wire.
- Cuppy wire. This defect is characterised by a lack of ductility in the wire when it is tensile tested. The fracture has a well defined cup and cone appearance but there is little localised reduction of area at the site of the fracture. Cuppy wire results from excessive or uneven drawing of the wire. The flow of the steel in the centre of the wire is so uneven that minute conical cracks occur. The uneven flow is often a result of segregation in the rod, furnace stoppages or sometimes non-metallic inclusions in the steel.
- Incorrect tensile strength. The most usual cause of incorrect tensile strength is the use of an incorrect rod in the drawing process. This defect is always identified and obviously results in unwanted product. The more complicated

problem associated with incorrect tensile strength is a change in the strength of a drawn wire from the start to the finishing end. This type of problem is the result of non uniform size or condition of the rod. Changes in patenting temperatures during processing of a rod could alter the structure of the steel to such an extent that a significant change in tensile strength is the result. This type of defect is also always identified. The finished coil of wire is split in half and retested until the tensile strengths at each end remain within the tolerance.

- Poor torsions (see page 52). These often result from inadequate cooling in the wire drawing machine, but can result from several other factors. After a retest if the poor results persist the relevant coils of wire are rejected. It should be noted that some rope specifications require the testing of wire from a completed rope for torsions. Lower torsions are expected due to the further working of the wire and also local nicking in rope making. These tests are not usually done in South Africa as it is considered that the tensile testing of the finished rope gives a superior indication of wire quality and rope making excellence. In fact there is justification for believing that this practice may in fact result in a less satisfactory rope product.
- Poor bend test (see page 53). The bend test is not a very common test for roping wire but is one of the tests carried out on wire for hoisting ropes. Poor results are difficult to interpret but it is considered that the results give some indication of the adequacy of the patenting process.
- Longitudinal cracks. If a longitudinal crack becomes obvious in the wire drawing process it usually results in a wire break, from which the problem can be identified and corrected by replacing the rod being processed. Cracks due to laps or seams which survive the wire drawing process are usually identified in the torsion test if they are continuous. Intermittent defects of this type which survive the drawing process can sometimes be found in finished ropes but are not usually the cause of any problems. Another type of longitudinal crack is one associated with incorrect drawing practice. This type of defect is identified by cracks which appear in the tensile test or the torsion test. Wire with this defect is always identified and rejected before being used for rope making.

(4) Corrosion Protection.

Some of the coatings used for drawing wire offer a certain amount of protection against rusting or corrosion of the wire in storage or subsequent use. Lime coatings give little or no protection but coatings of phosphate can give protection for a time. If wire ropes are to be used in environments conducive to corrosion it is appropriate to galvanise the wire. There are two methods used in South Africa related to the time at which the zinc coating is applied. The wire or rod can be galvanised before or after drawing. In both cases the hot dip process is used in preference to the electro-galvanising process. The hot dip process is carried out in much the same way as the patenting process in that the wire or rod is unwound from a coil and passed through cleaning tanks of hydrochloric acid, washing tanks and a tank containing flux, dried and then passed through a bath of molten zinc maintained at a temperature of about 450 °C and then coiled onto a take-up frame. The wire or rod is immersed in the bath of molten zinc by means of a sinker roller or skid and for best results is withdrawn from the bath vertically through a wiping bed of suitable material. At present the materials used in the wiping bed are granular charcoal mixed with a suitable oil. This controls the surface finish of the galvanising, the weight of coat being determined by the time of immersion in the bath, the temperature of the zinc and the speed of travel of the wire.

* **Drawn Before Galvanising.** Wire which is drawn before galvanising is usually termed "hot dipped galvanised". The weight of coat of the zinc on the wire is as high as can be obtained in a simple process so this method is the preferred one for applications where the best corrosion resistance is required. Because the heat of the galvanising process alters the mechanical properties of the wire, the input wire must be selected with sufficient tensile strength to allow for a reduction and so achieve the required strength. Other properties of the wire are changed; the number of torsions in the torsion test are reduced and the type of fracture obtained is also modified; the tensile ductility of the wire is improved as well as the elongation measured after fracture. These changes to properties limit the strength which can usefully be obtained from this type of wire and a maximum limit of 1600 MPa is usual. Even though it is possible to obtain a strength of 1800 MPa in certain sizes the other properties are affected to an extent that is unacceptable.

* **Drawn After Galvanising.** This is usually termed "drawn galvanised wire" and has a lighter weight of zinc coating than hot dipped galvanised wire. On the other hand because the wire is not subjected to any further heat after being drawn the mechanical properties are similar to those of ungalvanised wire and most specifications require the identical properties. The zinc coating is drawn as well as the steel so that there is a relatively low weight of coat on the wire. The brittle nature of the zinc-iron alloy formed in the zinc bath limits the maximum tensile strength which can be obtained. In the wire sizes usual in winding ropes the practical upper limit is 1900 MPa, but ongoing development effort is aimed at achieving good quality drawn galvanised wire of 2100 MPa .

(5) Testing.

Wire is characterised by two things, its size (or diameter) and its mechanical properties. Size is a simple concept and is readily measured by means of commonly available instruments such as vernier gauges or micrometers. Mechanical properties are a different thing entirely and require expensive and complicated machinery and instruments for measurement. Many procedures are time consuming and inappropriate for a production environment so a set of relatively simple tests has been developed in tandem with the development of wire drawing practice. These tests are specified in BS 4545 "Methods for Mechanical Testing of Steel Wire". The results required from these tests are incorporated into standard specifications of which the British Standard BS 2763:1982 is the most generally used in South Africa. Table VI gives typical requirements for mechanical properties for a couple of wire sizes as specified in BS 2763:1982.

Discussion of tests specified in BS 2763 follows, as well as additional testing required for specific purposes.

Table VI Typical Mechanical Properties of Steel Wire for Ropes BS 2763:1982

WIRE DIAMETER mm	Tensile Strength		Torsion Test		Bend Test		
	Grade	MPa Range	Minimum Number of Twists on 100 × dia.		Bend Radius	Minimum Number of Bends	
			Ungal	HDG	mm	Ungal	HDG
1,00	1570	1570-1810	34	-	2,50	10	-
	1770	1770-2010	31	-		9	-
	1860	1860-2100	28	-		9	-
	1960	1960-2200	25	-		8	-
3,00	1570	1570-1790	29	14	7,50	8	5
	1770	1770-1990	24	-		7	4
	1860	1860-2080	21	-		7	-
	1960	1960-2180	-	-		6	-

Table VII Tolerances on Nominal Diameter of High Duty Rope Wire. As Specified in BS 2763 : 1982

Nominal Diameter of Wire		Bright Wire or Drawn Galvanised Wire	
From mm	Up to but excluding mm	Plus mm	Minus mm
0,80	1,00	0,015	0,015
1,00	1,60	0,02	0,02
1,60	2,40	0,025	0,025
2,40	3,70	0,03	0,03
3,70	4,10	0,04	0,04

* **Diameter.** The diameter of a wire is the mean of two measurements taken at right angles at a particular place. The measurements are usually made by means of a micrometer. As in all engineering practice a tolerance related to the nominal size is allowed. Table VII lists the British Standard diameter tolerances of wire for mine winding ropes. For a coil of wire this tolerance applies along its length and any measurement outside this tolerance is cause for rejection. Slightly different tolerances are used in South Africa and these are listed in Table IX.

* **Tensile Test.** Besides producing a wire of the correct size, wire drawing is also the means of producing a product with a definite and extremely high tensile strength. The strength of a wire is determined by measuring the load at which it fractures and relating this to the ultimate tensile stress by using the nominal wire diameter. The allowed tolerance on ultimate tensile stress is related to the wire diameter and can

be + 260 MPa for a 0,80 mm diameter wire to + 220 MPa for a 4,10 mm diameter wire. The rate of loading of the wire is usually specified. The rate of separation of the grips of the tensile test machine should not be more than 40 % of the test length per minute.In establishing the tensile strength of a coil of wire, both ends are tested and must be within the required tolerance.

There are various other tests related to the tensile test which need to be considered as they are sometimes appropriate when assessing a particular wire characteristic such as ductility, or when special properties are required. However, these tests are not a usual requirement for roping wire but can be used for development and other purposes.

- Total elongation after failure. This is a measure of the ductility of the wire and is obtained by marking a standard gauge length, such as 250 mm on the wire before the test, placing the fractured pieces firmly together at the fracture and then measuring the extension of the marks. As the extension in the wire localises just before fracture the test gauge length is important if results are to be compared with either the specification or other results.
- Reduction in area at the fracture. A similar test to the previous one in evaluating the ductility of the wire this test is performed by measuring the wire diameter at the most necked portion of the fracture, calculating the area and comparing this with the original area of the wire.
- Proof Testing. This is a test carried out on a metallic material which has no definite yield point. The Proof Stress (or Proof Load) is the stress which, when applied and subsequently removed, leaves the specimen with a permanent set, usually 0,1 or 0,2 per cent of the original gauge length. Figure 38 illustrates the method of establishing the 0,2 % proof load. On the load elongation diagram a line is drawn parallel to the tangent to the load elongation curve at the minimum load (usually 10 % of the breaking load) and offset by the stated percentage of the gauge length. The load where this line intersects the load elongation curve is the proof load.

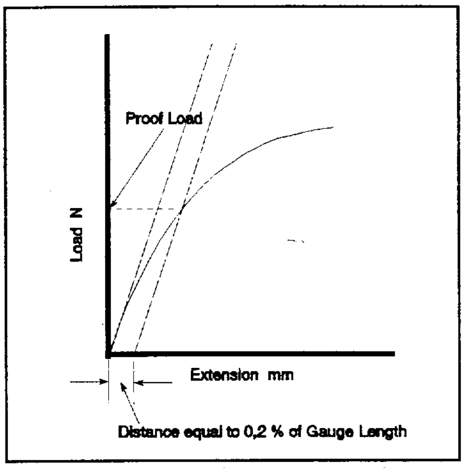


Figure 38 0,2 % Proof Load Diagram

- Modulus of Elasticity. This is the name given to the value for the slope of the stress / strain diagram of a drawn wire at the normal operating stress. In a drawn roping wire there is no uniform modulus of elasticity until the wire has been repeatedly loaded to about 50 % of its breaking strength about 10 times. A uniform slope will be achieved to about 40 % of the breaking strength with a value of about 200 GPa for high carbon steel. Even so there will not be a definite point at which the wire begins to yield and in fact the wire will tend to revert to its as drawn condition if it is now bent over a sheave or other device.

* **Torsion Test.** This test consists of twisting a wire about its axis and measuring the number of 360° twists the wire will accept in a length 100 times its diameter before failure. This test is a measure of the shear ductility of the wire but does not

necessarily indicate longitudinal ductility. The test is valuable for determining the surface condition of the wire as well as the uniformity of the deformation due to drawing within the wire. When a torsioned wire fractures it should have a smooth fracture surface which is perpendicular to the axis of the wire and the torsioned surface should be smooth and uniform. Therefore, besides the actual number of torsions, the appearance of the torsioned wire also gives a good indication of wire quality. Table VIII gives a classification of the appearance of a torsioned wire with an appropriate interpretation.

Table VIII Recommended Classifications of Torsion Test Samples

Classification	Characteristics	Wire Condition
A	Uniform torsioning throughout test length. No spiral splitting or waviness. Clean transverse shear fracture. High angle of shear at fracture point. High number of twists to failure.	Wire in unaged condition.
B	Uniform torsioning throughout test length. Spiral splitting and some waviness. Stepped transverse shear fracture. High angle of shear at fracture point. Number of twists to failure still high.	Wire slightly aged, but not harmful for most applications. Might also indicate the presence of longitudinal surface defects.
C	Local torsioning to varying degree. Spiral splitting and waviness. Ragged splinter fracture. High angle of shear at fracture point, usually very localised. Number of twists to failure falls rapidly as extent of local torsioning increases.	Wire aged, extent of local torsioning increasing with degree of ageing. Wire not suitable for some applications.
D	Low angle of shear at fracture point. Low number of twists to failure. Fracture characteristics probably irregular.	Wire quality suspect; possibly embrittled or containing serious transverse defects.

* **Bend Test.** This test determines the number of times a wire can be bent back and forth through 180°, over a radius of about 4 times the wire diameter before fracture occurs. It is normally regarded as a test of the ductility of the material. This is only an indirect result as the bend test is essentially a high strain fatigue test where the material is subjected to plastic strain in each of the bends. Although specified in British Standards this test is not commonly used for most roping wire and is not

included in American specifications. In South Africa most wire destined for winding ropes is required to pass the bend test.

* **Galvanising Test.** There are basically two tests used for assessing the quality of the zinc coating of galvanised wire. The one test measures the mass of zinc per square metre of wire surface and the other determines the concentricity or uniformity of the zinc coating. In both cases the zinc is dissolved, in one case in acid and in the other in copper sulphate. The weight of coat of zinc on the wire is assessed as follows:- The zinc is stripped from a weighed length of wire, in inhibited hydrochloric acid. The diameter of the stripped wire is measured and the wire weighed again. The mass of the zinc coating is calculated from these results. The concentricity test involves dipping the wire in a specific concentration of copper sulphate for short periods of time and observing the deposition of copper on the steel surface exposed. If the zinc coating is eccentric the copper will only coat one side of the wire first, indicating the lack of uniformity. In both these tests the required results are stated in the relevant specification.

* **Wrap Test.** The wrap test is basically a ductility test. The wire is wrapped round a bar of either its own diameter or four times its own diameter. The wire is wrapped for eight turns and it must survive unwrapping of four turns without fracture. This test is usually required for galvanised wire and is also a means of establishing the quality of the zinc coat which must not flake to any significant extent. This test is never done on wire for mine winding ropes as it is not suitable for assessing properties required for this application.

2.2.2 PROPERTIES.[12]

Having considered methods of producing high tensile wire for mine winding ropes it is appropriate to examine properties which are achieved and which can be varied to some extent in the manufacturing process.

(1) Size.

Obviously the production of the required sizes and the control of size is the prime requirement of wire drawing. As in any engineering process it is impossible to obtain an exact size, even if it were possible to measure it, so the wire is produced to a diameter measured within an agreed tolerance of the required size. It is wasteful to attempt to manufacture too many sizes and unacceptable to the rope-maker to have too few. A compromise solution is a series of nominal wire sizes based on the appropriate tolerance for the size and which approximates to a geometric series. See Table IX for figures used in South Africa. These approximate to but are not exactly the same as those used in other countries.

The smallest wire size used for rope is 0,14 mm diameter. Smaller wires are used in specialised applications such as tyre cord, hose armouring etc. On the large side fewer sizes are required, especially in sizes greater than about 4 mm diameter. The range of wire sizes used in mine winding ropes is from about 2,00 mm dia to about 3,35 mm diameter.

Table IX Size Tolerance and Size Steps for Roping Wire

Diameter Range		Tolerance		Size Steps
From - mm	To - mm	Plus - mm	Minus - mm	mm
0,14	0,25	0,01	0	0,01
0,26	0,40	0,01	0	0,01
0,41	0,60	0,01	0,01	0,02
0,61	1,00	0,015	0,015	0,03
1,01	1,60	0,02	0,02	0,04
1,61	2,50	0,025	0,02	0,04
2,51	3,70	0,03	0,02	0,05
3,71	5,00	0,05	0,03	0,08
5,01	6,50	0,05	0,03	0,08

(2) Strength.

Within limits it is possible to control the tensile strength of wire by choosing the carbon and manganese content of the steel and also the reduction in area due to drawing (see pages 38 and 42). It is also important that other mechanical properties are acceptable for the required application. In view of these constraints there are limits to the maximum tensile strength available dependent on wire diameter. Special micro-alloyed steels are being investigated with a view to increasing these limits without compromising the other mechanical properties required and promising results are being obtained. Figure 39 illustrates the maximum available strength for plain carbon hard drawn steel wire with

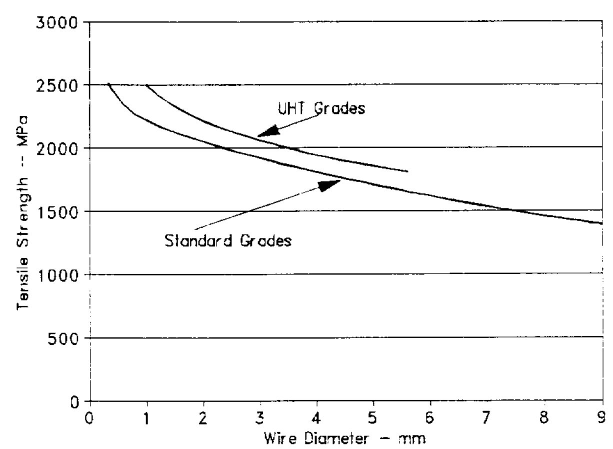


Figure 39 Maximum Tensile Strengths Available with Respect to Wire Diameter.

respect to wire diameter. The curves show available strengths for standard production wire suitable for hoisting ropes as well as maximum strengths available in the UHT grades where special practices in the production of the wire ensures good quality at these higher strengths.

(3) Ductility.

The engineer's interest in ductility of wire for wire ropes is concerned with the avoidance of premature wire failure at points of local stress concentrations due to inherent rope design characteristics such as internal nicking, localised pressure areas, external damage or applied forces and even defects in the wire or the eroding of design factors due to these conditions. The ductility of wire cannot be expressed in terms of a single finite value as it depends primarily on the stress system acting on it and is unique to that system. For this reason it is the practice of rope-makers to assess the ductility of wire by interpreting the results of several different types of test. Comments on testing of wire have been made on pages 50 to 54 many of which relate to ductility requirements for that particular test. An illustration of how ductility assessment is used to evaluate the acceptability of wire are the figures quoted in Table X which follows.

Table X Influence of Ageing on Wire Properties

Property	As Drawn	Aged
Limit of Proportionality (% of Tensile Strength)	20 - 25	50 - 55
0,01% Proof Stress (% of Tensile Strength)	30 - 40	65 - 75
0,1% Proof Stress (% of Tensile Strength)	65 - 75	90 - 95
0,2% Proof Stress (% of Tensile Strength)	70 - 85	-
Modulus of Elasticity GPa	150-180	190-210
Tensile Strength		Raised by 75 - 150 MPa

* **Ageing** As mentioned on page 48 strain ageing is the phenomenon of changes in tensile strength and ductility of the wire after drawing. If the wire gets hot during the drawing process or if it is deliberately heat treated at a temperature between about 100 °C and 450 °C the process of strain ageing affects the properties of the wire. The tensile strength increases and the ductility of the wire can be affected in a way that is unacceptable for roping wire. The changes could affect the behaviour of the wire in the rope making process and possibly the breaking strength of the rope relative to the aggregate breaking strength of the wires in the rope. In the high tensile strength wire used for mine hoisting ropes the temperature of the wire in the drawing process is carefully monitored and controlled especially for wire in tensile

strengths greater than 1950 MPa. At these strengths the wire can be affected by low temperature ageing so that ambient temperatures as low as 40 °C can affect the wire over a period of time. Modern machinery and process control can now ensure that this low temperature ageing phenomenon can be reduced to the extent that changes in properties are minimal in time periods of 5 years or more at ambient temperatures.

A further illustration of how ductility is assessed, especially with respect to the aged condition of the wire is the evaluation of the torsion test listed in Table VIII.

2.3 USES OF STEEL WIRE.

In this chapter we have considered the manufacture and properties of steel wire for use in wire ropes, especially those ropes used for mine winding. This is a most important application and one which requires specific wire properties which have been briefly described. Less than a quarter of the wire produced in the world is used for wire ropes. At least half the wire is low carbon and a small amount of alloy wire is produced, chiefly from stainless steel.

Besides its use in wire ropes, wire is used in every facet of modern life. Some of the other principal uses of steel wire are listed. Properties required are sometimes diametrically opposed to those desirable for wire ropes so production procedures would be different with the focus on requirements for that application.
The following list gives some idea of the range of other applications dependent on steel wire:-

Bedding and seating
Brushes
Cable armouring
Concrete pipe reinforcing
Filters
Hairpins
Hose armouring
Prestressing of concrete
Screens
Seizing
Springs
Spokes
Staples
Tyre bead and tyre cord
Welding

Chapter 3

ROPE MANUFACTURE

3.1 THEORY OF ROPEMAKING.

The making of ropes from steel wire developed from practices used to manufacture ropes from fibre. [1,2] The very first wire ropes manufactured in Europe applied techniques used in "rope walks" and were largely made by hand. Developments in the manufacture of fibre ropes had already progressed from the use of man power and animal power to rotating machines driven by steam. The concept of these machines for making fibre rope was that "to make a strand from yarns, as much twist has to be put into them individually as is taken out by the stranding". It was known that the strength of wire was adversely affected by twisting the wire while being loaded. Since these early fibre rope machines used appropriate principles they could be adapted to making wire ropes.

The basic concept in the manufacture of steel wire rope is that the wire of a strand should be helically formed round a central supporting unit without any twist being put into the wire. So it can be considered that the wires should be bent into shape and not twisted. In the same way strands should be helically formed round a core, without twist being introduced in any direction, to form a rope. Different types of rope-making machine achieve the required results to varying extents with the exception of one type which in fact twists the wires in the forming process.

3.1.1 EXPLANATION OF ROPEMAKING TERMS.

All technologies develop their own terminology for actions and processes which becomes a jargon which is not immediately understood by persons in other disciplines. Many of these terms are included in the Glossary at the end of the book, or descriptions in Chapter 1 and Chapter 2. Reference should be made to these for a better understanding of the following text.

3.1.2 LAY BLOCKS

There are two basic requirements in the manufacture of a strand or wire rope. The means of forming (or bending) the wires or strands round the central core must be provided. This is usually by means of one of the various machines described in this chapter. The other is the necessity to ensure that equal lengths of wire or strand are put into the rope and to maintain constant tension in the parts as they are formed. The most effective and simplest way of doing this is by the use of a lay block. The general arrangement of a lay block is illustrated in Figure 40. The block is made of tool steel, although in the past cast iron was the favoured material. The bore of the block is drilled with the two halves clamped onto a packing piece which, when removed, allows for the space needed to provide the necessary draw. The entrance to the block is shaped to a bell-mouth to allow unrestricted entry for the wires or strands. The length of the block is generally the same as the lay length of the product being formed.

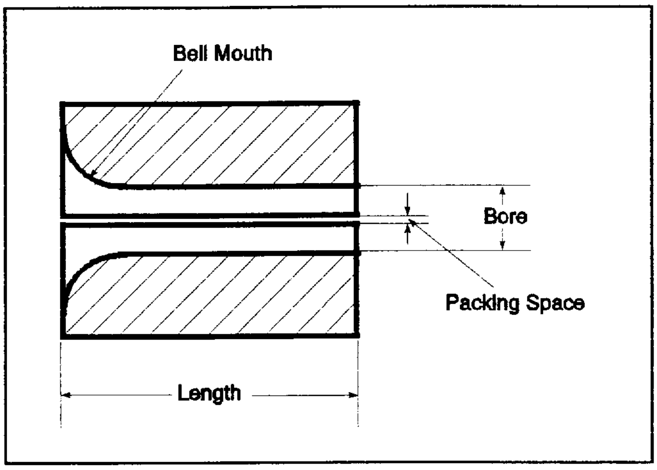


Figure 40 Cross Section of a Lay Block

In manufacture of a strand or rope the lay block is mounted in the machine with its centre-line exactly on and in line with the axis of the machine. The wires or strands are loosely formed and fitted into the bore of the lay block. A transverse force is applied by suitable clamps as the machine is slowly rotated. When the required force is achieved to bring the strand or rope to the correct diameter, the machine is ready to run. It has been found that a very stiff clamping device is required for the best results so that size variations are minimal.

Because of the length of the block relative to the clamping force, sufficient friction is generated between the lay block and the wires or strands to ensure that even lengths of wire or strand are pulled through the block. The forces involved are considerably greater than required in back tension from the bobbins. It is only if excessive bobbin tensions occur that unevenness will be passed into the rope.

3.1.3 MACHINERY.

Rope-making machinery provides the means for forming wire or strand round a central unit, which may be either a wire, a strand, or another rope; made from fibre, steel or other material. The machine is required to form the wires (or strands) with a uniform pitch and tension under controlled conditions. Three basic systems are used for these machines, each of which has specific advantages.

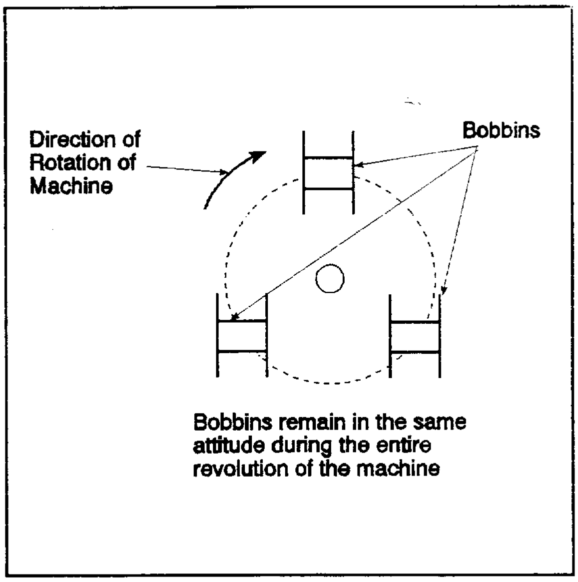


Figure 41 Arrangement of Bobbins in a Sun and Planet Machine Showing Attitude of Bobbins During Operation

(1) Sun and Planet Machines.

The most versatile of all the rope-making machines, the sun and planet machine is used for both stranding and closing operations.

In this machine the bobbins are supported in rotatable frames called "flyers", see Figure 42. The flyers are connected to the axis of the machine by epicyclic gearing, or other device, and so are kept in the correct attitude (alignment of bobbin in space) during rotation of the machine.

Figure 41 illustrates the usual attitude of bobbins in a sun and planet machine where, in general, the bobbins are arranged to operate continuously in a substantially upright position. This arrangement is satisfactory for the simpler types of rope.

* **Bobbin Rotation** Unfortunately the operation of the machine with the bobbins always moving in the same attitude only approximates to the requirement that no twist is imparted to the wire or strand. Twist is in fact produced which is a function of the lay length being used in operating the machine. It can readily be seen that if the machine operates with zero lay length the twist imparted will be one twist for every rotation of the machine, whereas if the machine operates at an infinite lay length there will be zero twist for each rotation of the machine. The actual twist imparted is between these two extremes.

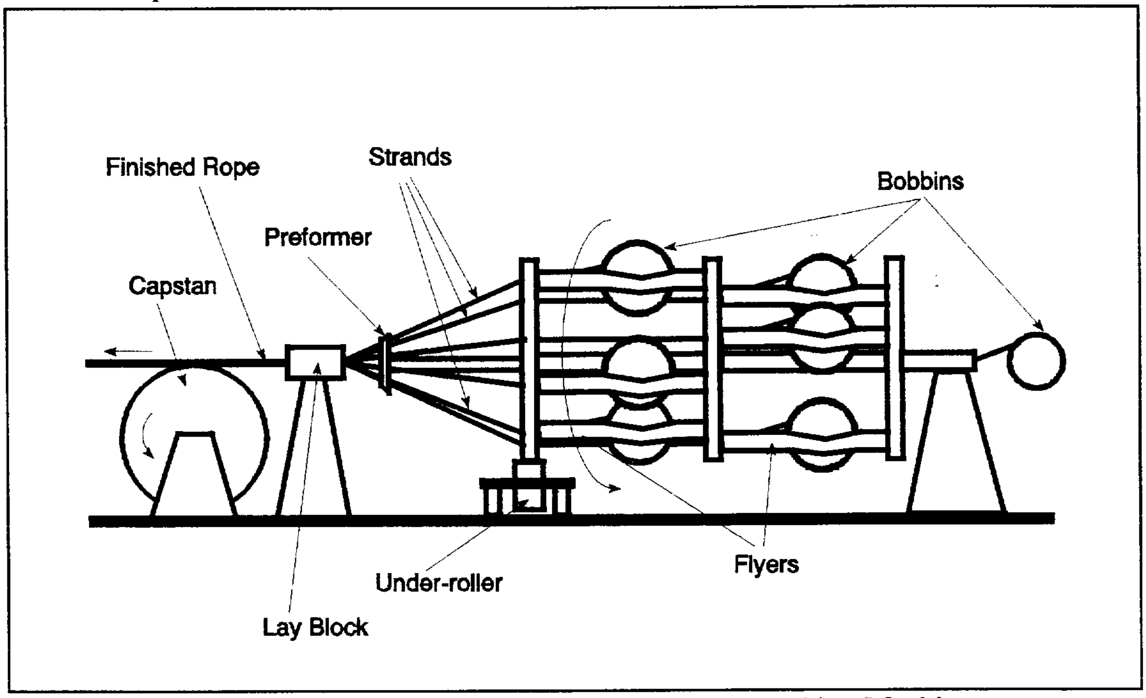


Figure 42 Schematic Diagram of a Sun and Planet Rope-making Machine

The approximate twist imparted can be determined from the formula:-

$$\theta = 360\ (1 - \cos\alpha)$$

Where:-
θ = Twist imparted per revolution of the machine (°)
α = Lay angle of wires or strands (°)

The direction of the twist is opposite to the direction of rotation of the machine. For a rope with a lay angle of 20° the angle of twist per rotation is 21,7°, which is one full turn imparted for every 16,6 revolutions of the machine.

(2) Tubular Machines.

In contrast to the sun and planet, a tubular machine has its bobbins arranged in line and supported on freely suspended cradles which allow the machine to rotate without affecting the bobbins. The wire (or strand) is passed from the bobbin, through the trunnion at the front of the cradle and then to the outside of the machine, from where it is guided to the forming point. The path of each individual wire (or strand) can be likened to the action of a skipping rope. The action of this type of machine in forming the wire or strand is similar to the sun and planet machine. The schematic arrangement of a tubular machine is illustrated in Figure 43. Only 3 bobbins are shown in this figure but the number can be as required for the particular strand or rope. Machines with as many as 48 bobbins are fairly common. This type of machine is most commonly used for stranding of round strand products and closing the smaller rope sizes.

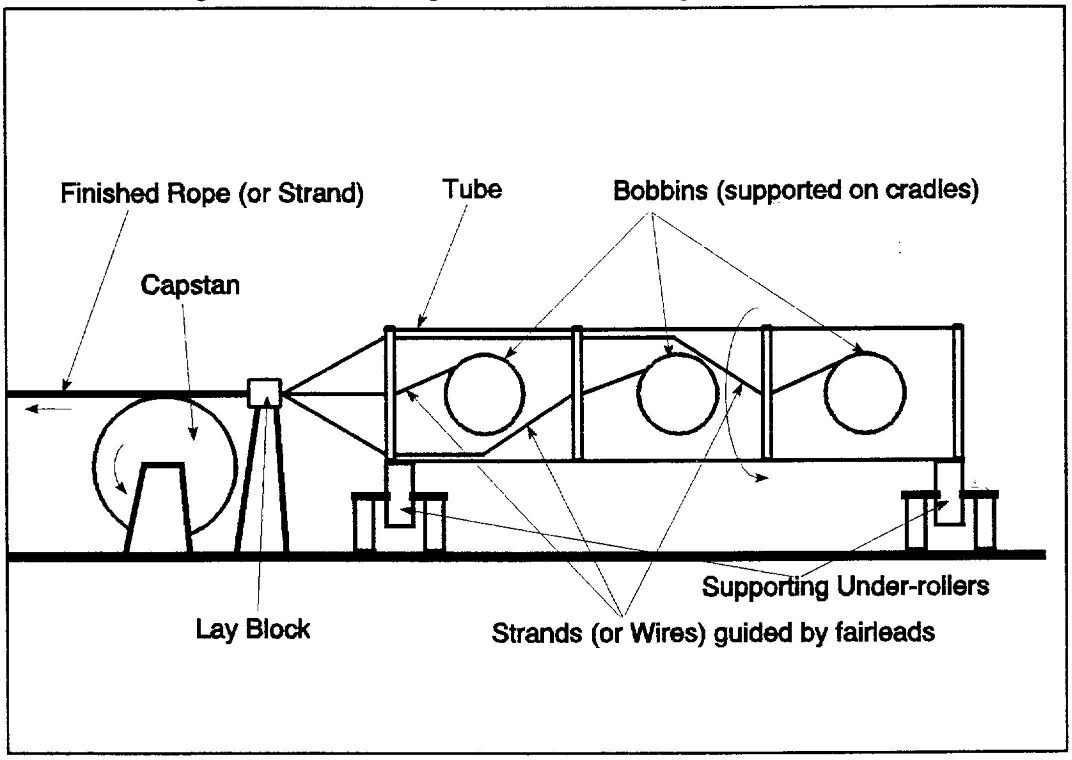


Figure 43 Schematic Diagram of a Tubular Machine

Tubular machines are considerably faster than an equivalent sun and planet machine and so are favoured for high output of rope or strand. Considerations of bobbin rotation are generally ignored since these machines are mostly used in the manufacture of round strand products.

The provision of bobbin rotation on tubular machines is complicated and expensive and so is seldom undertaken. Where such machines are used the product is one of the high value products where excellent quality is required. Shaped strands for non-spin ropes are often made in this type of machine.

(3) Bunchers.

Where large volumes of one size and construction of rope are required the buncher has proved to be an excellent machine for producing large quantities of round strand. It is not suitable for closing ropes.

The use of bunchers for stranding ignores the old established principles of rope-making in that twist is introduced into every wire continuously along its length. For success, an excellent wire quality is required so that wire breaks in stranding are eliminated and fatigue and other properties of the completed rope are indistinguishable from those of rope made in other more conventional machines.

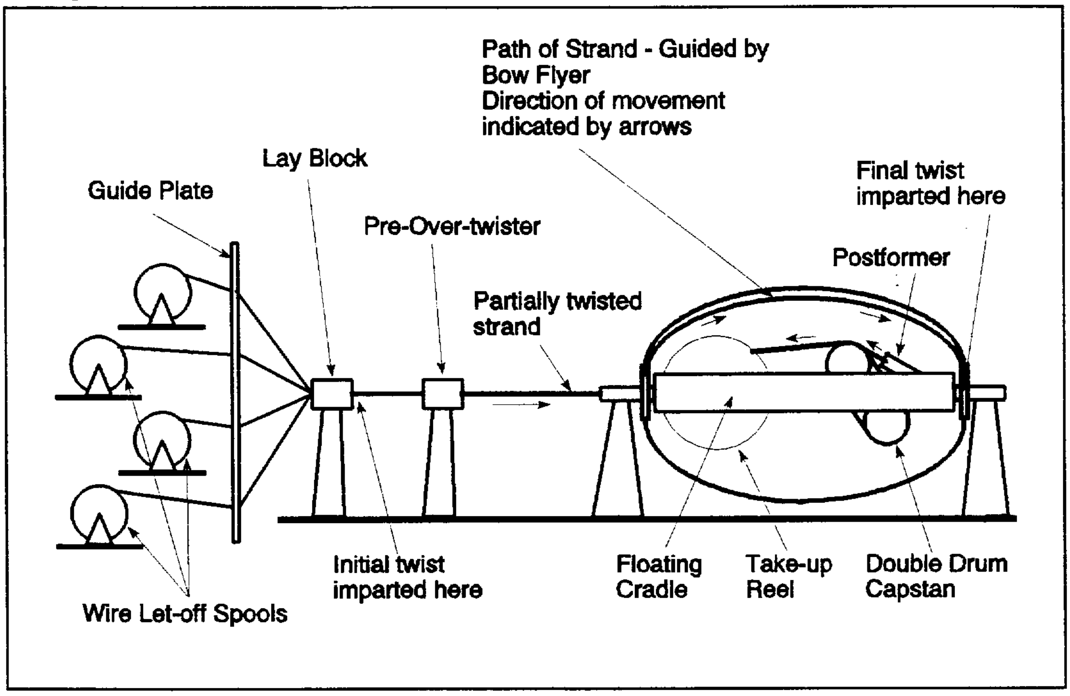


Figure 44 Schematic Layout of a Double Twist Buncher

The most successful variant of this type of machine is termed a double twist buncher. The schematic arrangement illustrated in Figure 44 shows the bobbins of wire mounted on fixed footings so that large bobbins can be used, thus reducing time spent in changing bobbins. The wire is led through a fixed guide or lay plate to a collector block (or twister block) where the strand is formed and the first twist imparted. The strand is pulled through this block and a overtwister by means of a double drum capstan mounted on a large cradle and collected on a take-up reel (or bobbin) also mounted in the cradle. The path of the partly twisted strand passes through the trunnion and along counterbalanced bow type flyer to the far end of the machine. At this end the strand passes into the trunnion where the twisting is completed. It now passes through a postformer to the double drum capstan with the correct attributes for a strand to be closed into a rope.

3.1.4 ROPE DESIGN.[13]

Rope design evolved over the years from the completely trial and error approach involving a rope-making machine in which different wire sizes and lay lengths were tried until a satisfactory looking strand was achieved. Modern designs are generated by sophisticated computer programs which are able to solve the intractable mathematical formulae accurately and quickly. These programs have incorporated as much of the old rope-maker's knowledge as possible and integrated this with theoretical considerations which have been proved in practical applications.

(1) Basic Concepts.

Computers enable rapid calculation, and of course, do not forget important considerations. Nevertheless the basic parameters remain and these are valid whatever the mode of calculation. Many of the basic considerations relating to rope design have already been dealt with in Chapter 1 so that what follows amplifies those comments and adds some simple methods of calculation.

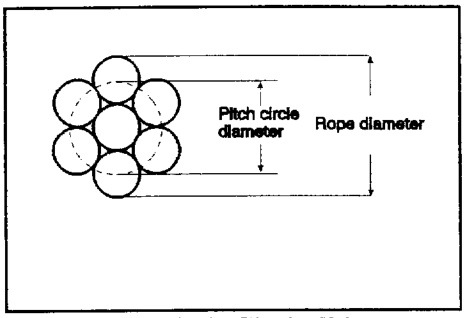


Figure 45 Pitch Circle Diameter of a Six Strand Rope

* **Pitch Circle Diameter.** This is the diameter of an imaginary circle which passes through the centre of a particular layer of wires in a strand or strands in a rope. This measurement is the basis for many of the calculations required in designing ropes. See Figure 45 which illustrates the pitch circle diameter of a six strand round strand rope.

* **Lay and Lay Length.** A wire rope is laid up by forming the wires in the strands and the strands in the rope in a helical path round an underlying unit which could be a wire, a strand, rope or fibre. The lay length is the longitudinal distance which the centre of the wire (or strand) traverses along the axis of the rope in one helical turn. This is illustrated in Figure 46 where the path taken by the centre of the strand (or wire) is shown. The lay

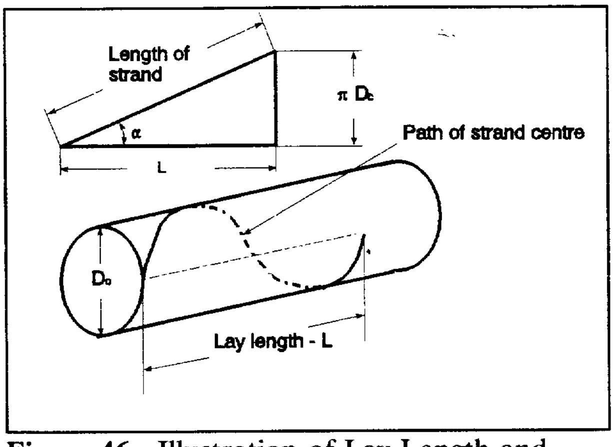


Figure 46 Illustration of Lay Length and Derivation of Lay Angle

angle is derived from the triangle whose sides represent the lay length and the pitch circle circumference and is found from the following formula:-

$$\alpha = \arctan\left(\frac{\pi\ D_c}{L}\right)$$

Where
α = Lay angle (°)
D_c = Pitch circle diameter (m)
L = Lay length (m)

The direction and type of rope lay are determined by practical considerations related to the rope application. It is in the choice of the lay lengths for a particular rope construction, as well as other factors, that the rope designer influences the performance of the rope in service.

From long experience rope-makers have established suitable parameters for specifying rope lay length. The strands of round strand ropes have lay lengths of seven to ten times the strand diameter, the shorter lay being used for strands with a large number of wires and the longer lays for the least number of wires. In the case of rope lay the criterion is complicated by the usual requirement that the rope be fully preformed (see page 78) so that in the unused condition it remains inert when it is cut. This factor is usually between 6 and 6,5 for round strand ropes and about 7,5 for triangular strand ropes.

* **Wire and Strand Gap.** For a wire rope to operate satisfactorily it is necessary that gaps between wires, or strands, of a particular layer are present in the as manufactured rope. This ensures that the components all bed down correctly with proper support. If gaps are not present the rope or strand will form a tube which is initially self supporting. When the rope is loaded or bent this tube collapses and the rope or strand distorts. In this condition the rope is termed to be hidebound. In assessing the required support to maintain suitable gaps these gaps must be calculated. Within limits determined by the small lay angle the cross-sectional shape of the round wires or strands is approximately elliptical when seen from a cross-section of a strand or rope. The gap shown between them is exaggerated and is termed the apparent gap. The actual gap which can be measured with feeler gauges is somewhat smaller and is related to the apparent gap as given in the following formula:-

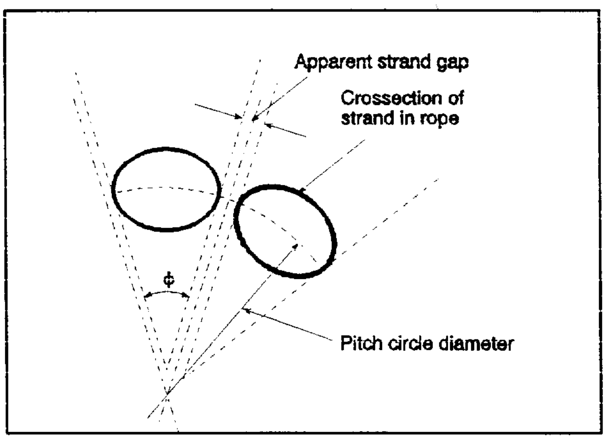


Figure 47 Cross-section of Wires (or Strands) Showing Elliptical Shape and Apparent Gap

$$p = \frac{g}{\sec\ \alpha}$$

Where
p = Actual gap (m)
g = Apparent gap (m)
α = Lay angle (°)

The relationship between the various parameters is given as follows[12, 13]:-

$$D - d = D_c = d\left(\sqrt{1 + \cot^2\frac{\phi}{2}\sec^2\alpha} + \frac{p\operatorname{cosec}\frac{\phi}{2}}{\cos\alpha}\right)$$

$$\textit{where} \quad \phi = \frac{360}{N}$$

and

D	= Diameter of strand or rope (m)
D_c	= Pitch circle diameter (m)
d	= Diameter of wires or strands (m)
N	= Number of wires or strands
α	= Lay angle (°)
p	= Actual gap as a decimal of the wire or strand diameter

The rope designer needs to exercise judgement in deciding on the correct gap to be used. Too small a gap between wires or strands can cause a hidebound condition whereas too large a gap carries penalties regarding rope strength and also rope performance. If gaps are too large wires can easily be moved during operation causing premature fatigue, or sometimes the internal pressure distribution between the wires can result in early fatigue of inner wires.

* **Strand Configuration.** The different strand configurations such as equal lay and unequal lay with differing numbers of wires have been discussed in Chapter 1. However, the implication of the strand arrangements on design parameters needs to be considered.

It is found that six wires will fit exactly round a core wire of the same size, if there is no lay angle. The introduction of a lay angle increases the space needed by the outer wires to avoid crowding. To achieve this the core wire is increased, with some allowance for compression and nicking, to the extent required to achieve a suitable gap between the wires. (See discussion on wire and strand gap on page 65). This principle applies to the covering layers of wires in both types of strand arrangement.

- Unequal Lay. In this configuration further layers of wires can be added in separate operations and the number of wires in the covering layer can be increased by six more than the underlying layer to enable the use of the same wire size. Because of the effects of nicking and compression the core wire must be proportionately larger; in strands with more than three layers of wires the core wire is required to be so large that it is often more appropriate to slightly increase the wire diameter of the inner wires. Since these strand configurations require that each wire layer be applied in a separate operation the cost of the stranding operation now outweighs the benefit of a small number of wire sizes. In addition, with three or more layers the rope performance is somewhat poorer than for strands made in one operation.

- o Equal Lay. These are strands which are made in one operation. Because of the geometric arrangement of the wires these strands have a high fill factor. This coupled with the fact that contact between wires is not point but line contact makes for a solid strand in which compression of the wires in strand manufacture is relatively small. Minimal adjustments are needed to ensure that strand gaps remain as required.

(2) Selection of Wire Diameters.

The determination of wire diameters for a particular rope follows a logical progression which starts with various assumptions. These are largely based on the experience and expertise of the designer and involve the following:-

- o The actual rope oversize diameter, on which the design is based. Because ropes generally bed down after a short time in service it is usual to design the rope so that it attains an actual diameter equivalent to the nominal diameter after this initial period.
- o The strand and rope lay angles to be used. This is often determined by using lay factors.
- o The wire and strand gaps to be used. These are always a percentage of the relevant wire size.
- o The maximum wire diameter tolerance which can be absorbed by wire gaps in a particular strand. This is particularly important in equal lay strands having three or more layers.
- o The related consideration of whether special tolerances are required for the wire to be used in the rope.
- o The compression factors which must be applied to strands and rope to allow for internal nicking and deformation of wire, strands and core.

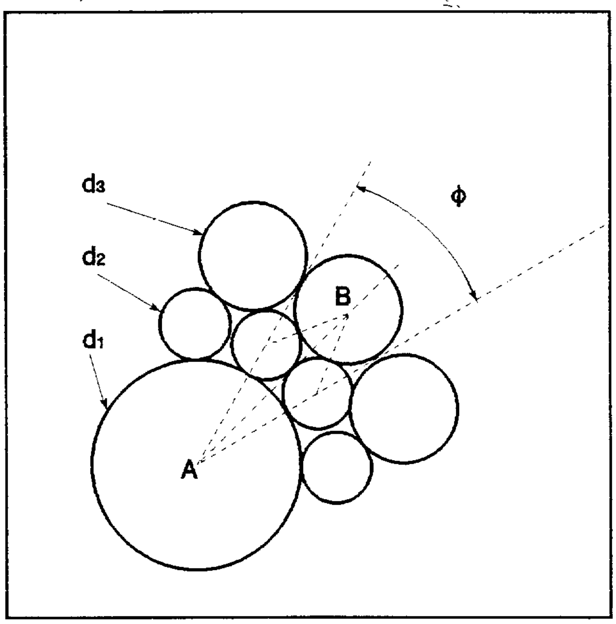


Figure 48 Geometrical Arrangement of Wires for Seale Construction

- * **Strand Diameter.** The first procedure is to determine the strand diameter required for the rope. The formula on page 66 is used in conjunction with the relevant assumptions for the rope in question. This formula can be solved graphically but is more appropriately solved by iteration using a computer.

- * **Wire Diameters** The wire diameters are now determined. The method used for the 19 wire Seale construction is described so as to illustrate the procedures to be followed.
  - o Firstly a ratio between the diameter of the core wire and the first layer of covering wires must be established. This is achieved on the assumption that the diameter of this strand has a diameter of one unit and the gap is a percentage of the

covering wires with an assumed lay angle of 10°. The formula on page 66 is again used for the calculation.

- This strand diameter now forms the basis of a calculation to determine the outer wire size, using the same formula, appropriate gaps and lay length (or lay angle).
- Having established a theoretical wire diameter the closest of the available standard wire sizes must be chosen. See Chapter 2, paragraph 2.2.2 (1) on page 54. This wire size is then checked against the required strand size to establish the effect on the gap, using the same formula. If the gap is within the required tolerance proceed to the next step otherwise re-evaluate the chosen wire size with respect to strand diameter and gap. It is sometimes necessary to increase (or reduce) the strand diameter slightly to accommodate the available wire choice to the chosen parameters.
- Referring to Figure 48 the following formulae are used to calculate the required diameters of the inner wires and core wire.

$$\textit{Strand Dia} = 2\,AB + d_3 \qquad \phi = \frac{360}{N}$$

$$AB = \frac{1}{2}\left((d_1 + d_2)\cos\frac{\phi}{2} + \sqrt{(d_2 + d_3)^2 - (d_1 + d_2)^2 \sin^2\frac{\phi}{2}} \right)$$

Where

d_3 = Outer wire diameter (mm)
d_2 = Inner wire diameter (mm)
d_1 = Core wire diameter (mm)
N = Number of outer wires

- It is again necessary to choose standard wire diameters to suit the theoretical inner and core wires which have just been established.
- Having done this, strand diameter and lay lengths are calculated from the above formulae and then all gaps are rechecked to establish if they are within tolerance. If necessary, new wire choices must be made until all the appropriate tolerances are satisfied.

It may seem that this is quite a rigmarole to be followed but it demonstrates the care which must be taken in deciding on wire diameters and also the invaluable aid provided by computers. In this regard, older simplified formulae are quoted since the accurate formulae recently developed for design purposes can be only solved using computers.

* **Triangular Strand and Other Ropes with Shaped Strands.** Similar procedures to those described are applied in establishing wire sizes for triangular strand ropes and non-spin ropes with shaped strands. In general these ropes are unequal lay construction so the geometry of the wire arrangement is not so complicated. However the shape of the strands needs to be carefully described in mathematical terms so that the actual rope parameters match the intended design.

Triangular strands, in particular, must be arranged in such a way that adequate support is given to the sides of the triangle. If there is no support the triangular shape becomes deformed leading to unintended slackness of wires inside the rope which tends to reduce rope performance in service.

* **Calculation of Approximate Outer Wire Diameters.** It is not always feasible to do a design calculation to establish the outer wire diameter of a particular rope, especially if an approximate figure is all that is required. In this case the following empirical formulae are useful for six strand ropes.

$$d = \frac{D}{(N + 3)} \quad \textit{for round strand ropes}$$

$$d = \frac{D}{(N + 2)} \quad \textit{for triangular strand ropes}$$

Where

d = Outer wire diameter (mm)
D = Rope diameter (mm)
N = Number of outer wires in one strand of six strand rope

(3) **Tensile Strength of Wire.**

The tensile strength of the wire to be used in a rope is usually standardised. However there are often occasions where very high tensile strengths are used and these pose some additional problems in the design of the rope. As the tensile strength of a wire increases its sensitivity to compressive transverse forces also increases. In view of this it is necessary to give extra attention to inter-wire and inter-strand gaps in the rope design stage. It is sometimes necessary to choose wire sizes different from the standard list or to specify a smaller size tolerance. Much of this decision making is the result of practical experience, so no hard and fast rules have been established.

(4) **Rope Core.**

The core of a wire rope is the base on which the structure is built. The core size, compressibility, modulus of elasticity and stability can determine the success with which a rope achieves its purpose.

* **Fibre Core.** The most generally used core for a wire rope is one made of fibre - usually a three strand fibre rope. This material is the most versatile for this purpose and is only replaced by other types of core when it is unable to support the rope strands satisfactorily. The most usual reason is when ropes operate in a hot environment such as on cranes handling ladles of molten metal. Another is when operating pressures on drum or sheave become so great that the fibre core is severely crushed.

Fibre ropes for wire rope core have to be specially made. It is not practicable to use normal cordage for the following reasons:-

- o Cordage is made to achieve an appropriate strength for the size. Fibre core on the other hand must have compressive strength and is generally made more dense with a harder lay-up achieved by shorter lay lengths.
- o The available sizes of cordage do not suit the size requirement appropriate for wire rope core. Wire rope is available in sizes such as 10 mm, 13 mm, 16 mm etc and the fibre core must be an appropriate size within recognised tolerances such as those specified in BS 525 "Fibre cores for wire ropes".
- o The lubrication of cordage is not usually suitable for wire ropes.

In deciding on the size of fibre core for a particular wire rope it is usual to choose a core having a diameter 50 % larger than the diameter of the space it must occupy. Therefor for six strand round strand ropes the size of core used is half the diameter of the completed rope.

* **Steel Core.** When the necessity arises, a steel core can be used. This type of core is generally a wire rope itself and is termed an IWRC. For standing ropes where extremely long life is expected a steel core is used and this is usually a single strand having the same construction as the rope strands. In both cases it must be noted that the rope becomes very sensitive to handling as turn put into or taken out of the rope can cause distortion of the rope or core.

  As in the case of fibre cores the size of core required is determined by the available space to be filled, with allowance being made for any compression or nicking. The lay lengths of steel cores are also adjusted to achieve an appropriate modulus of elasticity.

3.2 ROPE-MAKING PROCESSES

In producing a steel wire rope the rope-making procedure follows a well defined path, no matter what rope size or construction is required. The first action is to obtain all the required materials:- wires of the correct sizes, tensile grade, and finish; core or core materials; lubricants or rope dressing; and also the required drum or reel for transporting and storing the rope. When the required wire is available it is wound onto bobbins for stranding and then the finished strands are closed into the rope.

3.2.1 STRANDING

The efficiency of the stranding process, where the individual wires are combined into a unit having a specified diameter and lay length, to a large extent determines the effectiveness of the manufacturer and the quality of the finished product. Various aspects which determine these features are considered and some effects on rope quality or performance discussed.

(1) Wire Winding

The wire which is obtained from the wire-drawer can be supplied in coil form or on large bobbins. In coil form it is either supplied on a former (or dolly), which enables heavy masses to be handled effectively, or in loose coils which are secured by means of

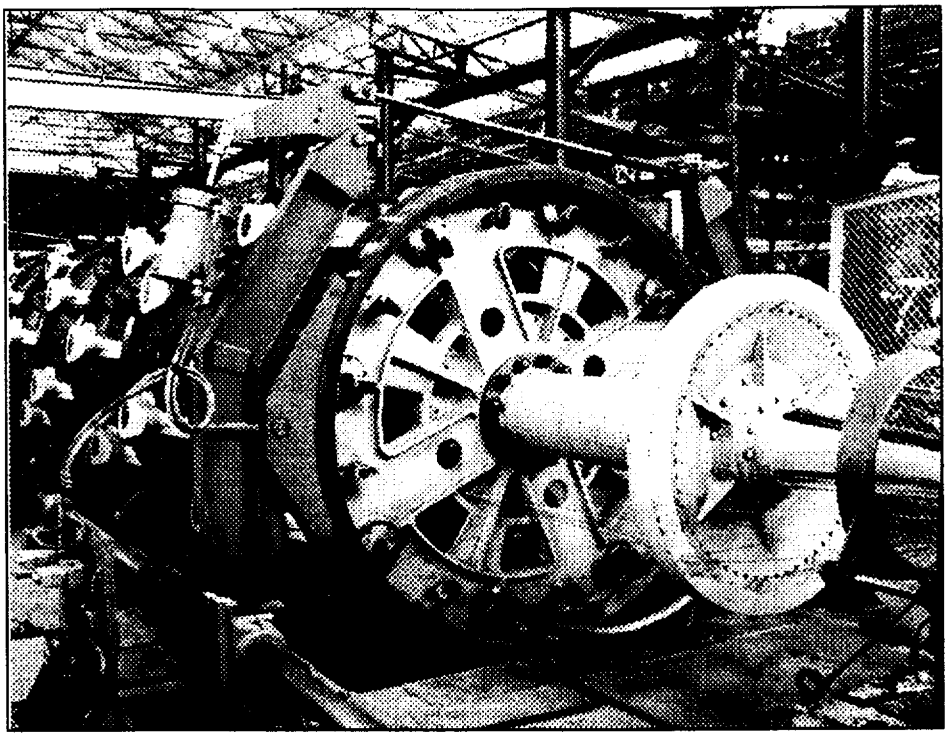


Figure 49 Sun and Planet Strander

binding wire. Loose coils restrict the mass of individual coils, depending on the wire diameter. Heavier coils are possible with larger wire sizes.

The alternative means of handling wire is on bobbins. A closely associated wire manufacturer can supply wire on bobbins suitable for the stranding machine on which it will be loaded. This is an ideal arrangement and leads to efficiency in the rope making process. However this is only efficient for long runs, where thousands of metres of the same rope is made on a continuous basis. In many rope factories the demand is for much shorter lengths and jobbing is the normal type of operation.

Both tubular and sun and planet stranding machines (Figure 49) have limitations on the maximum length of wire which can be wound onto a bobbin. This is determined by the allowable bobbin mass for which the machine has been designed. The mass of strand which can be handled is usually so large that many bobbin changes are required in producing the required length of strand. Wires are generally joined by electric butt welding or brazing, but in the smallest sizes can be joined by tucking. Good rope making practice, as reflected in the various standards, requires that these joins be adequately separated from one another. This is achieved by good planning in the bobbin winding process.

For good efficiency it is essential that the wire winding be carefully done. The wire must be evenly wound onto the bobbin with an even tension, so that there is no danger of the wire pulling into underlying coils, or coils becoming loose and snagging on wire which is being paid out from the bobbin in the stranding machine. These raffled bobbins contribute to inefficiency in the rope making process but do not often result in inferior product.

(2) Joining of Wires

Because of the limitations in bobbin capacity of stranding machines it is necessary to join each wire at regular intervals. The most usual method is by electric butt welding. Special machines have been developed to join wires in this way. The end of each wire to be joined is straightened and the end prepared by cutting with an even cut at right angles to the axis of the wire. The wires are clamped in the machine with the ends aligned and touching. An electric current is passed through the wire and at the same time a force is applied, moving the wires towards each other and so forming a join where the metal has fused together. A flash is formed by the excess metal at the join. This must be carefully removed by filing, or grinding, along the axis of the wire to produce a smooth join of the correct diameter. The wire must now be annealed at this place to ensure that there is no brittleness and that the microstructure changes uniformly from that of the parent wire to the fully annealed condition and back.

A correctly made butt weld will never fail in a rope and will last until the rope is discarded. However if there are deficiencies in the process the wire will probably fail at this place with a typical square ended fracture. The fact that it is a weld which has failed can be ascertained by observing the grinding or file marks in the surface of the wire.

(3) Lay Plate

In all stranding operations the wires need to be guided as they approach the entrance to the lay block. This is particularly required in the case of multiple wire equal lay strands, where each wire is required to fit into an exact geometrical position. To achieve this the wires are guided by means of a lay plate which is mounted fairly close to the lay block such that the wires form an angle, approximating to the lay angle, between the lay plate and the lay block. The guide holes in the plate are geometrically arranged in accordance with the construction. Figure 50 illustrates the arrangement required for the guide holes in a lay plate for a 19 wire Seale's construction.

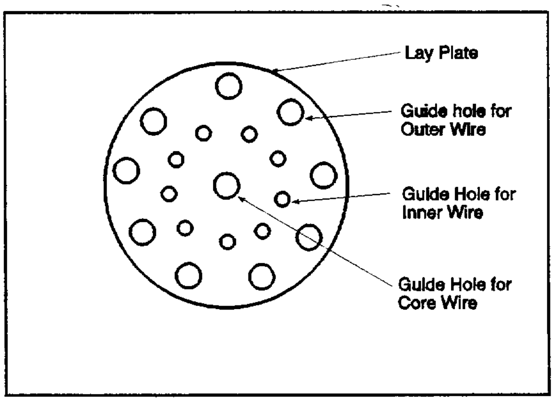


Figure 50 Arrangement of Guide Holes in Lay Plate for 19 wire (9/9/1) Seale's Construction

(4) Round Strand

Stranders for producing round strands are the least complicated of the rope making machinery. The number of bobbins in the machine determines the maximum number

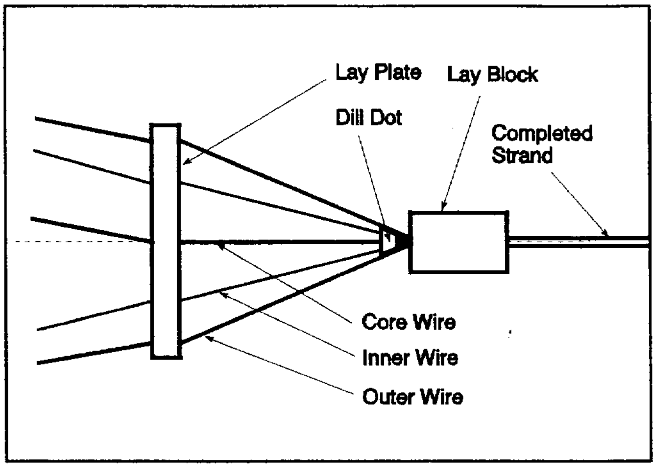


Figure 51 General Arrangement of Lay Plate With Respect to the Lay Block

of wires which can be formed into a strand. In some cases, particularly sun and planet machines (Figure 49) used to make large diameter strands, arrangements are made to twist the wire slightly as it is being formed into the strand. This twist is in a backward direction and assists in producing a strand which is easy to handle when being loaded into the closing machine.

Most round strand ropes are of equal lay construction. The geometric arrangement of the wires in the strand is a key factor in the satisfactory operation of these ropes, so the wires must be laid into their correct positions with no possibility of crossing or moving out of place. A lay plate similar to that illustrated in Figure 50 provides the basic control. However further control is achieved by the use of dill-dots, see Figure 51, which maintain the individual layers of wires in their correct position.

A dill-dot is a conically shaped ferrule which is placed between the outer layers of wires at the entrance to the lay block. The internal bore is suited to the diameter of the layer of inner wires so that these wires cannot be forced out of place by pressure from the covering wires.

(5) Postforming

In the manufacture of round strand ropes it is usually important to arrange that the completed rope is completely dead when the end is cut and the seizing removed.

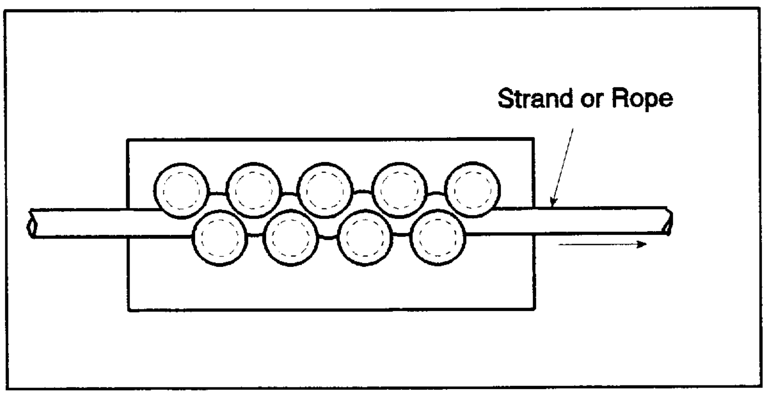


Figure 52 9 Roller Postformer

The first requirement in achieving this goal is to produce a strand that is also completely dead. That is, it is inert and will not turn or unlay if it is allowed to lie freely without any seizing. The means of achieving this is to postform the strand as it emerges from the lay block. Figure 52 illustrates the general arrangement of a postformer. The strand is pulled through this arrangement of small diameter rollers which are profiled to the diameter of the strand. The effect of this is to stress the wires to such an extent that they become set in their position in the strand. i.e. Residual wire bending stresses due to stranding are reduced. Obviously, care must be taken to ensure that the wires are not overstressed which will result in slackness of the wires.

(6) Shaped Strands

The stranding of shaped strands involves different techniques compared to round strands. These differences result in more complicated machinery which requires different techniques for setting up and running.

- A strand must be bent into place when it is being closed into a rope. See discussion on page 59. When a shaped strand is being made, an allowance must be made for this requirement. The means for doing this is to match the attitude of the shape of the strand with its position in the rope and to make the strand so that its attitude varies along its length to correspond with its final position in the rope. This is achieved by introducing another lay, termed the flat lay, into the strand as it is being made. This lay is achieved by rotating the forming rollers at a fixed ratio to the strand lay, while the strand is being made. The flat lay is a function of the rope lay length, the rope lay angle and any bobbin rotation introduced in the closing operation.
- The shape of the strand and the complication of the flat lay make the use of a lay block impractical in the stranding operation. The shape of the strand is therefore achieved by the use of rollers, mounted in various ways. Because of this bobbin tension is of critical importance to ensure that wire lengths are equal. The care needed to maintain uniform tensions is of a high order and constant checks are necessary.

* **Triangular Strand** The shape of any shaped strand is determined by the shape of its core. In the case of a triangular strand the relative size of the core also determines the definition of the triangular shape. A small core will result in a strand with a very rounded appearance, whereas if the core is relatively large the strand will have a pronounced triangular shape. The more rounded strand shape tends to be difficult to close as the correct attitude of the strand is more difficult to establish.

The core is the base on which a strand is built. In the case of a triangular strand the core travels up the centre of the machine to the forming point and it must have the correct flat lay to suit the strand being made. A plaited core (or a BRangle core) is made in a separate operation as a straight triangular entity. The core is fed into the back of the stranding machine and twisted to achieve the correct flat lay. As the machine rotates the core bobbin is also rotated to suit the flat lay in synchronism with the forming rollers. Careful monitoring of the core is necessary to avoid the possibility of the core turning over at the forming point.

Postforming of shaped strands is not done in South Africa. If a triangular strand is postformed its triangular shape is modified and becomes more rounded, both damaging the strand and making it more difficult to successfully close into a rope. To some extent, life in the strand is reduced by introducing a certain amount of back rotation into the wires during stranding.

* **Ribbon and "Fishback" Strand** Other shaped strands are made which are a function of the core used. In the case of ribbon strands no core is used and the correct ribbon shape must be maintained by the forming rollers in combination with the correct bobbin tension. To a large extent the manufacture of ribbon strands is a skilled operation which has been developed over many years. A similar looking product used for the smaller non-spin ropes is the six wire hollow strand construction. This strand is made as a coreless round strand and then crushed into shape in the closing machine. This is a most successful method for the smaller size ropes with wire sizes less than 3,00 mm diameter. In some cases however these strands are also made as ribbons with a flat lay.

  The "Fishback" strand is so named because of its appearance on the bobbin after stranding. It is generally manufactured with a pair of core wires which lie parallel to each other in the strand, as this is now the favoured configuration. This type of strand can also be made with three or more parallel core wires, but there is no necessity to consider this arrangement. In the same manner as for triangular strands the core wires are fed up the centre of the stranding machine. To maintain their relative position in the strand these wires have to be guided at the entrance to the forming point by rotating guides which synchronise with the forming rollers to create the required flat lay.

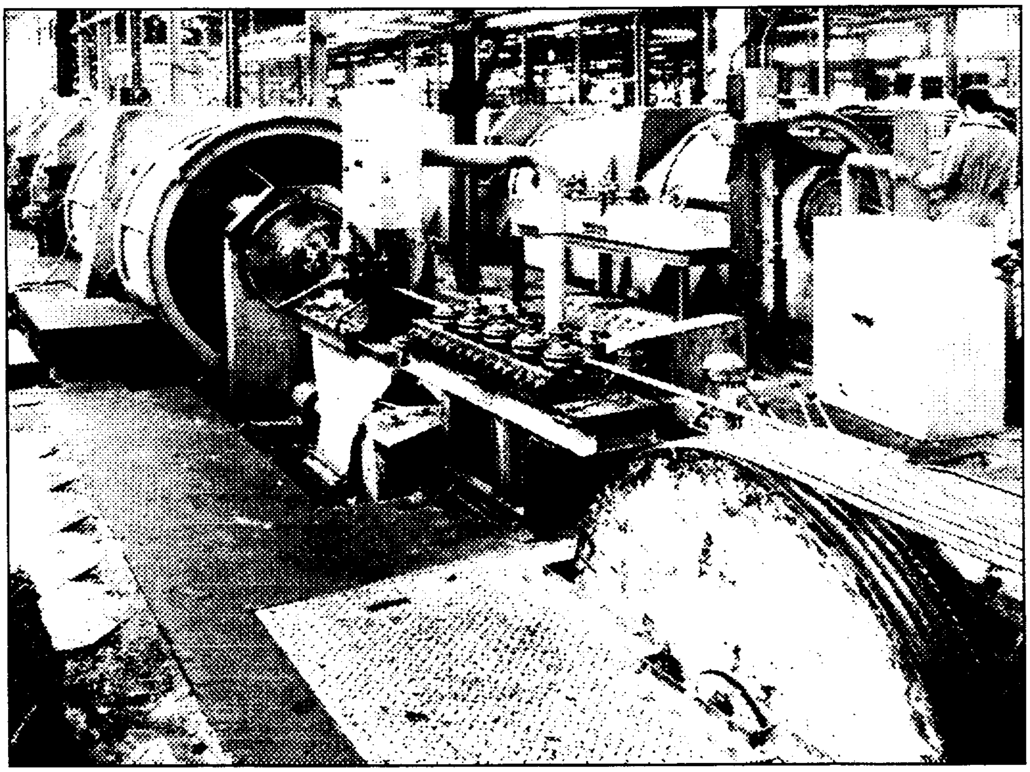


Figure 53 Tubular Closing Machine

3.2.2 CLOSING

The closing process matches stranding in most respects. However there are important differences which influence the characteristics of the finished rope. As in all other rope making processes, machine speed has a considerable impact on the cost of the finished product. Tubular machines are the fastest, but are not suited for the manufacture of all types of ropes without extremely complicated arrangements for controlling bobbin rotation. Sun and planet machines on the other hand are much slower which makes them ideal for the closing of ropes with shaped strands.

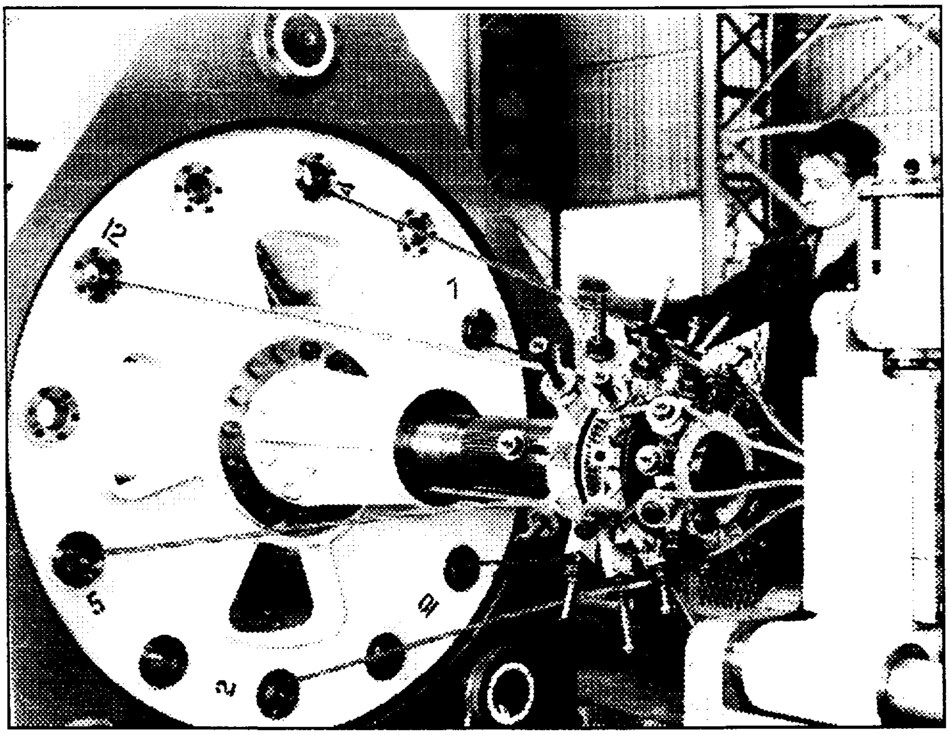


Figure 54 Triangular Strand Rope being Closed

(1) Tubular Closers

These machines are ideally suited to the closing of the smaller diameter ordinary lay ropes. The machine size required for ropes larger than about 35 mm diameter reduces the rotational speed to the extent that there is not a significant benefit. Most factories require a variety of machines for the optimum manufacture of a wide range of products. Most tubular closers, (similar to that illustrated in Figure 53), are not equipped to rotate the bobbins while in operation. This limits their product range to round strand ordinary lay ropes and certain constructions of lang's lay ropes.

(2) Sun and Planet Closers

These are the most flexible of the closing machines, (Figure 55), and always have the facility to rotate bobbins. In many machines it is only possible to rotate all the bobbins in unison but for machines designed to close ropes with shaped strands, individual

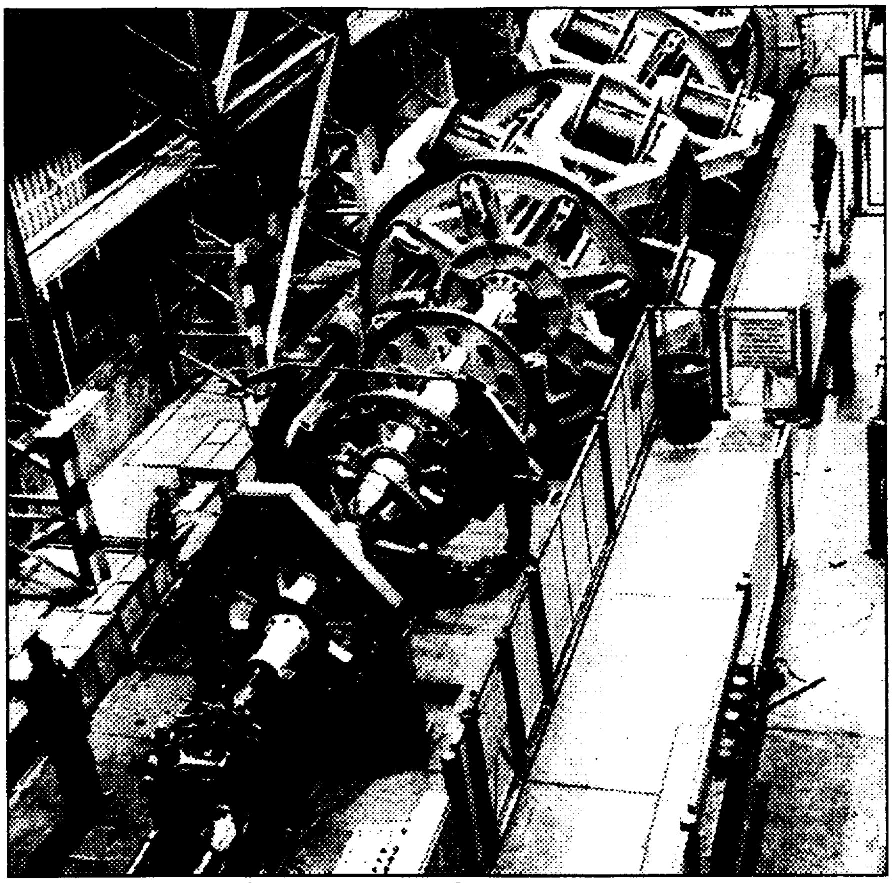


Figure 55 Large Sun and Planet Closing Machine

bobbins can be rotated as required. Round strand ordinary lay ropes are closed without any bobbin rotation but for the langs lay constructions forward rotation as calculated by the formula on page 61 is used.

* **Closing of Shaped Strands** Special techniques are required in closing ropes with shaped strands. The rope lay length has to be matched to the flat lay introduced in stranding and modified by the amount of forward rotation to be used. Since the available lay lengths are limited by the designs of the strander and closer, adjustments to achieve an exact match are made to the amount of forward rotation used.

  In closing shaped strands, (Figure 54), the attitude of the strand must fit exactly into the correct position as the strands are formed into the rope. To achieve this the strands are first fitted into the rope at the lay block and then clamped in shaped rollers a fixed number of flat lays away from the forming point. Each strand must have the same number of lays from the clamp to the forming point. Indicator devices, called butterflies, are mounted on each strand about three or four flat lay lengths closer to the bobbins. These indicators can be monitored while the machine is rotating, as they maintain a nominally fixed attitude in space. However, any variations in flat lay will be indicated and action can be taken to adjust the attitude of that bobbin with respect to the others as required. On older machines this adjustment required stopping the machine and unclutching the bobbin, so it could be rotated the correct amount. More modern machines are arranged so that this adjustment can be made while the machine is running.

(3) Preforming

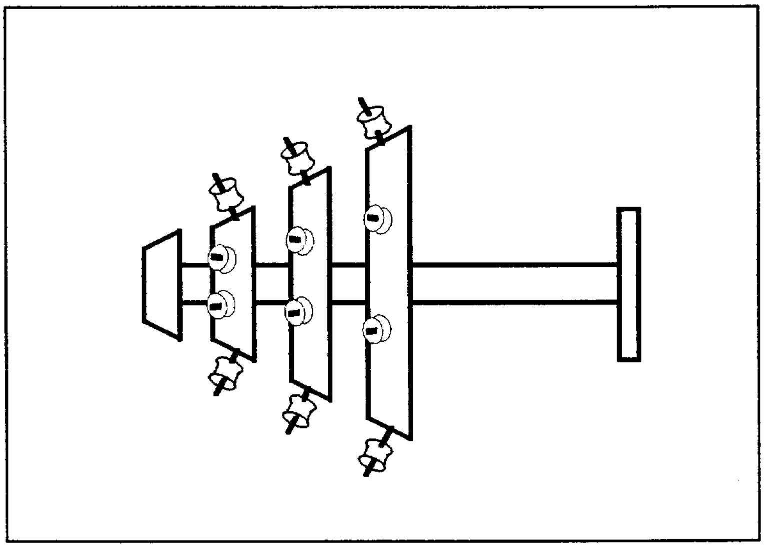


Figure 56 Schematic Arrangement of Preformer

Most ropes are required to be dead, or inert, when they are made, for ease of handling during installation into their operating environment. This inertness is achieved by preforming the strands as they are being closed into the rope. There are several devices used for preforming strands. Their action is usually based on bending the strand round a suitably sized roller while the roller is being rotated in the machine. The radius of the bend is controlled so that a permanent set is produced in the strand which matches the diameter and lay length of the rope. A schematic diagram of one of the most usual types of preforming device is illustrated in Figure 56. The strand path through the preformer can be seen in Figure 54. In adjusting the preformer the rollers on the centre disk are circumferentially displaced by a predetermined amount to produce the required set in the strand. The distance between the three disks can also be adjusted to influence the set and the resulting lay length.

(4) Postforming

In some cases, especially flexible ordinary lay round strand ropes, the effect of the preformer is not sufficient to produce the required properties. In this case a postformer similar to those used in stranding (Figure 52) is placed between the lay block and the capstan, as can be seen in Figure 53.

(5) Maximum Length or Mass

In stranding, the maximum length of strand which can be made is merely limited by the size of the take-up reel, or bobbin. However, the maximum economic length of rope which a machine can make is limited by the size of the machine bobbins. Each bobbin is designed to accept a maximum mass of strand when it is fully wound. The length of strand on the bobbin will then depend on its size. So in order to determine the maximum length of rope a machine can make the sum of the mass of all bobbins plus the mass of the core (assumed as the same as the strand mass for six strand ropes) gives the maximum mass the machine can handle. If this mass is divided by the unit mass of the rope the maximum length for a particular rope can be determined. There are limitations, however, because there are practical considerations relating to the strength of the strand related to the total mass of the bobbin.

3.3 INSPECTION AND TESTING

Formalised inspection and testing is required at all stages of manufacture. These operations are laid down in quality standards. Most inspection is the responsibility of the manufacturing unit concerned, but testing is often undertaken or required to be done by outside agencies. In general, continuous inspection by operating personnel is desirable from a purely economic point of view. It is obviously counterproductive to further process material which is faulty or does not meet the required specifications.

(1) Wire

The testing of wire is fully discussed in Chapter 2. This inspection and testing is done at the wire factory and the rope maker usually only confirms the results by suitable sampling.

(2) Strand

When the strand is started the settings of the postformer are checked and the life in the strand is checked by means of a "bight test". In this test a loop of strand which has been made is pulled from the takeup and observed. If the strand is dead the bight pulled from the takeup will not exhibit any tendency to twist. Any life is an indication that the amount of postforming is inadequate.

It is the machine operators responsibility to visually check the strand as it is being made. Deformation caused by broken wires or slackness of any sort is identified and immediately corrected. Regular checks of strand diameter and lay length are made both by the operator and supervisor. A continuous check, usually by automatic means, is made on wires to ensure that broken wires which might occur are immediately detected and rejoined by electric butt welding. A missing wire in a strand is a defect which should never occur, since the operator will always be aware of this fact.

A problem which sometimes occurs is the manufacture of a strand which is short. All rope making machines are equipped with at least two independent measuring devices for measuring the length of strand or rope produced. In addition it is common for wire lengths to be measured when being wound onto the bobbins for shorter lengths of rope. In spite of these precautions and due to inherent inaccuracies in the measuring devices, measured lengths are not always accurate. To counteract this, excess lengths are always made but mistakes here can lead to short strand lengths. If a short strand is closed with others of the correct length, the rope will be short since it is not practicable to increase the length of a short strand.

(3) Rope

The initial set up of the rope is carefully checked both by the closer operator and the supervisor. An initial length of rope is manufactured and when the front end of the new rope reaches the takeup reel samples are cut for inspection. Strands are removed and the diameter and lay length of the preforming are measured. If these are within the required tolerances the rope is passed for completion of the manufacturing process.

The responsibilities for inspection by the operator during rope manufacture are similar to the strander operator. In addition the closer operator has to monitor the preforming and the butterflies in the case of ropes with shaped strands.

After the rope has been completed test samples are removed from the end and the completed rope visually inspected on the reel to verify that it is tight and uniform and that the lubrication is as required. The preforming is often rechecked and the required samples are submitted for mechanical testing, the requirements of which have been discussed in Chapter 1.

(4) Rejection and Concessions

The results of all the inspections and tests are considered before the rope is passed for sale to a customer. Decisions regarding inspection findings are not always cut and dried. Obviously if the rope meets all the requirements it can be despatched immediately. Any adverse findings are carefully considered.

* **Outside Tolerance** There are three aspects in which a rope can be outside the allowed tolerance. These are Diameter tolerance, Length tolerance and Strength tolerance.
  - If the rope is outside the diameter tolerance a sample is usually remeasured under a tension of 10 % of the breaking force. If it now falls within the tolerance it is considered to comply with the specification. If it is still outside the tolerance the rope is rejected unless the customer is prepared to accept this condition. In general if a rope is found to be out of tolerance after manufacture, it is usually oversize as an under tolerance would have been corrected when the rope was set up.
  - As previously mentioned a rope can sometimes finish shorter than the ordered length. In many cases this does not present any difficulty to the client and the order can be amended to the actual length produced. However rope lengths can be critical for applications such as Koepe winding and in such cases the rope will have to be remade. With nothing else wrong with the rope it can be put into stock and used for some other application for which it is suitable.
  - The most serious of the out of tolerance conditions is if the rope strength falls below the estimated (or guaranteed) breaking force. There are some applications where this can be tolerated and the rope accepted but in general the rope will have to be remade. If there are no defects associated with the low breaking force the rope can be put into stock for use in another application.

* **Defects** Due to the nature of the manufacturing process most rope defects are identified and corrected during manufacture. In some cases the defect cannot be corrected but the rope is completed and action taken concerning the defect

subsequent to manufacture. Descriptions and action taken with regard to some defects are of interest.

- o Missing wires:- An outer wire missing over a short length is of little consequence and the rope can be safely used. However missing inner wires can cause rapid and early rope deterioration. If the part of the rope with the missing wire can be exactly identified, this piece of rope can be cut out and discarded and the remaining rope used, provided a suitable length remains. If the place with the missing wire cannot be found it is appropriate to reject the rope.
- o Deformation:- A rope or its strands can easily be deformed. Deformation can take the form of birdcaging, sloughed wires, looping wires or other wire deformation, kinked strands etc. In many cases the deformation is local and the reason easily identified. In this case the rope can be cut at this point and the deformation removed. If the remaining lengths are suitable the rope can be used. Deformation such as birdcaging is usually of such a nature that it occurs along the complete length of rope. Such ropes should be discarded.
- o Damage:- Localised damage to strands or completed rope can occur due to impact with some other object. These defects should be cut out of the rope and the shorter lengths used where possible.
- o Unacceptable Mechanical Properties:- Sometimes a rope will fail the breaking force test having brittle wires or a large number of wires with shear breaks. If there are more than one or two brittle wires the rope should be retested. It should be discarded if a retest exhibits the same problem. Shear breaks on the other hand indicate the presence of low temperature ageing which is not necessarily a problem. Such ropes often give good performance so care must be taken in deciding whether to use or discard the rope.

* **Disposal** As indicated it is often possible to cut a defect out of a rope and use the remaining pieces satisfactorily. Other defects where the rope is to be discarded need careful handling. In many cases it is possible to dispose of the rope where it is to be destranded and used for some such purpose as sidewall support in the mining industry. In no case should the rope merely be sold as scrap, as it has often occurred that substandard rope has been purchased from a scrap merchant and used, with subsequent problems. If a rope is to be completely scrapped it should first be destroyed by cutting into short lengths and then sold as scrap.

Chapter 4

RECOMMENDATIONS FOR USE OF ROPES IN VARIOUS HOISTING APPLICATIONS

4.1 BASIC CONSIDERATIONS.

As in many other engineering applications, the choice of a wire rope for a particular application is often a compromise arrived at by assessing the relative importance of different rope characteristics and then making a suitable selection based on the requirements of the application. The various rope properties which affect this choice are discussed as follows.

4.1.1 STRENGTH.

There are various aspects to strength requirements. The tensile strength of the steel in the rope obviously affects the size of rope required for a particular application, but there are considerations relating to the tensile grade which should be used, based on the proposed application. In addition the design factor, or factor of safety, is also dependent on the application for which the rope is to be used.

(1) Tensile Grade of Steel.[5]

The standard tensile grade of most ropes is considered to be 1800 MPa (1770 MPa in Europe). Different tensile grades are used to suit certain applications and some of these are listed as follows:-

- 1600 MPa is commonly used for ropes operating in marine environments as this is the most practicable tensile grade for hot dipped galvanised wire.
- 1900 MPa to 2100 MPa grades are often used for tower cranes and mobile cranes, especially in Europe.
- 1150 MPa is common on elevators in South Africa. Factors of Safety are in excess of 10 and due to requirements of limited elongation with change in load a relatively large steel area is required.
- 1900 MPa to 2200 MPa grades are in use on mine winding ropes for drum winders. With hoisting depths in excess of 1800 m the use of these Ultra High Tensile grades (UHT) is often justified, especially when depths of 2500 m and deeper are planned. A maximum of 1800 MPa is recommended for Koepe head-ropes.
- Sinking stage ropes are supplied in tensile grades ranging from 1800 MPa to 2150 MPa. Where tensile grades in excess of 1900 MPa are required for non-spin ropes the "Fishback" construction is preferred. Although kibble ropes of 2000 MPa have been used, tensile grades less than 1900 MPa are preferred particularly as it is recommended that kibble ropes be galvanised, which limits the tensile grade which can be used.

(2) Breaking Strength of Rope.

The strength of rope required for a particular application is dependent on the design factor, commonly termed the Factor of Safety (FoS), which is the ratio of the breaking strength of the rope to the maximum static tensile force in the rope. This factor is chosen to suit the particular application under consideration and is often specified in Government or other regulations relating to the proposed use. In many cases the factors are specified in ISO or other Standard Specifications. In some cases the factor has been specified by an insurance or underwriting company. Table XI lists factors for some of the more important applications.

Table XI Factors of Safety for Various Applications

Application		Recommended Factor	Specified by Authority
Crane hoist ropes	Gantry crane Tower crane Mobile crane	6 6 4,5	6 6 As in Standard
Boom suspension ropes		3	
Mast guys		3	
Aerial ropeway	Track ropes Haulage rope Chair-lift	3,5 6 6	 6
Suspension bridge	Main cable Droppers	3 4,5	
Rock winders	Drum winders (up to 1800 m) Drum winders (over 1800 m) Koepe winders	>9 at connection >4,5 at drum >7 and increasing with depth	>9 at connection >4,5 at drum >(8,1 - 0,00135L) with minimum of 5,62 for 4 ropes
Shaft sinking	Kibble ropes Stage ropes	As for drum winders ditto	As for drum winders ditto
Slings	Single leg Multiple leg Grommet	6 6 8	6 6 8
Cable belt conveyors		4	
Mono winch ropes		6	
Scraper ropes		5	

The required breaking strength of the rope is found from the following general formula:-

$$B = P \times s$$

Where
B = Required Breaking Strength of Rope (kN)
P = Maximum Static Tensile Force in Rope (kN)
s = Factor of Safety

The maximum static tensile force in the rope is not always easy to establish. For a mobile crane it is simply the force exerted by the end load and attachments divided by the number of falls of rope supporting the load. However, for an aerial ropeway track rope the geometry of the system magnifies the force in the rope compared with the load being carried which makes the assessment of the force a difficult calculation.

4.1.2 FLEXIBILITY.

A major feature of a wire rope is its ability to transmit a tensile force in a curved path such as while moving over a sheave or being wound on a drum. The size of sheave or drum with respect to the rope diameter and wire diameter is important as excessive bending will result in poor rope performance. Wire diameters are dependent on rope construction and ropes with smaller wires can be operated over relatively smaller sheaves.

Table XII gives recommended minimum sheave or drum diameters (single layer coiling) in terms of rope diameter for various constructions at speeds below 1 metre per second. For every 0,5 metre per second increase in speed above 1 metre per second 5% should be added. The correct figure can easily be calculated from the following empirical formula.

$$D = \left(\frac{V + 9}{10}\right) Kd$$

Where
D = Sheave or Drum diameter (m)
d = Rope diameter (m)
K = *Recommended ratio of sheave or drum diameter to rope diameter. See Table XII*
V = Rope speed (m/s)

It should be noted that a change in direction of a rope of 15° or more is generally accepted as constituting a complete bend to which the recommended sheave diameters refer. When the angle of deflection is less than 15°, sheave or roller diameters may be relatively smaller. In the case of support rollers and when the deflection is less than 2° the diameter should never be less than one lay length (i.e. 6 to 7,5 x rope diameter depending on the construction) for a grooved sheave, or 1,5 lay lengths in the case of flat rollers. If diameters less than these are used the rope will "chatter" with detrimental effects to itself as well as the roller.

When more than one sheave is used in a system the distance between sheaves carrying the same rope is of importance. In the case of a bend in excess of 15° it is recommended that the length of rope from point of departure on one sheave to point of contact on the other should not be less than that given by the formula:-

$$L_s = vt = 0{,}5v$$

Where
L_s = Rope length between sheaves (m)
v = Maximum rope speed (m/s)
t = Readjustment time of 0,5 s

When sheaves are spaced closer together than this the wires in the rope are subjected to excessive force to enable them to change position in time and severe fatigue occurs. In the case of non-spin ropes distortion may result.

Table XII Recommended D/d Ratios

Rope Construction	Recommended Minimum Drum and Sheave Diameters
6×7(6/1)/F	38,5 × rope diameter
6×19(9/9/1)/F	28 × rope diameter
6×25(12/6F+6/1)/F	23 × rope diameter
6×36(14/7+7/7/1)/F	19 × rope diameter
Triangular Strand ropes	42 × rope diameter
Non-spin Winding ropes	42 × rope diameter
15 Strand Non-spin 9×8/6×29(11/12/6▵)/WMC	42 × rope diameter
18 Strand "Fishback" Non-spin 12×10(8/2)/6×29(11/12/6▵)/WMC	42 × rope diameter

Note:- When tread pressures are important larger ratios should be chosen.

4.1.3 WEAR RESISTANCE.

The deformation of the wires of a wire rope is influenced by various factors. One is wear, or the removal of metal from the wires of the rope by abrasive action. Another, is the plastic deformation of the wire by pressure from sheaves or drum. There is also a combination of both features in differing proportions (often called plastic wear), which complicates the assessment of rope condition.

(1) Abrasive Wear.

Features of wire rope which affect abrasive wear are:- rope construction which governs the wire size relative to rope diameter as well as the effective pressure to which the wire is subjected and method of manufacture of the wire which is dependent on the required tensile grade of the steel.

The simplest construction such as the 6×7(6/1)/F obviously has the largest outer wires which enables the rope to absorb a relatively large amount of wear before the wires become so weakened that they loosen and then fracture. Strand constructions which are considered to provide good wear properties are those with 9 outer wires or less such as the 7(6/1) strand, the 19(9/9/1) strand or 17(8/8/1) strands. Ropes having strands with 10 or 12 outer wires are regarded as good all round constructions which provide adequate wear properties. Another feature of rope construction which affects wear performance is the use of shaped strands in constructions such as the triangular strand rope. The feature of this type of rope is the reduction in pressure between the rope wires and the drum or sheave surface as a result of the strand shape.Another alternative has arisen from recent developments of some ropes by the use of drawn strands. In manufacture the strands are drawn through a die which deforms the wires in the strands and increases the surface of wire in contact with sheaves etc.. The effect of this is to reduce the initial pressure on the wires and so reduce the rate of the wear process.

The factor of wire manufacture which influences wear is the chemical composition of the steel. Within limits, steel with carbon and manganese contents in excess of 0,7% will exhibit improved wear characteristics. However the choice of carbon for a particular wire is restricted to a great extent by the tensile strength required and steel with varying manganese content is not readily available. See Chapter 2 for a discussion of wire characteristics related to drawing. It must also be noted that the danger of the wire developing surface martensite in service increases with increased carbon content. This is often the main consideration when choosing a wire specification for a particular application. For example, it has proved advantageous to limit the carbon content of the wire in dragline drag ropes and avoid the brittleness associated with martensite at the expense of slightly increased wear.

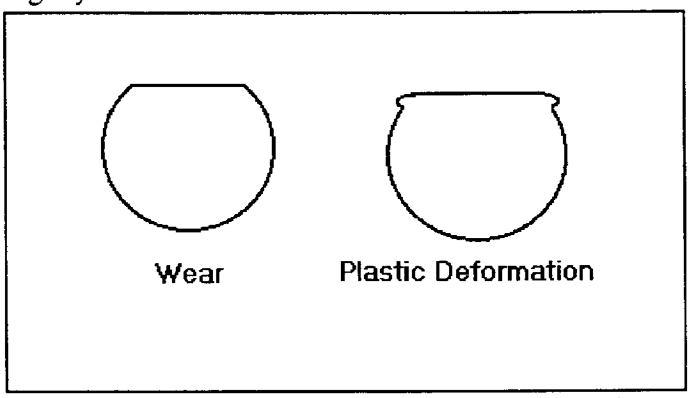


Figure 57 Difference between Wear and Plastic Deformation

(2) Plastic Deformation.

When a wire is subjected to radial compressive forces it tends to deform and flatten. Any wire rope which operates over sheaves or is wound onto a drum will be subjected to repeated radial forces which flatten the external surface of the wires in the rope. This flattening has the appearance of wear but as there is no removal of material the strength of the rope is not affected until the plastic deformation becomes excessive and lips or fins develop on the edges of the deformed area. Figure 57 illustrates the difference between abrasive wear and plastic deformation.

4.1.4 FATIGUE PERFORMANCE.

The fatigue performance of a rope is affected by factors which include the chosen construction, design of rope, wire quality and tensile strength as well as operating conditions and the type of application on which the rope is used.

(1) Tension-Tension Fatigue.

There are relatively few applications where tension-tension fatigue is the primary fatigue mechanism and they are all stationary (static) applications subjected to dynamic load variations. As a general rule the simpler the rope and strand construction the better the resistance of the rope to tension-tension fatigue loading. A 7 wire strand would give better performance than a 19 wire strand and a 6x7(6/1)/F rope would be better than a 6x19(12/6/1)/F. The equal lay constructions are also more fatigue resistant than the unequal lay constructions of similar flexibility.

(2) Bending Fatigue.

If ropes were operated in bending conditions where the bending stresses were minimal the simplest rope constructions with the largest outer wires would also give the best performance. However in most applications the size of sheaves and drum are severely limited by practical considerations, one of which is cost. Because of this these sizes are kept as small as practicable and rope construction is varied to suit. Under these circumstances the more flexible constructions develop the lower bending stresses and therefore, within limits, give better bend fatigue performance.

In general it is acknowledged that the equal lay constructions give better bend fatigue performance than the unequal lay constructions. It must also be noted that the round strand constructions with 16 or 18 outer wires do not necessarily give improved fatigue performance over those with 14 outer wires.

(3) Corrosion Fatigue

Corrosion fatigue is a combination of the normal fatigue pattern, where the wire develops a square ended fracture surface, and corrosion of the steel within the fatigue crack as it develops. Corrosion pits promote crack initiation and corrosive attack at the crack tip increases the rate of crack propagation. The corrosion also selectively attacks the steel along the grain boundaries and creates further stress raisers in the form of internal pitting. Rapid deterioration of a rope can be expected under these circumstances. Where corrosive environments are encountered rope maintenance should be increased or the use of galvanised wire considered. There are no other conventional rope design or manufacturing techniques which can be used to reduce this problem.

(4) Splitting Fatigue

It is known that when a circular cylinder is subjected to a compressive force across a diameter a tensile stress is developed at the centre at right angles to the applied force. Figure 58 illustrates the relationship between these forces. If this compressive force is applied repeatedly, as in a mine winder application, the tensile stress in the centre of the wire has a fatiguing effect at the centre of the wire which is the part of the wire most prone to segregation problems and in the direction of the weakest plane in the wire. Any drawn wire subjected to this type of fatigue stress will eventually split, so to avoid this problem the compressive stresses must be kept low enough to ensure that this type of fatigue is not a feature of rope discard. To some extent the method of wire manufacture can influence the resistance of the wire to splitting fatigue and of course any central defects in the wire will reduce its resistance and early failure can be expected. Figure 59 illustrates a wire which has split while in service on a drum winder.

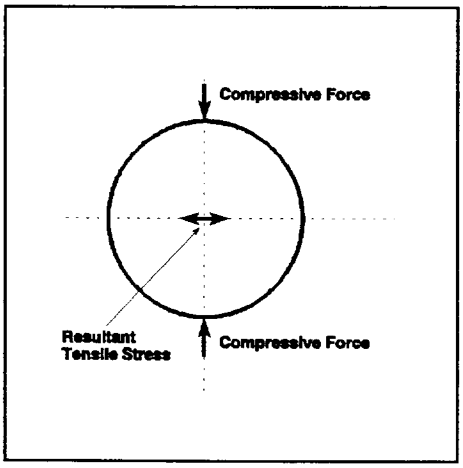


Figure 58 Stress Distribution due to Compressive Stress

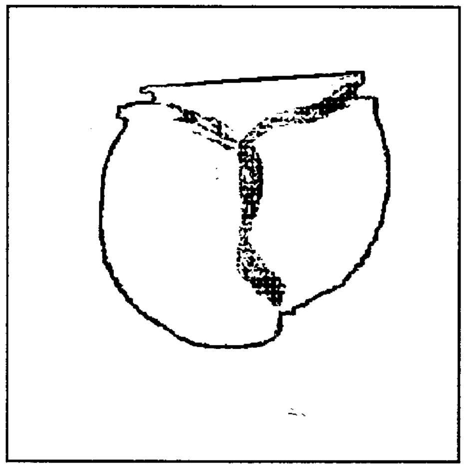


Figure 59 Effect of Splitting Fatigue on Wire

4.1.5 LAY.

Ordinary lay is the standard supplied for most round strand ropes. This is the most versatile lay and can be used when the rope end is free to rotate, provided only short lengths are involved. Ropes made with this lay have good stability and crush resistance. On the other hand Langs lay has improved wear and fatigue performance characteristics compared to ordinary lay and is usually chosen when both ends of the rope are fixed, slightly higher torque is acceptable and improved performance is required. Single layer Langs lay ropes must never be used with an end free to rotate. In South Africa all ropes with shaped strands are made Langs lay, consequently non-spin ropes for shaft sinking etc. are made Langs lay even though these are allowed to hang free in the shaft.

4.1.6 TORQUE.

When any rope is loaded it will develop a torque of some magnitude. In the case of ordinary lay ropes and non-spin ropes operating with a free end, the rope will rotate about its axis until the torque reduces to zero. In ordinary lay ropes this rotation can be of some magnitude but because of its stability the rope does not distort. When the load is released or reduced the rope will again rotate, but in the opposite direction. This feature is often seen in dock-side cranes where the rope is connected to the crane hook through a swivel. In the case of non-spin ropes, after this initial adjustment the rope behaves with minimal rotation with change in load. In shaped strand non-spin ropes very slight (if any) rotation is observed even when operating at depths of 2000 m. In ropes such as the 18 strand non-spin 12×7(6/1)/6×7(6/1)/F the rotation is negligible until suspended lengths of 50 m to 100 m are reached.

Unfortunately it is not a simple matter to estimate how much a rope will rotate with a change in load but the torque generated when loading a rope in the as manufactured condition can be calculated from the following formula:-

$$T = C\,d\,P$$

Where
T = Torque (Nm)
P = Tensile load in rope (N)
C = Torque factor (mm per mm of rope diameter)
d = Rope diameter (m)

Representative estimates of the torque factor for ropes in the as manufactured condition are given in Table XIII.

Table XIII Torque Factors

Rope Construction	Torque Factor in mm per mm of rope diameter
6×19(9/9/1)/F Langs Lay	0,157
6×19(9/9/1)/F Ordinary Lay	0,098
6×25(12/6F+6/1)/F Langs Lay	0,143
6×25(12/6F+6/1)/F Ordinary Lay	0,089
6×30(12/12/6▵)/F Langs Lay	0,165
15 Strand Non-spin 9×8/6×29(11/12/6▵)/WMC	0,019
18 Strand "Fishback" 12×10(8/2)/6×29(11/12/6▵)/WMC	0,016
15 Strand "Fishback" 9×10(8/2)/6×14(8/6▵)/WMC	0,062

4.1.7 RESISTANCE TO CRUSHING.

In applications where multi-layer coiling is a feature of drum design resistance to crushing is a requirement.

The least crush resistant ropes are those with fibre in the strands as well as the core and the most crush resistant, ropes with the greatest steel area.

Triangular strand ropes have considerable crush resistance inherent in their design. Round strand ropes on the other hand have very variable resistance to crushing. Six strand ropes have satisfactory configuration. Resistance to crushing is also improved when the strands have the least number of wires. The use of an IWRC is also beneficial.

4.1.8 CORROSION RESISTANCE.

One of the most insidious causes of rope deterioration is corrosion, which can be external, or more seriously, internal or both. In most rope applications, the application of rope dressing at regular intervals during service is sufficient to ensure protection from this type of deterioration. However, more aggressive environments quickly overcome the protection afforded by rope dressings and other means of protection must be sought.

In marine environments, the use of ropes made from hot dipped galvanised wire provides adequate protection to enable satisfactory performance to be achieved. A disadvantage of this product is that the galvanising process adversely affects some mechanical properties. As a consequence the tensile grade of the rope is usually limited to 1600 MPa or possibly lower. For fishing and other marine applications this is not always a disadvantage as the occurrence of martensite in operating ropes is reduced. The use of hot dipped galvanised wire is also common when a rope is required to be completely unlubricated, such as for slings.

There are many applications where the limitations of hot dipped galvanised wire are unacceptable but in which the thinner zinc coatings of drawn galvanised wire are sufficient. In mining applications such as mine hoisting or cable belt conveyors higher tensile wire with good mechanical properties is required and this is only available in drawn galvanised wire. However, many mining environments are slightly acid and unprotected zinc would quickly be stripped off. It has been found that provided a suitable rope dressing is maintained on the rope the combination of the thin layer of zinc and the rope dressing gives good protection and a satisfactory performance.

The extra process of coating the wire with zinc as well as the cost of the zinc itself adds to the price of the rope so this is also a consideration in the choice of galvanising. There is obviously no benefit if the improved life of the rope does not cover the extra cost.

4.1.9 STABILITY.

There are many applications which impart unusual forces to ropes or even cause considerable variations in the manufactured parameters.

Ropes operating on endless systems such as cable belt conveyors, brick conveyors, chair-lifts etc. are subjected to a change in load at the drive that induces torque in the rope which causes the rope to twist, or rotate during operation. This is a natural phenomenon and must be counteracted by adjustment of the alignment of certain sheaves in the system. Sometimes the effect of these forces is sufficient to cause strands to move out of position and cause what looks like a cork-screw. The choice of suitable rope lays can sometimes avoid this problem.

Mine hoisting also provides conditions where ropes can be distorted. In drum winding the rope hangs in the shaft with the ends restrained, however there is a variation in load along the length of the rope due to the mass of the rope itself. This variation induces a variable torque in the rope which then adjusts its lay to equalise the torque along its length. When shafts become very deep the lay length variation which occurs is sometimes sufficient to cause a cork-screw in the rope at the most deformed part. Because of the lay length change in drum winder ropes it is seldom advisable to use a rope with a WMC or an IWRC as these types of core can cause slackness and bird-caging of the rope. In severe cases the core becomes prone to premature failure.

In view of the various types of distortion possible it is necessary to assess the potential of the system for causing distortion and then choose the simplest rope which will suit the application.

4.1.10 RESERVE STRENGTH

Unless affected by corrosion, the inner wires of a single layer rope are usually intact after many outer wires have broken due to wear or fatigue. The ratio of metallic area of inner wires only to total metallic area of the whole rope, multiplied by 100 gives the percentage reserve strength.

Table XIV Reserve Strength

Rope Construction	Percentage Reserve Strength
Single layer ropes	
6×7(6/1)/F	14%
6×14(8/6$_\Delta$)/F	19%
6×28(10/12/6$_\Delta$)/F	27%
6×19(9/9/1)/F	31%
6×25(12/6F+6/1)/F	42%
6×36(14/7+7/7/1)/F	48%
Non-spin ropes	Based on outer strands
18 Strand Non-spin	
12×7(6/1)/6×7(6/1)/F	66%
14 Strand Non-spin	
8×6/6×10(7/3$_\Delta$)/WMC	49%
15 Strand Non-spin	
9×8/6×29(11/12/6$_\Delta$)/WMC	40%
15 Strand Non-spin "Fishback"	
9×10(8/2)/6×13(7/3$_\Delta$)/WMC	56%
18 Strand Non-spin "Fishback"	
12×10(8/2)/6×29(11/12/6$_\Delta$)/WMC	47%

Although a somewhat theoretical figure, it is of interest when choosing the best construction for an application where rope safety is of great importance. In many cases consideration of reserve strength will help in deciding on the relative importance of flexibility and wear resistance.

In the case of non-spin ropes this concept is complicated by the mode of deterioration of the rope in its particular application. In most cases non-spin ropes deteriorate internally due to fatigue of wires in the inner rope. Because of difficulties in inspecting non-spin ropes the concept of reserve strength becomes valuable if it is changed to mean the strength of the outer strands when all the wires of the inner rope have failed. By using this concept, assessment of any deterioration or damage to the outer strands is put into perspective and should be considered to be more serious than at first apparent. This would apply even if it is known that external wear of the outer strands is the prime mode of deterioration.

Table XIV gives percentage reserve strengths for commonly used single layer rope constructions and for non-spin ropes the values are related to the strength of the outer strands when all the inner strands have failed.

4.1.11 GENERALISED ASPECTS OF CHOICE.

Figure 60 gives a visual impression of the relative interaction of wear resistance, crushing resistance and flexibility for a representative range of constructions which are in common use in engineering and mining applications. This emphasises the concept that the most important property must be chosen and a compromise made relating to the other properties when a rope is selected for a particular application.

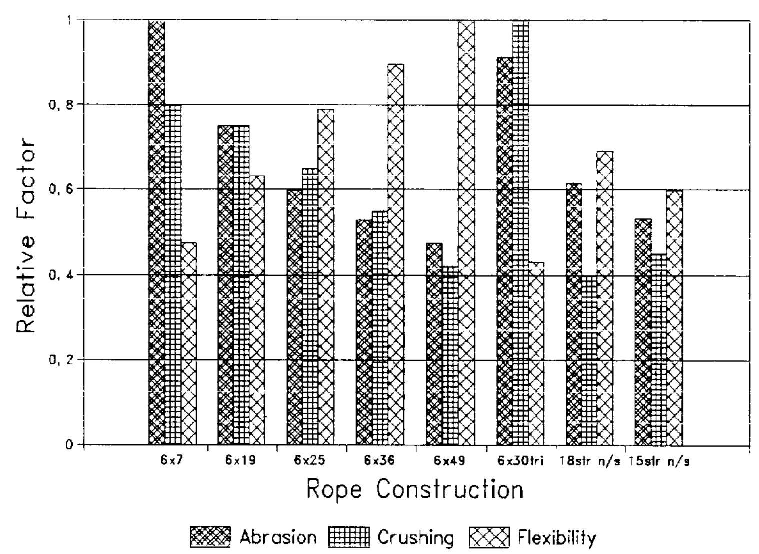


Figure 60 Comparison of Various Rope Constructions

The constructions listed in Figure 60 are more accurately defined as follows:-

6×7(6/1)/F Langs lay
6×19(9/9/1)/F Ordinary lay
6×25(12/6F+6/1)/F Ordinary lay
6×36(14/7+7/7/1)/F Ordinary lay
6×49(16/8+8/8/8/1)/IWRC Langs lay
6×30(12/12/6▵)/F Langs lay
18 Strand Non-spin 12×7(6/1)/6×7(6/1)/F Ordinary lay
15 Strand Non-spin 9×8/6×29(11/12/6▵)/WMC Langs lay

4.2 ROPES FOR MINE HOISTING. [14]

Probably the most demanding and critical of all rope applications, mine hoisting ropes need to be considered with care and a measure of conservatism. There are many arrangements for the hoisting of men, rock and materials each of which requires its own approach to ensure safe and satisfactory rope operation.

There are two basic hoisting systems; a system involving the use of drums to which the rope is attached and a system in which friction is used as the means of driving the ropes. Each system has several sub-types and those in use in South Africa will be considered.[15] Condensed recommendations for rope constructions for mine hoisting are to be found in Table XIX on page 125.

4.2.1 DRUM WINDING.

The two basic drum winding systems are differentiated by the types of ropes used, flat ropes and round ropes.

An old system using flat ropes wound onto reels was discontinued in South Africa many years ago but is still sometimes used in Europe.

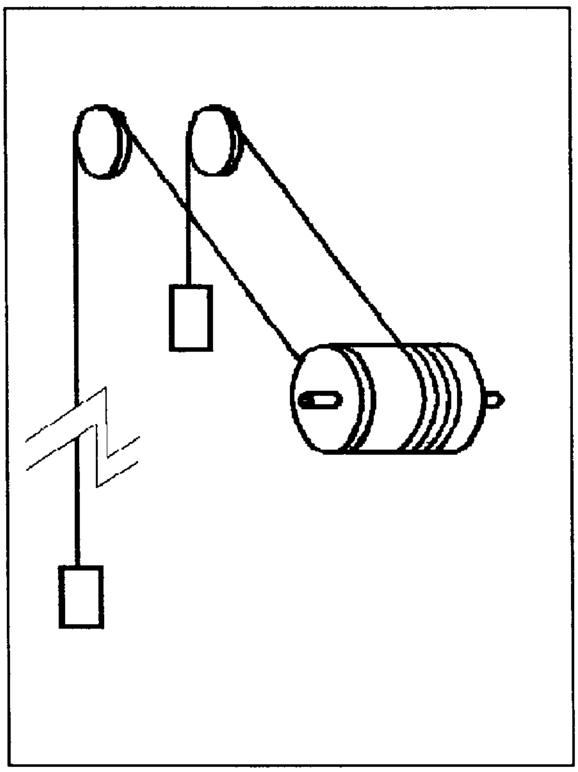


Figure 61 Parallel drum Winder

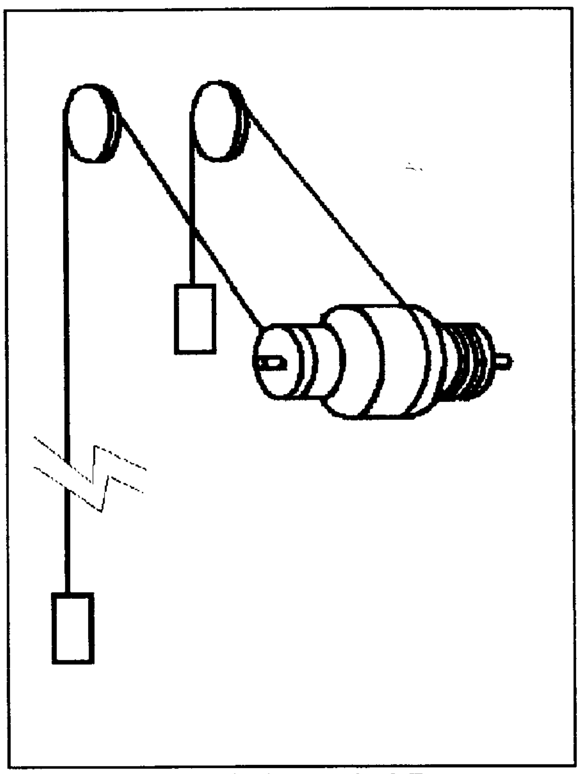


Figure 62 Bi-cylindro-conical Drum Winder

The system with round ropes is the most generally used and incorporates several variations:-

- o Single drum winder with plain or grooved cylindrical drum and with one or more layers of rope.
- o Double drum winder with drums as above in which the rope is paid out from one drum while the other rope is being wound onto its drum. (Figure 61)
- o Vertical, inclined or compound shafts in which there is a change in inclination at some point in the shaft.
- o Winders with conical drums.
- o Winders with cylindro-conical or bi-cylindro-conical drums. (Figure 62)
- o Blair multi-rope winders. (Figure 63)

In all these variations the basic rope choice and maintenance considerations apply. Some additional factors relate to use of ropes in compound shafts but will not be considered as these shafts are no longer in use. Of course when there is single layer coiling on the drum many problems are simplified and in some cases rope choice is extended.

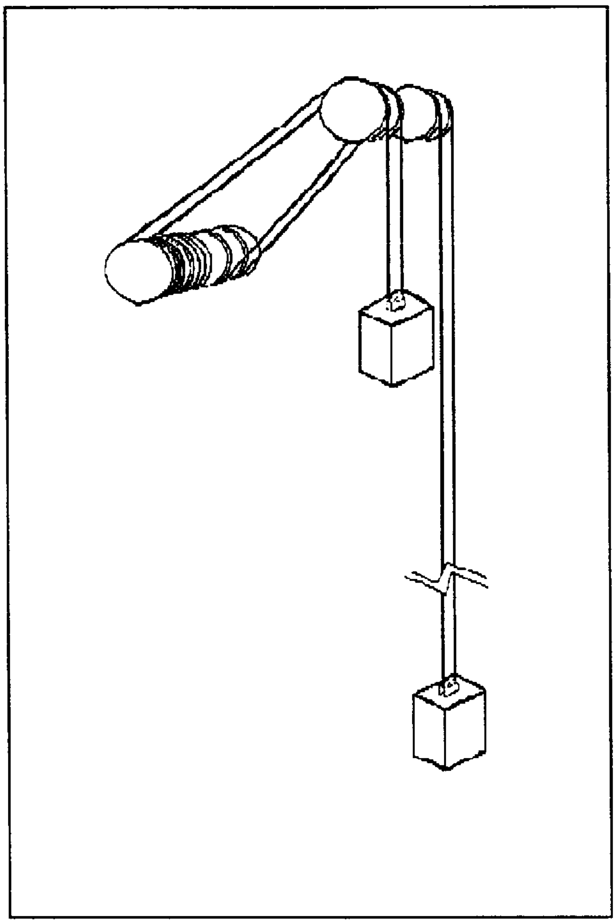


Figure 63 Blair multi-rope Winder

Table XV Approximate Efficiency Factors for Various Types of Rope

Rope Construction	Efficiency Factor (Nm/kg)					
	1800 MPa	1900 MPa	1950 MPa	2000 MPa	2050 MPa	2100 MPa
6×19(9/9/1)/F	158 000	-	-	-	-	-
6×25(12/6F+6/1)/F	162 000	-	-	-	-	-
6×13(7/6_{Δ})/F	160 000	-	-	-	-	-
6×14(8/6_{Δ})/F	156 500	-	-	-	-	-
6×15(9/6_{Δ})/F	160 000	-	-	-	-	-
6×26(8/12/6_{Δ})/F	166 000	177 000	180 000	184 000	188 000	192 000
6×27(9/12/6_{Δ}/F	166 000	177 000	180 000	184 000	188 000	192 000
6×28(10/12/6_{Δ})/F	171 000	177 000	180 000	184 000	188 000	192 000
6×29(11/12/6_{Δ})/F	171 000	177 000	180 000	184 000	188 000	192 000
6×30(12/12/6_{Δ})/F	170 500	176 000	180 000	184 000	188 000	192 000
6×31(13/12/6_{Δ})/F	170 500	176 000	180 000	184 000	188 000	192 000
6×32(14/12/6_{Δ})/F	170 000	175 000	179 000	183 000	187 000	191 000
6×33(15/12/6_{Δ})/F	169 500	174 000	179 000	183 000	187 000	190 000
6×34(16/12/6_{Δ})/F	169 000	173 000	178 000	182 000	186 000	190 000
8×6/6×10(7/3_{Δ})/WMC	166 000	174 000	-	-	-	-
9×6/6×10(7/3_{Δ})/WMC	166 000	174 000	-	-	-	-
9×8/6×27(9/12/6_{Δ})/WMC	166 000	175 000	179 000	-	-	-
9×10(8/2)/6×14(8/6_{Δ})/WMC P61	162 500	-	-	-	-	-
P11	166 000	174 000	179 000	183 000	187 000	191 000
12×10(8/2)/6×29(11/12/6_{Δ})/WMC	167 000	175 000	188 000	184 000	188 000	193 000
12×19(9/9/1)/6×19(9/9/1)/WMC	-	169 500	174 000	178 000	182 500	-

Note:- A value of the efficiency factor to within + or - 5% can be obtained by multiplying the Tensile Strength Grade Number by 90.

(1) Vertical Shafts.

The first action in choosing a rope for a drum winder is to make a general assessment of the type of rope which should be used. Guidance in this is given in the following sections. Having chosen the type of rope it is necessary to establish the required rope size, breaking force and mass per metre.

Calculations of the required breaking force of a rope for a particular application by trial and error can be a tedious matter. By using the concept of an efficiency factor (see Table XV) the calculation is considerably simplified and convenient formulae for the initial calculations to determine the required breaking force of a winding rope are as follows:

The greater of:-

i) $$B = \frac{M\, g\, s_c}{N}$$

or

ii) $$B = \frac{M}{N\left(\frac{1}{sg} - \frac{L}{f}\right)}$$

Where

B = Required breaking force (kN)
M = Mass of loaded conveyance (t)
N = Number of ropes supporting end load
s = Factor of Safety
s_c = Capacity Factor (Factor of Safety at conveyance end of rope)
L = Length of suspended rope (m)
g = Acceleration due to gravity (approximately 9,8 m/s^2)
f = Efficiency factor for rope (Table XV) (Nm/kg) (ratio of breaking force to mass per unit length of rope).

It should be noted that having arrived at a breaking force and chosen a rope the actual design factor of safety should be checked using figures quoted in the manufacturers tables of mass and breaking force because the efficiency factor given for the rope in Table XV is an average figure, the actual varying slightly from rope to rope.

(2) Incline Shafts.

Because of the additional abrasion which occurs in incline shafts, rope construction choices are limited to ropes with the largest appropriate outer wire size.

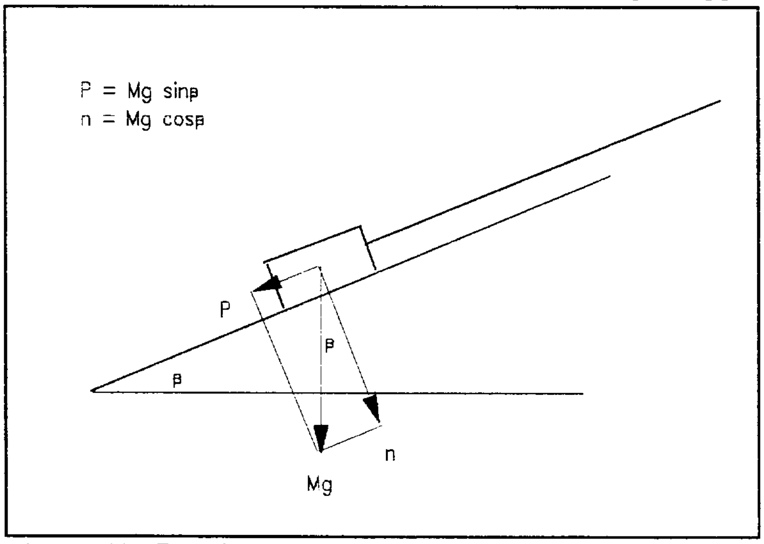


Figure 64 Resultant Rope Tension on an Incline

In addition the effect of the incline is to reduce the static rope forces without affecting the dynamic forces associated with acceleration, deceleration and braking, especially emergency braking. In the preliminary assessment of rope size it is recommended that design factors considerably in excess of the statutory ones be applied when calculating the required breaking force.

Having chosen a rope size, calculations of dynamic forces should be done to confirm that the correct size rope has been chosen. Figure 64 illustrates the effect of the incline on the static forces acting on the rope.

The formulae for calculating the required breaking force of the rope are modified by the effect of the incline from the formulae for vertical hoisting. In addition an allowance of 1,05 for the effect of friction must be added to the formulae in accordance with the requirements of the South African Minerals Act and Regulations. The required breaking force is therefore:-

The greater of:-

i) $$B = \frac{1{,}05\ M\ g\ \sin\beta}{N\ s_c}$$

or

ii) $$B = \frac{1{,}05\ M\ \sin\beta}{N\left(\frac{1}{s\ g} - \frac{1{,}05\ L\ \sin\beta}{f}\right)}$$

Where

B = Required breaking force (kN)
M = Mass of loaded conveyance (t)
N = Number of ropes supporting end load
s = Factor of Safety
s_c = Capacity Factor (Factor of Safety at conveyance end of rope)
L = Maximum length of rope down incline (m)
g = Acceleration due to gravity (approximately 9,8 m/s^2)
f = Efficiency factor for rope (Table XV) (Nm/kg) (ratio of breaking force to mass per unit length of rope).
β = Angle of incline to horizontal

(3) Type of Guides.

In South Africa most vertical shafts are equipped with fixed guides, which are fixed to the shaft buntons or the shaft side-wall. These guides will resist the torque developed by any of the rope constructions, so 6 strand ropes are usually chosen.

* **Timber Guides.** Timber guides are still used in older shafts. A feature of a shaft with timber guides and timber support is the necessity to avoid dry rot of the timber. To achieve this the shafts are kept wet by means of water sprays at the bank. Although clean and neutral water is used there is still a rather hostile environment. Rope dressing tends to be washed off the rope and special attention must be given to the type of dressing and the method of application. In spite of care, ropes often deteriorate due to corrosion and are discarded before the onset of fatigued wires. In a well maintained shaft, timber guides provide a stable guiding system and seldom cause excessive oscillation of the conveyance. The most serious problems arise when excessively worn guides are replaced and inadequate arrangements made for the transition from an adjacent worn guide to the new guide. In this case the conveyance

is subjected to impulses which can cause excessive localised deterioration of the rope on the drum.

* **Steel Guides.** All modern shafts in South Africa are equipped with steel guides of various designs. These shafts are all maintained to be as dry as possible so corrosion does not present such an important problem, unless water seeps in from the surrounding rock or leaks from water pipes or backfill pipes. A problem which is related to the steel support of shafts is an occasional occurrence of severe vibration which can affect either the conveyance or the rope.

* **Rope Guides.** The use of ropes for guiding conveyances in shafts is a common practice. All sinking shafts in South Africa use ropes to guide the kibbles. These ropes are also provided to support the sinking stage. Rope guides in permanent shaft arrangements are less usual in spite of some obvious advantages such as:-
  - o Provides a very smooth guiding system.
  - o Can accommodate very high conveyance speeds which are only limited by aerodynamic effects.
  - o Has reduced resistance to the flow of ventilation air.
  - o Can be quickly installed.

  The disadvantages however have limited the usefulness of the system;-
  - o Non-spin or Locked coil hoisting ropes must be used.
  - o The perceived danger of using 6 or 8 conveyances in a shaft, limit the shaft output which could be achieved.
  - o Extra spacing of conveyances required to avoid contact with other conveyances or the shaft wall reduces possible shaft output.
  - o In deep shafts could be more expensive than conventional fixed guides due to increased strength requirements in the shaft collar and head-frame.
  - o Adequate guiding capability reduces with depth. Although resistance to impulse loading remains high due to inertia effects, the resistance to constantly applied forces, such as the torque in the winding rope, reduces rapidly with depth. A useful rule of thumb for designing rope guides, or evaluating an existing installation, is:- that the constantly applied force required to deflect the guide rope by 150 mm at the centre of the shaft should be at least 90 N.

(4) Depth of Wind.

There are different requirements for ropes operating at depth compared with shallow winds. These differences are incorporated in the mining regulations of many countries besides South Africa.[16] A feature of these regulations is the reducing factor of safety allowed with increasing depth of wind.

* **Shallow Wind.** There is a perception that ropes operating on shallow winds are more prone to deterioration due to vibration and other causes and the regulations take this into account. It is also apparent that shorter ropes have less resilience than longer ropes and for many years there has been a perception that there is a critical depth relating to this factor. Recent research has established that for practical purposes there is no critical depth and that the prime consideration for ropes operating at shallow depths is the fatiguing effect of the tension variations (often called the load range) in the rope. If the winder is operated without tail (or balance)

ropes the tension variations in a rope reduce with depth. As a result for drum winders it is appropriate to reduce factors of safety with depth to a certain minimum.

These considerations indicate that a rope with good fatigue performance is appropriate for shallow winds. If the drum is sufficiently large so that there is only one layer of rope on the drum, a round strand rope is preferred. However, if there is more than one layer of rope on the drum, wear and crushing considerations indicate the advisability of using a triangular strand rope. The recommended ropes would be as follows:-

- Small winder with ropes less than 25 mm diameter:-
  - $6\times19(9/9/1)/F$ Langs lay for speeds below 2,5 m/s alternatively $6\times13(7/6_{\Delta})/F$ Langs lay.
  - $6\times14(8/6_{\Delta})/F$ Langs lay or $6\times15(9/6_{\Delta})/F$ Langs lay for speeds in excess of 2,5 m/s.
- Winder with single layer of rope, at all speeds:-
  - $6\times19(9/9/1)/F$ Langs lay up to 41 mm diameter.
  - $6\times25(12/6F+6/1)/F$ Langs lay over 41 mm diameter.
- Winder with two or more layers of rope, at all speeds:-
  - $6\times26(8/12/6_{\Delta})/F$ Langs lay up to 34 mm diameter.
  - $6\times27(9/12/6_{\Delta})/F$ Langs lay from 35 mm to 37 mm diameter.
  - $6\times28(10/12/6_{\Delta})/F$ Langs lay from 38 mm to 39 mm diameter.
  - $6\times29(11/12/6_{\Delta})/F$ Langs lay from 40 mm to 42 mm diameter.
  - $6\times30(12/12/6_{\Delta})/F$ Langs lay from 43 mm to 45 mm diameter.
  - $6\times31(13/12/6_{\Delta})/F$ Langs lay from 46 mm to 48 mm diameter.
  - $6\times32(14/12/6_{\Delta})/F$ Langs lay from 49 mm to 51 mm diameter.
  - $6\times33(15/12/6_{\Delta})/F$ Langs lay from 52 mm to 62 mm diameter.
  - $6\times34(16/12/6_{\Delta})/F$ Langs lay from 55 mm to 68 mm diameter.

An outer wire diameter in the range 3,10 mm to 3,35 mm has been shown to offer the best compromise between good mechanical properties and size, with a diameter of 3,20 mm being considered the optimum. From this comes the concept that the preferred rope sizes for triangular strand ropes are, 33 mm $6\times26_{\Delta}/F$, 36 mm $6\times27_{\Delta}/F$, 38,5 mm $6\times28_{\Delta}/F$, 41 mm $6\times29_{\Delta}/F$, 44 mm $6\times30_{\Delta}/F$, 47 mm $6\times31_{\Delta}/F$, 50 mm $6\times32_{\Delta}/F$ and 53 mm $6\times33_{\Delta}/F$ diameters. Other diameters are available and the manufacturers should be consulted before ordering these, especially in sizes above 53 mm diameter.

Full locked coil ropes are sometimes used overseas and give good results. Although lives are usually much longer than those of stranded ropes the high cost of the ropes often makes them uncompetitive. In addition the strength to mass ratio is considerably lower than that of triangular strand ropes so that in shafts deeper than 1500 m they are at a further disadvantage. In sizes above 44 mm diameter performance can be erratic and it is recommended that full locked coil ropes in excess of 56 mm diameter be avoided.

* **Deep Wind.** A depth of wind in excess of 1500 m is generally regarded as being a "deep wind". Winders operating in these shafts usually hoist at 12 m/s or more. Because of the amount of rope to be wound onto the drum there are usually two or more layers of rope. The tension variation in the rope is usually not sufficient to lead to deterioration due to tension/tension fatigue and multi-layer coiling results in wear and pressure, particularly between layers, being the chief causes of rope deterioration. Triangular strand ropes have proved themselves in this type of application and are generally chosen.

  A further feature of deep winds is the payload which can be hoisted for a given winder and shaft layout. Rope mass becomes an important factor and it is necessary to choose a rope with a high strength to mass ratio. Triangular strand ropes with plaited strand cores have the highest strength to mass ratio of all the ropes commonly used on drum winders. The use of BRangle strand cores is not favoured due to the extra mass of steel in this type of core. Round strand ropes have higher spinning loss than triangular strand ropes and so are heavier for equivalent breaking strengths. Although having relatively low spinning loss full locked coil ropes are not made with shaped wires of sufficient tensile strength and so are also heavier for a particular breaking strength.

  The choice of triangular strand ropes for deep winds is based on the same principles as for the shallow winds listed above and so is not repeated.

(5) **Rope Speed.**

Although there have been winders licensed to operate at speeds of up to 24 m/s, there are no winders currently in use which operate at such high speeds. The highest speed of wind is 19 m/s, but most winders operate at either 12, 15 or 18 m/s.

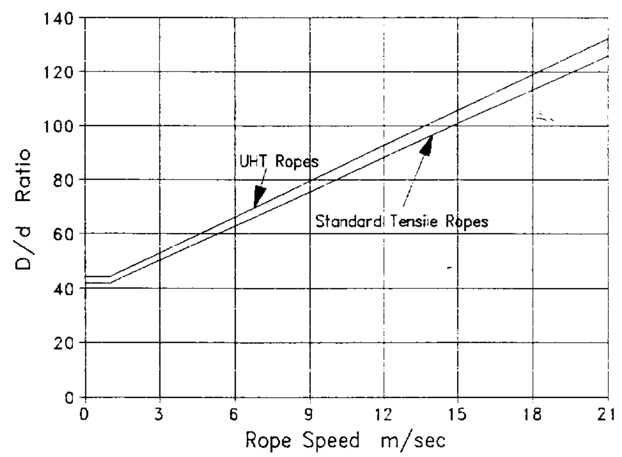


Figure 65 Recommended D/d Ratios for Triangular Strand Ropes

When a rope is bent round a sheave the wires and strands move relative to one another to equalise the stresses as far as possible. This movement is reversed when the rope leaves the sheave and continues in a straight line. Obviously a force is required to produce this movement and the more rapid the movement the greater the force. In order to counteract this effect, it is common practice to increase the sheave (or drum) to rope diameter ratio with increase in rope speed. Figure 65 shows recommended sheave to rope diameter ratios for triangular strand ropes. It should be noted that for UHT ropes the ratio is increased slightly.

Another effect of rope speed is the occurrence of rope oscillation between the drum and the headgear sheave. At very low speeds the impulses imparted to the rope at turn and layer cross-overs are small and can be neglected. However with increase in speed the impulse increases and can be sufficient to cause large oscillations of the rope, even to the extent of inducing miscoiling. A further complication is the effect of rope harmonics on the amplitude of the oscillation. It often happens that rope tensions during the wind, distance of sheave from drum and rope mass combine to create harmonic oscillations during the wind. The rope behaves like a stretched string and the formula for the vibration of a stretched string can be used with reasonable accuracy to assess the likelihood of problems arising from a particular layout. It is easier to correct this type of problem on the drawing board than later when the winder has been erected. Care should be taken to see that the impulse from turn cross-overs on the drum does not coincide with the fundamental frequency of vibration of the rope between the headgear sheave and the drum or the second or third harmonic.

The frequency of the fundamental vibrations may be found as follows:-

$$\omega = \frac{1}{2\,L_c}\sqrt{\frac{P}{m}}$$

Where
ω = Fundamental frequency (Hz)
L_c = Rope length from headgear sheave to drum (m)
P = Tension in rope (N)
m = Mass per unit length of rope (kg/m)

(6) Drums.

The design of winder drums is a subject for study in its own right. However there are several concepts relating to rope usage and performance which must be incorporated in the design if adequate rope performance is to be achieved. These are listed as follows:-

- The drum barrel must a circular cylinder or cone. If the barrel runs out of true, vibrations and stresses will be set up which will result in poor performance.
- The drum barrel must be stiff enough to ensure that the hoop stresses caused by the rope coiling on the drum do not cause sufficient deflection of the drum for some of the rope turns to become slack.
- Drum flanges must be perpendicular to the axis of rotation of the drum, especially in the case of multi-layer coiling.
- Drum flanges must be stiff enough to resist dishing due to rope forces in the case of multi-layer coiling.

Of course these are features of drum design and manufacture which are often out of the control of the rope user. Nevertheless it is important to be aware of problems which can arise from these causes.

There are other factors relating to drum design which provide considerable choice to rope users.

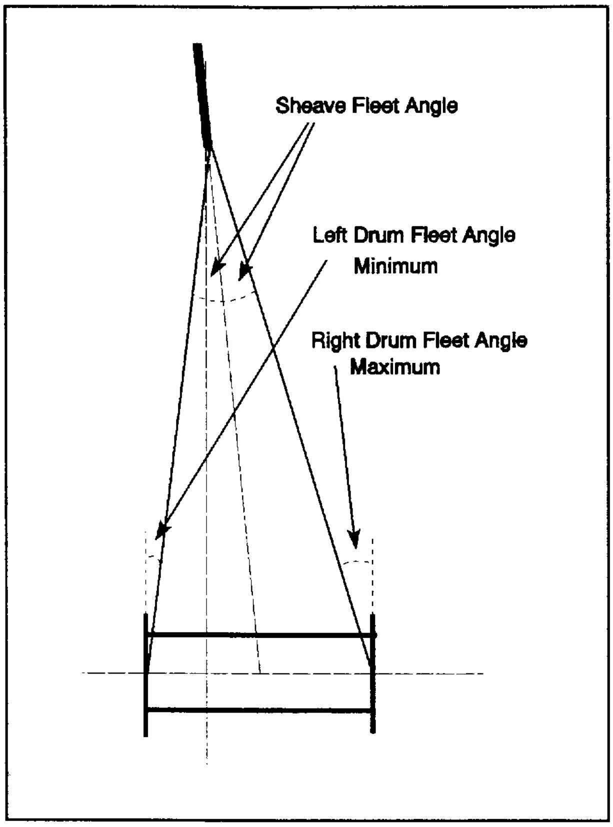


Figure 66 Fleet Angles

* **Fleet Angle.** The angle formed between the rope and the perpendicular to the drum axis is termed the fleet angle. When the rope is in contact with the flange at either extremity of the drum the angle between the rope and the flange itself is called either the maximum or minimum fleet angle. Figure 66 illustrates this concept. For high speed mine hoisting ropes the maximum fleet angle should not be more than 1°30′. The minimum fleet angle should not be less than 0°15′ with 0°30′ being the preferred figure. The danger of too small a fleet angle at the flange, is the possibility of the rope climbing on itself for part of a drum turn and then falling off with a resultant bang and impulse in the rope. Too large a fleet angle can give problems with miscoiling.

* **Plain Drums.** The simplest arrangement, and one which is often used, is to operate the rope on a plain drum. This involves careful planning of fleet angles and rope size to fit the drum. When the rope is coiled onto a parallel plain drum to form the first layer, the last turn must fit snugly against the far flange in order to avoid damage to the rope at the layer cross-over due to poor coiling. i.e the rope must just fill the bottom layer on the drum. If this does not occur naturally some arrangement must be made which ensures that it will happen every time the rope coils on the drum irrespective of speed or loading. A simple solution is to introduce mild steel rods or a strand of suitable diameter between the dead turns on the bottom layer, see Figure 67. The rod or strand should be of such diameter that the dead turns of rope on the bottom layer are spaced out to make the last turn fit snugly against the

flange. Care must be taken when deciding on the required gap, to ensure that there are sufficient dead turns which are not spaced out so that there is sufficient rope to allow for back-end and front-end cuts without interfering with the spacer.

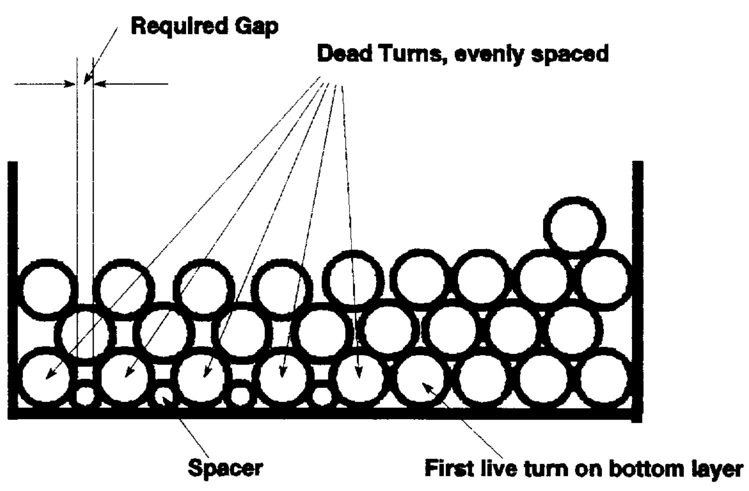


Figure 67 Spacer for Gap between Drum Turns

The theoretical diameter of spacer rod required to give a particular gap, see Figure 67, can be found from the following:

$$D_s = \frac{(d + G)^2}{4d}$$

Where

D_s = diameter of spacer (m)
d = rope diameter (m)
G = required gap between adjacent coils (m)

This method is satisfactory where the number of rope layers will not exceed three as the bottom layer turns are not regularly spaced. Poor coiling will result if this method is used for more than three layers.

When a plain drum is used it is important to select the correct hawse hole for anchoring the rope to the drum because the plain drum does not provide a definite guide to the rope. Where the perpendicular from the sheave to the drum centre line does not fall on the centre of the drum but to one side of it the hawse hole on that side should be used irrespective of the hand of lay of the rope. The number of dead turns should be arranged so that the operating turns are always beyond this point. Reference to the section on Fleet Angle which follows and Figure 66 will clarify this concept. Right hand lay rope is generally supplied and used, but if poor coiling or plucking of the outer wires occurs it may be advantageous to change to the other

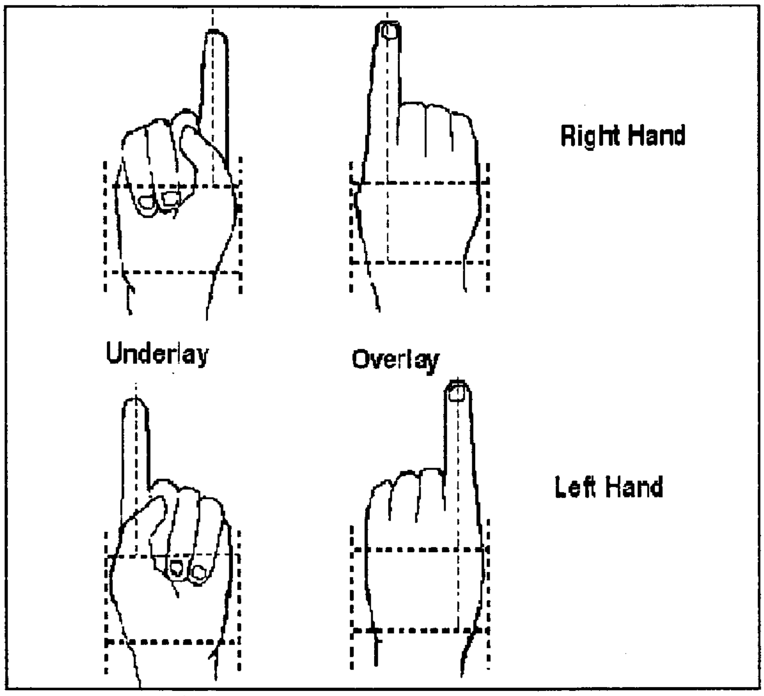


Figure 68 Method of Determining Direction of Coiling

hand of lay. If a choice needs to be made before ordering the rope then the following rule should be followed to decide on the appropriate hand of lay. Figure 68 illustrates the rule as follows:-

The left and right hands are used to represent the direction of lay of the rope and the extended index finger represents the rope leaving the drum. The flange from which the rope should coil is that adjacent to the index finger.

* **Grooved Drums.** The most positive method of controlling the coiling of rope onto the drum is by the use of grooved drums.

One of the oldest methods of grooving a drum was to merely provide parallel grooves on the drum spaced at the appropriate pitch. The depth of groove was only about 10% of the rope diameter as the rope had to climb over the ridge at each turn cross-over.
The dimensions of the parameters for groove pitch and groove diameter are shown in Figure 69.

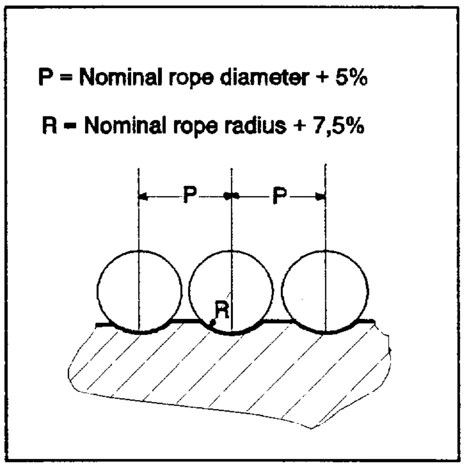


Figure 69 Dimensions of Parallel Grooving

This method works extremely well up to four layers of rope, after which coiling tends to be somewhat erratic.

Because the actual point of turn crossover is not precisely controlled, but is dependent on the actual rope diameter the coiling pattern changes as the rope beds down and wears. This feature tends to spread the localised wear at turn and layer cross-overs with positive effects on rope performance. A disadvantage of this system is the tendency for the drum grooves to wear at the cross-over points which in time become so irregular that the rope is often damaged at these places.

Where more than four layers of rope are to be used on the drum or where perfect coiling is required as on a Blair multi-rope winder then one of the patterned coiling systems should be used. The best known in South Africa is the Lebus[17] system which can provide perfect coiling for as many layers as are required. In this system the rope is guided in grooves to operate with two half cross-overs on every turn. This pattern repeats on every layer resulting in perfect coiling. Advantages and disadvantages are listed in Table XVI:-

Table XVI Advantages and Disadvantages of Lebus Coiling

Advantages	Disadvantages
Perfect repeatable coiling. Can operate on as many layers as are required. Multiple ropes can be made to coil in unison. The rope is subjected to a lower transverse impulse at the turn crossovers which can reduce rope oscillation in the catenary between the drum and the headgear sheave.	The perfect coiling means more localised wear which can result in shorter rope life. To spread the wear there is additional maintenance required such as more frequent pulling in the rope on the drum to move the parts which have been subjected to localised wear. Rope dimensions and changes in diameter due to wear or operating conditions are more critical. Usually supplied as grooved wrapper plates which have to be fitted to the drum. This system often results in loose fixing bolts which can damage the rope or the possibility of the wrapper plate becoming slack and allowing the rope to loosen on the drum which can lead to premature rope deterioration and discard.

As is often the case the advantages outweigh the disadvantages and this system is commonly used on South African winders, especially those operating at great depth.

* **Drum (or Sheave) to Rope Diameter Ratio.** Figure 65 illustrates the effect of speed on the recommended D/d ratios. Table XII, on page 86, gives recommended figures of the base D/d ratios for various rope constructions. The formula for allowing for rope speed is to be found on page 85. Of course these figures are recommendations of the rope manufacturers whose objective is to recommend parameters which will give acceptable (or expected) rope life. Most winders have parameters differing from

these recommendations and in some cases rope performance is poor where the D/d ratios are lower than recommended. There is some scepticism regarding recommended D/d ratios for speeds over 18 m/s and in these cases the ratio should be assessed in accordance with recommendations for maximum tread pressure.

* **Drum (or Sheave) Pressure.** Current practice is to assess drum (or sheave) tread pressure in terms of the projected area of the rope and not on actual contact pressure between the rope wires and drum. The formula for calculating tread pressure is as follows:-

$$p = \frac{2P}{dD}$$

Where
p = Tread pressure (Pa)
P = Tension in rope (N)
d = Rope diameter (m)
D = Drum (or sheave) diameter (m)

Recent assessment of many existing winders has established that there is a very wide variation of tread pressures from a low figure of 1,79 MPa to a high figure of 3,635 MPa for drums and 4,086 MPa for sheaves. Comparison of these figures with rope performance suggests that drum (or sheave) pressure should not exceed 3,2 MPa (neglecting the effect of overlying layers of rope).

* **Number of Layers of Rope.** A further complication related to the assessment of drum tread pressure is the effect of overlying layers of rope on the actual pressure between rope and drum and between rope and the underlying rope layer. Because there is an interaction between the rope tension and pressure the increase in pressure with number of layers is not a linear function directly proportional to number of layers. Certain winder manufacturers have empirical formulae to make some allowance but the simplest approach of choosing a maximum pressure and neglecting the effect of number of layers gives adequate results provided there are no more than 8 layers of rope on the drum. There is obviously a benefit in limiting the number of layers of rope on the drum but practical considerations of shaft depth and winder drum size have resulted in many installation operating with 6 layers.

* **Pairing of Ropes.** It is not usual for mines to order hoisting ropes to be supplied in matched lengths. Very often ropes are ordered singly to be installed with previously supplied ropes. Variations in the measuring equipment on different rope-making machines often result in ropes of differing length being supplied and installed on a particular winder. The practice of rope rationalisation where one spare set of ropes is kept for several different winders on a mine can also result in ropes of differing lengths being installed.

In practice a small discrepancy in rope lengths is not a problem, but on multi-layer winders the effect of differing rope lengths can result in considerable waste of time or alternatively spillage in the shaft. The following method can be used for determining what should be cut off to make the ropes of equal length.

Suppose after the two winding ropes have been installed on the drums of a certain winder it is found that the rope in one compartment, say A, is too short. The empty skips are run through the shaft compartments and the A skip is set accurately at the ore box underground. In this position the A drum of the winder is unclutched and the B skip is set accurately in the headgear tip. The hoist is then clutched and the A skip is moved into the tipping position in the headgear. Suppose in this position it is found that the B skip is below the position required at the ore box underground, it follows that more rope has been paid out from the B drum than has been wound on the A drum. Assume also that there are three layers of rope on the drums.

All the adjustment can then be made to the B rope without interfering with the rope in the A compartment. If one turn of rope is cut off from the outside layer of the B drum the active number of turns on this third layer of the drum is decreased by one whereas the active number of turns on the first layer is increased by one.

If D_b is the pitch circle diameter in metres of the first layer of rope and D_t is the pitch circle diameter of the third layer in metres, then the decrease in active length of rope on the third layer is πD_t whereas the increase in active length of rope on the first layer is πD_b.

Therefore the total decrease in active length of rope is $\pi D_t - \pi D_b$ for a length D_t cut off. Thus for a unit decrease in active length of rope the amount:

$$\frac{\pi D_t}{(\pi D_t - \pi D_b)} = \frac{D_t}{(D_t - D_b)}$$

must be cut off the rope

Therefore the total amount to be cut off from the rope

$$L_c = \frac{L_u D_t}{(D_t - D_b)}$$

Where

L_c = Length of rope to be cut off (m)
L_u = Distance of skip below loading box (m)
D_t = Pitch circle diameter of top layer of rope (m)
D_b = Pitch circle diameter of bottom layer of rope (m)

Similar procedures may be adopted for the pairing of ropes on bi-cylindro-conical drums.

(7) Kibble Ropes.

In shaft sinking of vertical shafts the drum winder is used to hoist buckets (called kibbles) loaded with broken-rock, men or materials. As there are no guides at the shaft bottom where the sinking is carried out the kibble must leave the guides and complete the trip to the shaft bottom with no restraint. The rope must be able to accept the change in load from zero when the kibble is detached to the maximum end load for which it is designed without spin. If there are only a few lazy turns this is satisfactory. A list of constructions which meet this requirement are as follows:-

- 18 strand non-spin 12×7(6/1)/6×7(6/1)/F Ordinary lay 1800 MPa in sizes up to 24 mm diameter. This rope construction is only suitable for use at depths not greater than 150 m.
- 14 strand non-spin 8×6/6×10(7/3$_{\Delta}$)/WMC 1800 MPa in sizes from 16 mm to 36 mm diameter. This rope construction is suitable for use to depths of 1000 m.
- 15 strand non-spin 9×6/6×10(7/3$_{\Delta}$)/WMC 1800 MPa in sizes from 25 mm to 42 mm diameter. This rope construction can be used to whatever depth is required.
- 15 strand non-spin 9×8/6×29(11/12/6$_{\Delta}$)/WMC 1800 MPa in sizes from 42 mm to 55 mm diameter. This rope construction can be used to whatever depth required.
- 18 strand "Fishback" non-spin 12×10(8/2)/6×29(11/12/6$_{\Delta}$)/WMC 1800 MPa and 1900 MPa in sizes from 44 mm to 64 mm diameter. This rope construction can be used to any required depth and has the added advantage that if required can be supplied in tensile grades up to 2000 MPa.
- Full locked coil ropes in sizes from 26 mm to 46 mm diameter. Sizes larger than this are available but could develop problems with slack outer wires. These ropes do not have as high a strength to mass ratio as stranded ropes and so are often uneconomic to use.

In all cases galvanised ropes are recommended. Because the ropes are subjected to zero loads at the shaft bottom they can slacken to the extent that water from the shaft can enter the rope and cause severe internal corrosion. The combination of the zinc layer and the rope lubricant are sufficient to prevent this, even in the case of slightly acidic water.

(8) Small Hoists.

The definition of a small hoist is 'a winding plant driven by an engine or motor developing not more than 100 kW, not used for the raising and lowering of persons and not used in a shaft where it can interfere with the operation of a licensed winder in any way'. Many of the regulations for winding plant are not applicable to small hoists. However the recommendations made in this section relate to good practice and should be appropriately applied. In many cases small hoists operate on inclines where abrasion is a major factor. In this case it is appropriate to consider the use of the 6×7(6/1)/F rope construction. The reserve strength of this construction is not very high so care must be taken to discard the rope as soon as wires tend to become slack due to wear when tension is released.

4.2.2 FRICTION HOISTING.

There are four friction hoisting systems which have been used in South Africa:-

- Koepe Winding
- Blair Stage Winder
- Elevators
- Whiting Hoists (The last of the Whiting Hoists was removed from service in the 1970's. This hoist is on exhibition at the Gold Mining Museum. The hoist operates on the principle of a double drum capstan but will not be discussed as there are none in service.)

In all cases the ratio of the rope tensions entering and leaving the drum cannot exceed the value given by the formula:-

$$\frac{T_1}{T_2} = e^{\mu\theta}$$

$$i.e. \quad \log_{10} \frac{T_1}{T_2} = 0{,}43429\mu\theta$$

Where

- T_1 = Maximum tension in rope at the drum (kN)
- T_2 = Tension in rope on other side of the drum (kN)
- e = Exponential constant (e = 2,71828...)
- μ = Coefficient of friction
- θ = Angle of wrap of rope around the driving drum (rad)

The coefficient of friction is usually accepted as being 0,1 for metal to metal contact, up to 0,2 for ropes operating on a tread material. For elevators the groove shape modifies the actual coefficient to an effective one which is somewhat larger.

(1) Koepe Winding.

This is the simplest of the friction winding systems. The rope makes approximately half a turn round the driving drum and is supported on an insert made of friction material which provides the required force to drive the system. The rope arrangement comprises a head-rope, a tail (or balance) rope and either two conveyances or a conveyance and a counterweight. More than one head-rope may be used and there are systems in the world which have as many as 10 head-ropes, however four or six head-ropes are most common in South Africa. The tail-ropes are required to balance the system. There is no necessity to have an equal number of tail-ropes as head-ropes as long as the total mass per unit length of all the tail-ropes is the same or slightly heavier than the total of all the head-ropes.

* **Layout of Winder.** Two alternative arrangements are used. A tower mounted system or a ground mounted system.

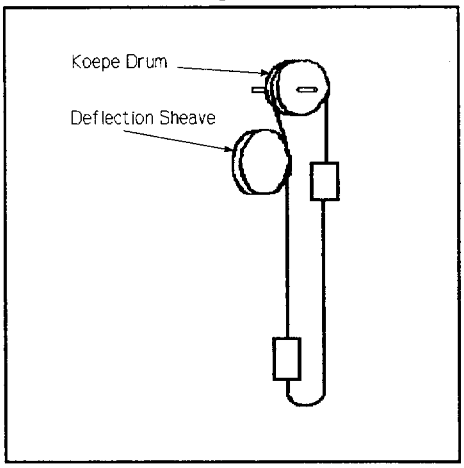


Figure 70 Tower Mounted Koepe Winder

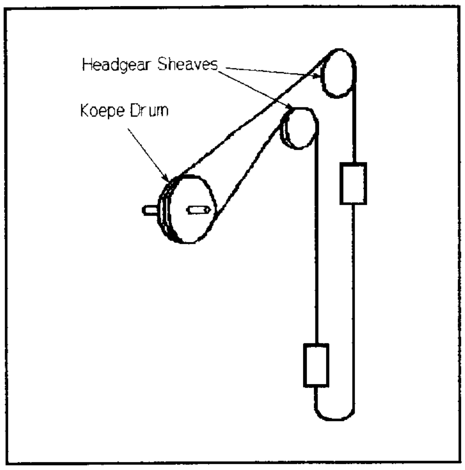


Figure 71 Ground Mounted Koepe Winder

- **Tower Mounted.** The tower mounted system, Figure 70, often incorporates a deflection sheave to align the ropes with the centre-lines of the shaft compartments. This obviously introduces additional bending of the ropes which affects rope performance. It has been found that winders with no deflection sheaves give better rope performance and so are preferred.

- **Ground Mounted.** The ground mounted system also has two arrangements; one in which the headgear sheaves are in line with the ropes and mounted one above the other, Figure 71, and the other where the headgear sheaves are mounted side by side at the same level. The latter arrangement, having the sheaves side by side, is not favoured as it introduces the complication of a permanent fleet angle which can affect rope performance. In spite of the extra bending introduced by the headgear sheaves, ground mounted Koepe winders have one definite advantage over the tower mounted ones. The layout ensures that the conveyances do not approach too closely to the winder drum and so the effect of discrepancies in tread lengths are not as critical to rope performance and tread wear.

- **Fleet Angles.** As far as possible Koepe winders should be designed and operated without fleet angles. Because of the nature of non-spin ropes even a small permanent fleet angle will cause rotation of the rope and this continuous alternating rotation often causes distortion of the rope in the form of either bird-caging or the formation of corkscrews. Two arrangements which can cause problems are the fleet angle introduced on ground mounted winders by having the headgear sheaves on the same level and also a fairly common practice of securing the ropes to the conveyance at different centres to the drum grooves or sheaves.

* **Head-ropes.** In a friction winder system each end of the head-rope is attached to a conveyance so that on every wind the rope is end for ended. The effects of this must be taken into account when choosing a rope construction.

  - **Shallow Wind.** The end for ending of the head-rope is not of great importance on shallow winds of less than 500 m as most ropes can survive the small amount of twisting that is introduced. Ordinary lay six strand round strand ropes are commonly used and even triangular strand constructions give good performance. 6×25(12/6F+6/1)/F Ordinary lay or 6×36(14/7+7/7/1)/F Ordinary lay are the preferred constructions.

    With depths of wind between 500 m and 1000 m the six strand constructions give excessive tread wear due to rotation of the rope on every trip. Simple non-spin ropes such as the 18 strand non-spin 12×7(6/1)/6×7(6/1)/F give satisfactory performance. The 15 strand "Fishback" non-spin 9×10(8/2)/6×14(8/6▵)/WMC is also a good construction for this depth.

  - **Deep Wind.** From 1000 m to 2000 m non-spin ropes having low torque characteristics should be used as head-ropes. Rope constructions such as the 18 strand "Fishback" non-spin 12×10(8/2)/6×29(11/12/6▵)/WMC or the 34 LR non-spin 16×19C(9/9/1)/6×19C(9/9/1)+6×19C(9/9/1)/6×19C(9/9/1)/WMC are suitable, but should not be expected to give outstanding performance at depths greater than 1500 m. The reason for this is the combined effect of rope fatigue at the high load range and the transfer of load from outer to inner strands due to the torque effects at these depths. An indication of the effect of the total load range on rope life is illustrated in Figure 72.[18]

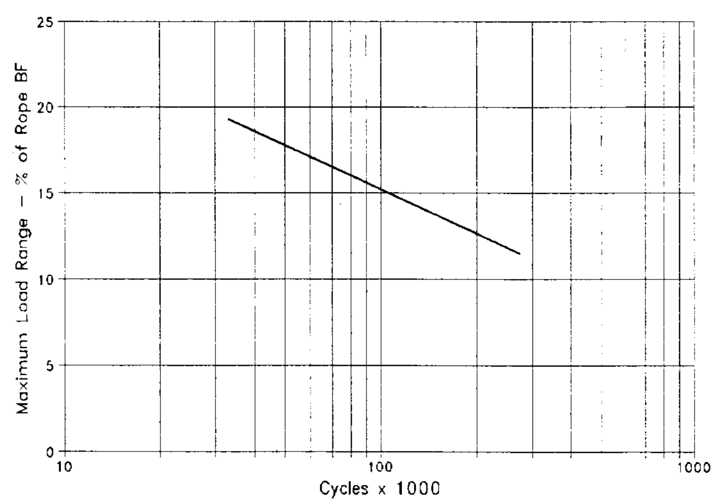


Figure 72 Relationship between Maximum Load Range and Rope Life (Based on Performance of Various Koepe Winders)

The design parameters relating to Koepe head-ropes are of significant importance. There are statutory requirements for Factor of Safety which must be complied with, but which do not necessarily provide for the most economic winder performance.

The following recommendations are listed in the Haggie Rand Ltd handbook on Mine Winding Ropes.

- **Static Factor of Safety.** On conventional drum winders it is common practice that the factor of safety is reduced somewhat with increase in depth. Although incorporated in mining regulations this is not appropriate for Koepe head ropes. Because the load range increases with depth rope fatigue is hastened at the expense of rope life. It is therefore recommended that a static factor of safety of not less than 7 be used and in general it should increase with depth, conforming with the formula:

$$s = \frac{1}{\left(2R - \frac{L_d\, g}{f}\right)}$$

Where

s = Static Factor of Safety
R = Maximum static load range (fraction of head rope breaking force)
L_d = Depth of wind (m)
f = Rope efficiency factor (Nm/kg)
g = Acceleration due to gravity (9,81 m/s^2)

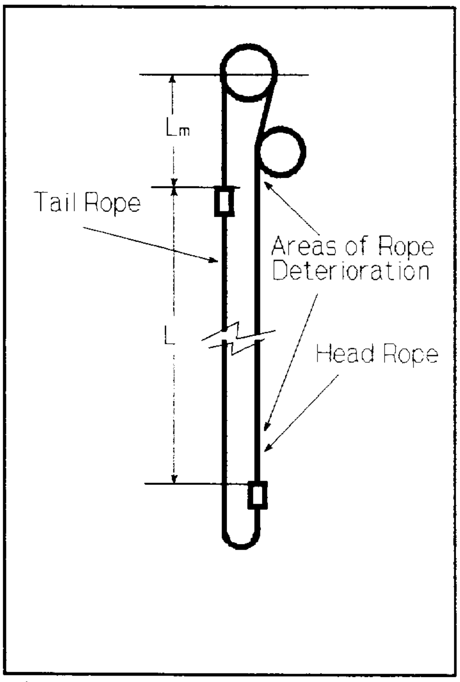


Figure 73 Regions of Deterioration

- **Static Load Range.** As mentioned above, the load range increases with depth. This load range is the change in tension in any particular part of the rope during a winding cycle and is a maximum in that portion of the rope which is at the Koepe drum at the ends of the wind. A schematic diagram illustrating the resulting deterioration pattern at discard of a typical stranded non-spin is shown in Figure 74.

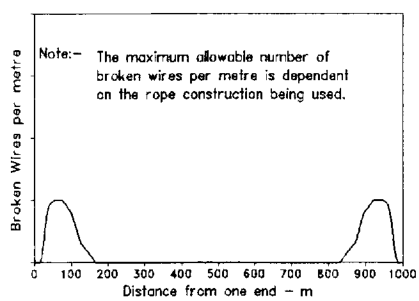


Figure 74 Schematic Illustration of Broken Wire Distribution at Discard

There is a direct relationship between this factor and rope life in service. For economic performance it is recommended that the maximum static load range should not exceed 11,5% of the estimated rope breaking force.
Formulae for calculating the maximum static load range are given below. Depending on which is the heavier, the head-ropes or the tail-ropes, the appropriate formula should be chosen, i.e. the formula which gives the greater figure should be used.

$$R = \frac{\dfrac{m\,g\,N\,L_d}{1000} + M_p}{N\,B_h}$$

or

$$R = \frac{\dfrac{m_t\,g\,N_t\,L_d}{1000} + M_p}{N\,B_h}$$

Where
B_h = Breaking strength of one head-rope (kN)
R = Maximum static load range (fraction of head-rope breaking force)
N = Number of head-ropes
N_t = Number of tail-ropes
m = Mass per metre of head-rope (kg/m)
m_t = Mass per metre of tail-rope (kg/m)
M_p = Mass of payload (t)
L_d = Depth of wind (m)

- **Dynamic Load Range.** This incorporates peak acceleration forces at the start of the wind as well as the minimum force which occurs due to rope oscillation when the empty conveyance is stopped at the loading box. These changes in force should be incorporated in the formulae for static load range to give the dynamic load range which should not exceed 15% of the estimated rope breaking force.

- **Acceleration and Deceleration.** Winder control should be smooth and even and acceleration and deceleration should be kept as low as possible. The maximum peak acceleration should not exceed 1,5 m/s^2 and changes in acceleration should not be abrupt.

- **Rope Length between Drum and Tip.** This distance, which should be as large as possible, plays a part in rope life in that it is in this section of rope that inequalities in rope length and differences in drum paths, become evident in multi-rope systems. One adverse effect is the extra load which can be applied to some of the head-ropes in an area which is subjected to the highest fatigue loading. The other and more serious effect is the reduction in load in one of the ropes to the extent that the rope could become slack and distort or slip on the winder drum tread causing excessive and uneven tread wear.

An indication of the minimum practical distance can be gained from the following formula which is based on the concept that the cumulative maximum difference in tread length should not be more than the elastic elongation of the head ropes in the length of rope between the highest tipping point and the winder drum under full load at the end of the wind.

$$L_m = \alpha \frac{y\, d^2\, L_d\, E\, s}{\pi\, D\, B_h}$$

Where

α = Maximum practical allowable difference in tread circumference between rope grooves (m) (this would normally be about 0,00046 m)

d = Rope diameter (m)

L_d = Length of wind (m)

L_m = Rope length from highest tipping point to Koepe Drum (m)

D = Drum diameter (m)

E = Apparent Modulus of Elasticity of head-rope (Pa) (117 GPa for stranded non-spin ropes)

B_h = Breaking strength of one head-rope (N)

y = Area factor for head-rope construction

s = Factor of Safety of Head-rope

- **Drum and Deflecting Sheave Diameter.** Because of problems relating to the maintenance of tread length differences a rule of thumb for assessing drum diameter is that the drum should not rotate more than 100 times when hoisting for the full depth of wind. This factor coupled with achieving the drum tread pressure allowed for the type of friction material used are the parameters for determining drum diameter. Having chosen a drum diameter the D/d ratio should be checked to see that it conforms to parameters suggested in Figure 65. As a general rule the drum diameter should not be less than 105 rope diameters for rope speeds of 15 metres per second. There should preferably be no deflecting sheave but if this is not possible its diameter should not be less than 120 rope diameters (for rope speeds of 15 metres per second) and should be spaced at least 7,5 metres from the drum at this speed. Most winder layouts are designed with the deflecting sheave the same diameter as the drum, but it is probable that there is a penalty in terms of rope life.

- **Drum Tread Pressure.** It is recommended that this be kept to below 1,72 MPa. Most rope constructions can tolerate tread pressures higher than this but consideration of tread wear is the prime concern. Recommendations of tread manufacturers should be considered before making a decision on this parameter. Tread pressure is given by the following formula:-

$$p = \frac{2P}{dD}$$

Where

p = Tread pressure (Pa)
P = Maximum Static Tension (N)
d = Rope diameter (m)
D = Drum diameter (m)

- **Drum Tread Material.** Both hard rubber and polyurethane have proved themselves to be dependable tread materials on deep level Koepe hoists. The hardness considered most effective is between 80 and 85 IRHD (International Rubber Hardness Degrees). There are many proprietary brands of tread material on the market which give excellent performance and these should be considered.

- **Permanent Rope Stretch.** When Koepe winders operate with two conveyances the effect of permanent rope stretch needs to be considered. Permanent stretch characteristics are illustrated in Figure 75. The characteristics for other rope constructions can vary being somewhat greater for six strand ropes, rather less for the 34LR construction and much less for full locked coil ropes. Adequate design of skip loading arrangements or over-run space at the top of the wind will ensure that in the initial stages of rope operation length adjustment can be done at convenient intervals.

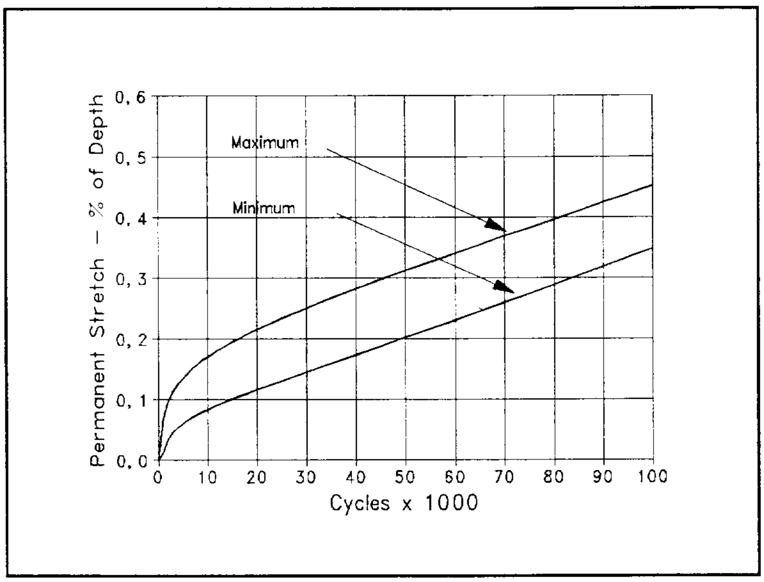


Figure 75 Expected Permanent Rope Stretch for 15 strand "Fishback" Non-spin at 11% Static Load Range

(2) Koepe Tail-ropes.

The Koepe system incorporates the use of balance ropes to reduce the requirement for frictional force at the Koepe drum. This balance is most necessary in shallow winders and becomes less critical as the depth of wind becomes deeper, where the total mass of the system increases and the T_1/T_2 ratio reduces. It is usual to arrange for the mass per metre of the tail-ropes to match that of the head-ropes or to be slightly heavier. A difference in mass of up to 5% can be beneficial from the power consumption and braking point of view if the tail-ropes are the heavier.

There are two distinct types of ropes used as tail-ropes, flat ropes and round ropes. The use of flat ropes is most usual on the continent of Europe but not in the United Kingdom. These ropes are naturally non-spin and if well made and maintained operate in a stable manner. However they are hand made by stitching several individual ropes together by means of iron wire and so are extremely expensive. Because of their shape they are prone to damage in the shaft due to spillage and other falling objects. The nature of the rope also makes it prone to corrosion and internal wear. One of the last flat balance ropes used in South Africa was on a drum winder at Robinson Deep where it fractured due to corrosion with loss of life. This is the occurrence which prompted the current regulations which require regular cutting of the rope at the end connection and the carrying out of a destructive test and examination of a sample so cut off. Since then the use of flat ropes has not been favoured in South Africa.

Round ropes on the other hand are the type generally used. The construction of rope is usually non-spin, the choice of which is dependent on the tail-rope control arrangements in the shaft. The two control systems are either to allow a free loop at the shaft bottom which is only constrained in the operating compartments or to control the rope by means of a sheave at the shaft bottom. See Table XVIII for condensed recommendations on the use of tail-ropes which are discussed as follows.

* **Free Loop.** The most generally favoured tail-rope system is that with a free loop. Most Koepe winders in South Africa operate with free looping tail-ropes. As far as is known all Koepe winders in the United Kingdom, Canada and Australia also operate with free loops, but with considerable differences in the detailed arrangements.
  The rope characteristics required for free looping tail-ropes are as follows:-
  - The rope must be inherently stable.
  - Slightly higher torque factor required than for a kibble rope.
  - Good wear resistance is required.
  - Sufficient flexibility required for the rope to form a natural loop which is less than the centre to centre distance between the anchorage points on each conveyance.
  - The rope must have good internal wear characteristics and also be corrosion resistant.
  - The external rope lubricant must not be sticky enough to cause multiple ropes to stick together in the shaft during a wind.

  The rope constructions which satisfy these requirements to the greatest extent are listed in Table XVII.

Table XVII Available Tail-rope Constructions for Free Loops

Rope Construction	Size	Minimum Loop Diameter
To depths of 1000 m		
18 strand non-spin 12×7(6/1)/6×7(6/1)/F	up to 30 mm dia.	40d
18 strand non-spin compact strand 12×7C(6/1)/6×7C(6/1)/F	up to 38 mm dia.	45d
To depths of 2000 m		
14 strand non-spin 8×6/6×10(7/3▲)/WMC	up to 36 mm dia.	76d
14 strand non-spin 8×8/6×27(9/12/6▲)/WMC	20 to 50 mm dia.	45d
15 strand non-spin 9×6/6×10(7/3▲)/WMC	up to 42 mm dia.	45d
15 strand non-spin 9×8/6×29(11/12/6▲)/WMC	42 to 65 mm dia.	39d
15 strand "Fishback" non-spin 9×10(8/2)/6×14(8/6▲)/WMC	35 to 48 mm dia.	45d
18 strand non-spin 12×16(9/6/1)/6×19(12/6/1)/F	40 to 50 mm dia.	35d
18 strand "Fishback" non-spin 12×10(8/2)/6×29(11/12/6▲)/WMC	44 to 64 mm dia.	45d

Other suitable ropes may be available on application to the rope manufacturers.

In choosing a tail-rope it is advantageous to operate with as few ropes as possible. Shaft layout, the centre to centre distance between compartments and the capability for handling heavy ropes are factors which affect the choice and these are usually the limiting factors.

Swivels. The operation of free looping tail-ropes is completely dependent on swivels except for relatively short winds in shafts which operate without any abrasive spillage or corrosive conditions. In the latter case ropes can be provided which are completely spin free and which can remain in this condition provided there is no internal wear or deterioration to affect the torque characteristics. In South Africa where shafts can have corrosive conditions and where abrasive particles are a common feature of water in the shaft this type of rope cannot be used satisfactorily.

The behaviour of a tail rope loop is dependent on the relative reaction between the rope and the swivels[19 20 21 22 23]. It is extremely important that the swivels should be as free as possible. It is recommended that the swivel design characteristics should provide a starting torque less than 27,12 Nm under 89 kN load and less than 2,7 Nm under 2,1 kN load. (i.e. Starting torque(Nm) $\leq$ 0,281 $\times$ load(kN) + 2,11).

These figures are possible to obtain and should be maintained during the life of the swivel.

Because of this interaction between the rope and swivel the tail-rope loop will be seen to move in the compartment in a regular manner. The ropes do not necessarily move in unison and may cross or touch each other at the loop.

Restraint of Loop. The movements of the tail-rope loops and the possibility of sticking swivels necessitate some type of loop control. It is recommended that the rope be protected from the shaft steelwork by timber beams lined with a low friction material so that the loop can move freely and is only restrained at the perimeters of the compartments see Figure 76. In any free loop system there is always the possibility that the reaction between the rope and swivels could cause the rope to 'figure eight' at the loop. This is a condition which could cause considerable damage to the rope and also possibly the shaft. To reduce this possibility a timber baulk should be placed at the centre of curvature of the loop and a trip wire mounted beneath it to stop the winder in the case of serious interference.

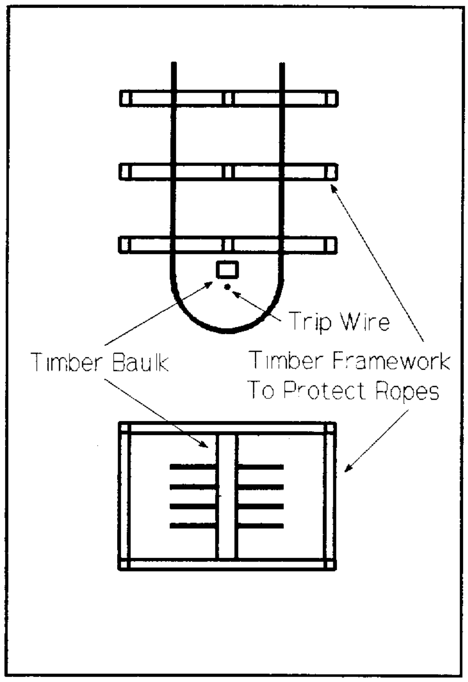


Figure 76 Control of Tail-rope Loop

The bottom of each tail-rope loop should be maintained within a range of 150 mm of each other to ensure that if ropes do wrap around each other there is no damage to the ropes. For this reason it is also recommended that the ropes should not be separated from each other by dividers or other arrangements.

Because the starting torque of swivels is proportional to the load on the swivel the control of tail-rope loops and maintenance of swivels on deep winds becomes more critical. The deepest wind on which free looping tail-ropes are used is 1500 m and in this case the centre to centre distance of the winder compartments is 118 times the tail-rope diameter. The tail-rope loops are stable in this case but there is some doubt as to what the minimum ratio should be at this depth.

* **Tail Sheave.** When the depth of wind gets very deep the expectation of problems in operating with free loops increases due to the starting torque characteristics of swivels. The solution has been to use tail sheaves to control the tail-rope loop. The use of sheaves in this position is a different proposition to the use of sheaves in other applications. The rope is bent round the sheave at a minimum load and so any misalignment is of significant importance. The tread pressure between the rope and sheave is very low but in spite of this, wear of the sheave can be extremely rapid so that groove profiles can quickly become unacceptable. Because the rope is in contact with the sheave under low tension, rope constructions which are susceptible to fatigue such as those with ribbon strands do not give good performance. The rope

constructions which have given the best performance are round strand non-spin constructions such as the 18 strand ordinary lay 12/6/F, (or 12/6/WMC) or 33 strand ordinary lay 16/11/6/F. These ropes are supplied in various strand constructions and as a general rule give good performance.

Properties which are required to achieve good performance are as follows:-

- Rope must be stable under a wide range of tensions.
- Rope must have good fatigue properties, especially under very low tensions in contact with the sheave.
- Low torque characteristics are desirable but not a necessity.
- The rope must be wear resistant, both external and internal wear must be considered.
- Good corrosion resistance is desirable.
- Rope must be robust and able to accept damage from falling object without strands coming loose, breaking or raffling.

The following rope constructions have performed well when operating with tail sheaves.

17 strand non-spin 11×19(9/9/1)/6×19(9/9/1)/WMC Ordinary lay.
18 strand non-spin 12×16(9/6/1)/6×19(12/6/1)/F Ordinary lay.
33 strand non-spin 16×7(6/1)/11×7(6/1)/6×7(6/1)/WMC Ordinary lay.

Other ropes are being considered by the manufacturers in an endeavour to avoid the occasional early rope deterioration causing premature discard.
The minimum sheave to rope diameter ratio for these ropes is 35d, this ratio has worked even at speeds as high as 18 m/s . However it is not known if this high speed could be a cause for erratic rope performance in certain winders where this minimum D/d ratio is used.

Use of Swivels. It is not recommended that ropes be operated continuously with swivels. Experience has shown that it is advantageous to install the tail-rope from the shaft bottom with the rope attached to a swivel as it is being pulled into the shaft and then operated with a swivel for the first few cycles. The swivel is then removed or locked. Thereafter the rope is operated with swivels for a few cycles at intervals of a month or two depending on the work done by the winder.

Sheave Tread Materials. Cast iron or steel sheaves tend to wear extremely rapidly due to slip between the rope and sheave during acceleration and deceleration periods. Maintenance of the metal treads has been a problem and so inserts have become a practical solution. It has been established that low friction material inserts give the best overall performance especially with respect to rope behaviour. When high friction material was used rope distortion became a problem.

* Condensed Recommendations for Tail-ropes.

Table XVIII Condensed Recommendations for the Satisfactory Operation of Tail-ropes

Item	With tail sheaves	Without tail sheaves
Rope Construction	Spinning characteristics are only important in so far as rope fatigue is concerned where the inner rope takes too much of the load. Suitable Construction 12×19(9/9/1)/6×19(9/9/1)/IWRC Ordinary lay	Good non-spinning characteristics are advantageous for shallow winds but for the deep winds a certain amount of spin is advantageous to keep swivels operating satisfactorily. Suitable Construction 8×8/6×27(9/12/6▲)/WMC
Loop to rope diameter ratio	Not less than 35:1	Not less than 45:1 (other constructions are available which allow for greater or lesser ratios)
Swivels	Swivels need not be used	Freely operating swivels are required on both ends of rope. Behaviour and stability of ropes are dependent on swivels being completely free at all times. Maximum swivel starting torque should not be more than (0,281 × load in kN + 2,11) Nm at any point in the wind.
Lubrication	Good quality rope dressing should be used	Non-tacky exterior rope dressing should be used otherwise no outer lubrication.
Maintenance	Effects of internal wear in rope should be counteracted at regular intervals by allowing the rope end to turn in direction to tighten outer strands. Swivels can be used to achieve this. Tail sheave grooves should be maintained in good condition and be machined to 10% larger than the nominal rope diameter when new rope is installed.	When more than one tail rope is used, ropes should not be divided from each other but should have a baulk through the centre of the loops. Height of loops should be maintained within 150 mm of each other.
Rope installation	Care must be taken to ensure that turn is not put into the rope during installation. The use of swivels is advantageous with certain rope constructions.	Rope connected to swivel for installation.

(3) Blair Stage Winder Ropes.

The Blair stage winder (see Figure 77) has made the use of stage ropes for deep shafts a relatively simple matter. Whereas on drum stage winders the high tension of the operating part of the ropes superimposed on the relatively untensioned rope turns still on the drum causes considerable difficulty with coiling and the tendency of the rope to pull into underlying turns on the drum, this difficulty has been overcome as the rope on the takeup reel is not much above the tension with which the rope was coiled onto the drum in manufacture.

In earlier designs the winder was equipped with a fleeting wheel designed for operation in both directions. However there were often problems with snatching, especially when lowering the stage, and the use of a double drum capstan has solved this problem. This winder is ideally suited for operating with very long ropes so the use of multiple falls of rope in sinking deep shafts is a practical undertaking. Sinking stages supported on two ropes, each with four falls, is commonplace and there have been several shafts sunk using six falls of rope.

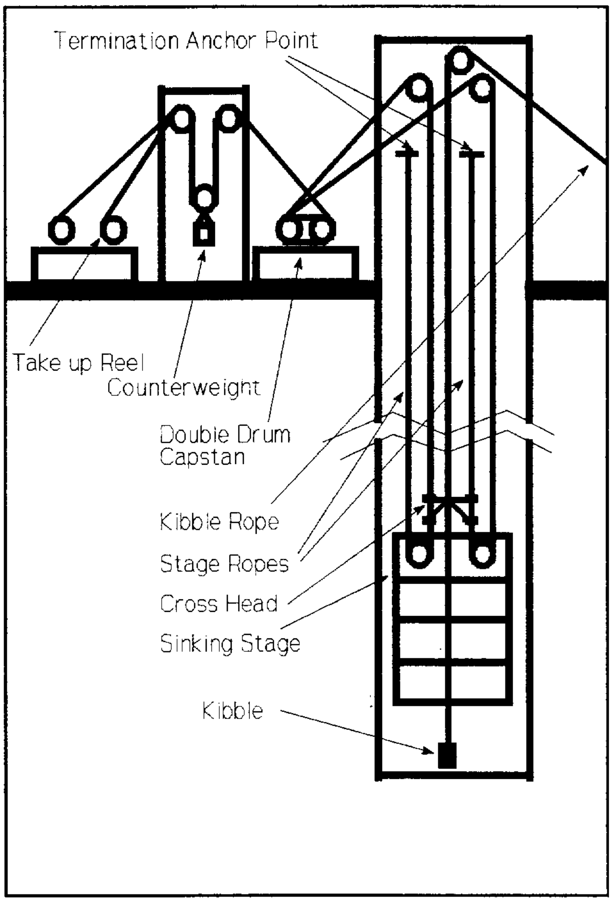


Figure 77 Schematic Arrangement of Blair Stage Winder

In theory because two ropes are used any rope construction is suitable and torque balanced by using left hand and right hand ropes of the same construction. Practical considerations have ruled out the use of six strand rope for more than two falls as the tendency to kink when the rope becomes unloaded far exceeds that of a non-spin rope. Another reason is that existing rope-making machinery, with minor modifications, is used for making the very long ropes required. Non-spin ropes have effectively become the standard for this type of winder. The following ropes are those most generally used for this application:-

- 15 strand non-spin 9×6/6×10(7/3$_{\Delta}$)/WMC 1800 MPa . This construction can be made in any length with a maximum mass of 120 tons.
- 15 strand "Fishback" non-spin 9×10(8/2)/6×14(8/6$_{\Delta}$)/WMC in tensile grades up to 2000 MPa . This construction can be made up to a mass of 160 tons.
- 18 strand "Fishback" non-spin 12×10(8/2)/6×29(11/12/6$_{\Delta}$)/WMC in tensile grades up to 2100 MPa . This construction can be made up to a mass of 160 tons and if adequate notice of an order is given to the rope manufacturer, machinery modifications can be made to allow manufacture to a maximum mass of 250 tons.
- 18 strand non-spin 12×19(9/9/1)/6×19(9/9/1)/WMC Langs lay over ordinary lay in tensile grades up to 2150 MPa . This construction can be made up to a maximum mass of 120 tons. Although this rope is relatively simple to make it has two definite disadvantages. The first is that wear characteristics are inferior to the other constructions listed due to small outer wires. The other is the necessity to use left and right hand ropes to balance the torque inherent in this construction.

(4) Elevators.

Elevators are basically friction winders which are arranged to be operated by the passenger by means of push buttons. Because there is no driver and because inspections and maintenance are done at greater intervals than for normal mine winders the operation must be fail safe. The penalty for these arrangements is the very much higher design factors (factors of safety) specified by licensing authorities. Another difference is the arrangement of the friction drum grooving which is designed for metal to metal contact.

Figure 78 illustrates various arrangements of drum grooving for enhancing the tractive force which the drum can apply. In recent times there has been an overlap between the elevator systems and the Koepe system. There are many Koepe winders which are licensed as elevators with the appropriate factors of safety and one of the elevator manufacturers has recently incorporated a plastic tread material into the drum design. The various elevator systems relate to the type of grooving used.

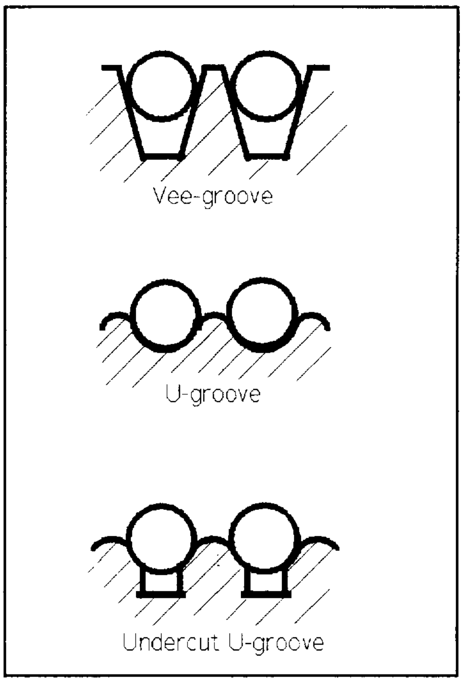


Figure 78 Types of Grooving for Elevator Drums

* **Gearless.** This machine is noted for rope speeds (up to 10 m/s) which are high for the drum diameters used and also related to traditional speeds of operation. U-grooves are used and adequate traction is achieved by using a double wrap system, see Figure 79.

  In this arrangement the double wrap is achieved by means of an idler drum. Both drums are grooved but only one drum provides the driving and braking force. The extra frictional force is achieved by the doubling of the arc of contact of the rope on the drum. This arrangement is often used when the ropes support the conveyance on two parts and usually for high speed elevators operating at winding depths in excess of 100 m .

  The most commonly used rope is the 8×19(9/9/1)/F ordinary lay with a tensile grade of 1150 MPa, although in some cases higher tensiles are used. In Europe the ropemakers have standardised the tensile strength of elevator ropes at 1600 MPa. However, elevators are operated at factors of safety in excess of 10 and the chief consideration is not primarily to reduce rope size but to achieve minimum stretch with change in load, so that there is minimal movement of the elevator car at loading stations. Because stretch is inversely proportional to steel area and directly proportional to stress in the rope the use of higher tensile steel merely increases the operating factor of safety without reducing stretch. This can in fact reduce rope life as secondary bending becomes an increasing problem with reduced load in the

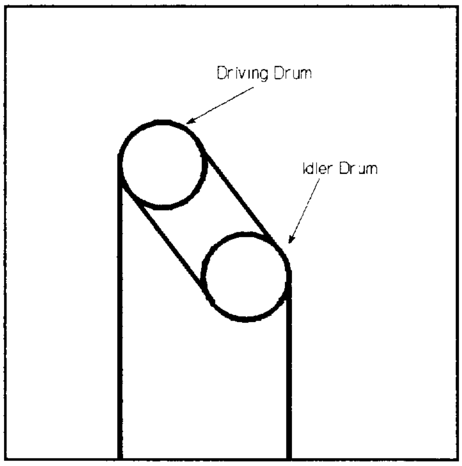


Figure 79 Arrangement of Gearless Elevator Drum

rope. In view of this the criterion for the 1150 MPa grade of steel is the requirement for limited stretch with change in load and the low carbon steel needed to avoid excessive wear of the elevator drum grooves. Nevertheless higher tensile grades are sometimes used, such as on mines where there are not such critical requirements for limiting rope stretch. In some cases ropes with an IWRC are used to reduce the stretch.

* **Traction.** With the short winds associated with elevators in buildings or in mines it is difficult to achieve adequate pay-loads when the rope is merely hung over the driving drum as in the single wrap system. The means adopted to improve the traction of the elevator is the use of specially shaped grooves. The vee-groove (see Figure 78) is not used for passenger elevators but only for material lifts such as dumb waiters. The undercut u-groove is the groove of choice and the traction provided can be modified by changing the width of the undercut with respect to the groove diameter. The rope construction most commonly used in this application is the 8×19(9/9/1)/F ordinary lay 1150 MPa tensile grade. Sometimes the 6×25(12/6F+6/1)/F or IWRC ordinary lay is used, especially if higher breaking strengths are required with some limit to the extra elongation which will occur with changes in load.

* **Governor, Compensator and Selector Ropes.** In general the ropes used for governor and compensator applications are the same as used for the hoist ropes, although the 8×25(12/6F+6/1)/F is often used for the governor. Selector ropes are not much used and are usually small diameter ropes so the 6×7(6/1)/WMC construction is usually preferred.

  Elevators which operate with compensator ropes are always equipped with tail sheaves. Special arrangements are made to ensure that these sheaves contribute to the safety of the system by means of tie down arrangements and trip switches. The chief purpose of compensator ropes is to balance the system and as for Koepe ropes there is no necessity for an equal number of head and tail ropes. There are many applications in South Africa where a single non-spin compensator rope is used to balance six head ropes. On some mines where operating speeds are fairly low a compensator chain is sometimes used.

4.2.3 SINKING ROPES.

The use of Kibble ropes has been discussed in the section on drum winder ropes and these recommendations also apply to stage ropes which are operated with a drum system. In many cases four drums are used so care must be exercised in coiling the ropes on the drum so that the ropes operate uniformly. There is some latitude for adjustment of rope lengths by clutching but this can lead to delays in the program if adjustments have to be made very often.

A most important consideration when planning kibble ropes for sinking a deep shaft is the length of rope which should be used. It has been found that if the full length of rope which is needed to complete the sinking is installed at the beginning, problems always develop in the operation of the rope. Even if it is possible to install the rope onto the drum under the operating tension there is always the problem of underlying turns of rope becoming slack, developing bird-cages and becoming damaged if the rope is not regularly retensioned with sufficient free length to allow for readjustment. On very long ropes at the beginning of sinking this is impractical and it is recommended that short ropes be installed for the initial stages of sinking and the longer ropes when a suitable depth has been reached. It is often advisable to use three sets of rope in sinking deep shafts.

4.2.4 CONDENSED RECOMMENDATIONS FOR WINDERS.

Table XIX Recommended Rope Constructions for Various Winder Applications

Type of Winder Application	Rope Construction
Small drum winder operating at less than 2,5 m/s in vertical shaft with fixed guides or incline shaft	6×19(9/9/1)/F Langs Lay. 6×13(7/6▲)/F Langs Lay.
Small drum winder operating in vertical shaft with rope guides	18 Strand Non-spin Langs Lay 12×7(6/1)/6×7(6/1)/F.
Large drum winder operating in incline shaft	Compound triangular strand Langs Lay rope having relatively large outer wire sizes.
Large drum winder operating in vertical shaft with fixed guides	Compound triangular strand Langs Lay ropes with an outer wire size of approximately 3,20 mm.
Large drum winder operating in vertical shaft with rope guides	15 Strand "Fishback" Non-spin 9×10(8/2)/6×14(8/6▲)/WMC or 18 Strand "Fishback" Non-spin 12×10(8/2)/6×29(11/12/6▲)/WMC or Full Locked Coil.
Blair multi-rope winder	Compound triangular strand Langs Lay rope
Koepe winder to depth of 500 m	6×25(12/6F+6/1)/F Ordinary Lay 6×36(14/7+7/7/1)/F Ordinary Lay or 15 Strand "Fishback" Non-spin 9×10(8/2)/6×14(8/6▲)/WMC
Koepe winder operating at depth between 500 m and 1 000 m	18 Strand Non-spin Ordinary Lay 12×7(6/1)/6×7(6/1)/F or 15 Strand "Fishback" Non-spin 9×10(8/2)/6×14(8/6▲)/WMC
Koepe winder operating at depth between 1 000 m and 2 000 m	18 Strand "Fishback" Non-spin 12×10(8/2)/6×29(11/12/6▲)/WMC or 15 Strand "Fishback" Non-spin 9×10(8/2)/6×14(8/6▲)/WMC
Sinking stage winder	14 Strand Non-spin 8×6/6×10(7/3▲)/WMC or 15 Strand Non-spin 9×6/6×10(7/3▲)/WMC or for ropes larger than 41 mm diameter 15 Strand "Fishback" Non-spin 9×10(8/2)/6×14(8/6▲)/WMC 18 Strand "Fishback" Non-spin 12×10(8/2)/6×29(11/12/6▲)/WMC (for rope mass in excess of 100 t) Sometimes triangular strand ropes are used but LH and RH ropes are required to balance rope torque.
Kibble winder. Ropes less than 42 mm diameter	15 Strand Non-spin 9×6/6×10(7/3▲)/WMC
Kibble winder with ropes 42 mm diameter and larger.	15 Strand Non-spin 9×8/6×29(11/12/6▲)/WMC 18 Strand "Fishback" Non-spin 12×10(8/2)/6×29(11/12/6▲)/WMC
Tail (or balance) rope	18 Strand Non-spin Ordinary Lay 12×7(6/1)/6×7(6/1)/F or 14 Strand Non-spin 8×8/6×27(9/12/6▲)/WMC

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APPENDIX A

LIST OF SYMBOLS USED IN FORMULAE

Note:- Symbols do not necessarily comply with international usage. They do not have exactly the same meaning in every formula. The various meanings are listed against the symbol used together with the relevant units and multiples or sub-multiples relating to the particular formula.

A	=	Area of wire (square metres) (m^2): or Metallic Area of rope (square metres) (m^2)
B	=	Required Breaking Strength of Rope (kilonewtons) (kN): or Required breaking force (kilonewtons) (kN)
B_h	=	Breaking strength of one head-rope (kilonewtons) (kN): or Breaking strength of one head-rope (Newtons) (N)
C	=	Torque factor (mm per mm of rope diameter)
D	=	Diameter of bend (metres) (m): or Sheave or Drum diameter (metres) (m): or Drum diameter (metres) (m)
D_b	=	Pitch circle diameter of bottom layer of rope (metres) (m)
D_s	=	Diameter of spacer (metres) (m)
D_t	=	Pitch circle diameter of top layer of rope (metres) (m)
d	=	Rope diameter (metres) (m)
E	=	Apparent Modulus of Elasticity of wire (pascals) (Pa): or Apparent Modulus of Elasticity of rope (pascals) (Pa): or Apparent modulus of Elasticity of head rope (pascals) (Pa) (117 GPa for stranded non-spin ropes)
E_s	=	Modulus of Elasticity of steel (pascals) (Pa)
e	=	Exponential constant (e = 2,71828...)
f	=	Efficiency factor for rope (newton metres per kilogram) (Nm/kg) (ratio of breaking force to mass per unit length of rope).
G	=	Required gap between adjacent coils (metres) (m)
g	=	Acceleration due to gravity (metres per second squared) (m/s^2) (approximately 9,8 m/s^2)
K	=	Ratio of sheave or drum diameter to rope diameter. Also shown as D/d.
L	=	Length of rope under load (metres) (m): or Length of wire under load (metres) (m): or Length of suspended rope (metres) (m)
ΔL	=	Elongation (metres) (m)
L_c	=	Rope length from headgear sheave to drum (metres) (m): or Length of rope to be cut off (metres) (m)
L_d	=	Depth of wind (metres) (m): or Length of wind (metres) (m)
L_m	=	Rope length from highest tipping point to Koepe Drum (metres) (m)
L_s	=	Rope length between sheaves (metres) (m)
L_u	=	Distance of skip below loading box (metres) (m)
M	=	Mass of loaded conveyance (tons) (t)
m	=	Mass per metre of rope (kilograms per metre) (kg/m): or Mass per unit length of rope (kilograms per metre) (kg/m): or Mass per metre of head-rope (kilograms per metre) (kg/m)
m_t	=	Mass per metre of tail-rope (kilograms per metre) (kg/m)
N	=	Number of ropes supporting end load: or Number of head-ropes

N_t	=	Number of tail-ropes
P	=	Maximum static tension (newtons) (N): or Maximum static tensile force in rope (kilonewtons) (kN): or Tension in rope (newtons) (N): or Static tension in rope (newtons) (N): or Tensile load in rope (newtons) (N): or Tension in wire (newtons) (N)
p	=	Maximum tread pressure on Koepe drum (pascals) (Pa): or Tread pressure (pascals) (Pa)
R	=	Maximum static load range (fraction of head rope breaking force)
s	=	Factor of Safety: or Static Factor of Safety: or Factor of Safety of Head-rope
s_c	=	Capacity Factor (Factor of Safety at conveyance end of rope)
T	=	Torque (newton metres) (Nm)
T_1	=	Maximum tension in rope at the drum (kilonewton) (kN)
T_2	=	Tension in rope on other side of the drum (kilonewton) (kN)
t	=	Readjustment time of 0,5 second (second) (s)
V	=	Rope speed (metres per second) (m/s)
v	=	Maximum rope speed (metres per second) (m/s)
α	=	Maximum practical allowable difference in tread circumference between rope grooves (metres) (m) (this would normally be about 0,00046 m)
β	=	Angle of incline to horizontal (degrees) (°)
δ	=	Diameter of outer wire (metres) (m)
μ	=	Coefficient of friction
σ	=	Bending stress (pascals) (Pa)
θ	=	Angle of wrap of rope around the driving drum (radians) (rad)
ω	=	Fundamental frequency (hertz) (Hz)

APPENDIX B

GLOSSARY

The purpose of this glossary is to define many words and terms used in this manual. Some have not necessarily been explained in the text.

Abrasion - That action which creates surface wear on the wires of a wire rope by the mechanical removal of particles of metal from the surface.

Acceleration - The rate of change of velocity (or speed) of a moving body. When considering a rope, acceleration when picking up or moving a load increases the tension in the rope above that due to the static load. Acceleration is commonly understood as being the rate of change of velocity which increases the velocity, whereas deceleration refers to a decrease in velocity.

Alternate lay - Lay of rope in which alternate strands have wires laid left hand and right hand.

Area; metallic - Sum of the cross-sectional areas of all the wires in a strand or rope. Usually based on the circular cross-section of each wire.

Back-end - The part of the rope that is securely fixed to the drum (of a winder or other appliance).

Backstay - Guy or guys used to support a boom or mast; section of a suspension bridge cable leading from towers to anchorage.

Basket of socket - The conical portion of a socket into which a splayed (broomed, or brushed) rope-end is inserted and then secured, usually by metalling.

Bail (socket) - The U-shaped part of a closed socket.

Becket loop -

a) The attachment on a sheave block to which the dead end of the fall or rope is made fast.

b) A loop of small strand or rope fastened to the end of a large or heavy rope to facilitate handling and anchoring the rope.

Bending stresses - The stresses imposed on the wires of a rope by bending it over a drum or sheave. These stresses are difficult to determine absolutely but are essentially proportional to the relative radius over which the rope is bent. The stresses can be estimated by means of empirical formulae. They are also considerably influenced by the rope construction and the length and type of lay.

Bight - The looped part of a rope when it is formed into a loop.

Birdcage - A springing of the wires or enlargement of a rope due to the moving of the wires or strands away from the core. This can often be caused by a sudden release of load or the massaging of slackness to a localised part of the rope. It can also result from dragging a rope over a small diameter under load.

Black rope wire - see ungalvanised wire.

Breaking force (or strength) -

a) Actual (or ultimate) - is the force required to pull a wire or rope to destruction. (Note:- It is not usual in a breaking force test to totally separate the rope but to cease pulling when one or more strands fail. The force required to pull apart the remaining strands is always less than that at the first fracture.)

b) Aggregate - is the sum of the individual breaking forces of all the wires in a strand or rope. The aggregate can either be based on the actual strength of each wire or the nominal strength.

c) Estimated - The "catalogue" strength of a strand or rope is that shown in makers catalogues or in Standard Specifications. It is usually determined from the nominal wire size and the mean tensile grade of the wire and allows for the reduction in strength from the aggregate due to the geometrical and other effects in a wire rope. It is variously called the "Estimated breaking strength", "Minimum breaking strength" or the "Guaranteed minimum breaking strength". It is the strength at or above which the rope is expected to break when tested to destruction as a single unit.

Breaking stress - The load per unit area induced in a rope, or wire at the time of failure.

Bridge cables - Galvanised steel wire ropes used for the main suspension ropes or for deck suspender ropes in a suspension bridge. Also, deck suspender ropes used in other types of bridge structures such as stayed deck or concrete arch bridges. (Sometimes used to refer to Structural Rope or Strand).

Bridge socket - Steel casting, forged or profiled steel forging with a conical basket to secure the end of a bridge rope by means of zinc, or resin, capping and with two holes to take adjustable anchor bolts.

Bronze ropes - Ropes made of bronze wire.

Cable - A term often applied to wire ropes or strands as well as to fibre ropes and electrical conductors. e.g. brake cable, aircraft control cables etc. The term has a nautical origin.

Cable laid wire rope - Name applied to a wire rope consisting of a number of individual unit ropes.

Cableway - An aerial rope conveying system used for transporting and placing loads along a track cable or rope suspended between towers, one or both of which may be movable.

Capel - Term applied to the mechanical friction device used to make the connection between a mine winding rope and the conveyance.

Catenary - The plane curve made by a rope suspended between two supports, not necessarily at the same level, or a support and a point load on a rope suspended between two supports.

Circumference - The length of the perimeter of a circle. It is an outdated term for specifying the size of a wire rope. Rope size is often determined by measuring the perimeter of the circle circumscribing a rope. However, it is specified by the diameter of this measurement.

Clamps - A pair of heavy steel or cast iron plates grooved to take two parts of rope or strand side by side and held together by one or more pairs of bolts to clamp the ropes.

Clips (strand or rope) - A fitting comprising a malleable iron or forged steel saddle piece (grooved to suit lay) and a "U" bolt used to hold two parts of rope together particularly to form a loop in a rope for an end connection.

Closed socket - See socket. A socket in which the basket and the curved bail are integral.

Closer or closing machine - The machine in which wire strands are formed (or laid up) over a core to make a completed rope. May be of the planetary or tubular type.

Coil - Circular bundle of wire, strand or rope, usually held in place with wire or strip ties - not fitted on a reel. Also refers to a length of rope supplied for a specific purpose and identified by a unique number.

Coil number - A unique number given to a length of rope for identification purposes. This number is different from the works number used by the rope-maker as several lengths of rope, each with its own coil number can be cut from a single length of rope made under a particular works order number.

Compression - The amount by which the actual diameter of a strand, or rope, differs from the sum (or calculated diameter) of the nominal wire diameters. A percentage figure is assumed, based on experience, and used in designing a rope or strand.

Construction - Term used to describe the arrangement of wires and other components which make up a particular rope. It covers the number of wires in a strand, the number of strands in a rope, the direction and type of lay as well as the type of core and any other material included in the lay up of the rope.

Constructional stretch - The non-elastic stretch which occurs when a rope is first loaded. It is due to the helically laid wires and strands creating a compressive force when loaded which compresses the core and brings all of the rope's elements into close contact.

Continuous bending - See Repeated bending.

Cord - See Small cord.

Cordage - Ropes made of vegetable fibre. e.g. jute, hemp, sisal, manila etc. Also refers to ropes made of man made fibres in a similar manner to ropes made of vegetable fibre. The term has a nautical origin.

Core - Term describing the centre unit upon which rope strands are laid up to form the finished rope. May be fibre, a wire strand, an independent wire rope or synthetic material. Also refers to the central unit of a strand which could be a wire, strand or fibre or synthetic material. A strand core wire is often called a king wire.

Corrosion - The gradual oxidation or rusting of rope wires by exposure to moisture, chemical substances etc.

Corrugated sheaves or drums - Term describing worn grooves of sheaves or drums which show the lay marks of the rope.

Counterweight rope - Rope operating a counterweight, used to provide a balancing force on a winder (or elevator) operating in a vertical shaft.

Creep (Drum) - The small amount of back (or forward) movement of a winding rope on a drum while it is being wound on to, or off, the drum after the rope tension has been reduced (or increased) due to a change in the payload. This movement occurs continuously over the length of the wind. (On drum winders this is sometimes referred to as backslip.)

Cross-over - On a drum winder, the part of the rope which crosses over another underlying coil of rope when there is more than one layer of rope on the drum. A layer cross-over is where the rope moves from one layer to the next.

Cross-over wear - Localised wear of a rope which occurs at a drum turn cross-over or a layer cross-over on a drum winder.

Cross-section - An end view of a rope, strand or wire taken at right angles to its centre line.

Cross lay - A rope or strand in which underlying strands or wires are laid in opposite directions to the covering strands or wires. This term should not be confused with "unequal lay" which is used to describe standard multiple operation strands where the wire layers are laid in the same direction but with different lay lengths.

Design factor - The ratio of the nominal strength of a rope to the total working load on that rope.
Diameter - The measurement of the straight line through the centre of the circle circumscribing the outer wires of a strand or the outer strands of a rope.
Dog-leg - Term used to describe a permanent "knuckle" or bend in a wire rope which has been deformed.
Drawn galvanised - Process where the wire is galvanised by the hot dip method and then drawn to its required size and tensile strength.
Drum - A cylindrical or conical flanged barrel of cast iron or steel on which rope is wound for storage or operation. Can also refer to the wooden or steel reel on which a rope is wound for transport and storage.
Drum turn - This is the coil of rope formed, or path travelled by the rope on the drum, in one complete revolution of the drum.
Ductility - The property of a material which enables it to be drawn into a wire. The property of a wire which allows it to be reduced to a smaller size.
Efficiency - The comparison of the actual performance to the ideal or theoretical performance. See Spinning loss, Efficiency factor, Efficiency of splice etc.
Efficiency factor - A factor used to assist in determining the required breaking force of a winding rope. It is the factor obtained by dividing the breaking force of a rope by its mass per metre. This factor is practically a constant for the range of rope sizes of a particular construction and tensile strength.
Elasticity - The ability of a rope to return to its original length after being loaded in tension and the load released.
Elastic limit - Term applied to the limit of load or stress after which permanent stretch takes place in a rope when the load is released. This limit can vary from approximately 40% to over 70% dependent on conditions to which the rope has been subjected.
Elongation - See Stretch.
End termination - The treatment at the end or ends of a length of a wire rope, usually made by forming an eye or attaching a fitting for permanently connecting the rope to the load.
Eye splice - An eye, or loop, formed with or without a thimble on the end of a wire rope by either (a) tucking strand ends under and over, or around, the strands of the main part of the rope; or (b) by swaging or pressing the one end of a rope to the main part with aluminium alloy or steel ferrule fittings. This is one method used for connecting a rope to the system in which it is being used.
Factor of safety - Term applied to the required ratio of rope breaking strength and total rope load. Normally set by Statutory bodies, such as the Department of Mineral Affairs. This term is no longer used in the USA. Design factor is used instead.
Fatigue - Term commonly applied to the progressive failure (fracture) of wires in a rope due to cracks propagating from some form of surface damage on the wire.
Fibre - A vegetable (or man made) fibre used to manufacture yarns, strands or fibre ropes for use as cores for wire ropes. The most favoured materials are the natural fibres, manila and sisal or the man made fibre produced from polypropylene.
Filler wires - Small wires used for positioning or spacing the other wires in a round strand to allow for the parallel laying up of the strand wires in one operation. Also, wires used in triangular strand cores to provide adequate support for covering wires.
Fittings - Any accessory equipment used as an attachment on a wire rope to fulfil a definite purpose.
Flat drum - See Plain drum.

Flat rope - Wire rope that is made of a series of parallel, alternating right hand lay and left hand lay ropes, sewn together with relatively soft wires.

Flattened strand ropes - Ropes made with 6 wire or 8 wire ribbon strands. (Usually non-spin ropes). A term incorrectly used to describe triangular strand ropes or ropes with elliptical strands.

Fleet angle - The angle on the plane between the centre line of the rope at the end operating wrap on either side of the drum and a line drawn at right angles to the drum centre line through the centre of the sheave nearest to the drum. Also refers to the angle the rope makes with the centre line of the sheave tread when the rope is at its greatest deflection away from the centre line.

Flexibility - A term describing the readiness with which a rope may be bent and straightened. The greater the number of wires the more flexible a rope will be. In the rope trade it is often applied to describe the ability of a rope to withstand repeated bending under load. (This approach must be used with caution as some flexible ropes do not have very good performance in bending).

Front-end - The part of a drum winder (or other appliance) hoist rope which is attached to a conveyance, or an anchor point in the case of multiple reeving with an even number of falls.

Galvanised ropes and strands - Ropes and strands made of zinc coated (galvanised) wire for protection against corrosion.

Grade - Refers to the classification of ropes by tensile strength of their wires. The grade is quoted as the minimum tensile strength (in Megapascals) of the tensile strength range quoted in the specification. In America it is still common to quote the grade in terms of the old trade terms (such as Improved Plow etc.) as American practice specifies differing tensile strength ranges for each wire size.

Grooves - Depressions cast or machined in sheaves or drum barrels to seat, support and guide the rope in operation.

Hidebound - A condition where the outer wires or strands of a rope are too large to suit the diameter and so form a tube which either collapses and deforms or is excessively stiff when bent.

Idler - Sheave or roller used to support or guide a rope.

Independent Wire Rope Core (IWRC) - A wire rope used as a core for ropes subject to:-

a. Heavy bearing pressures (High tread pressures).
b. High tensile loads.
c. High temperatures.

Inner wires - All of the wires in a strand except the outer or surface wires.

Kink - A "snarl" or partial twist in a strand or rope which has produced a bend in the rope accompanied by a disturbance of the lay. It represents irreparable damage to and an indeterminate loss of strength in the rope.

Lagging - Term used for:-

a. External timber covering on a reel of rope or strand for protection in transit and in storage.
b. Timber used to form the barrel of a drum or to increase its diameter.

Lay - Term used to denote:-

a. The act of forming wires round a supporting wire or unit to create a strand, or to form strands over a supporting unit to create a rope.
b. The direction of laying of wires and strands. i.e. LH or RH.
c. The type of laying up. That is the direction of the wires in each layer of a strand or the relative directions of the wires and strands in a rope. So an Ordinary lay rope is one in which the strands are laid in the opposite direction to the wires in the strand and a Lang's lay rope is one in which both wires and strands are laid in the same direction.
d. The pitch of the helical path into which wires or strands have been formed. See lay length.

Lay angle - The angle the strands make with the centre line of the rope or which the wires make with the centre line of the strand. Is also defined by the formula which relates the tangent of the angle to the ratio of the pitch circle circumference to the lay length.

Lay length - The pitch of the helical path into which wires or strands are formed. Usually measured over several helices to improve accuracy. It is the distance by which a strand or rope moves in a rope-making machine, as it is being formed, in one 360 degree rotation of the machine. (This is not applicable to bunchers or other machines of this type).

Lay up - To form wires into a strand or strands into a rope.

Locked coil rope - A strand which has been made with shaped outer wires which interlock to prevent a broken wire from sloughing and tangling with other parts of the system. The exterior surface is normally smooth due to the nature of the interlocking wires. There are two types, identified by the type of shaped wire used. The full locked coil is composed of a full layer of external wires which have a z or a s section. On the other hand the half locked coil has an outer layer composed of alternate round and rail shaped wires.

Martensite - A brittle micro-constituent of steel formed when the steel is heated above its critical temperature and rapidly quenched. This occurs in wire rope as a result of frictional heating and the mass cooling effect of the cold metal beneath. Martensite cracks very easily and such cracks can propagate from the surface through the entire wire.

Modulus of elasticity - Mathematical quantity expressing the ratio, within the elastic limit, between a definite range of stress on a wire rope and the corresponding unit elongation (known as strain).

Multiple operation laid strand - A strand in which at least one layer of wires has a different pitch, or lay length, to the other layer or layers of wires and is laid up in more than one stranding operation. Also known as an unequal lay strand when all layers have a different lay length. Also known as an unequal lay strand.

Nicking - Wires in the rope interior which cross one another will cut into one another to some extent. These indentations are termed nicks. The amount of nicking is dependent on various factors such as design of rope, pressure on the rope in manufacture and in service, the extent to which the wires move while in operation and other factors such as lubrication, corrosive environment etc..

Non-preformed rope - A rope in which the strands are not preshaped in the helical form they assume in the finished rope.

Non-rotating rope - See non-spin rope.

Non-spin rope - A rope of two or more layers of strands counter laid to achieve opposing torques under load and reduce the tendency of the rope to rotate under load.

Open socket - Wire rope fitting with tapered basket to contain the metalled end of the rope and fitted with two integral lugs through which a pin connection is made to the load or anchorage.

Overlay rope - A rope which comes off, or winds on to, the top of a winding drum or reel.

Parcelling - A hessian or canvass wrapping applied over a splice before applying a marline serving to protect and finish it. Normally applied with the lay.

Peening - A hammering action due to chatter over roller or sheave systems.

Plain drum - A winder drum with a parallel, ungrooved barrel.

Plastic deformation - The deformation of the surface of rope wires without loss of material.

Plastic flow - The spreading of the surface of rope wires due to slipping or skidding over sheaves, drums or metallic surfaces under load.

Plastic wear - A term often used to describe the combination of wear and plastic flow on the wires of a rope.

Postforming - A process in which the completed strand or rope is passed through a series of staggered rollers in one or more planes to set the rope and reduce stretch under load.

Preforming - The process in which the strands of a rope are pre-shaped to match the proper helical lay and set of the strands in the finished rope.

Preformed rope - A rope which has been preformed.

Prestretching - The loading of a rope to between 33% and 50% of its breaking load to remove constructional stretch and allow more accurate measuring of rope length for special purposes.

Reserve strength - The theoretical strength of a single layer rope assuming that all the outer wires in the outer strands do not contribute to the rope strength. The inner wires are assumed to be free from corrosion and serious nicking. In the case of non-spin ropes it is considered to be the strength of the outer strands assuming that all the wires of the inner strands are fractured.

Reverse bend - Term used to describe the operation of a rope over a sheave or drum system so that it bends in opposite directions.

Running rope - A moving rope which operates over sheaves. Is subjected to variable loads and is driven by a drum or friction device.

Seale construction - A strand with two layers of wires, each layer having the same number of wires. The outer layer of wires lies in the interstices formed between the underlying wires.

Seale-Warrington strand - A Strand in which the outer layer of equal sized wires is parallel laid (i.e. in one operation) with a Warrington laid centre strand.

Seize - To bind a rope or strand securely with annealed wire or strand to prevent running of the lay or unlaying of the rope when cutting. Should be done against the lay of the rope so that it tends to tighten with any tendency of the rope to unlay.

Seizing - The annealed galvanised or ungalvanised soft wire or 7 wire strand used to seize a rope.

Serve - To cover the surface of a rope with a neat and tight wrapping of wire, marline or other fibre cord. Usually to cover the ends of the tucks on a splice. Usually done with the lay of the rope.

Shackle - A forged steel U-shaped fitting with a screwed or cottered pin used to couple a load to a rope.

Sheave - A flanged pulley, grooved to support a rope in operation.

Small cord - Either ropes or single strands in sizes below 10 mm diameter used as control cables, yacht rigging and numerous similar applications.

Socket - A forged, profiled or cast steel fitting used to connect a load to a wire rope. Can be either of the open or closed type.

Spiral grooved drum - Drum on which the rope supporting groove is made in the form of a helix or spiral.

Splicing - The interweaving or tucking of two parts of rope to make the eye on the end of a rope, or to connect two ends of a rope together.

Stainless steel rope - A wire rope made from corrosion resisting steel. Usually made of 18/8 nickel-chrome steel.

Standing rope - A rope which does not run over sheaves although it can be subjected to bending. It is usually fixed in position and is not driven in any way. Guide ropes, bridge ropes etc are common standing ropes.

Strand - A number of wires in one or more layers laid round a centre wire or other material with a uniform length of lay in each layer. The wires are laid helically and may be round or shaped or a combination of both.

Strand core - See wire main core.

Stranded rope - A rope made of three or more strands as compared to a full locked coil rope which is in fact a single strand.

Strander - A machine that lays wires together helically to form a strand.

Stretch - The elongation of a rope due to load. The elongation per unit length may be proportional to the stress in the rope and this would be known as elastic stretch. If the rope has elongated permanently after loading and unloading, the stretch is known as inelastic (or permanent) stretch. See also, Constructional stretch.

Tolerance - Allowable variation in size, weight, strength or length. Generally quoted as a percentage of a nominal figure.

Underlay rope - A rope which comes off, or winds on to, the underside of a winding drum, or reel.

Unequal lay - A strand in which at least one layer of wires has a different pitch, or lay length, to the other layer or layers of wires and is laid up in more than one stranding operation. Also known as an unequal lay strand when all layers have a different lay length. Also known as a Multiple operation laid strand.

Ungalvanised wire - Wire which has not been galvanised. Otherwise known as bright or black wire.

Warrington strand - A strand laid up in one operation with the outer wires being alternately large and small in that layer. The large wires lying in the interstices of the underneath layer and the small wires lying on the crowns of the underlying wires.

Whip - Term given to the slapping or vibration set up in an operating drum winder rope by impulses imparted at drum turn intervals.

Whipping - Term often used for seizing on a rope.

Wire main core - A wire strand used as the core of a wire rope. Commonly used as a core in non-spin ropes. Sometimes referred to as a wire strand core.

APPENDIX C

LIST OF RELEVANT STANDARDS

The following is a list of International and National Standards which have some relevance to wire ropes in general and those used for mine hoisting. In South Africa winding ropes are manufactured generally in accordance with British Standards with many parameters being in excess of the requirements of the standards to ensure the best possible match between the ropes and the required application.

Note:- Standards are periodically reviewed and revised. When referring to a particular standard the latest version should always be consulted.

International Standards

ISO 00752-81	Zinc ingots.
ISO 01968-73	Ropes and cordage - Vocabulary.
ISO 02232-90	Drawn wire for general purpose non-alloy steel wire ropes.
ISO 02262-84	Rope thimbles.
ISO 02307-90	Ropes - Determination of certain physical and mechanical properties.
ISO 02408-72	Steel wire ropes for general purposes; characteristics.
ISO 02532-74	Steel wire ropes - Vocabulary.
ISO 02701-77	Drawn wire for general purpose non-alloy steel wire ropes; terms of acceptance.
ISO 03108-74	Steel wire ropes for general purposes - Determination of actual breaking load.
ISO 03154-88	Stranded wire ropes for mine hoisting - Technical delivery requirements.
ISO 03155-76	Stranded wire ropes for mine hoisting - Fibre components - Characteristics and tests.
ISO 03156-76	Stranded wire ropes for mine hoisting - Impregnating compounds, lubricants and service dressings.
ISO 03178-88	Steel wire ropes for general purposes; terms of acceptance.
ISO 03189:1-85	Sockets for ropes for general purposes. Part 1: General characteristics and conditions of acceptance.
ISO 03189:2-85	Sockets for ropes for general purposes. Part 2: Special requirements for sockets produced by forging or machined from the solid.
ISO 03189:3-85	Sockets for wire ropes - Part 3: Special requirements for sockets produced by casting.
ISO 03534-77	Steel wire ropes - Standard designations.
ISO 04101-83	Drawn steel wire for elevator ropes.
ISO 04308:1-86	Cranes - Selection of wire ropes.
ISO 04309-90	Cranes - Wire ropes - Code of practice for examination and discard.
ISO 04344-83	Steel wire ropes for lifts.

ISO 04345-88	Steel wire ropes - Fibre main cores.
ISO 04346-77	Steel wire ropes for general purposes - Lubricants: basic requirements.
ISO 05614-88	Locked coil wire ropes for mine hoisting: Technical delivery requirements.
ISO 06984-81	Unalloyed steel wires for stranded wire ropes for mine hoisting.
ISO 07531-87	Wire rope slings for general purposes - Characteristics and specifications.
ISO 07595-84	Socketing procedures for wire ropes - Molten metal socketing.
ISO 07800-84	Metallic materials - Wire: simple torsion test.
ISO 07801-84	Metallic materials - Wire: reverse bend test.
ISO 07802-83	Metallic materials - Wire: wrapping test.
ISO 07989-88	Zinc coatings for steel wire.
ISO 08369-86	Large diameter steel wire ropes.
ISO 08457-89	Steel wire rod. Part 1: Dimensions and tolerances.
ISO 08792-86	Wire rope slings - Safety criteria and inspection procedures for use.
ISO 08793-86	Steel wire ropes - Ferrule-secured eye terminations.
ISO 08794-86	Steel wire ropes - Spliced eye terminations for slings.
ISO 10092-90	High breaking load steel wire ropes - Specifications.
ISO/TR 07596-82	Socketing procedures for wire ropes - Resin socketing (Technical report).

South African Standards

SABS 0020-77	Primary zinc.
SABS 0811-74	Rope thimbles.
SABS 0812-73	Mild steel shackles.
SABS 0813-73	Clamps for wire ropes.
SABS 0935-93	Hot-dip (galvanized) zinc coatings on steel wire.

British Standards

BS 0302:1-87	Stranded steel wire ropes. Part 1. General requirements.
BS 0302:2-87	Stranded steel wire ropes. Part 2. Ropes for general purposes.
BS 0302:3-87	Stranded steel wire ropes. Part 3. Zinc coated ropes for ships.
BS 0302:4-87	Stranded steel wire ropes. Part 4. Ropes for lifts.
BS 0302:5-87	Stranded steel wire ropes. Part 5. Ropes for hauling purposes.
BS 0302:6-87	Stranded steel wire ropes. Part 6. Ropes for mine hoisting.
BS 0302:7-89	Stranded steel wire ropes. Part 7. Large diameter ropes for general purposes.
BS 0302:8-89	Stranded steel wire ropes. Part 8. Higher breaking load ropes.
BS 0463:1-58	Drop-forged sockets for wire ropes.
BS 0463:2-70	Sockets for wire ropes. Part 2. Metric units.
BS 0464-58	Thimbles for wire ropes.
BS 0525-91	Fibre cores for wire ropes.
BS 0643-70	White metal ingots for capping steel wire ropes.
BS 1290-83	Wire rope slings and sling legs for general lifting purposes.

BS 1692-71	Gin blocks.
BS 1757-86	Power-driven mobile cranes.
BS 2052-89	Ropes made from manila, sisal, hemp, cotton and coir.
BS 2763-82	Round carbon steel wire for wire ropes.
BS 2772:2-89	Iron and steel for colliery haulage and winding equipment. Part 2. Wrought steel
BS 2772:3-57	Iron and steel for colliery haulage and winding equipment.
BS 3436-86	Ingot zinc.
BS 3551-62	Alloy steel for shackles.
BS 3810:4-68	Glossary of terms used in material handling. Part 4. Terms used in connection with cranes.
BS 3810:5-71	Glossary of terms used in material handling. Part 5. Terms used in connection with lifting tackle.
BS 3810:6-73	Glossary of terms used in material handling. Part 6. Terms used in connection with pulley blocks.
BS 3810:7-73	Glossary of terms used in material handling. Part 7. Terms used in connection with aerial ropeways and cableways.
BS 3810:8-75	Glossary of terms used in material handling. Part 8. Terms used in connection with lifts, lifting platforms and inclined haulages.
BS 3876:1-90	Rope rollers, pulleys, mountings and assemblies for colliery track haulage. Part 1. Specification for parallel barrel rollers, mountings and assemblies.
BS 3876:2-90	Rope rollers, pulleys, mountings and assemblies for colliery track haulage. Part 2. Vertical spindle pulleys, mountings and assemblies.
BS 3876:5-90	Rope rollers, pulleys, mountings and assemblies for colliery track haulage. Part 5. Specification for suspended pulley assemblies and clamps.
BS 4018-66	Pulley blocks for use with wire rope for a maximum lift of 25 tonf in combination.
BS 4344-68	Pulley blocks for use with synthetic fibre ropes.
BS 4429-87	Rigging screws and turnbuckles for general engineering, lifting purposes and pipe hanger applications.
BS 4445-89	Design and construction of electric hoists for both passengers and materials.
BS 4545-70	Mechanical testing of steel wire.
BS 4854-72	Cars for manriding in mines.
BS 4878-73	Large (vee-throated) haulage rope pulleys for mines and quarries.
BS 5281-75	Ferrule-secured eye terminations for wire ropes.
BS 5744-79	Safe use of cranes (overhead/underhung) travelling and goliath cranes, high pedestal and portal jib dockside cranes and others.
BS 6166:1-86	Lifting slings. Part 1.
BS 6166:2-86	Lifting slings. Part 2.
BS 6166:3-88	Lifting slings. Part 3. Guide to selection and safe use of lifting slings for multi-purposes.
BS 6210-83	The safe use of wire rope slings for general lifting purposes.

BS 6570-86	The selection, care and maintenance of steel wire ropes.
BS 6994-88	Steel shackles for lifting and general engineering purposes: grade M(4).
BS 7035-89	Socketing of stranded steel wire ropes.
BS 7166-89	Wedge and socket anchorages for wire ropes.
BS 7167-90	Bordeaux connections.
BS CP 3010-72	Code of practice for safe use of cranes (mobile cranes, tower cranes and derrick cranes).
NCB 175-68	Wire ropes for mineral haulage and manriding.
NCB 176-68	Stranded wire ropes for winding.
NCB 186-70	Locked coil winding ropes.
NCB 366-68	Round strand wire ropes for mineral haulage.
NCB 367-68	Triangular strand wire ropes for mineral haulage.
NCB 368-68	Wire ropes for manriding haulage.
NCB 388-70	Half-locked coil guide ropes.
NCB 465-65	Sockets for use with white metal cappings.

German Standards

DIN 00741-72	Clips for free ends of wire ropes; to meet requirements of minor importance.
DIN 01142-75	Clips for free ends of wire ropes; to meet safety requirements.
DIN 01548-79	Zinc coating on round steel wires.
DIN 02078-78	Steel wires for wire ropes.
DIN 03051:1-72	Steel wire ropes, characteristics; survey.
DIN 03051:2-72	Steel wire ropes, characteristics; types of ropes, terminology.
DIN 03051:3-72	Steel wire ropes, characteristics; calculation, factors.
DIN 03051:4-72	Steel wire ropes, characteristics; technical terms of delivery.
DIN 03055-72	Steel wire ropes; round strand rope 6 × 7.
DIN 03056-72	Steel wire ropes; round strand rope 8 × 7.
DIN 03057-72	Steel wire ropes; round strand rope 6 × 19 Filler.
DIN 03058-72	Steel wire ropes; round strand rope 6 × 19 Seale.
DIN 03059-72	Steel wire ropes; round strand rope 6 × 19 Warrington.
DIN 03060-72	Steel wire ropes; round strand rope 6 × 19 Standard.
DIN 03061-72	Steel wire ropes; round strand rope 8 × 19 Filler.
DIN 03062-73	Steel wire ropes; round strand rope 8 × 19 Seale.
DIN 03063-73	Steel wire ropes; round strand rope 8 × 19 Warrington.
DIN 03064-72	Steel wire ropes; round strand rope 6 × 36 Warrington-Seale.
DIN 03066-72	Steel wire ropes; round strand rope 6 × 37 Standard.
DIN 03067-72	Steel wire ropes; round strand rope 8 × 36 Warrington-Seale.
DIN 03069-72	Steel wire ropes; spiral round strand rope 18 × 7, non-rotating.
DIN 03070-72	Steel wire ropes; oval strand rope 10 × 10, non-rotating.
DIN 03071-72	Steel wire ropes; spiral round strand rope 36 × 7, non-rotating.
DIN 03078-82	Steel wires for winding ropes and for working platforms.
DIN 03088-76	Wire rope slings for attaching loads to hooks.
DIN 03090-77	Thimbles; shaped steel thimbles for wire ropes.
DIN 03091-76	Thimbles; solid thimbles for wire ropes.
DIN 03092-79	Metal socketing of wire ropes; safety requirements and testing.
DIN 03094-78	Reel for wire ropes.

DIN 03095	Steel wire ropes - Flemish eye with steel ferrule.
DIN 05881:1-79	Petroleum industry; wire ropes and rope reeving; wire ropes.
DIN 05881:2-79	Petroleum industry; wire ropes and rope reeving; rope reeving.
DIN 06890-64	Wire ropes; technical terms of delivery.
DIN 06891-60	Wire ropes; terminology.
DIN 15020:1-74	Lifting appliances; basic principles for rope reeving components; computation and design.
DIN 15020:2-74	Lifting appliances; basic principles for rope reeving components; maintenance in service.
DIN 15021-79	Lifting appliances; capacities.
DIN 15315-69	Lifts; cable joints.
DIN 15060-64	Wire rope slings for attaching loads to crane hooks.
DIN 17140:1-83	Wire rod for cold drawing.
DIN 21186-75	Lifting rope assembly for shaft sinking operations.
DIN 21251-65	Winding ropes; round ropes made of wires of equal nominal diameters.
DIN 21252-65	Winding ropes; flat type.
DIN 21254-80	Winding ropes, special ropes for working platforms; technical delivery requirements, stranded wire ropes and flat ropes.
DIN 21255-65	Winding ropes; round ropes; Warrington type.
DIN 21256-77	Balance ropes for mining; flat type.
DIN 21258-86	Impregnation agents and lubricants for Koepe pulley winding ropes.
DIN 51201-61	Testing of wire rope.
DIN 51210:1-76	Testing of metallic materials; tensile test on wires without extensometer measurement.
DIN 51210:2-76	Testing of metallic materials; tensile test on wires with extensometer measurement.
DIN 51211-78	Testing of metals: reverse bend testing of wire.
DIN 51212-78	Testing of metals: torsion testing of wires.
DIN 51213-70	Testing of metallic coatings of wires; coatings out of tin or zinc.
DIN 51215-75	Testing of metallic materials: wrapping test for wires; directives.
DIN 59110-62	Steel wire rod: dimensions, permissable variations, weight.
DIN 82236-63	Rope sheaves for wire ropes.
DIN 83313-63	Wire rope sockets.
DIN 83318-59	Splices for wire ropes.

Canadian Standards

CSA G0004-76	Steel wire ropes for general purpose and for mine hoisting and mine haulage.
CSA G0004M-77	Steel wire ropes for general purpose and for mine hoisting and mine haulage.

American Standards

ANSI M11.1-80	Wire rope for mines.

API 9A-84	Wire rope.
AS 1394-84	Round steel wire for ropes.
AS 1426-73	Steel wire ropes for mines.
AS 1656-74	Steel wire ropes (other than for mining purposes).
AS 1666-76	Wire rope slings.
AS 2759-85	Steel wire rope - application guide.
AS MBI-68	SAA steel wire rope manual.
ASTM A0318-56	Tension testing of steel wire.
ASTM A0641-89	Zinc coated carbon steel wire.
ASTM A0641M-84	Zinc-coated (galvanised) carbon steel wire (metric).
ASTM A0853-85	Steel wire, carbon, for general use.
ASTM B0006-83	Zinc (slab zinc).
ASTM E0558-83	Torsion testing of wire.
Fed RR-S-550D-80	Sockets, wire rope.
Fed RR-W-410D-84	Wire rope and strand.

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