Safety in Mines Research Advisory Committee

Literature Survey on Anti-Vibration Gloves

Final Report

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EXECUTIVE SUMMARY

Anti-vibration gloves are used to reduce the vibration exposure of workers using vibratory tools. In this survey, the possible application of anti-vibration gloves to reduce hand-arm vibration exposure of workers, in particular rock drill operators, in the South African mining industry was investigated. Hand-Arm Vibration Syndrome (HAVS) is a compensable occupational disease caused by excessive exposure to vibration and the first cases of HAVS have recently been diagnosed in South Africa.

An extensive literature survey produced only one article on the effectiveness of anti-vibration gloves to prevent the symptoms associated with HAVS despite a large number of anti-vibration gloves being commercially available. On the other hand, there are a number of articles identifying difficulties with ISO 10819, the standard defining how to test and qualify anti-vibration gloves. These difficulties include the control over the orientation of the adaptor plate inside the glove used to measure the vibration, resonance of the handle, the grip and push forces, as well as difficulties in meeting the strict tolerances on the input vibration spectrum. A number of alternative testing procedures are proposed and verified.

A list of commercially available anti-vibration gloves is included.

It is concluded that at this time commercially available anti-vibration gloves are not a suitable intervention to prevent HAVS in the SA mining industry because anti-vibration gloves in general do not attenuate vibration below 100 Hz. However, if the other steps currently available to reduce vibration exposure are not reasonably practical then it consideration may be given to developing an anti-vibration glove suitable for the underground environment. If these gloves are introduced into the workplace then it is imperative to conduct a pilot study, including an epidemiological study, to prove the effectiveness of the gloves.

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LIST OF SYMBOLS

BS	British Standards Institution
CEN	The European Committee of Standardisation
dB	Decibel
g	Gravitational acceleration constant (9,8 m/s^2)
Hz	Hertz
ISO	International Organisation for Standardisation
N	Newton
rms	Root mean square value

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1. Introduction

Prolonged exposure to vibration affects the human body in many different ways. Diseases in the hand and arm area due to exposure to vibration are fast becoming a serious concern, especially in the mining industry. The main health risk associated with vibration exposure, HAVS (Hand-Arm Vibration Syndrome) is a compensable occupational disease according to the Compensation for Occupational Injuries and Diseases Act, Act 130 of 1993. Different measures have been implemented to eradicate vibration-induced diseases but with very marginal success. The acceptable hand-arm vibration level in European countries is typically 2,5 m/s^2. In a study done by Van Niekerk et. al. (1998), the averaged acceleration level of rock drills in the South African mines was measured to be as high as 24 m/s^2. This level of vibration is almost ten times higher than the European action level and the mining industry has realised that this problem needs to be addressed.

In the past, HAVS was first diagnosed in quarry workers and later in foundry workers and power saw operators. In these industries, a number of improvements have been made to both the tools and the working environment to reduce the exposure of the workers with an accompanying decline in the number of reported cases of HAVS.

In a recent epidemiological study, (Nyantumbu et. al. 2002), the first cases of HAVS in South African rock drill operators were diagnosed. The prevalence of HAVS in the exposed group was 15% of whom 8% had both neurological and vascular symptoms, 5% had only neurological and 2% only vascular symptoms. This prevalence is less than that found in other studies abroad, or expected from the high vibration levels to which rock drill operators are exposed. One of the possible reasons for this may be the warm working environment in the gold mine studied. The mean wet bulb temperature in the stopes was 28.6^{o}C.

The use of anti-vibration gloves is one possible solution to lower the vibration levels that are transmitted to the hand and arm area of operators using vibrating equipment. These gloves provide anti-vibration material in the finger and palm areas to absorb the vibration energy from the machine in order to lower the level of vibration reaching the operator's hand. The effective use of the gloves should be evaluated as an economical means of reducing vibration, as a form of personal protection.

The purpose of this literature survey is to investigate the possible effectiveness of anti-vibration gloves to reduce the risk of hand-arm vibration exposure in the South African mining industry.

After an overview of the general effects of hand-arm vibration and hand-arm vibration syndrome (HAVS) and possible mitigation measures, the general principles of anti-vibration gloves are introduced. The applicable standards, and especially those relevant to the testing of anti-vibration gloves, are discussed. A list of commercially available anti-vibration gloves is provided followed by recommendations and conclusions.

2. Hand Arm Vibration Syndrome (HAVS)

Hand-arm vibration is defined as a “local vibration” referring to vibration entering the body through the hand and palm areas (Griffin, 1990: p 531). This vibration is caused by vibrating tool handles that transmit vibration to the hand and affects the fingers, hands, elbows and shoulders. A rock drill is an example of a tool that produces very high vibration levels. The operator’s fingers grip the handle while the palm area is used to apply a force to the drill. Dangerous levels of vibration are transmitted from the handle into the hand and forearm areas during the operation of a rock drill.

Epidemiological studies have revealed that millions of workers are exposed to hand-transmitted vibrations when operating power tools in various industrial applications (Thomas, 1998). The exposure to vibration causes diseases that have negative influences on both the effectiveness and productivity of the workers (Griffin, 1990). The first cases of HAVS have recently been diagnosed in South Africa, (Nyantumbu et. al. 2002).

2.2 Human Response to vibration

Extended periods of exposure to high vibration levels can cause several serious health hazards and cause discomfort to the worker. Vascular and non-vascular effects arise in persons that operate vibrating machinery (Griffin, 1990).

- Vascular diseases.

Vibration White Finger Disease also known as, Hand-arm Vibration Syndrome (HAVS) or Traumatic Vasospastic Disease (TVD), is one of the diseases associated with hand-arm vibration exposure. Blood vessels in the fingers contract due to over exposure to vibration, limiting the blood flow to the finger tips. A discoloration in the finger tips occurs, turning them white. Hence the term vibration white finger. This blanching may be triggered by exposure to cold and may occur away from the work environment. Warming the hands may return circulation of blood through the fingers causing an intense red flush to the fingers accompanied by painful throbbing, (Guild et. al., 2001). The parts of the hand that are affected tend to have no sensation of pain or any sensitivity to heat, cold, or touch and this lack of sensitivity can be very dangerous in a working environment.

HAVS has been described in several countries and in a variety of different industries.

In the USA, it is estimated that between two and four million workers are exposed to hand-arm vibration in their working environment. Symptoms associated with HAVS will develop in 50% of these workers at some stage during the time that they operate vibration machinery (Reynolds, 1999).

Jackleg and stoper operators showed symptoms of episodic blanching of the middle three fingers after an average exposure of seven and a half years (Brubaker et al. 1986).

In the most severe cases, blood circulation is permanently impaired and the fingers may become dark and blue-black in appearance. In extreme cases, the fingers can become ulcerated and even gangrenous due to inadequate circulation, (Franz & Phillips, 2001).

- Non-vascular diseases

Acute injuries such as bone and joint disorders occur at lower frequencies of vibration or high magnitudes of shock. Pain is experienced in the joints of the hand, elbow or shoulder.

Neurological disorders are associated with the diminishing of finger sensitivity. The first symptom is a tingling in the fingers and is more noticeable straight after exposure to vibration, numbness of the fingers may accompany the tingling, (Franz & Phillips, 2001).

HAVS can mimic the symptoms associated with Carpal Tunnel Syndrome (CTS). CST is the experience of pain caused by compression of the median nerve that gives sensation to the thumb, middle and ring fingers. The carpal tunnel is a small opening in the wrist through which all the tendons of the fingers pass and swelling of the tendons will pinch the median nerve, causing pain. Bending of the wrist while gripping with the fingers may also cause pain in the hands.

Muscle weakness, particularly in the middle finger and diminishing of grip strength is also associated with long-term exposure to vibration, (Neckling, 2002). Directly exposed hand muscles are more likely to be weakened by prolonged vibration exposure than the muscles in the forearm, leading to the lowering of both grip and punch strength of the hands.

For more information on this subject consult the SIMRAC Handbook on Health and Safety (Franz & Phillips 2001)

3. Mitigation of hand-arm vibration exposure

A number of different approaches exist to reduce the vibration exposure of workers using vibratory tools:

- Reduction of the exposure time, i.e. the time the workers use the tools and proper training in the use of the tools
- Redesign of the tools, reducing the vibration levels of the tools
- Change of tool or work methods and/or procedures to reduce vibration exposure
- Remote operation of vibratory tools
- Personal protection in the form of anti-vibration gloves

The problem can be defined as excessive vibration exposure, i.e. vibration levels with an amplitude and frequency range sufficient to affect persons exposed over a period of time. The vibration levels can cause discomfort and ultimately lead to the onset of vibration induced symptoms in the hands and arms of operators. Since it is a dose dependent effect both the level of vibration as well as the time of exposure can be controlled to reduce the overall risk.

3.1 Reduction of exposure time and training

Workers need to be well informed regarding the risk and hazards involved when operating vibrating power tools. Management should ensure that all employees are properly informed regarding the risks, safe practices and diseases associated with the use of vibration machines.

Machines of older design, sometimes with high vibration outputs are being used in many applications. Convincing both employers and employees to replace these machines with newer, safer, machines may prove to be a sensitive issue. Employers may be slow to see the benefits of replacing older machines with new designs. Employees may prefer to use machines and tools with which they are familiar.

3.2 Reduction of vibration levels

Examples of the methods that may be employed for prevention of hand-arm vibration syndrome are the modification of the tool and/or tool handles to reduce the vibration levels. These prevention methods focus on the reduction of the vibration in such a way that either vibration is completely prevented from reaching the hand, or the vibration that does act on the hand and arm is minimised.

De Souza, (1993) conducted a study regarding the use of a cushioned handle for jackleg rock drills, and found that it reduced the vibration levels reaching the hand by a factor of three. The cushioning in the handle is achieved by manufacturing it from an elastomer material, and the vibration level was compared to that of a steel handle.

Tudor, (1996) discussed the development of an ergonomic handle for a string trimmer that would be more comfortable for the operator to use. The handle is slightly curved, has a foam surface and is also longer than the previously used version or D shaped handles. The newly designed handle effectively reduced vibration levels to an acceptable level, and resulted in a vast improvement in comfort, grip, fatigue reduction and grip strength.

3.3 Redesign of tools

Tools that are designed efficiently to ensure lower vibration intensity transmission can reduce the risk of developing vibration diseases. Greenslade et al. (1997) proved this by showing that chainsaws used by Finnish lumberjacks, after being redesigned, reduced the transmitted vibration levels from 14 m/s^2 to 2 m/s^2. The prevalence of Vibration White Finger Disease was reduced from 40% to 5% and numbness in the hands decreased from 78% to 28%, in the period from 1972 to 1990. This is an indication of the effectiveness of redesigning certain aspects of machinery to improve the quality of the operator's working circumstances, hence reducing the possibilities of injuries and vibration induced diseases.

3.4 SIMRAC Projects

In South Africa, SIMRAC has funded research into the design of a vibration attenuating handle for rock drills (GAP 634).

SIMRAC has also developed a quiet, self thrusting rock drill which completely isolates the operator from vibration produced by the rock drill (GAP 642). The amount of noise to which the operator is exposed, is also reduced.

4. Anti-Vibration Gloves

The use of gloves may be an economical and effective way of reducing the level of vibration exposure that affects the hand and arm. Current legislation in SA determines that personal protection, such as anti-vibration gloves, may only be used as a last resort to protect workers from occupational hazards. Anti-vibration gloves are usually lined with special materials that are intended to attenuate the vibration from the source prior to reaching the hand, (Bendall, 1997). The principal of operation is to introduce a compliant layer between the vibrating tool and the hand to decouple the hand from the tool. The vibration attenuating material is placed in the palm of the glove and in some designs also incorporates a lining inside the fingers. The vibration reduction is limited by the practical restrictions imposed by the thickness and softness of the lining material. Normally anti-vibration gloves should provide some degree of protection against vibration at frequencies from 100 Hz up to 600 Hz, but in some cases a reduction at lower frequencies may also be possible.

It is very important to note that anti-vibration gloves may not completely prevent the wearer from developing HAVS, they merely extend the vibration exposure time that it will take for the operator to develop the disease. The reason for this is that, at most, the gloves will reduce the level of vibration that the worker is exposed to and not remove the vibration altogether. The difference in vibration levels produced by various tools and different machines will have an influence on the efficiency of the gloves. The vibration isolation performance of a glove is tool or excitation spectrum specific (Dong et al 2002). Bendall (1997) designed a checklist that can be used as a reference guide when purchasing anti-vibration gloves (see Appendix B). It should be considered that the application and efficiency of gloves will differ from industry to industry and only the use of the correct type of glove, that needs to be matched to the frequency spectrum of the vibration, will effectively slow the onset of vibration-induced diseases.

The versatility of gloves might prove to be a considerable additional benefit as they are easy to implement in current working environments, providing protection to the operator without requiring any modification to the equipment.

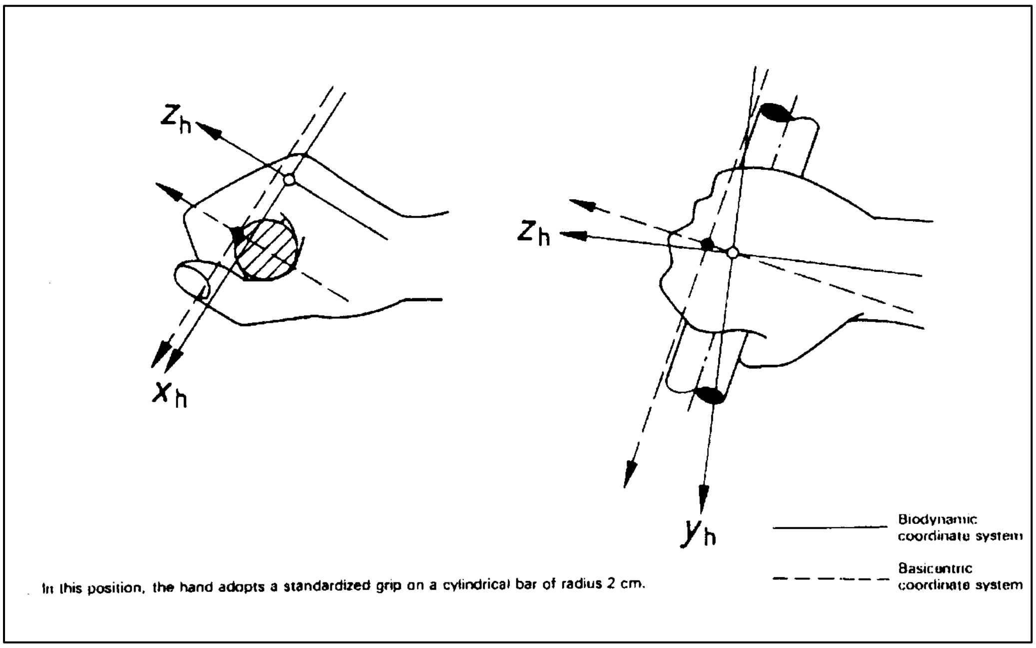
4.1 Effects of hand forces

The push and grip forces produced during operation of equipment are major factors that affect the vibration levels that reach the hand. Any increase in these forces will also have an increasing effect on the vibration intensity that will reach the hand. Hartung et al. (1993) studied the effects that the coupling between the hand and the handle of the vibrating tools has on the stresses to which the hand-arm system is exposed. The results indicated that an increase in the grip and push forces from 12 to 100 N enhanced the biodynamic responses in two ways:

? At frequencies above 20 Hz, the transmission factor increased considerably. As the coupling intensity increases, the peak transmission between the hand and the handle shifts towards higher frequencies.

? An increase of the intensity at the wrist was considerable when the vibration was in the z- and y-axes (directions as described in ISO 5349, Figure1), while excitations along the x-axis showed no increase in intensity at the wrist.

Intensity in the elbow was considerably less that in the wrist and in the shoulder it was less.



In this position, the hand adopts a standardized grip on a cylindrical bar of radius 2 cm.

Figure 1: Coordinate system for hand-arm vibration. (ISO 5349)

Mital (1999), reported that when the operator is wearing gloves, a fraction of the forces generated by the muscular contractions directed at maintaining the grip may result in reduced grip force on the handle. He also reported a reduction of 20 % in the grip force and 30 % in strength when gloves were used. A peak torque exertion when using hand tools such as wrenches and screwdrivers increased with the use of gloves. A reduction in the transmission of vibration energy, while wearing gloves, was found.

Externally applied high surface pressure on the fingers may cause painful compression of nerves and blood vessels, and is a contributing factor for vibration induced white finger. Björing et al. (2002) studied the influence of this pressure level on the hand using an electric hand drill. Factors such as the feed force, vibration, horizontal and vertical drilling, high or low centre of gravity, handle softness and handle width were varied. The results indicated that the total pressure in the hand significantly increased when the feeding force increased. This level was significantly decreased when gloves or covered handles were used and it was found that vibration using a narrow or wide handle did not increase the total pressure level.

Chang et al. (1999) studied the effects of wearing gloves and wrist support when using an in-line pneumatic screwdriver. Cotton, nylon and open finger gloves were tested as well as the wearing or not wearing of wrist support. The nylon glove reduced the triggering force by 18,2% with low forearm exertion and reduced the vibration by 15% in the multi axes. With wrist support, it was found that a greater triggering force was needed and that more vibration was transmitted. Hertzog (1973) reported a reduction in grip strength when gloves were worn.

4.2 Evaluation of anti-vibration gloves and materials

Bingham et al. (1992) evaluated commercial anti-vibration gloves and normal gloves fitted with sponge rubber cushions, to determine the vibration transmittance of these gloves. The vibration was generated using an electrodynamic shaker over a frequency range of 2,5 to 1000 Hz, with an acceleration of 2,5g rms. An ISO isolation index system was used, and bare hands were recorded with a value of 33 while with gloves the range was 10 to 14. The results indicated that the gloves isolated a significant amount of the vibration, but that there were no significant differences between the different gloves tested. Bingham further recommended the wearing of gloves when vibrating machinery is operated.

A new glove designed and tested by Reynolds (1999), uses a thin layer of air to isolate the hand from vibration. The glove was tested according to ISO standards and showed significant reduction in the vibration levels of high and low frequency ranges. It was compared to other anti-vibration gloves (Gelfôm, Sorbothane, Viscolas and Akton), and was the only glove to meet all the requirements of the ISO standard for anti-vibration gloves, ISO 10819. The air bladder is thin and flexible giving the operator more dexterity and sensitivity when wearing the gloves. The air bladder gloves are also more comfortable to wear than gloves with a thicker padding.

In the South African mining industry it has been found in past studies, by Vosloo et al. (1975), that gloves that are not ergonomically designed are uncomfortable to wear, and therefore not used by the mineworkers. No research on the use of anti-vibration gloves in the South African mining industry has been reported to date.

Gloves tested at the Health and Safety Laboratory, UK (Stevenson & Corbishley 1997) elicited some complaints from the workers who wore them. The gloves affected dexterity and caused excessive sweating of the hands. There were also complaints of aches and pains in the hands due to the extra force required to hold tools in place while wearing the gloves. When evaluating gloves, the acceptability to the workers and the possible medical problems that may arise from excessive sweating need to be considered.

4.3 Effectiveness of anti-vibration gloves to reduce the risk of HAVS

Very few references on the effectiveness of anti-vibration gloves are available. In a recent three-year study by Jetzer, et al. (2003), a number of workers in the roofing tile industry, who are exposed to hand-arm vibration and among whom symptoms of HAVS have been previously diagnosed, were followed to determine the effectiveness of anti-vibration gloves, as well as other ergonomic interventions used to reduce the risk of hand-arm vibration exposure. The conclusion from this study is that personal protective equipment can be as effective as job modification in arresting the progress of HAVS. The best results were obtained where both the level of vibration exposure was reduced and the workers used anti-vibration gloves while using vibratory tools.

The lack of literature on the effectiveness of anti-vibration gloves makes it very difficult to judge whether the use of these gloves is in fact effective.

5. Standards

There are a number of international and national standards that govern hand-arm vibration measurement. The measurement and assessment of hand-arm vibration is specified in ISO 5349 (2001). In this revised standard, a number of changes have been introduced that will, in general, lead to an increase in the overall estimated hand-arm vibration values compared to the values specified in the previous, 1987, version.

ISO 5349 (2001), MECHANICAL VIBRATION - GUIDELINES FOR THE MEASUREMENT AND THE ASSESSMENT OF HUMAN EXPOSURE TO HAND-TRANSMITTED VIBRATION

> *This standard covers guidelines for the evaluation of hand-transmitted vibration in terms of frequency-weighted measured acceleration and daily exposure time. The standard specifies general methods for measuring hand-transmitted vibration exposure in the three orthogonal axes. A frequency range from 5Hz to about 1000Hz is covered. However, the standard offers limited guidance regarding safe vibration exposure limits.*

ISO 10819 (1996) are used in the evaluation of different kinds of gloves in order to determine the transmissibility properties of the gloves and whether or not they can be classified as anti-vibration gloves.

ISO 10819 (1996), MECHANICAL VIBRATION AND SHOCK – HAND-ARM VIBRATION – METHOD FOR THE MEASUREMENT AND EVALUATION OF THE VIBRATION TRANSMISSIBILITY OF GLOVES AT THE PALM OF THE HAND

> *This standard covers the laboratory measurement, data analysis and the reporting of vibration transmissibility of anti-vibration gloves. The standard involves the measurement of vibration transmission from a handle to the palm of the hand using a suitably designed adapter. The standard can be used as a screening test for the anti-vibration gloves.*

Standards are guidelines that should be used to determine the details of the measurement procedure, the evaluation and interpretation of data collected and the assessment of the values. Standards are set to assist with testing procedures to ensure that the data that are collected are accurate and repeatable. They also define the assessment procedures, so making the comparison of data collected at different locations feasible.

In BS 1651 (1986) the design features of industrial gloves are defined and these features should be incorporated into anti-vibration gloves to offer the best possible protection for the workers.

BS 1651 (1986) BRITISH STANDARD SPECIFICATION FOR INDUSTRIAL GLOVES

> *This standard specifies materials, manufacturing details and performance requirements for gloves that afford protection to the hands for manual operations, common to the industrial workplace.*

6. Testing Procedures

The human hand is a complex system enabling a range of movements and dexterity. Furthermore, grip strength and push force is difficult to estimate and keep constant. These complexities make the measurement of hand-arm vibration in a glove a challenging task. The type of sensors used, placement of sensors, attachment, etc. all influence the measurement, reliability and repeatability of the results.

In this review only ISO 10819(1996), the standard dealing with the testing of anti-vibration gloves, will be dealt with in more detail.

6.1 Testing of AV Gloves according to ISO 10819

The specified testing of anti-vibration gloves makes use of a special handle, designed to measure both the feed force as well as the grip strength. These forces have to be kept within predetermined limits and the grip and feed forces are continuously monitored to indicate to the subject if the grip force needs to be adjusted. A small adaptor fitted with an accelerometer is placed into the palm of the subject's hand, inside the glove, to measure the vibration at the interface between the hand and the glove. The adaptor is first used on a bare hand and then placed between the glove that is tested and the hand. An electro-dynamic shaker provides the excitation, and two different tests are performed: one for each of the different frequency ranges as specified by the standard. Figure 2 shows a drawing of the test handle and the suggested position of the sensors.

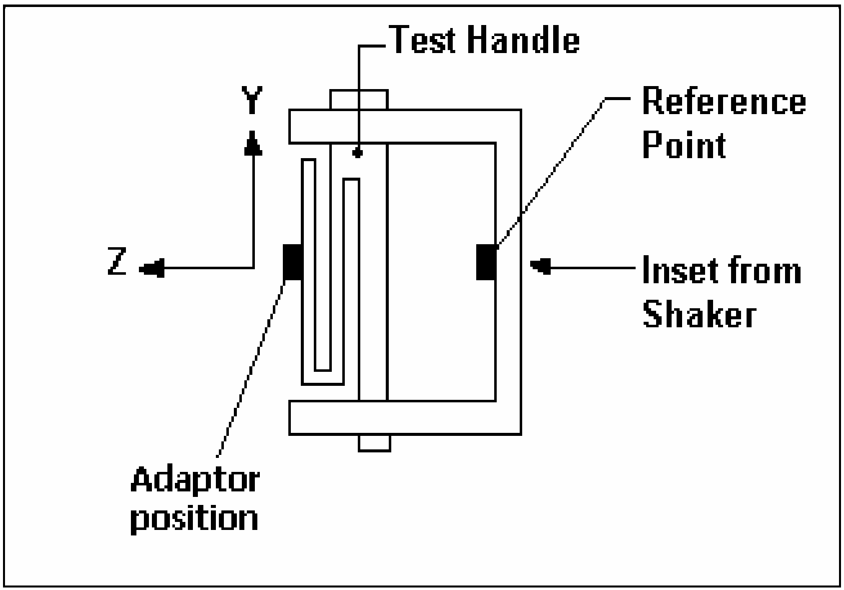


Figure 2: Test handle with placement of sensors (ISO 10819, 1996)

The posture of the operator could affect the level of vibration transmitted to the hand since a change in the posture may cause instability, which in turn will lead to the operator gripping the vibrating tool handle with a different grip force. Therefore the standard suggests the appropriate orientation of the body. The correct body posture for the test is standing in an upright position, with the forearm held horizontally. The direction of the forearm should be in the primary direction of excitation. The elbow is not allowed to touch the body, and the lower and upper arms must form a right angle with each other. The wrist should be held in line with the arm but if any discomfort is felt, the wrist can be bent in a slightly upward direction.

The handle is set perpendicular to the direction of maximum vibration of the shaker, see Figure 3.

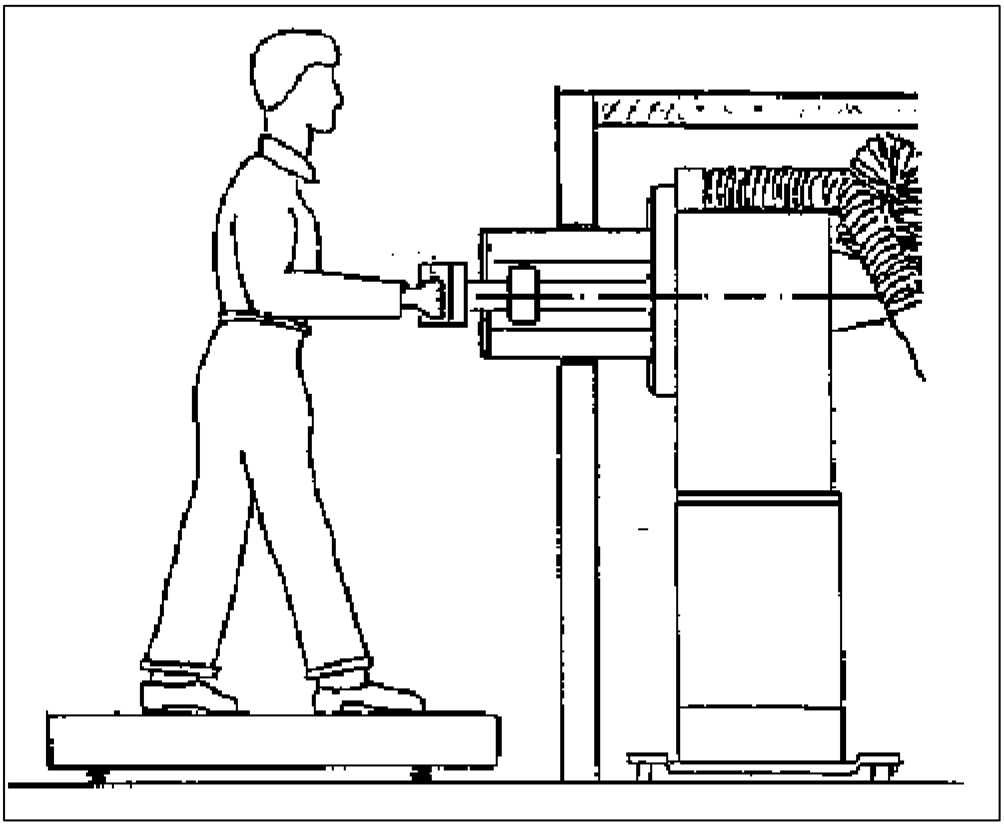


Figure 3: Operator's posture and handle direction (ISO 10819, 1996).

The transmissibility is determined by a comparison of the data from the bare hand test to that of a gloved hand test. A glove will be considered as an anti-vibration glove if the transmissibility of the glove is less than 1 for the frequency range 0-400 Hz, and less than 0,6 for the frequency range 300-1600 Hz.

6.2 New testing methods and sensors

To test gloves for their anti-vibration protection, strict conditions and specialised equipment are needed and this leads to a very expensive testing procedure. Voss (1996) describes a material test, where the resilient materials used for the manufacturing of anti-vibration gloves are tested according to ISO 13753. ISO 10068 describes the impedance of the human hand-arm system and was used, in conjunction with ISO 13753 tests, to determine the transmissibility of the materials as if loaded with the human hand. If a material does not pass this material test it will not pass the anti-vibration glove test. However, good results in the materials test do not necessarily ensure good results in the glove test since many other factors such as the fitting and sewing pattern of the glove will influence the performance of the material.

Hewitt (1996) highlights some of the difficulties associated with testing according to ISO 10819. These include implementing the testing procedure because of the very narrow tolerances required for the frequency spectra of the input vibration, the fact that both feed and grip forces have to be measured and two separate tests have to be performed for the two different frequency ranges. The author describes a modified test that uses the same equipment but is easier to conduct and the results provide more useful information on the differences between gloves for the prospective buyer. The differences in the modified test are that only the feed force (and not the grip force) is monitored, simplifying the test handle, the tolerances on the input vibration spectrum are wider and all frequencies are tested simultaneously. It should be mentioned that the proposed test method still has some of the limitations of the standard method, e.g. the vibration is still measured in the palm of the hand and not on the fingers.

Further problems with ISO 10819, are the possible misalignment of the adaptor used to measure the vibration inside the glove and the dynamic characteristics of the special handle to conduct these tests with. These add to the errors encountered when implementing this test method. Dong et al. (2002) developed a method that is based on the total effective acceleration transmissibility, this minimises errors resulting from misalignment of the adaptor. The authors also concluded that the majority of the measurement errors are caused by the misalignment of the adaptor.

It was also found by Thomas et al. (1998) that the frequency-weighting filter specified by ISO 5349 does not consider any amplification by the hand-arm system and does not reflect the vibration measurements taken directly at the wrist. The new frequency weighting suggested is an increase in the factor between 8 and 31,5 Hz by 5 dB and a decrease in the weighting by 10 dB per octave for frequencies above 31,5 Hz. It should be noted that tests were performed only on grinders and a small number of subjects participated in the tests.

It is not only the testing procedures that are being debated, but also the measuring equipment. As stated by Dong & Rakheja et al 2002, the adaptor adds errors to measurements and an unknown is the contact between the adaptor and the handle. Burström et al. (1998) studied four different methods for measurement and designs for hand held adaptors. A final adaptor design is described consisting of four force transducers and piezo-electric accelerometers. This design will simplify field measurements on hand held power tools and will add to the knowledge of the different vibration exposures associated with these tools.

Problems encountered in implementing the set of standards included resonances produced in the split handle and it was mentioned that a solid handle would significantly reduce this resonance problem. It was also mentioned that the tolerances set on the frequency spectra that are to be measured seemed unnecessarily high. Misalignment of the palm sensor causes inconsistency in the results obtained and yet no mention is made in the standard regarding the importance of the alignment of the sensor.

A new test is proposed that has advantages over the standard test in the sense that the performance of the gloves can be estimated for a given vibration signal rather than merely measuring whether or not a glove has sufficient anti-vibration properties. The new test will have wider tolerances for the vibration input and only the feed force will be monitored to reduce resonance and all frequencies will be tested simultaneously.

Dong et. al. 2002 proposed a new test method for anti-vibration gloves, based upon the total effective acceleration transmissibility (TEAT). One of their major conclusions was that misalignment of the adaptor and non-axial source vibration could result in errors in the measurements and the new system aims to minimise these errors. Therefore, three different gloves were tested under predominantly axial vibration using the proposed method and the procedure in ISO 10819 (1996).

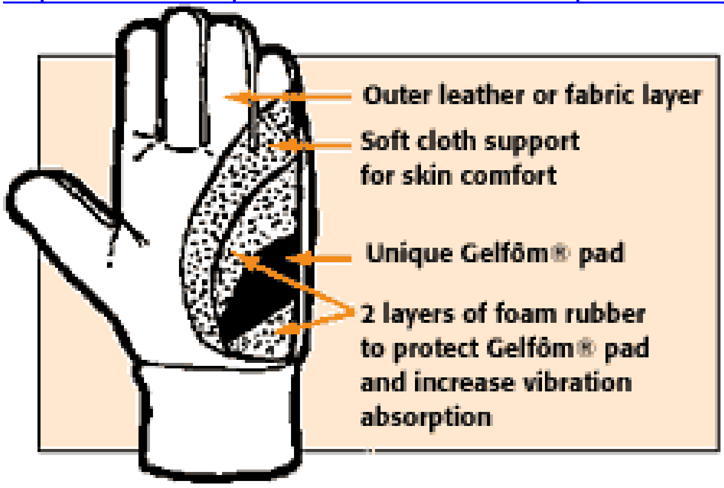
The tests used one male subject and a vibration exciter. The orientation of the adapter was changed in each test and the transmissibility of the gloves determined in both a medium and high frequency range for each change of the adaptor. The effectiveness of the TEAT is evident in the reduction of measurement errors, resulting from misalignment of the adaptor in the palm of the hand. Vibration transmissibility measured on the bare hand using standard methods, results in values smaller than one as the misalignment of the adaptor increases.

7. Commercially Available Anti-Vibration Gloves

This is a list of only some of the anti-vibration gloves available on the market; the list typically gives only one example of the types of materials used in the production of anti-vibration gloves.

Gelfôm®

http://www.deltaplus.fr/GB/matieres/composites.html



Gelfôm® is a viscous-elastic material that can be used in anti-vibration gloves to qualify them as such as defined by ISO 10819.

Sylomer®

http://www.yachtacoustics.com/AcousticMaterials/specs_flex.htm

Sylomer® is a another viscous-elastic material, which consists of polyurethane foam (Elastomer) with a half open-cell structure that is used in the manufacture of anti-vibration gloves

ElasticSupports.com

http://elasticsupports.com/anglov.html

The gloves consist of Gelfôm® shock absorbing pads in the palm and fingers of the hand. The gloves are made of pigskin leather for good dexterity and have elastic cuffs. The padding helps in controlling blistering on the palm and fingers Bolton thumb insets provide a more natural fit and Kevlar stitching is used to create burst proof seams. Full finger style features fluted fingers.

Viscolas Incorporated

http://www.viscolas.com/handgrip/handgrip.html

Viscolas® is a viscous-elastic polymer with a rubber-like feel, originally developed for orthopaedic use. The Viscolas® material in the gloves helps to reduce tool vibration and provides shock absorption. The gloves are made of Lycra®, with Viscolas® palms. Half finger style gloves are available. These gloves are ideal for hand-held vibrating pneumatic and impact tools.

MAGID

VISCOLAS™ and SORBOTHANE™ PALM PADDING gloves
http://www.magidglove.com/product.asp?dept%5Fid=262&pf%5Fid=421

A half-finger glove with Viscolas™ indside the palm. All gloves are made of leather for better durability and longer wear. Viscolas™ is a lighter material than Sorbothane™.

Sorbothane™ is an unique viscous-elastic polymer which when used as a vibration damping material, exhibits a much lower sensitivity to change in temperature and frequency. The material absorbs the energy and turns it into heat dispersing it. After compression, it returns to its original shape.

Hatch Anti-Vibration Gloves

Heavy Duty Gloves
http://www.seniorshops.com/heavdutpadgl.html

AKTON® viscous-elastic soft polymer, which feels like a gel, but is stable are used to absorb the vibration.

Full-finger dual Velcro system with Akton® Gel Pads to absorb the vibration impact, the gel covers the entire palm and extends into all digits. Adjustable wrist wraps stabilizes the wrist and locks out debris. Made of cowhide with breathable nylon backs.

R.J. Safety Co. Inc

Ergodyne® ProFlex® Anti-Vibration Gloves
http://www.rjsafety.com/GL44a.html

NU202 polymer vibration absorbing material is used in a ISO 10819 certified, full-finger glove made of pigskin leather palm and fingers with breathable, padded stretch spandex. The fingertips are reinforced and the gloves provide extra venting in a PVC shell with a buckle closure and pull on tab.

Ergo Tech

Ergodyne Proflex 9002 Anti-Vibration Gloves
http://www.ergo-tech.ca/gloves_industrial.html

Nu202 polymer vibration absorbing material, located in the palm, thumb and fingers past the last joint of the digit are used in a ISO 10819 certified full-finger glove.

8. Conclusion and Recommendations

From the literature and product information it is clear that there are a number of products available that are claimed to be “anti-vibration” gloves. Some of these gloves, when tested according to ISO 10819, do in fact qualify to be sold as anti-vibration gloves. However, there are some proven reservations regarding the validity of the testing procedures according to this standard, mainly due to the complexity of the testing procedure and the equipment involved. There is also a lack of published studies on the effectiveness of anti-vibration gloves to reduce the risk of HAVS.

It can therefore be concluded that, at this time, it is not possible to claim conclusively that anti-vibration gloves are in fact a suitable intervention to prevent HAVS among South African mineworkers.

An aspect relevant to the SA mining environment, and rock drill operators in particular, is that the primary percussion frequency is generally below 50 Hz, and frequently below 30 Hz. Most commercial gloves do not attenuate the vibration below 50 Hz and in fact only become effective above 100 Hz.

The following recommendations may be considered:

- Currently available anti-vibration gloves cannot be used as a measure to reduce the vibration exposure of rock drill operators until their effectiveness are frequencies below 50 Hz have been proven.
- A prerequisite prior to using anti-vibration gloves is to reduce the vibration exposure levels by:
  - Eliminating the use of tools that expose workers to high levels of vibration.
  - Procuring tools with lower levels of vibration
  - Reducing the actual exposure time of operators
  - Investigating the use of anti-vibration handles
  - Rotating operators of vibratory tools to other jobs with little or no vibration exposure

However, if none of the above measures are reasonably practical, and the exposure to high levels of hand-arm vibration exposure continue to be the norm in the SA mining industry, development of an anti-vibration glove, suitable for SA underground conditions, could be considered. The vibration isolation performance of anti-vibration gloves is tool specific (Dong, 2002). A suitable glove should be designed to attenuate frequencies below 50 Hz, even as low as 20 Hz, if possible, and should be made of materials capable of surviving the harsh underground environment. In addition, the problems associated with the wearing of anti-vibration gloves in the work place need to be evaluated. Dexterity and grip strength may be diminished. Excessive sweating may lead to skin problems. The materials from which the gloves are made must not give rise to allergies. The overall acceptability of gloves by the workers needs to be determined. After establishing the efficacy and acceptability of purpose designed gloves, a pilot study to introduce such anti-vibration gloves would be necessary to measure the cost effectiveness of the intervention strategy.

Mine management, engineering and occupational health professionals should continue to be vigilant of the dangers associated with hand-arm vibration and institute regular surveillance programmes to monitor the vibration exposure levels and identify workers with symptoms associated with HAVS.

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Appendix B: Anti-vibration glove Checklist (Bendall, 1997)

- List the tools that contribute significantly to vibration exposure
- Estimate reduction in vibration needed to reduce exposure below action levels
- Other information from supplier about glove performance
- Find glove tests when available
- Check gloves for CE mark
- Make sure gloves are suitable for the tools to be used
- Be aware of manufacturers recommendations for glove usage
- Check if gloves are acceptable to employees
- Check if tools can be accurately controlled when wearing the gloves
- Confirm other glove characteristics

Appendix C: Abstracts of References

Bendall, A.W., (1997).
Anti-vibration gloves explained.
Foundry Trade Journal
Volume171 No. 3526

OBJECTIVE
A description of an anti-vibration glove and what the term means, to assist the industry to understand what protection is given by these gloves. The author also highlights the fact that wearing gloves does not stop the occurrence of vibration diseases, but only prolongs the exposure time.

METHOD
A checklist is given for prospective buyers to assist in the purchasing of the correct glove, for a specific application and machine.

Bingham, M.D., Suggs, C.W., Abrams, C.F., (1992)
Vibration Attenuation of Cushioned Gloves
Applied Engineering in Agriculture volume 8(1), pp 4-8

OBJECTIVE
The study was done to test various glove designs, both commercially available models and some models of the authors' own design, for vibration isolation characteristics.

METHOD
The gloves included standard cotton and leatherwork gloves, leather gloves marked as special vibration absorbent gloves and cotton gloves with added foam rubber padding of different thickness.
Ten subjects (male and female) with varying body size were subjected to vibration white noise. Subjects gripped a T-shaped handle excited between 2,5 and 1000 Hz at an acceleration of 2,45 m/s^2 rms. The thickness of the cushion material in the gloves varied between 3 to 10 mm.

RESULTS
Wearing gloves while operating vibrating machinery can be helpful in reducing the amount of energy absorbed by the hands. It was found that softer padding would not lower the isolation because of the spring constant not being high enough to prevent the foam from collapsing when gripped.
It is recommended that gloves be worn when operating vibration-inducing machinery.

Björing, G., Johansson, L., Hägg, G.M., (2002).
Surface pressure in the hand when holding a drilling machine under different drilling conditions.
International Journal of Industrial Ergonomics
Volume 29, pp.255-261.

OBJECTIVES
The influence of different factors on the surface pressure of the hand while performing simulated drilling tasks on impact drilling machines was studied.

METHOD
Pressure was measured at 16 different points on the palm and fingers of the hand, the grip strength and the feed force were continuously measured and displayed to indicate deviations from a target value. Six male and six females were used in the study, each performed 16 sessions with the drilling machine.

RESULTS
The pressure in the middle of the palm was low in all situations and highest on the distal part of the web between the thumb and index finger. A supporting handle, gloves and compressible rubber on the handle decreased the total pressure level.

Chang C.H.,Wang M.J., Lin S.C., (1999)
Evaluating the effects of wearing gloves and wrist support on hand-arm response while operating an in-line pneumatic screwdriver.
International Journal of Industrial Ergonomics
Volume 24, pp 473-481

OBJECTIVE
Evaluate the effects of wearing gloves and wrist support on operating an in-line pneumatic screwdriver by investigating hand-arm response, including triggering finger exertion, force arm flexor digitorum EMG, and hand-transmitted vibration.

METHOD
Thirteen male students, none with experience in operation of a power screwdriver, were part of the study. An in-line pneumatic screwdriver, run at 700rpm with an air pressure of 6 kg/cm^2, was used in the experiment. Three types of gloves were evaluated: a cotton, nylon and an open finger glove. The wrist support was an adjustable neoprene type support.

RESULTS
Wearing a wrist support required greater triggering force than when not wearing the wrist support, but no difference was found in the flexor digitorum for wearing or not wearing the wrist support. A significant influence on hand-transmitted vibration was observed when wearing the support.
Wearing a thick glove reduces the flexibility and dexterity of the trigger finger and a loss in grip strength was found. The use of gloves can have a damping effect and hence effectively reduce the vibration exposure.

De Souza E.M., Moore T.N., (1993).
Field performance evaluation of rock drill handle design.
Mining Engineering.
Volume45 Number11 pp.1402-1405.

OBJECTIVES
An investigation on the long-term effectiveness of an elastomere-cushioned handle under different conditions underground.

METHOD
A jackleg drill with a steel handle was monitored, a cushioned handle was then monitored and the operator interviewed. Test holes were drilled in different rock types and steel rod lengths. The air pressure was standard mine pressure at 620 and 414 kPa.

RESULTS
The handle showed an increase in comfort for the operator, and overall vibration levels were reduced by a factor of three.

Dong, R.G., Rakheja, S., Smutz, W.P., Schopper, A., Welcome, D., Wu, J.Z., **(2002).**
Effectiveness of a new method (TEAT) to assess vibration transmissibility of gloves.
International Journal of Industrial Ergonomics, Vol. 30, pp. 33-48

OBJECTIVES
A new test method for anti-vibration gloves was proposed, based upon the total effective acceleration transmissibility (TEAT). Misalignment of the adaptor and non-axial source vibration could result in errors in the measurements and the new system aims to minimise these errors.

METHOD
Three different gloves were tested under predominantly axial vibration using the proposed method and the procedure in ISO 10819 (1996).

The test used one male subject and a vibration exciter, the orientation of the adapter was changed with yaw angles from 0° to 50°. The transmissibility of the gloves was measured in medium and high frequency ranges.

RESULTS
The effectiveness of the TEAT is evident in the reduction of errors resulting from misalignment of the adaptor in the palm of the hand. Vibration transmissibility, measured on the bare hand using standard methods, shows values smaller than one as the misalignment of the adaptor increased.

Gerhardson L., Balogh I., Scheuer J., Voss P., (1998).
Can new materials give better protection from hand vibration exposure?
International conference in Hand- arm vibration - Sweden.

OBJECTIVES
The comparison of the effectiveness of different commercially available vibration damping materials

METHOD
Gelfom, Sylomer and Colgrip were tested on a high frequency grinding tool (dental tool), wrench, surface grinder, keyhole saw and angle grinder.

RESULTS
The damping effect of Gelfom seemed to be the most prominent while better damping was observed without weighting for Colgrip on the dental tool.

Greenslade E., Larsson T., (1997).
Reducing vibration exposure from hand-held grinding, sanding and polishing power tools by improvement in equipment and industrial processes.
Safety Science
*Volume*25 Number3 pp.143-152.

OBJECTIVES
A literature survey on the environmental, technical and individual risk factors involved in operating vibration machinery. Descriptions are given of better tools designed and the results found from these designs.

Hartung E., Dupuis H., Scheffer M., (1993).
Effects of grip and push forces on the acute response of the hand-arm system under vibrating conditions.
Occupational and Environmental Health Vol. 64, pp. 463-467

OBJECTIVES
To study the effects of the grip and push forces on the acute reaction of the hand-arm system under vibrating conditions.

METHOD
Several series experiments were carried out using a vibration simulator, to study the biodynamic vibration behaviour, muscle response, skin temperature and vibration perception threshold. Field data were recorded to collect supplementary data.

RESULTS
Biodynamic Response: an increase in the grip and push force enhanced the biodynamic response; at frequencies above 20Hz, the transmission factor increased in the vibration direction. The increase in transmission factor resulted in an increase in the vibration transmission to the elbow but was less in the wrist.

Muscular Effects: when exposed to combined loads caused by mechanical vibrations in different alternating directions and by varying coupling intensities, all three muscle groups showed an increase in electrical activity. Vibration in the y and z-axes had a more pronounced effect than vibration in the x direction.

Vibration sensation threshold: At the lowest resting level, the average vibration threshold is about 0.13m/s^2. After vibration exposure, the threshold showed a significant increase and became more pronounced with increasing force.

Peripheral circulation: A reduction in skin temperature is at a maximum at a grip force of 30N; any further reduction is due to the mechanical compression of the blood vessels.

Hewitt S., (1998).
Assessing the performance of Anti-vibration gloves – A possible alternative to ISO 10819, 1996

The Annals of Occupational Hygiene.
Volume. 42 Issue2 pp. 245-252

OBJECTIVE
A detailed assessment of the ISO 10819 (1996) standard. The standard could give more information regarding the expected performance of a glove. Advantages and disadvantages of a new test method and the ISO method are given.

METHOD
An alternative test has been proposed: a transmissibility test in the octave bands with centre frequencies from 31.5HZ to 1kHz using pink noise vibration signals. The data are obtained in the same way as with ISO 10819, except that the figures are a result of averaging over fifteen measurements, five for each of three subjects. The test results are the mean plus one standard deviation of the transmissibility in each octave band.

RESULT
The new test has a wider tolerance on the vibration input spectrum and there is no requirement for a controlled loop feed mechanism. Only the feed force is monitored so simplifying the handle and reducing the likely hood of resonance of the handle. All frequencies are tested simultaneously, not in two separate tests, and the results of the alternative test can be used to estimate the performance of a glove for a given vibration signal.

Neckling L.E., Lundborg G., Friden J., (2002).
Hand muscle weakness in long-term vibration exposure.
Journal of the British Society for surgery of the hand.
Volume26 Issue 6 pp. 520-525

OBJECTIVES
The determination of the extent hand muscles are weakened when exposed to long-term vibration.

METHOD
An exposed group worked full-time on vibrating machinery at a rock-crushing manufacturing company in Sweden. A control group with no previous exposure to vibration was put under the same evaluation. The clinical examination included Tinel's, Phalen's and Allen's test and a visual inspection for muscle atrophy. Hand grip, thumb pinch, and strength and abduction of the index and little fingers were measured.

RESULTS
Intrinsic muscles of the hand are affected by long-term vibration exposure. Lower strength in the thumb, little and index fingers were found.

Reynolds, D.D., Jetzer, T.C., (1999)
Use of air bladder technology in anti-vibration gloves.
34th Group meeting on Human Vibration Responses to Vibration.
Dunton, Essex, England

OBJECTIVES

The comparison of an anti-vibration glove that uses a thin pliable air bladder between the hand and tool against Gelfôm, Sorbuthane, Viscolas and Akton gloves.

METHOD
A thin layer of air placed between a vibrating handle and the hand is the most effective means of attenuating vibration into the hand. An air bladder made by welding two layers of thin-film thermoplastic materials together with a quilted pattern of weld points and lines corresponding to the natural flex-lines of the hand was developed. The air bladder is inflated using a bulb inflator. Tests were done according to ISO Standard 10819 at three different laboratories.

RESULTS
The air bladder glove met all requirements of ISO 10819; it significantly reduced the vibration into the hand, was thin, pliable and flexible and was comfortable to wear. The worker experiences no loss of sensitivity as occurs with thicker padded gloves and control over a tool was maintained.
Air bladder technology used in gloves provides credible protection for workers exposed to hand-arm vibration.

Thomas M., Beaucamp Y., (1998).
Development of a new frequency-weighting filter for the assessment of grinder exposure to wrist-transmitted vibration.
Computers & Engineering
Volume35 Number 3-4 pp.651-654.

OBJECTIVE
The investigation of the exposure of workers in a foundry to vibration and physical stresses, the vibrating tools not only expose the worker to vibration but to also to physical stresses while a tool is running.

METHOD
Small hand grinders, scaling hammers, inline hammers and chipping hammers were investigated. Vibration measurements, observational analysis and electromyography were used.

RESULTS
The inline hammers had the largest vibration levels as well as muscle load while the grinder had the lowest. The tools expose the workers to high peak muscle loading, medium to high levels of hand repetition and extreme to awkward postures of the elbow and shoulder.

Tudor H.A., (1996).
Hand-arm vibration: Product design principles.
Journal of Safety Research
Volume27 Number3 pp 157-162.

OBJECTIVE
Several engineering approaches are applied to the design of a landscaping trimmer.

METHOD
Vibration is first mechanically reduced at the source, then the transmission path from tool to handle is modified by better ergonomics design.

RESULTS
Engineering modifications reduced the vibration to acceptable levels. Ergonomics design can improve the comfort reducing the fatigue and grip strength.

Vosloo P.J.E., Van Graan C.H., Van Heerden, J.G.A., (1975).
The design and evaluation of improved protective clothing: Gloves
Chamber of Mines South Africa Research Organization
Report No. 47/75 1975

OBJECTIVES
Evaluation of a new glove made of nylon stretch material and tight fitting wrist cuffs with only the palms of the gloves coated in PVC. Assessments were done on two gold mines to evaluate the effectiveness of the new gloves.

METHOD
A survey was conducted at two gold mines with observers visiting different work areas to ensure that the gloves are being used and to evaluate the state of the gloves. The gloves were subjected to surface inspection after each shift. Hand injury data were obtained and evaluated.

RESULTS
The new gloves had better ventilation, which resulted in dry hands and gloves that did not become soggy and malodorous. The wear resistance of the gloves was remarkably good, operators were very satisfied with the gloves and tried to keep them as long as possible. The only problem found with the gloves seemed to be the size, since they are too big for most of the operators. Cotton cuffs used on the gloves started rotting after a few days and nylon cuffs were suggested instead.

Voss, P., (1996)
Protection from hand-arm vibration by the use of gloves: Possibility of fraud
Proceeding of Internoise Liverpool

OBJECTIVE
To describe the situation for gloves and provide examples of efficient and non-efficient materials for anti-vibration gloves.

METHOD
A material test was performed according to ISO 13753. A sample of the material is placed on a table on an exciter, the sample is loaded with a rigid mass and the transfer function is measured between the table and the mass. If a material does not perform well in the materials test, there is no chance that it will perform well in the glove test.

A glove test was also performed according to ISO 10819. The operator grips a vibrating handle at a predetermined feed and grip force. The transmissibility of the gloved hand is compared to that of a bare hand.

RESULT

It is the subjective judgement of the author that the above tests render 90% of gloves on the market sold as anti-vibration gloves as unsuitable for application in vibration environments. Most high frequency power tools have their dominant vibration energy below 100Hz; therefore what happens in the high frequency range is not essential. Hand-arm vibration problems are not eliminated by the use of gloves, but these results show that gloves may protect operators against vibration from high frequency power tools.

PU foam, Gelfôm and foam combined with Viscolas were evaluated. The Gelfoam and foam combined with Viscolas showed vibration attenuation in the frequency range 63 to 250 Hz. The PU foam did not significantly lower the vibration levels.