Safety in Mines Research Advisory Committee

Final Project Report

DEVELOP TELE-CONTROLS FOR SELF-THRUSTING PERCUSSION DRILLING MACHINE AND ASSOCIATED INTERFACE

RW Ottermann
AJ von Wielligh
NDL Burger
Dr. VA Kononov

Research Agencies	**RE@UP, University of Pretoria**
	CSIR Miningtek
Project number	**GAP 702**
Date of report	**October 2001**

EXECUTIVE SUMMARY

The purpose of this project was to develop tele-controls to control drilling operations from a distance. The controls were fitted to the prototype quiet rock drill and demonstrated to be working.

Noise is a generic hazard common to all commodities and, to a greater or lesser extent, all operations within mining. More people are exposed to the risk of noise- induced hearing impairment than to any other hazard. The pneumatic percussion drill is a major contributor to noise-induced hearing impairment in mines. The design and development of tele-controls for drills so that the operator can be positioned away from the drill will reduce this risk. The tele-control of rock drills has the added advantage of increased safety to the drill operator by his positioning away from the rock face. During this project such a system was developed, tested and demonstrated.

After a literature survey was conducted a functional analysis was done from which a specification was drawn up. Different concepts were generated and evaluated. The preferred concept was presented to the SIMRAC technical committee for approval after which a detail design was done. An experimental development model (XDM) was built and commissioned. The XDM was successfully tested on surface and demonstrated.

The design of the quiet self-thrusting rock drill, developed during project GAP 642, was used and the tele-controls incorporated into it. The tele-control system consists of a hand held controller and the electronic unit in the drill unit, with which different valves are controlled. Radio control is used as communication between the hand held controller and the drill unit. A generator, powered by an air motor, is incorporated in the drill unit to charge a battery, which supplies electricity to the electronics.

As this was an experimental development model (XDM) no durability tests were performed and the electronics were also not built to withstand underground conditions. In order for this technology to be used underground the electronics have to be designed and packaged to withstand underground conditions. As a tendency exists for the introduction of drill rigs in mines it is also recommended that tele-controls be incorporated in drill rigs.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the Safety in Mines Research Advisory Committee (SIMRAC) for financial support of project GAP 702 and also for the interest and technical input of the SIMRAC Technical Committee.

To Dr. Valery Kononov and his team at CSIR Miningtek our sincere appreciation for their technical input and co-operation in making the project a success.

TABLE OF CONTENTS

TABLE OF FIGURES

1 INTRODUCTION

Noise is a generic hazard common to all commodities and, to a greater or lesser extent, all operations within mining. More people are exposed to the risk of noise- induced hearing impairment than to any other hazard. The pneumatic percussion rock drill is a major contributor to noise-induced hearing impairment in mines. The design and development of tele-controls for rock drills so that the operator can be positioned away from the drill will reduce the risk.

In addition to the cost of compensation and reduced productivity resulting from lost shifts, hearing conservation programmes (which have proven largely ineffective for a number of reasons) are expensive to implement and maintain. The impact of hearing loss/interference on productivity and safety also results in reductions in profitability. This indicates that engineering measures to control the noise hazard, which are generally accepted as the preferred approach to hearing conservation, offer better prospects for success than receptor control or personal protection strategies.

During project GAP 642, the Design and development of a quiet, self-thrusting blast hole drilling system, a percussion rock drill was developed with a reduced noise level. In order to reduce the noise exposure further, the operator has to stand away from the drill. This has the added advantage of increased safety to the drill operator by standing away from the rock face. During this project the quiet rock drill was further developed to include tele-control.

This is the final report on project GAP 702. During this project tele-controls for a self-thrusting percussion drilling machine and the associated interface was developed and demonstrated.

2 METHODOLOGY

The following methodology was followed during this project:

- A literature survey was done to determine the best technology on tele-control systems.
- After gathering information from industry, a functional analysis was done.
- From the functional analysis the requirements for the systems were concluded and the specification and design parameters drawn up.
- Different concepts were generated and evaluated against the specification and design parameters.
- The selected concept was then presented to the SIMRAC Technical Committee for approval.
- The selected concept was designed in detail after which a design audit was done.
- An experimental development model (XDM) of the drill was manufactured and commissioned.
- The XDM was tested and evaluated on surface.

3 LITERATURE SURVEY

A literature survey was conducted on use of standoff control and in particular for portable drills. The worldwide review of drilling technology show that no stand-off control and monitoring system was developed or is currently used in production. The same result was obtained in surveys conducted by *Carter (1993), Chadwick (1994,1999)* and *Woof(1997).*

A summary of the literature survey is attached in appendix A.

3.1 Definition of tele-controls

The term "remote control" has been acceptable nomenclature for any non-on-board method of control in the past. At present, tele-control is recommended as a far more appropriate and descriptive term for the diverse array of systems that have been developed over the last two decades for non-on-board control. Therefore, the principal methods of tele-control for underground mining applications are defined as follows:

Standoff control:
This refers to the use of a portable controller, whereby an operator can control a mining machine only within line-of-sight, relying solely on his own visual and auditory senses to monitor operational activities directly. Operator safety depends on his ability and common sense. The costs of installation and operation are low *(Thomas, 1988).* Only minor changes to the machine are required to introduce this method.

Remote control:
This method of tele-control enables mining operations to take place without the permanent presence of miners in a mining area. This concept involves control from beyond the range of visibility and, as such, the operator can be placed any distance from the machine that will ensure his safety.

Lack of sensory information for the operator can be overcome by using video, audio and other relevant systems. Information from sensors on the machine in the working area is transmitted via communication channels to the remotely positioned operator. This information may be processed before being presented to the operator. The same or separate communication channels can be used to transmit control instructions back to the machine, which can initiate on-board control functions. Significant changes to the machine and additional equipment as well as high levels of technology are required (*Kwitowski, 1992).*

3.2. Types of communication for tele-control

Tele-control systems can incorporate various types of communication between the control station and the controlled machine or equipment:

- Physical line or umbilical control (hydraulic hose, hard wires, electrical or fibre optic cable and machine trailing power cable).
- Wireless (radio, infrared and ultrasonic).
- Combined (i.e. using physical line and wireless communication)

The main factors that have to be taken into consideration when selecting a particular type of communication are:

- Method of tele-control.
- Type of machine to be controlled.
- Level of mobility of the machine.
- Mining conditions and associated constraints on technology that can be utilised.
- Presence of other machines in the same area.
- Electromagnetic compatibility of tele-control with other systems used in the vicinity.

4 FUNCTIONAL ANALYSIS AND SPECIFICATION

4.1 Functional analysis

A functional analysis based on the requirements for the tele-control of the self-thrusting percussion-drilling machine was done from which a design specification was compiled. In figure 4-1 the system level of the functional analysis is shown and the complete functional analysis is listed in Appendix B.

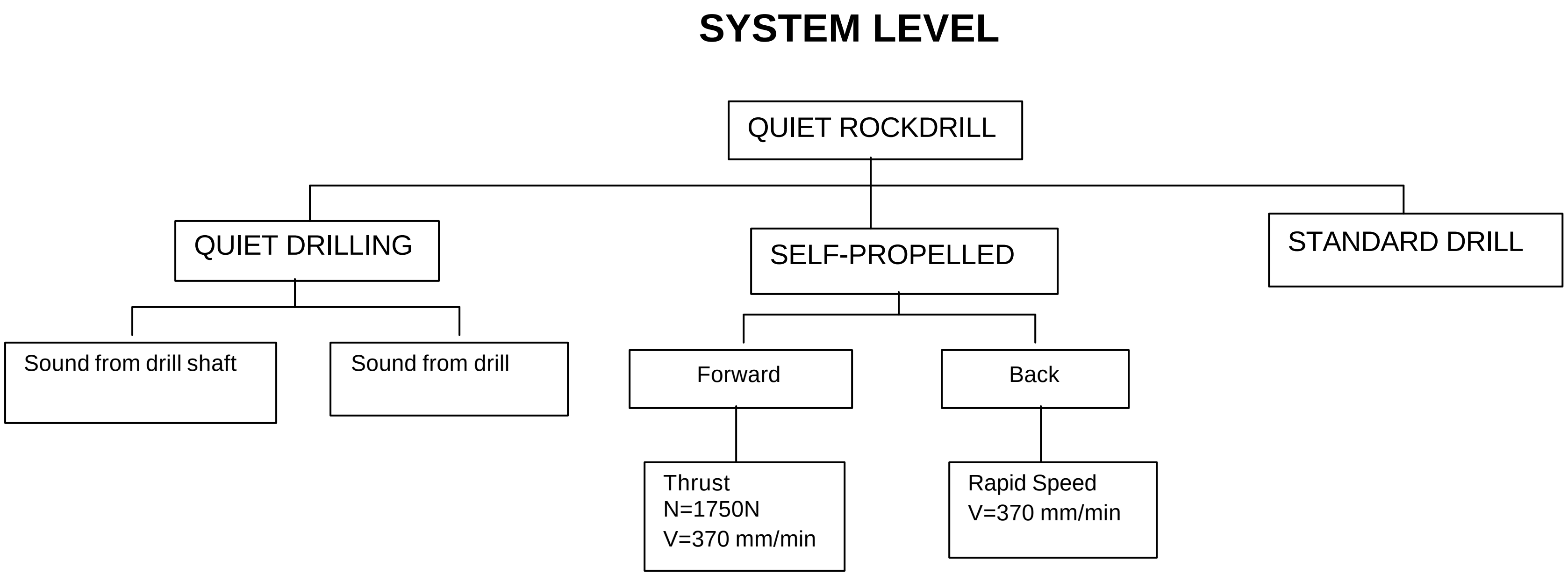


Figure 4-1: System level functional analysis

4.2 Specification

The functional analysis was used to compile the following system specification:

1. Control drilling operation from portable controller:
    - Activate forward motion
    - Apply thrust
    - Activate water/air
    - Activate reverse
    - Stop
2. Control two machines simultaneously.
3. Range of portable controller: 2-5m.
4. Drills must be capable of operating simultaneously and independently.
5. Stop in the case of a communication channel interruption between the portable controller and the drill.
6. Sense position of drill (drilling depth indicator).
7. Drilling cycle complete indicator.
8. Drill jammed indicator.
9. Selection of and calibration for different drill rod lengths.
10. End position switch in the front of the drilling unit to prevent over-travel.

5 CONCEPT DESIGN

The design of the quiet, self-thrusting rock drill, project Gap 642, was used as the basis for the concept of this project. The different concepts were based on different types of communication and thus the communication channel selection. In appendix A the different types of communication as well as their advantages and disadvantages are discussed.

5.1 Communication channel selection

As the concept for the drill itself was finalised during project GAP 642 the selection of the communication channel was the most important aspect on the implementation of tele-control.

The advantages and disadvantages of the communication channels discussed are presented in appendix A. During the selection of the communication channel three main factors were considered:

- At least two machines to be controlled simultaneously by the same controller;
- Harsh environmental condition and limited working space;
- Relatively small space available in the drill.

The use of an **umbilical cord** is too delicate and restrictive for the operator, particularly in such a restricted area as in a stope. The protection of the umbilical cord in underground conditions will be very difficult. Therefore, the umbilical control concept was not considered.

Wireless control provides better operational freedom and does not restrict mining operations. There are two alternatives available for implementation:

- **Infrared control**
- **Radio control**

The **infrared** channel can be utilized when used to control a single machine with a suitable place for the installation of a photo receiver. To fulfill the requirement to control two drills, an infrared transmitter will have to provide an exceptionally wide transmission angle in order to "illuminate" both drills. The width of the transmission angle required to cover two machines will have to be close to 180°, which is not practical. The re-orientation of the infrared controller implies that the drill will have to continue operating without a control signal, a situation that is not desirable from a safety point of view. With infrared control an optical window for the receiving photodiode has to be installed on the drill. The position of this window, durability and its cleaning are limiting factors for the use of infrared.

Radio control has the following advantages:

- Two or more machines can be controlled simultaneously.
- Line of site is not necessary.
- The receiver can be placed in a safe position away from the harsh environmental conditions.
- It can be fitted in limited space.

As umbilical cord and infrared control are not practical and because of the inherent advantages of radio control, radio control was chosen as the preferred concept.

5.2 Concept layout.

5.2.1 Control functions

1. The machine can be started and controlled by a portable controller within a range of 2-5 m.
2. Two machines be controlled simultaneously.
3. The machine should stop in the case of a communication channel interruption between the portable controller and the machine.
4. While one machine is being controlled, the other machine should continue implementing an earlier instruction. That is, all machines should be capable of operating simultaneously and independently.
5. Each machine be equipped with a revolution counter on the thrust screw, indicating the drilled depth.
6. For safety and calibration purposes, an end position switch be installed in the front part of the drilling machine to prevent over-travel. This switch also serves as the zero position and indicator to reverse the drill.
7. The drilling depth be transmitted to the portable controller. The depth is indicated on the portable controller by means of a bar display. A green light on the portable controller indicates the completion of the drilling cycle.
8. A red light on the portable controller indicates that the drill is jammed. If, during the drilling process, no movement is detected within two seconds, the red light comes on.
9. The operator is able to select between different preset drilling rod lengths. These must be selected to determine how far the machine must retract to get to the starting position.

5.2.2 Portable controller

The portable controller complies with the following specifications:

Operational frequency, MHz	
Transmitter	430
Receiver	418
Radiated power, mW	1,0
Instructions	2x6
Power supply, V	3 (2xAA)
Machine position indicators	2 bars
Cycle completion indicators	2 green
Machine jam indicators	2 red

5.2.3 Machine tele-controls

The drilling machine tele-control and interface unit complies with the following requirements:

Operating frequency, MHz	
Transmitter	418
Receiver,	430
Data packet size, bits	32
Power supply, V	12
Standby battery, V; A/h	12; 4
Valves to be controlled	3
Normally closed limit switches	2
Inductive revolution counter (3 impulses per revolution)	1
Standby mode ON/OFF, msec	400/800

6 DETAIL DESIGN

6.1 Drill

The design of the quiet, self-thrusting rock drill, developed during project GAP 642, was used as the basis for this project. A full set of detail drawings was made and included in the GAP 642 report.

6.2 Controls

6.2.1 Valve arrangement

The valve configuration in the drill is presented in figure 6-1. Three valves are used for the following functions:

1.Generator On/Off
2.Drill On/Off
3.Thrust Forward/Reverse

.

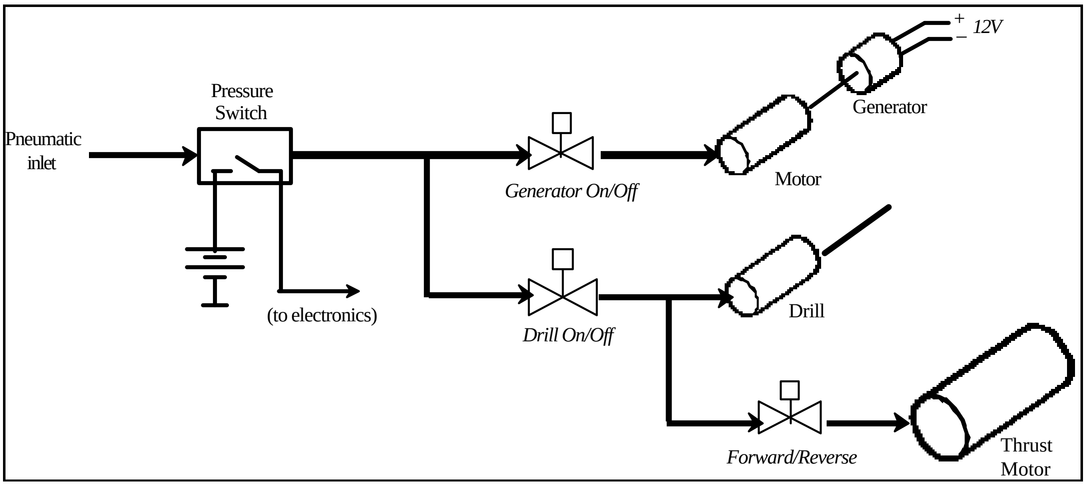


Figure 6-1: Valve configuration

6.2.2 Electronics in the drill

In figure 6-2 an overview of the electronic control layout in the drill is shown. The detail electronic layout is attached in appendix C.

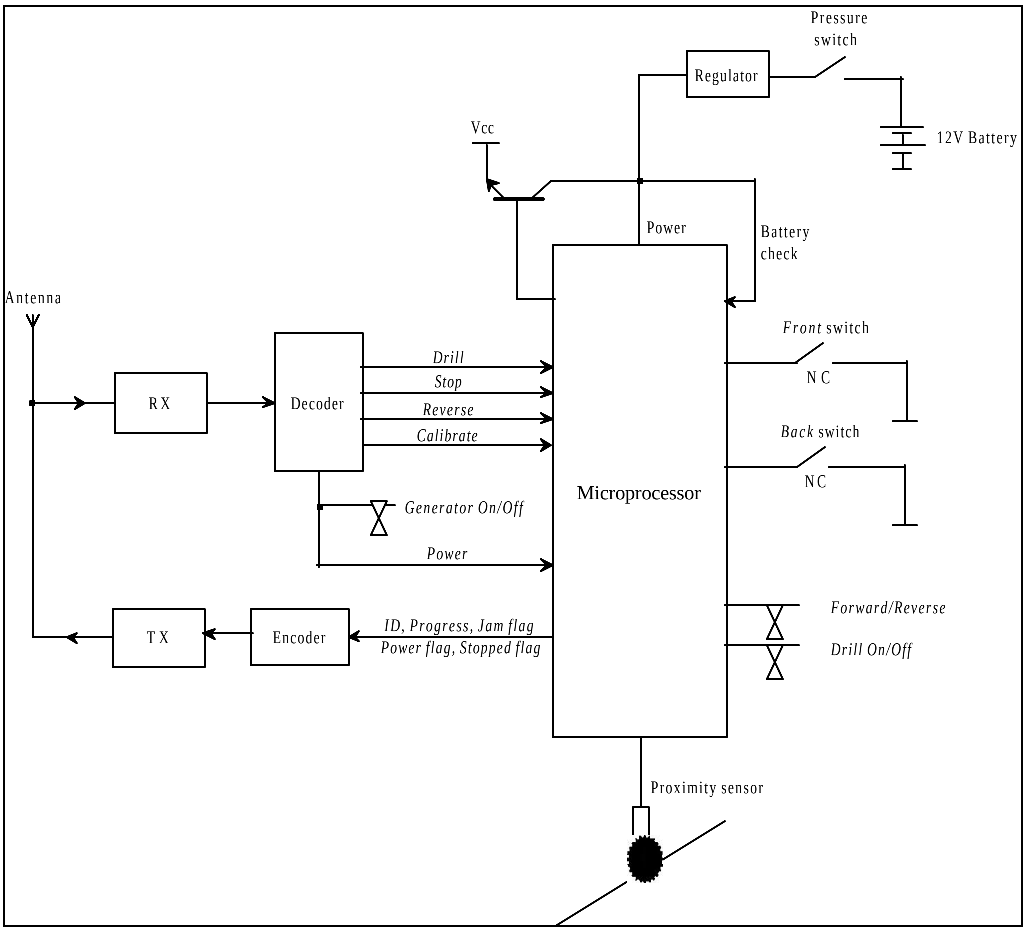


Figure 6-2: Schematic overview of electronic control layout in the drill.

Power is available to the electronics when the main pressure switch is closed, i.e. when the pneumatic hose is connected to the drill. Electronic filters on the pressure and limit switches eliminate unwanted effects such as switch bounce.

The microprocessor in the drill fulfils the following functions:

1. When the pneumatic hose is connected and the portable controller has not initiated a *Power On* command, the rig electronics is in standby mode, a power saving feature. In standby mode, the power to the electronics is cyclically switched on for 400 ms and then off for 800 ms. The system remains in standby mode until the user holds the portable controller *Power* switch down for two seconds. When this occurs the system is put into *operational mode*. In operational mode the power to the electronics is continuously on until the portable controller *Power* switch is held down for two seconds or the emergency stop switch is pressed.
2. The battery level is monitored. If the battery voltage drops below 10.5 volts, the generator is activated until the battery is charged. A 60 W air motor running at 6500 r.p.m powers a permanent magnet electric motor, which is used as generator. The

generator delivers 5 Amps at 13,5 Volts. A regulator fitted between the generator and the battery converts the generator output voltage (which often goes above 20 V) and regulates it to a smooth 13.8 volts for charging. The Generator On/Off valve enables and disables the generator. When the generator is turned on, the voltage immediately rises to the 13.8V charging level. The battery voltage cannot be sampled while it is being charged. Charging for five minutes, turning off the charger, waiting for the voltage level to settle, and then measuring before charging again accommodates for this. This process is repeated until the battery voltage reaches a sufficient level at which point the *Generator* valve is turned *Off*.

3. By monitoring the direction and the proximity sensor pulses, the drill position is tracked. When the machine is first put into use, an initial calibration is conducted to obtain the first reference. Each time the front limit switch is pressed, the reference position is zeroed and any accumulated error eradicated.
4. Control of the automatic drilling process. This is initiated by pressing the *Drill* button, and involves the following sequence: *Drill valve On, Forward valve On,* front limit switch activated, *Stop, Reverse valve On*. Since the controller knows the selected drill steel length, the controller issues the final stop command at reaching the correct retracted distance, which sets both the *Drill valve* and *Reverse valve* to *Off.*
5. Interpretation of the *Stop* and *Reverse* commands.
6. Partial control of the calibration procedure for changing drill steels: Upon receiving a *Calibrate* signal, the drill thrusts to the front limit and stops. Upon receiving a further *Calibrate* signal, retracts the drill. The portable controller issues the rod size selection and the final Stop command.
7. The following data stream is put onto the transmitter: An identity code, the drill position, jam indicator, power status indicator and a flag to indicate that the rig has stopped. This last flag acts as confirmation after the portable controller sends a stop command.

6.2.3 Electronics in the controller

Each drill controlled from the hand held controller is controlled by a separate identical microprocessor. The schematic layout of one of the two microprocessors with its peripherals is shown in figure 6-3. The detail electronic layout is attached in appendix C.

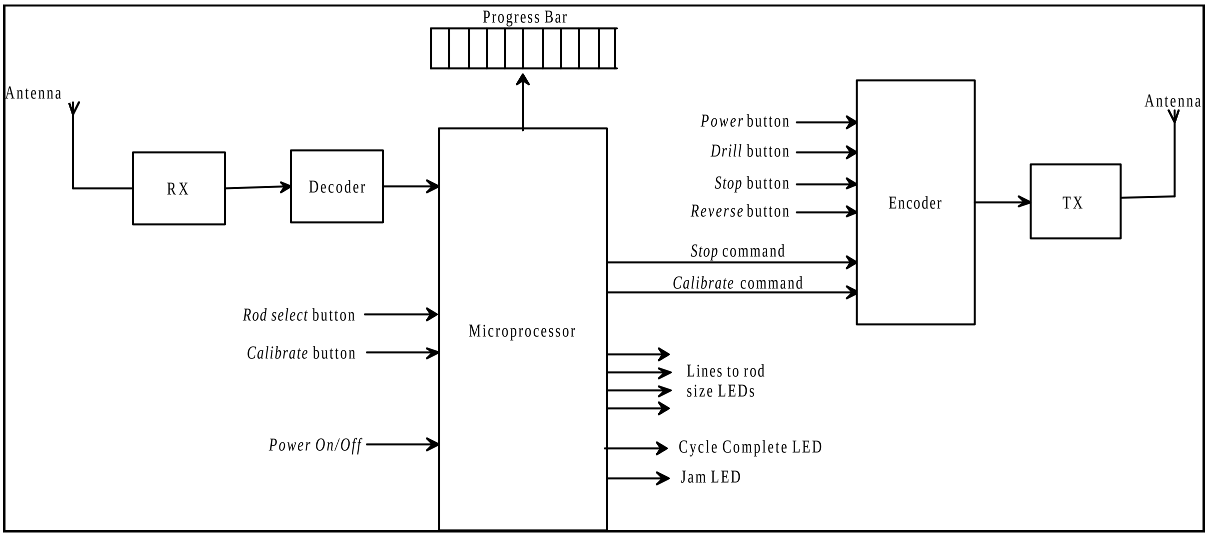


Figure 6-3: Controller microprocessor and its peripherals

The microprocessor in the controller fulfils the following functions:

1. Receive and interpret the data string sent by the drill unit (*ID, Progress*, *Jam_f, Power_f* and *Stopped_f*). If no data is received within 4 seconds, flash the red LED of the progress bar and issue a *Stop* command.
2. If the *Power* button is held down for two seconds and the drill has confirmed the power status (*Power_f* set) then toggle the power on and off.
3. Store the set drill rod size and drill rod position in EPROM.
4. Update the progress bar according to the current position.
5. In both the *Drill* and the *Calibrate* sequences it sends a *Stop* signal to the drill unit when the drill has retracted to the required position.
6. Control the *Cycle complete* and *Jam* LED's.

The schematic diagrams and the program description are given in the Appendix C.

7 OPERATIONAL PROCEDURE

(Notation: Throughout this document, words in Italics depict control panel buttons, valves, registers and indicator flags.)

The functions present on the remote controller are depicted in figure 7-1.

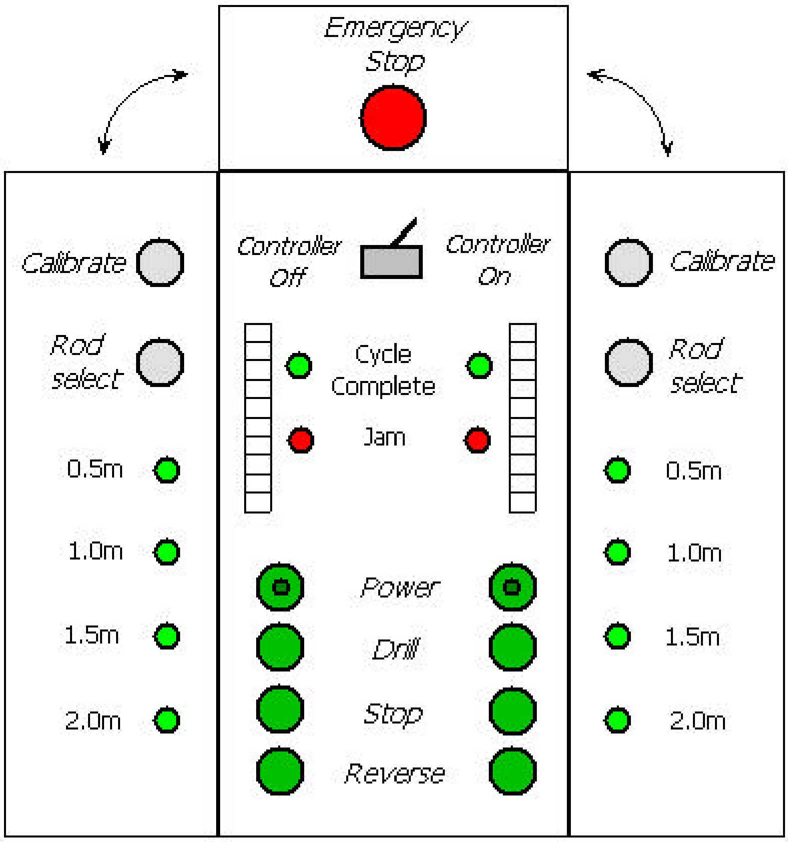


Figure 7-1: Functional representation of the remote controller

Normal Operation:

1. Ensure that the pneumatic and hydraulic hoses are connected to the drill units to be used.
2. Turn on the controller (*Controller On*). The yellow LED on the progress bar should illuminate indicating that the rig is in Standby mode.
3. Hold the *Power* button down for two seconds to set the rig to Operational mode. The yellow LED on the progress bar goes out and the previous system settings of rod size and progress are restored. If no drill progress has been made, the *Cycle complete LED* is lit up and the bottom LED in the progress bar will flash. Release the *Power* button.
4. When *Drill* is pressed, the automatic drilling cycle commences: If the drill rod was retracted to its proper starting position then the

Cycle complete LED turns off at this stage. The system will turn on the drill, thrust to the maximum extent of the currently specified drill rod, retract to the starting position and turn the drill off. Upon completion of the drill cycle, the Cycle complete LED lights up and the bottom LED of the progress bar flashes. This process can be interrupted at any time by pressing *Stop, Reverse* or *Emergency Stop*.

5. The drill unit goes back to Standby mode, by either holding the *Power* button down for two seconds, by turning off the controller (*Controller Off*) or by pressing *Emergency Stop.*

Drill steel length calibration:

1. Press the *Calibrate* button. The drill will be advanced to the front where it will stop. The drill steel can now be replaced.
2. Pressing *Rod Select* will alternate LED's between the various drill steel sizes. Select the desired drill steel length.
3. Once a drill steel has been selected, press *Calibrate to* retract the drill to the correct position for the specified drill steel.

Notes and troubleshooting:

1. The drill steel selection option is only available between the first and second time that the *Calibrate* button is pressed. During this time, both the *Drill* and *Reverse* buttons are deactivated. If the *Stop* button is pressed during the calibration process, the calibration process will be aborted and the previous set-up will be restored.
2. The *Emergency Stop* button can be pressed at any time. When this is done, the drill is stopped and will enter into Standby mode.
3. Other than during the calibration procedure, the *Reverse* button can be used at will. The drill steel will automatically be stopped if it reaches the starting point, that is, where the Cycle complete LED lights up. Pressing Reverse again can further retract the drill steel. The rear limit switch will halt the drill if the user doesn't press *Stop* in time.
4. If communication is lost between the drill unit and the controller the red LED of the bar display will flash. Each time the light flashes a *Stop* command is issued. If the user moves back into range, normal operation will commence. The delay between moving into range and the commencement of normal operation can at times be lengthy and it is recommended to turn the controller off and then on again.
5. If no drill movement is detected within two seconds when the drill steel is supposed to be moving forward or backward, the red Jam LED will illuminate. This LED goes off when the movement commences again. If the lack of movement turns out to be a problem, the user should press the *Stop* button and clear the problem.
6. If the pneumatic hose is connected for an extended period of time without activation of the drill, the battery may run down. If

the battery level drops below a specific level (10.5V) then the generator will automatically be activated for a time to recharge the battery (see paragraph 6.2.2). The hand held controller currently has no battery level monitor installed.

8 EXPERIMENTAL DEVELOPMENT MODEL (XDM)

The experimental development model (XDM) quiet rock drill was built and commissioned. During the commissioning numerous changes were made to the controls as well as to the hardware of the controls. After each change was implemented the unit was again tested. In figure 8-1 a photo of the assembled drill is shown and in figure 8-2 a photo of the hand held controller is shown.

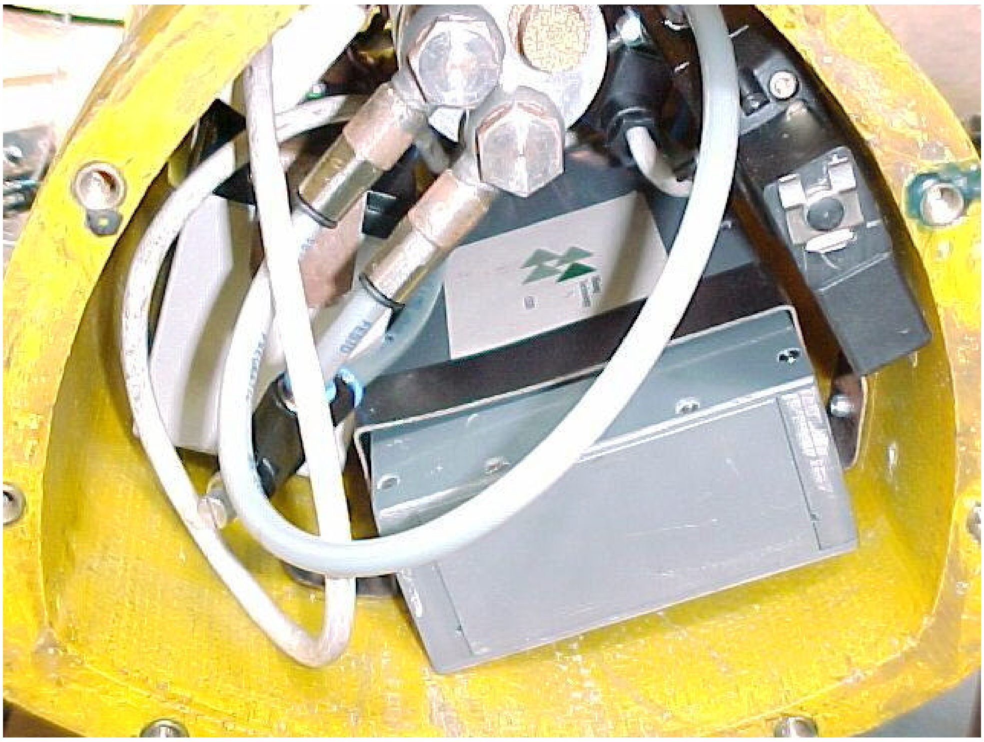


Figure 8-1: Assembled XDM quiet rock drill with tele-control

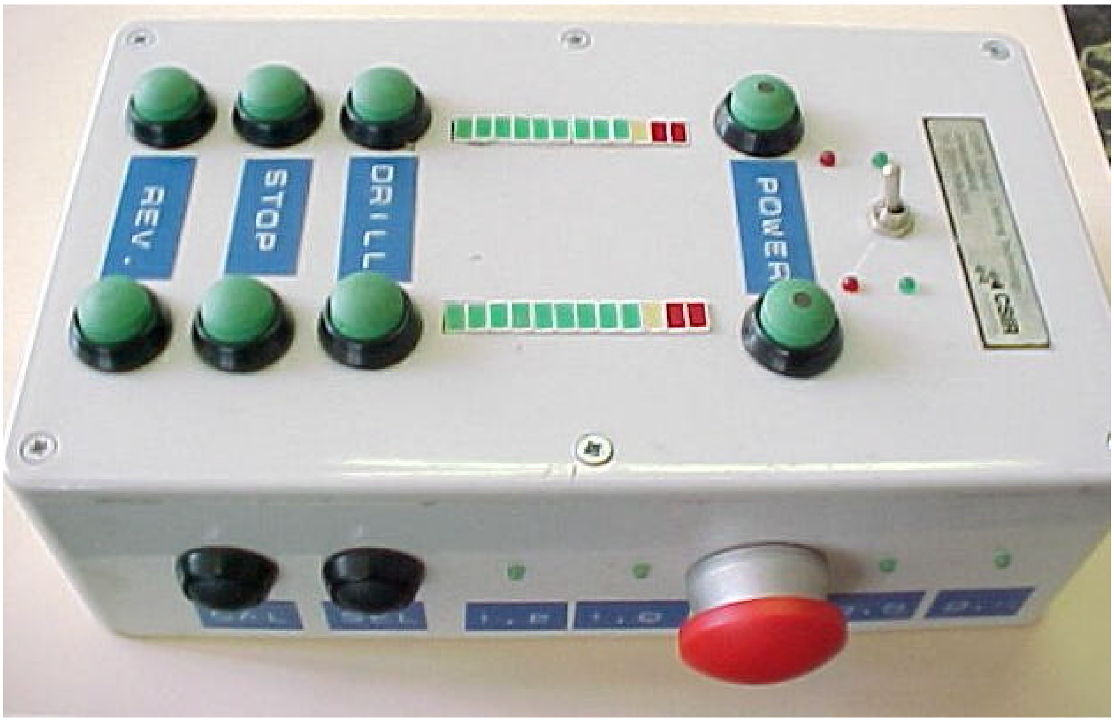


Figure 8-2: Controller of quiet rock drill with tele-control (XDM)

9 TEST AND EVALUATION (SURFACE)

Surface tests of the XDM quiet rock drill with tele-controls drilling into a norite block were done. The tests were done in an open area to reduce the effect of reflections from hard surfaces adding to the sound pressure level. In figure 9-1 a photo of the drill drilling into a granite block is shown. A standard muffled S215 rock drill was also tested to get comparative results.

Figure 9-1: Photo of the quiet rock drill drilling into a granite block

The noise levels were measured at predetermined points around the drill and are shown in figure 9-2. A standard muffled Seco S215 rock drill was also tested and the comparative results are shown in figure 9-3. The results of the tests show that the XDM quiet rock drill has a marked reduction in sound power levels measured.

From figure 9-2 it can be seen that the noise levels reduce considerably the further away from the drill unit. With the tele-control drill the operator can be positioned away from the drill were the noise levels are acceptable. With the operator positioned 2 m or further away from the quiet rock drill the sound levels he will experience will be less than 88 dBA compared with the 97 dBA experienced by a operator of a standard muffled Seco S215 rock drill in the same conditions on surface.

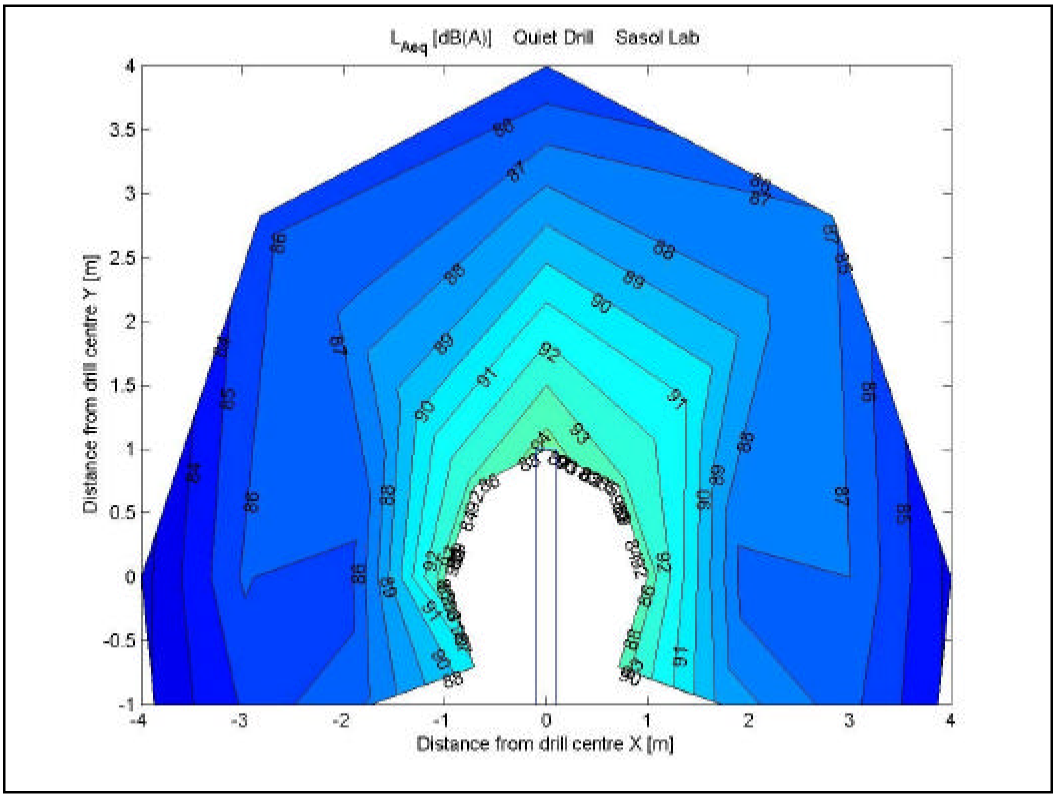


Figure 9-2: Sound levels (dBA) around the prototype quiet rock drill tested on surface.

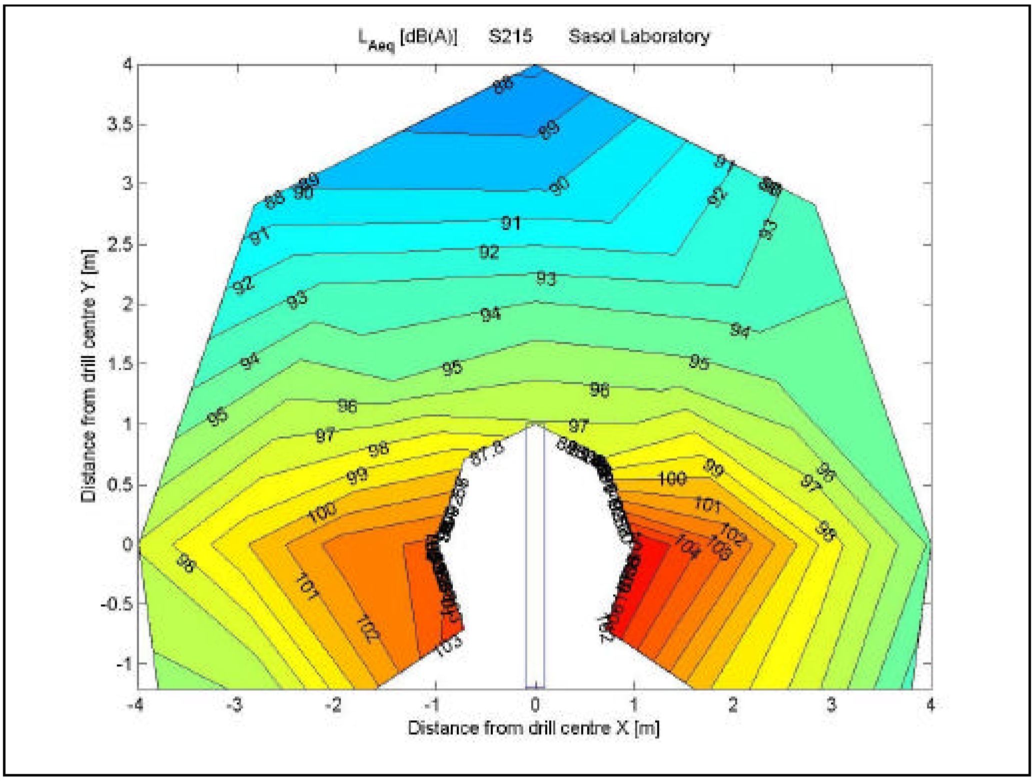


Figure 9-3: Sound levels (dBA) around a standard muffled Seco S215 rock drill tested on surface

Penetration rates were also measured with both the quiet rock drill and the standard muffled Seco S215 rock drill. A similar penetration rate of approximately 500 mm per minute was recorded with both drills.

As this was an experimental development model (XDM) the electronics were not built to withstand underground conditions and no durability tests were performed.

10 CONCLUSION AND RECOMMENDATIONS

The purpose of this project was to develop tele-controls to control drilling operations from a distance. The controls were fitted to the prototype quiet rock drill and demonstrated to be working.

Tele-controls were successfully developed for the quiet, self-thrusting blast hole drilling system (GAP 642) and demonstrated. The specified design criteria as set out in the system specifications were met. A considerable reduction in sound levels was achieved with comparable penetration rates to standard pneumatic drills. With the tele-control rock drill the operator can be positioned away from the drill where the noise levels are acceptable. This has the added advantage of increased safety to the drill operator by standing away from the rock face.

During this project the tele-control for drills has been successfully demonstrated. In order for this technology to be used underground the following is recommended:

- Design and package electronics to withstand underground conditions.
- As a tendency exists for the introduction of drill rigs in mines it is also recommended that tele-controls be incorporated in drill rigs.
- Monitor and display the battery life left in the hand held controller.

11 REFERENCES

Carter R.A..1993. New Technology makes mining remotely possible.
E & MJ, September.

Chadwick, J., November 1994, El Teniente's Sub-6 looks to automation, Mining Magazine, 266-270.

Chadwick, J., August 1999, Underground drilling and loading, Mining Magazine, 105-110.

Hamrin H. 1993. Automatic Drilling of Long Blastholes for Sublevel Stoping with Simba 269 in the LKAB Kiruna Mine. CSM Quarterly Review, Vol.93, No.3.

Harper, G.S., Scanlon, T., November 1997, Develop a quiet non-atmosphere polluting blast hole drilling system, Safety in Mines Research Advisory Committee, GEN 207.

Harper, G.S., Scanlon, T., January 1998, Evaluation and further development of a quiet non-atmosphere polluting blast hole drilling system, Safety in Mines Research Advisory Committee, GEN 311.

Kononov V.A. 1987. Infrared Communication Channel in underground mining conditions. Doctorate Thesis, Moscow Technical University (MVTU Bauman).

Kwitowski A.J, Mayercheck W.D and Brautigam A.L. 1992. Teleoperation for Continuous Miners and Haulage Equipment. IEEE Transactions on industry applications. Vol.28, No.5, September/October.

Martin D.P,Fitz M.M.1991. An Automated Drill and Blast System.Proceedings of International Symposium on Mine Mechanization and Automation, Vol.1, June 10-13, Golden, Colorado.

Miess C, Kowal H.1992. Secure Radio Control of Mining Machinery. The 11-th WVU International Mining Electrotechnology Conference, Morgantown, West Virginia, 29 July.

Thomas R.T&.Miess C. 1988. Radio Control and longwall shearers - a cost effective combination. Australian Mining, January.

Van Niekerk, J.L., Heyns, P.S., Heyns M., Hassall, J.R., The measurement of vibration characteristics of mining equipment and impact percussive machines and tools. Safety in Mines Research Advisory Committee, GEN 503.

Woof, M., October 1997, Production Drilling: The sophisticates, World Mining Equipment, 14-18.

APPENDIX A: LITERATURE SURVEY

A literature survey was conducted on stand-off control and in particular stand-off control for portable drills. The world-wide review of drilling technology conducted by *Carter (1993), Chadwick (1994,1999)* and *Woof (1997)* show that no stand-off control and monitoring system is currently used in production.

A.1 Definition of tele-controls

The term "remote control" has been an acceptable nomenclature for any non-on-board method of control in the past. At present, "tele-control" is recommended as a far more appropriate and descriptive term for the diverse array of systems that have been developed over the last two decades for non-on-board control. Therefore, the principal methods of tele-control for underground mining applications are defined as follows:

Stand-off control:
This refers to the use of a portable controller, whereby an operator can control a mining machine only within line-of-sight, relying solely on his own visual and auditory senses to monitor operational activities directly. Operator safety depends on his ability and common sense. The costs of installation and operation are low *(Thomas and Hiess, 1988).* Only minor changes to the machine are required to introduce this method.

Remote control:
This method of tele-control enables mining operations to take place without the permanent presence of miners in a mining area. This concept involves control from beyond the range of visibility and, as such, the operator can be placed any distance from the machine that will ensure his safety.

Lack of sensory information for the operator can be overcome by using video, audio and other relevant systems. Information from sensors on the machine in the working area is transmitted via communication channels to the remotely positioned operator. This information may be processed before being presented to the operator. The same or separate communication channels can be used to transmit control instructions back to the machine, which can initiate on-board control functions. Significant changes to the machine and additional equipment as well as high levels of technology is required (*Kwitowsk et al., 1992).*

A.2 Types of communication for tele-control

Tele-control systems can incorporate various types of communication between the control station and the controlled machine or equipment. Appropriate examples are as follows:

- Physical line or umbilical control (hydraulic hose, hard wires, electrical or fiber optic cable, machine trailing power cable);
- Wireless (radio, infrared, ultrasonic);
- Combined (using physical line and wireless channel).

The main factors, which have to be taken into consideration when selecting a particular channel, are as follows:

- Method of tele-control;
- Type of machine to be controlled;
- Mining conditions and associated constraints upon technology that can be utilized;
- Presence of other locally or tele-controlled machines in the same area;
- Level of mobility of the machine;
- Electromagnetic compatibility of tele-control with other systems used in the vicinity.

A.3 Physical Line Systems

The first remote control system for a mining machine using a hydraulic drive were via a pilot line from a portable controller incorporating manual pilot valves. Such umbilical control systems are still in commercial production. When an electro-hydraulic interface (set of solenoid valves), is installed on the machine, hard wires or cables can be used between the machine and a controller, which uses buttons and toggle switches. The practical limit on the length of a control cord for a stand-off control is 5-10 m.

<u>Advantages</u>

- Low cost and simplicity

<u>Disadvantages</u>

- Restriction of operator's movement
- Safety limitations

A physical link between a portable controller and a mobile machine was used in the first commercial application of stand-off control for mining machinery. This method of stand-off control can comply with machine control requirements but at the same time the umbilical control limits the freedom of the operator and physical damage to the cable is a frequent problem. A few cases have been registered where a control cable has been caught by caterpillar tracks or armed conveyer pads and an operator has been dragged under or into a machine when the portable controller was fastened to the operator's body *(Kononov, 1987)*. This method of stand-off control, is, therefore, not recommended for permanent control of a mobile machine unless some special measures were implemented.

A.4 Wireless Systems

A.4.1 Radio

The first attempt to use radio waves in mines took place in the 1920's. Today, radio stand-off control systems have several underground mining applications, notably for longwall, thin seam continuous miners and LHD machines. Without some casual "wave guide" such as cables, rails, steel ropes or pipes, a radio system cannot provide for long distance out-of-sight control. In most cases a "leaky feeder", installed throughout a mine, can provide reliable remote control links between a control suite and a mining machine.

<u>Advantages</u>

* It is easy to install, and only minor modification of machinery is required.
* Maintenance costs are moderate.
* It provides reasonable ruggedness and does not restrict day-to-day mining operations.

<u>Disadvantages</u>

* Propagation of radio waves is unstable.
  Propagation depends on:
  - Wavelength
  - Cross-section of mining development or face
  - Kind of rock, coal and moisture contents
  - Rock/coal stress
  - Conductive structures along propagation path.

* The electromagnetic field in a gate cross-section or near a machine chassis is unstable. Even a loose bolt on a machine in the immediate vicinity of the receiver antenna may be a source of interference and a cause of dropouts *(Thomas and Hiess,1988)*.

* Cross activation is possible. Cross activation is defined as the response of a radio controlled machine to a radio signal not directed to that machine *(Carter,1993)*.

* A stand-off control system may cost as much as 10% to 15% of the total machine price *(Thomas and Hiess , 1988)*. A reliable long distance remote control needs a costly leaky feeder.

A.4.2 Infrared

In the mining industry, infrared radiation as an open communication channel has been used since the late 1970's. In France it was used for automatic reversing of a mining plough, while in Germany infrared communication was employed for the tele-control of monorail haulage systems. In the United Kingdom infrared communication was utilized for coalface alignment and powered roof support initiation. In the former USSR the first research in propagation of infrared radiation in underground mines started in 1978 and commercial production of infrared stand-off control systems for LHD machines, loaders, roadheaders and shearers began in 1982 *(Kononov, 1987)*.

Research and practical experience has shown that even without special optical devices, and despite the presence of coal dust up to a level of 100 mg/m^3, a total LED radiation power of 200 mW can give reliable transmission distances of 30-40 m without a problem. A single lens at either the transmission or receiving side will increase the distance to 60-80 m. Due to the reflection of infrared radiation from road and pillar surfaces, as well as scattering at coal/rock dust particles, control is possible even without a direct propagation path between the infrared transmitter and receiver.

In stone dusted roadways or non-coal mines, the surface reflects 40% of incident 0.95 ìm radiation and an out-of-sight transmission distance of 10-15 m can be achieved. If a coal only surface is present which reflects only 6-8% of radiation, a distance of 2-4 m could be expected.

Both, line-of-sight and non-line-of-sight transmission distances are longer in non-coal mines.

The distance of non-line-of-sight control is dependent on parameters such as:

- Transmitted optical power
- Sensitivity of photo-receiver
- Optical direction of transmitter and receiver
- Mutual orientation of transmitter and receiver
- Roadway cross section
- Reflection coefficient of road/pillar surfaces.

Advantages

For standoff control an infrared channel has the following advantages:

* Fully independent of mining or technological conditions. If operator can see the machine it can be controlled at any condition within transmission range.
* High level of electromagnetic interference immunity and compatibility with other electronic and electrical equipment exists.
* Low cost.
* Harmless for human health.
* Deliberate delimitation of the control area is possible.

Disadvantages

* The non-line-of-sight communication distance is short and screening of direct infrared signals by moving equipment and personnel is possible. Using two or more spatially separated transmitters or receivers could prevent this problem.

* Periodical cleaning of transmission and receiving windows is needed.

A.4.3 Safety of wireless systems

Special attention has to be paid to the design of radio and infrared control systems to avoid cross activation. An underground mine in Ontario, Canada, reported at least one fatality in 1989 due to a radio cross activation *(Miess and Kowal, 1992).*

Using different separate frequency channels in the same work area is essential to prevent interference. A new concept of a smart wireless control to prevent cross activation has recently been proposed: each component of a wireless control system is assigned its own ID code at the factory - these ID numbers will be never used again. This allows the user to interchange machine and operator units without compromising the security of the wireless channel. To exchange the codes an operator connects a short cable between a portable controller and a machine unit. After about a second, the exchange or learning is complete and the system can be used in wireless mode. This operation must be done when any part of a system is changed.

A.5 Tele-control for drilling and charging

The main purpose of introducing tele-control and computer control for long-hole production drilling is to increase real drilling time, and to provide accurate control of hole length and deviation. Running time for a drilling machine is normally only 60-70% of the time available for drilling given travelling times, lunch breaks, ventilation requirements, etc. Computerisation of the drilling process enables rigs to work during these normally non-productive times, without operator's participation.

At Outokumpu Finnmine's Enonkoski Mine at least one hole is drilled by a Data Solo during the lunch break and one more while the shifts change, increasing overall drilling metres per day by about one-third *(Carter, 1993)*.

A rig can be left alone to drill the hole to the pre-programmed depth and after that to retract the drill string, dismantle it and put the rods in a magazine. Average increases of productivity can exceed 25% *(Chadwick, 1994)*. In drill and blast technology, accurate hole positions and orientations are the most critical factors affecting the tunnel dimensions or fragmentation of ore. Laser beams can be used to determine hole positions (drilling patterns) instead of manual marking-up of a face, and can reduce the amount of holes needed and the total drilling cycle time.

Computerised rigs are very complicated and expensive. The current difficulties with such drilling equipment are reliability and the lack of skilled personnel to maintain and repair such equipment.

Tele-control and computer control also provides better and safer working conditions for rig operators as they can be located away from the hazardous areas. In high grade uranium mines the application of computerised drilling equipment can improve safety and productivity significantly.

The Kurina Mine in Sweden has produced millions of tons of iron ore by sublevel caving. Their equipment includes a fully automatic SIMBA 269 (made by Atlas Copco) drill rig which can automatically extend, retract and store 54 drill tubes 1.875 m length. The operator is seated in a ventilated and heated cabin, supervising the rig via closed circuit TV *(Hamrin,1993)*.

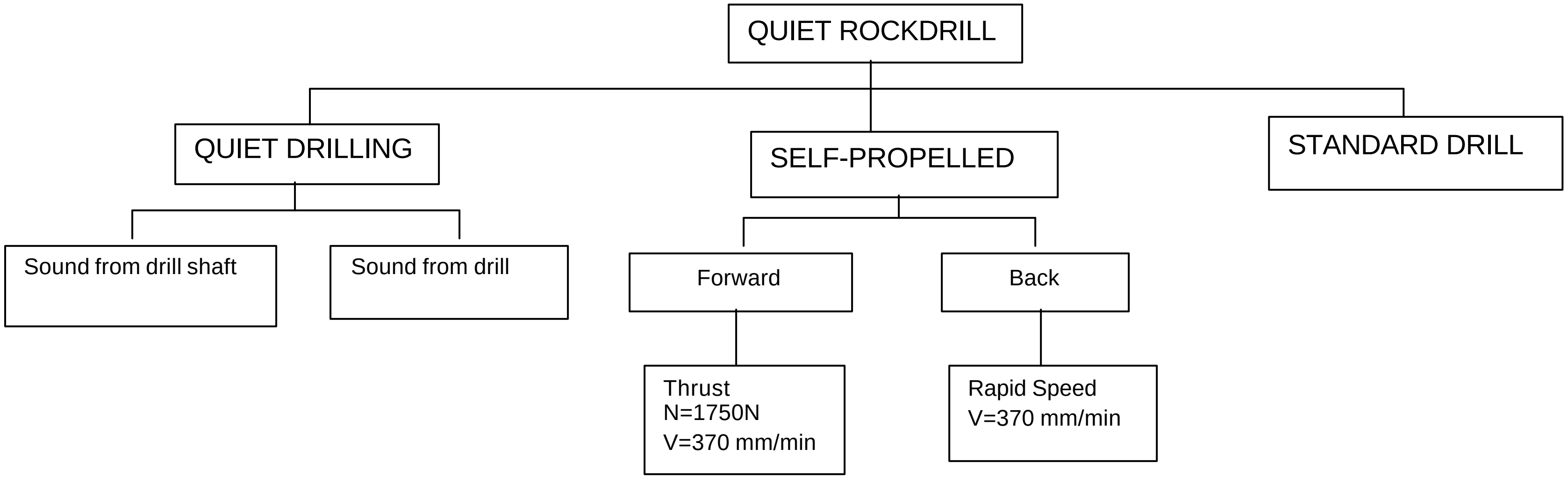
In spite of tele-control and computerisation, an operator's role will continue to be vital in order to control the quality of an excavation. He is also needed to adjust drilling parameters.

Tele-control for charging blast holes improves safety and operator working conditions. Infrared stand-off controlled pneumatic charging machines have been successfully used in Kombinat KALI in East Germany *(Kononov, 1987)*. The ROCMEC 2000, developed by Nitro Nobel AB, enables the operator to charge a hole and install the detonator from the machine cabin thereby reducing the risk of injury and eliminating manual labour.

A Miniature Blasting Method (MBM) was proposed in the late 1970's in the USA to reduce drill and blast cycle times. The method eliminates equipment "shuffling" in the face, drills small short holes, charges them with a small amount of explosive and blasts one hole at a time. It needs no fuse to detonate the charge. These Drill-Charge-Shoot Modules (DCS) can be installed on suitable vehicles or LHD machines and could be controlled in tele-control or automatic mode. Field tests were conducted at a quarry near Seattle. The basalt was drilled at a rate of 10 cm per minute. Thirty shots were made with the DCS and the performance of the explosive was reportedly excellent, using just 0.6 kg/m^3. The MBM has great potential for improvements through extended application of tele-control and automation, particularly, for small drifts *(Martin and Fitz, 1991)*.

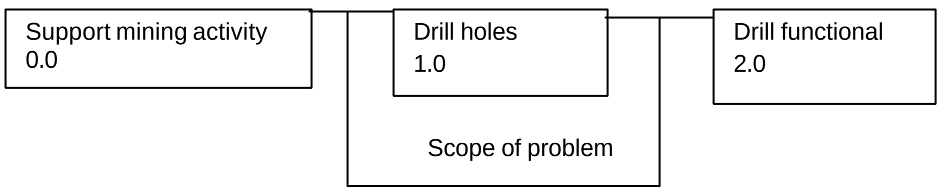
APPENDIX B: FUNCTIONAL ANALYSIS

SYSTEM LEVEL

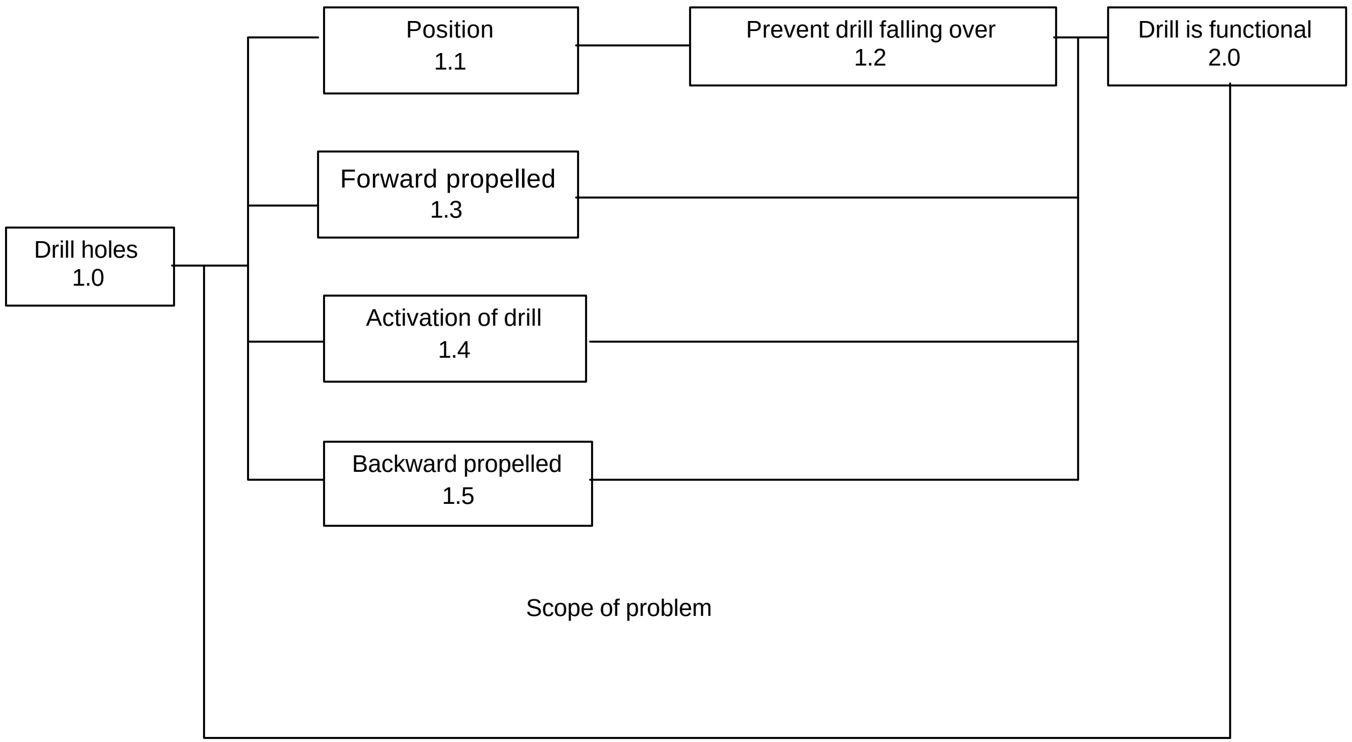


MISSION LEVEL

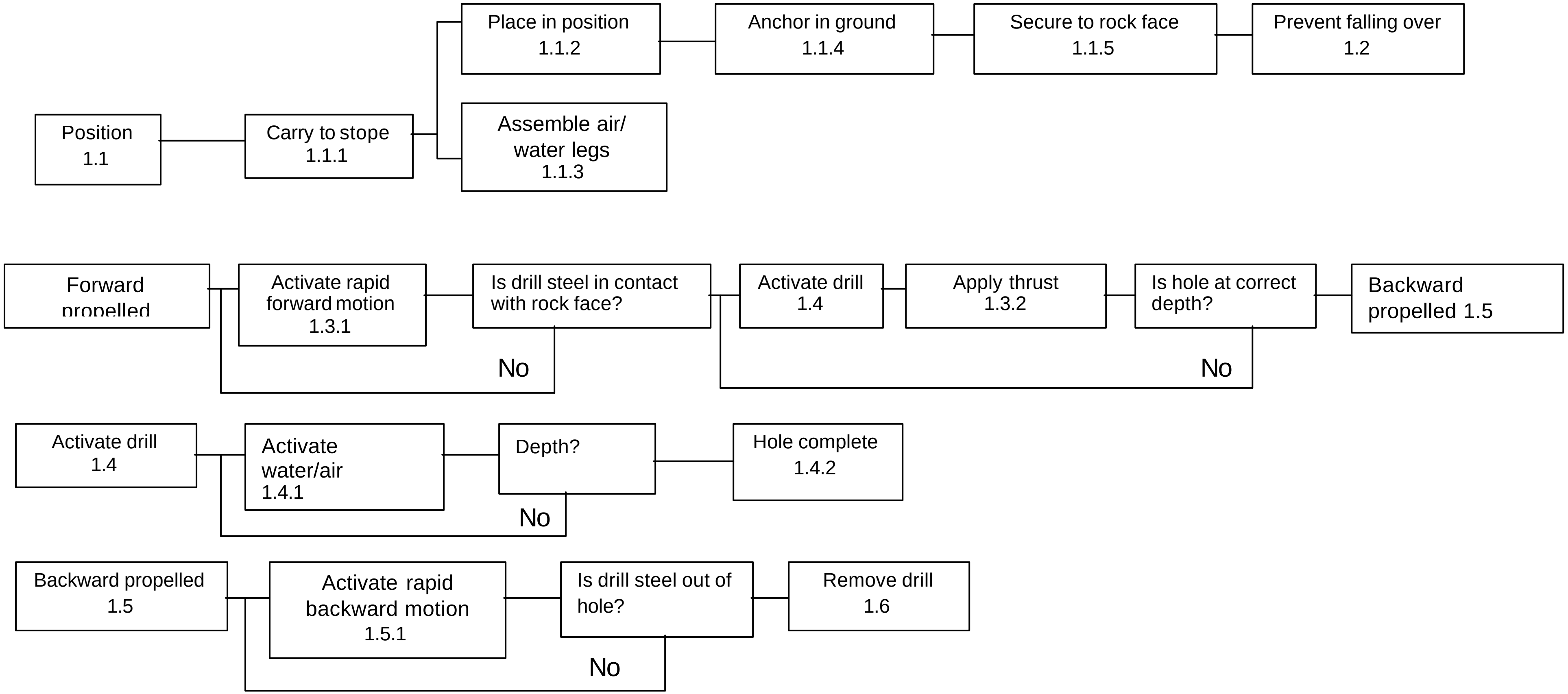
- Use of existing proven equipment
- Acceptable life expectancy
- Compatible
- Maintainable
- Reliable
- Compact
- Light
- Robust
- Simplicity
- Visible
- Sound power emission < 90 dBA
- Safety
- Self propelled
- Quick/easy drill steel assembly
- Flame proof
- Materials with low spark temperature
- Low vibration levels
- Remote control



SYSTEM LEVEL FUNCTIONAL DIAGRAM



FIRST LEVEL: FUNCTIONAL DIAGRAM



	FUNCTION	DESIGN PARAMETERS
1.1	**POSITION**	
1.1.1	Carry to stope	Light < 30 kg/ person
		Carry handle
		Bright colour (bright yellow)
		No protruding extension
		Robust (drop 3.5m onto 50mm steel ball –
		Denting not to affect function)
		Maintainable
		Corrosion resistance
		No lose items
		Two man operation
1.1.2	Place in position	Maximum length: 2000mm
		Two man operation
		No loose parts
1.1.3	Anchor in ground	Two-man operation
		No loose parts
		Maximum thrust: 1750N
		No rotation of drill
1.1.4	Secure to rock face	Two-man operation
		No loose parts
		Maximum thrust: 1750N
		No rotation of drill

1.2 PREVENT FALLING OVER

1.3 FORWARD PROPULSION

1.3.1	Activate rapid forward motion	Distance to travel: minimum Maximum speed: v = 370 mm/min Maximum air consumption: 55 l/sec @ 500 kPa. Maximum sound power emission: 90 dBA
1.3.2	Apply thrust	Thrust needed for drilling: 1750N Air consumption for air motor 16.5 l/s Air pressure for motor: 500kPa Maximum speed for drilling: v = 370 mm/min (40 mm drill bit) Maximum air consumption: 55 l/sec Maximum sound power emission: 90 dBA Drill steel release mechanism

1.4 ACTIVATE DRILL

1.4.1	Activate water and air	Maximum water consumption: 11 l/min@ 400kPa Maximum air consumption: 55 l/sec Maximum sound power emission: 90 dBA Effective flushing of hole
1.4.2	Hole complete	Depth: 1.2 – 2 m for 40 mm drill bit

1.5	**BACKWARD PROPULSION**	
1.5.1	Activate rapid backward motion	Minimum speed: 370 mm/min
		Distance to travel: 1200 mm + 100mm
		Maximum air consumption: 55 l/sec
		Maximum sound power emission: 90 dBA
		Maximum pull: 1750N
		Drill steel release mechanism
		Air pressure for motor: 500 kPa
1.6	**REMOVE DRILL**	Light < 30kg/person
		Carry handle
		100 – 200 (ergonomics sustained)
		Bright colour (bright yellow)
		No protruding extension
		Robust (drop 0.5 m onto 50 mm steel ball – Denting not to affect function)
		Maintainable
		Corrosion resistance
		No lose items
		Two man operation

DESIGN PARAMETERS FOR TELE-CONTROLS

	FUNCTION	DESIGN PARAMETER
1.3.1	Active rapid forward motion	Activation of forward motion of air motor Sensing of speed Sense drill position
1.3.2	Apply thrust	Supply motor with air and water Sense drill speed Sense drill position
1.4.1	Activate water/air	Activate water to drill Activate air to drill
1.4.2	Hole complete	Sense position of drill
1.5.1	Activate rapid backward motion	Activate reverse motion on air motor Sense travel speed Sense drill position
1.6	Remove drill	Shut off air to motor Shut off air to drill Shut off water to drill Signal hole complete

APPENDIX C : OPERATIONAL INSTRUCTIONS, ELECTRONIC CIRCUIT DIAGRAMS and PROGRAM FLOW CHARTS

C.1 Instructions for the Operator

Note: Throughout this document, words in italics depict control panel buttons, valves, registers and indicator flags.

The functions present on the remote controller are depicted in *Figure 7-1:* Functional representation of the remote controller.

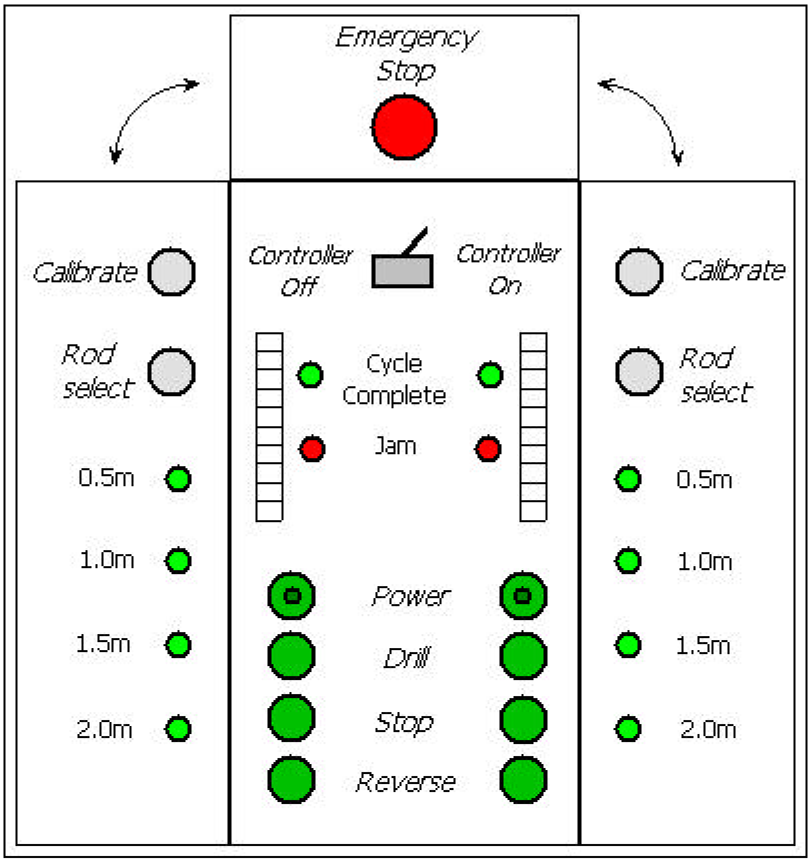


Figure 1. Functional representation of the remote controller

Normal Operation:

1. Ensure that the pneumatic and hydraulic hoses are connected to the rigs to be used.
2. Turn on the controller (*Controller On*). The yellow LED on the progress bar should illuminate indicating that the rig is in Standby mode.
3. Hold the *Power* button down for two seconds to set the rig to Operational mode. The yellow LED on the progress bar goes out and the previous system settings of rod size and progress are restored. If no drill progress

has been made, the *Cycle complete* LED[1] is lit up and the bottom LED in the progress bar will flash. Release the *Power* button.

4. When *Drill* is pressed, the automatic drilling cycle commences: If the drill rod was retracted to its proper starting position, then the *Cycle complete* LED turns off.. The system will turn on the drill, thrust to the maximum extent of the currently specified drill rod, retract to the starting position and turn the drill off. Upon completion of the drill cycle, the *Cycle complete* LED lights up and the bottom LED of the progress bar flashes. This process can be interrupted at any time by pressing *Stop, Reverse* or *Emergency Stop*.
5. The rig goes back into Standby mode by eiher holding the *Power* button down for two seconds, by turning off the controller (*Controller Off*) or by pressing *Emergency Stop.*

Drill steel length calibration:

1. Press the *Calibrate* button. The drill will be advanced to the front where it will stop. The drill steel can now be replaced.
2. Pressing *Rod Select* will alternate LED's between the various drill steel sizes. Select the desired drill steel length.
3. Once a drill rod has been selected, pressing *Calibrate* will retract the drill to the correct position for the specified drill steel.

Notes and troubleshooting:

1. The drill steel selection option is only available between the first and second time that the *Calibrate* button is pressed. During this time, both the *Drill* and *Reverse* buttons are deactivated. If the *Stop* button is pressed during the calibration process, it will be aborted and the previous set-up will be restored.
2. The *Emergency Stop* button can be pressed at any time. When this is done, the drill will be stopped and will enter into Standby mode.
3. Other than during the calibration procedure, the *Reverse* button can be used at will. The drill steel will automatically be stopped if it reaches the starting point, that is, where the Cycle complete LED lights up. Pressing Reverse again can further retract the drill steel. The rear limit switch will halt the drill if the user doesn't press *Stop* in time.
4. If communication is lost between the rig and the controller the red LED of the bar display will flash. Each time the light flashes a *Stop* command is issued. If the user moves back into range, normal operation will commence. The delay between moving into range and the commencement of normal operation can at times be lengthy and it is advisable to simply turn the controller off and then on again.
5. If no drill movement is detected within two seconds when the rod is supposed to be moving forward or backward, the red Jam LED will

[1] Note that the cycle complete LED is currently being used as an indication of the efficiency of the rig-to-controller communication channel. Each time that this LED is toggled, a packet of data has been successfully received from the rig. The cycle complete indication could easily be reintroduced.

illuminate. This LED goes off when the movement commences again. If there is a lack of movement , the user should press the *Stop* button to clear the problem.

6. If for example the pneumatic hose is connected for an extended period of time without activation of the rig, the battery may run down. If the battery level drops below a specific level (10.5V) then the generator will automatically be activated for a time sufficient to recharge the battery. The portable controller has currently no battery level monitor installed.

C.2 VALVE ARRANGEMENT

The valves present are :

1. *Generator On/Off*
2. *Drill On/Off*
3. *Thrust Forward/Reverse*

These are arranged as in Figure 6-1: Valve configuration below.

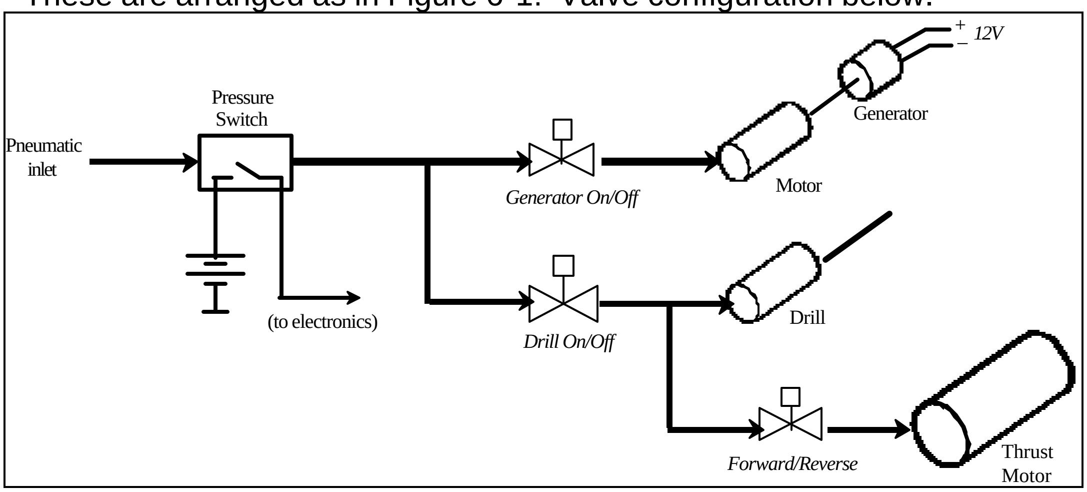


Figure 2. The required pneumatic valves

C.3 Rig Electronics

Figure 6-2: Schematic overview of electronic control layout in the drill.3 provides an overview of the electrical rig constituents , a more detailed diagram is presented in **Error! Reference source not found.**9 at the end of this document.

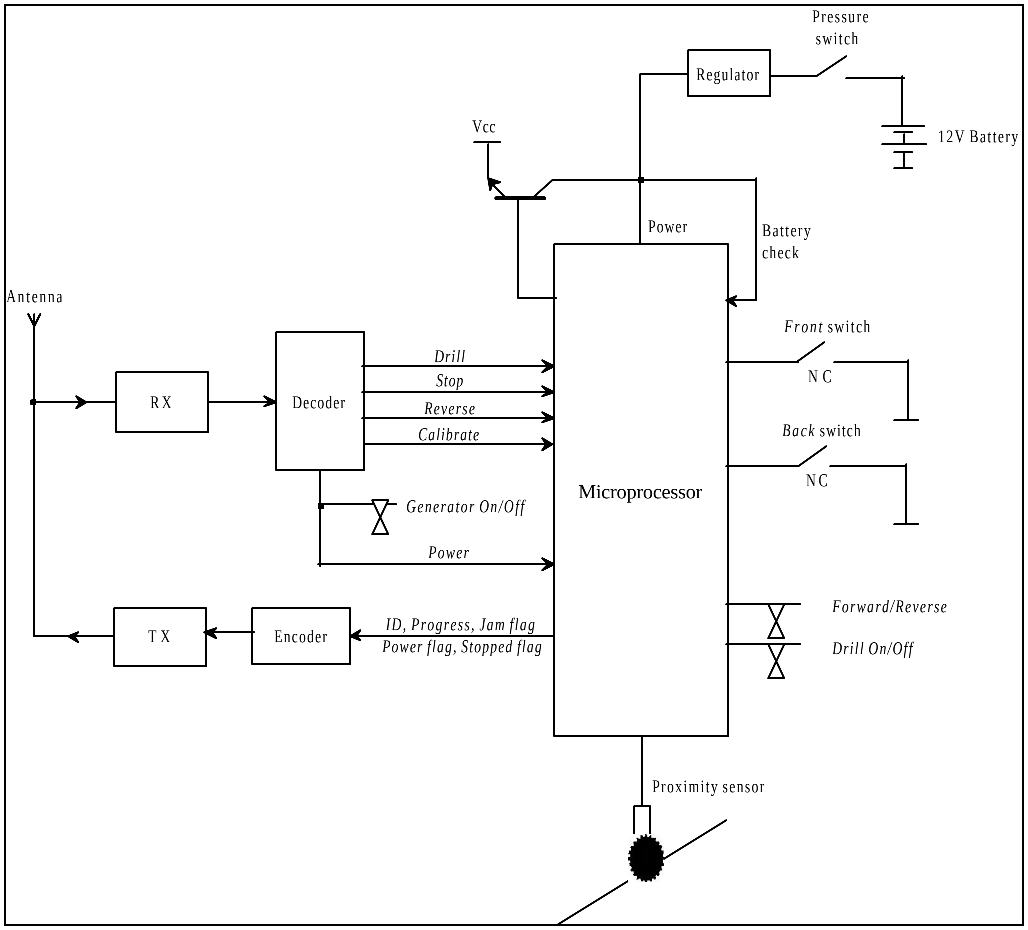


Figure 3. Schematic overview of the rig electronics constituents

Power is available to the electronics when the main pressure switch is closed, i.e. when the pneumatic hose is connected to the rig. A filter has been introduced on the pressure switch to eliminate unwanted effects such as switch bounce. Filters have also been introduced on the limit switch for similar reasons. The rig microprocessor fulfils the following functions:

1. When the pneumatic hose is connected and the portable controller has not initiated a *Power On* command, the rig electronics is in standby mode, a power saving feature. In standby mode, the power to the electronics is cyclically switched on for 400 ms and then off for 800 ms. The system remains in standby mode until the user holds the portable controller *Power* switch down for two seconds. When this occurs the system is put into

operational mode. In operational mode the power to the electronics is continuously on until the portable controller *Power* switch is held down for two seconds, or the emergency stop switch is pressed.

2. The battery level is monitored. If the battery voltage drops below 10.5 volts, then the generator is activated until the battery is charged. A regulator has been fitted between the generator and battery. It converts the messy generator output voltage (which often goes above 20 V) and regulates it to a smooth 13.8 volts for charging. Enabling and disabling the generator is done using the *Generator On/Off* valve. When the generator is turned on, the voltage immediately rises to the 13.8V charging level. The battery voltage can thus not be sampled while it is being charged. This is accommodated for by charging for five minutes, turning off the charger, waiting for the voltage level to settle, and then measuring. This process is repeated until the battery voltage reaches a sufficient level at which point the *Generator* valve is automatically turned *Off*.
3. By monitoring the direction and the proximity sensor pulses, the drill position can be tracked. When the machine is first put into use, an initial calibration should be conducted to obtain the first reference. Each time the front limit switch is pressed, the position reference is zeroed and any accumulated error is eradicated.
4. Control of the automatic drill process. This is initiated by pressing the *Drill* button, and involves the following sequence: *Drillvalve On, Forwardvalve On,* front limit switch pressed, *Stop, Reversevalve On*. Since only the controller knows the selected rod size, the controller issues the final stop command. This sets both *Drillvalve* and *Reversevalve* to *Off.*
5. Interpretation of the *Stop* and *Reverse* commands.
6. Partial control of the calibration procedure for changing drill rods: Upon receiving a *Calibrate* signal, thrust to the front limit and stop. Upon receiving a further *Calibrate* signal, retract the drill. The rod size selection and the final *Stop* command is issued by the portable controller.
7. The following data stream is put out onto the TX: An identity code, the drill position, a jam indicator, a power status indicator and a flag to indicate that the rig has stopped. This last flag acts as confirmation after the portable controller sends a stop command. There is ample room to accommodate information regarding additional system errors.

C.4 Program description:

Error! Reference source not found. and **Error! Reference source not found.**5 present very simplified flowcharts depicting the core features of the software. Indicator flags are depicted by the suffix "_f".

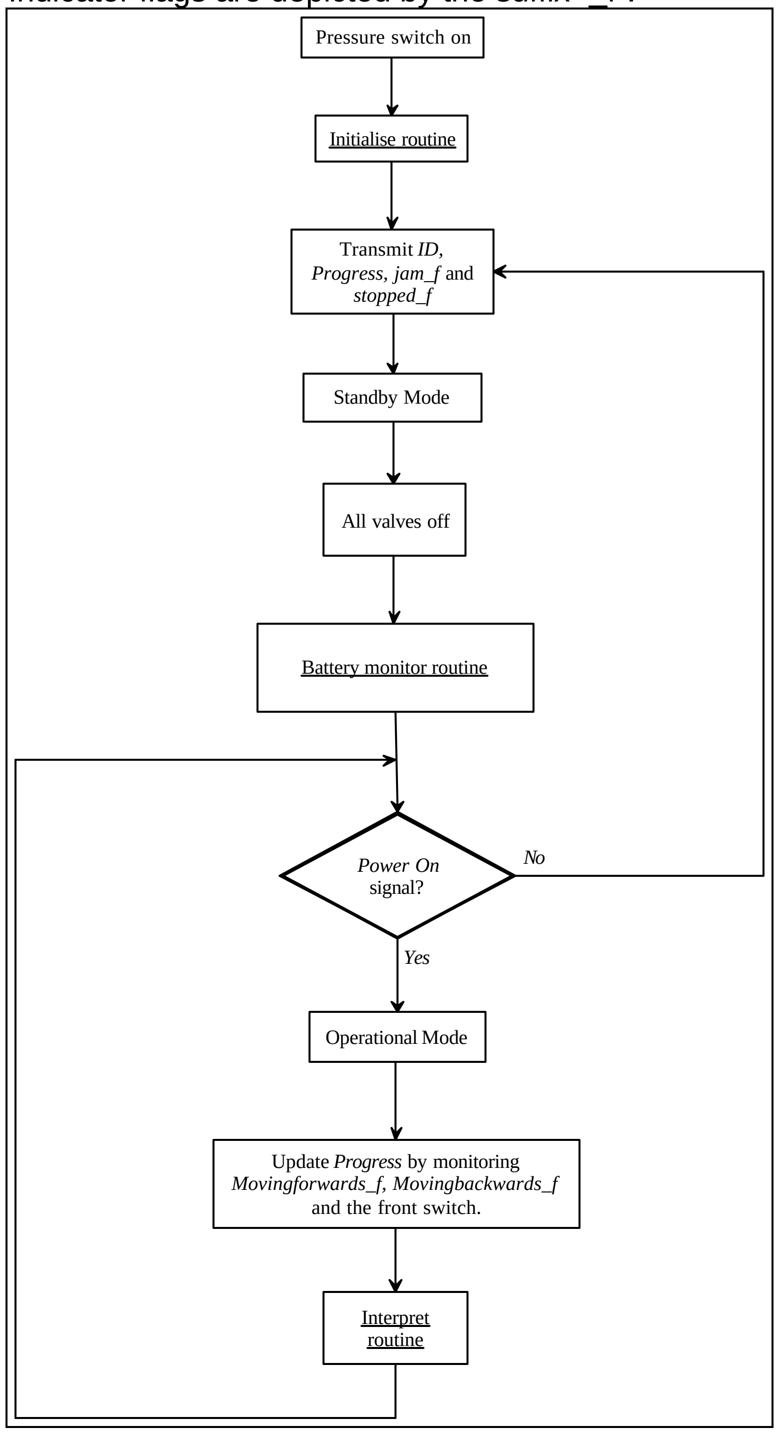


Figure 4. Main program loop for the rig microprocessor

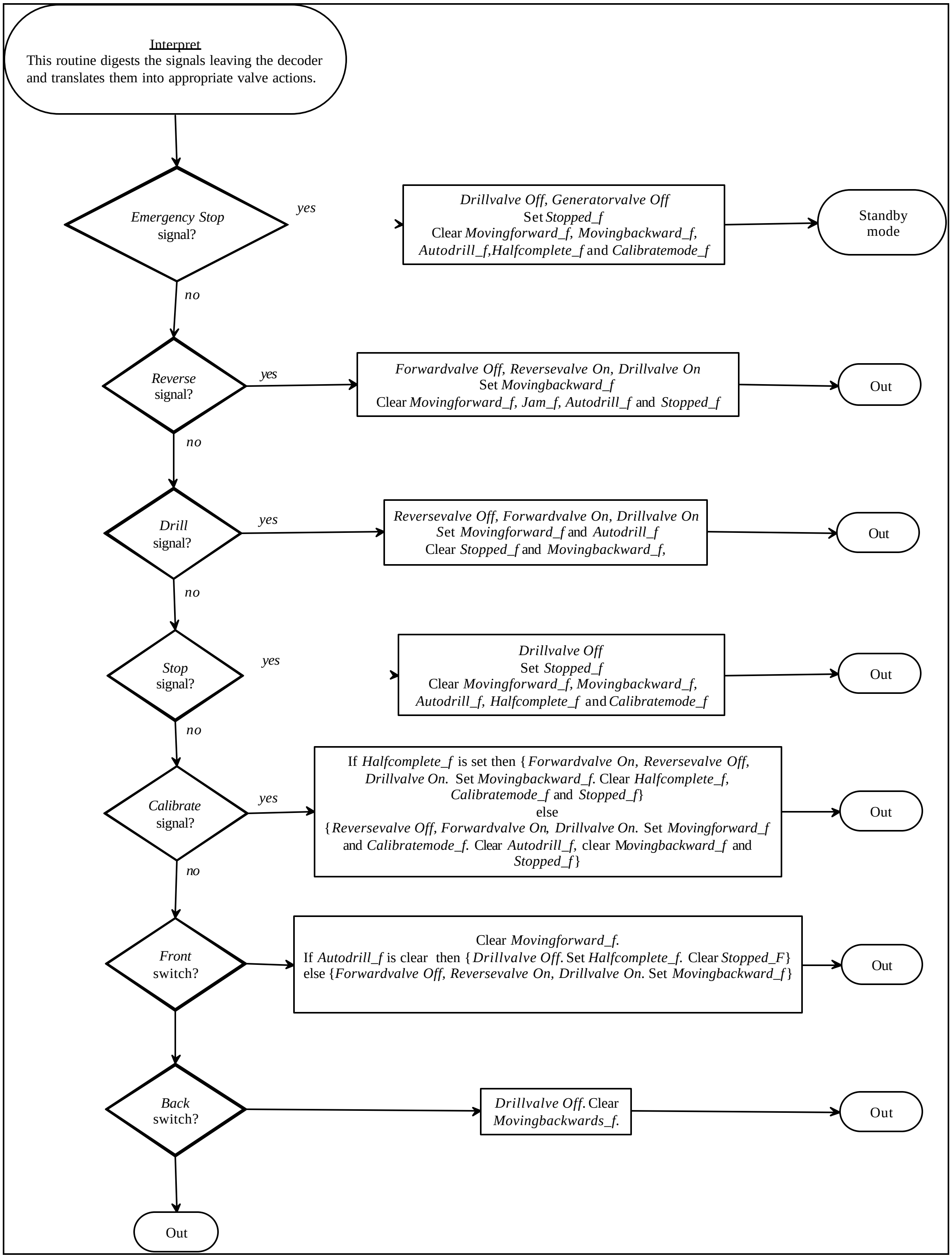


Figure 5. Interpret routine for the rig microprocessor

C.5 Controller Electronics

Each rig is controlled by a separate identical microprocessor. An electrical schematic of one of the two microprocessors is given in **Error! Reference source not found.**. A more detailed diagram is presented in **Error! Reference source not found.**8. at the end of this document.

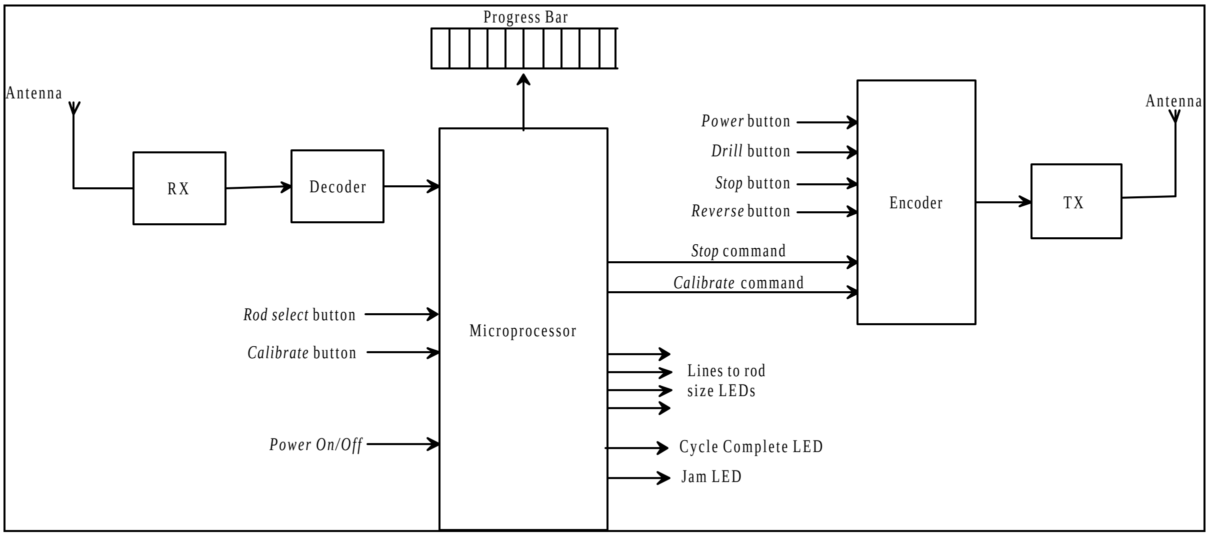


Figure 5. Controller microprocessor and its peripherals

The microprocessor in the controller has the following functions to fulfil:

1. Receive and interpret the data string sent by the drill rig unit (*ID, Progress*, *Jam_f, Power_f* and *Stopped_f*). If no data is received within 4 seconds, flash the red LED of the progress bar and issue a *Stop* command.
2. If the *Power* button is held down for two seconds and the drill rig has confirmed the power status (*Power_f* set) then toggle the power on and off.
3. Store the set drill rod size and drill rod position in EEPROM.
4. Update the progress bar according to the current position.
5. In both, the *Drill* and the *Calibrate* sequences, this controller is required to send a *Stop* signal to the rig when the drill has retracted to the required position.
6. Control the *Cycle complete* and *Jam* LED's.

C.6 Program description:

The program essentials are represented in **Error! Reference source not found.**.

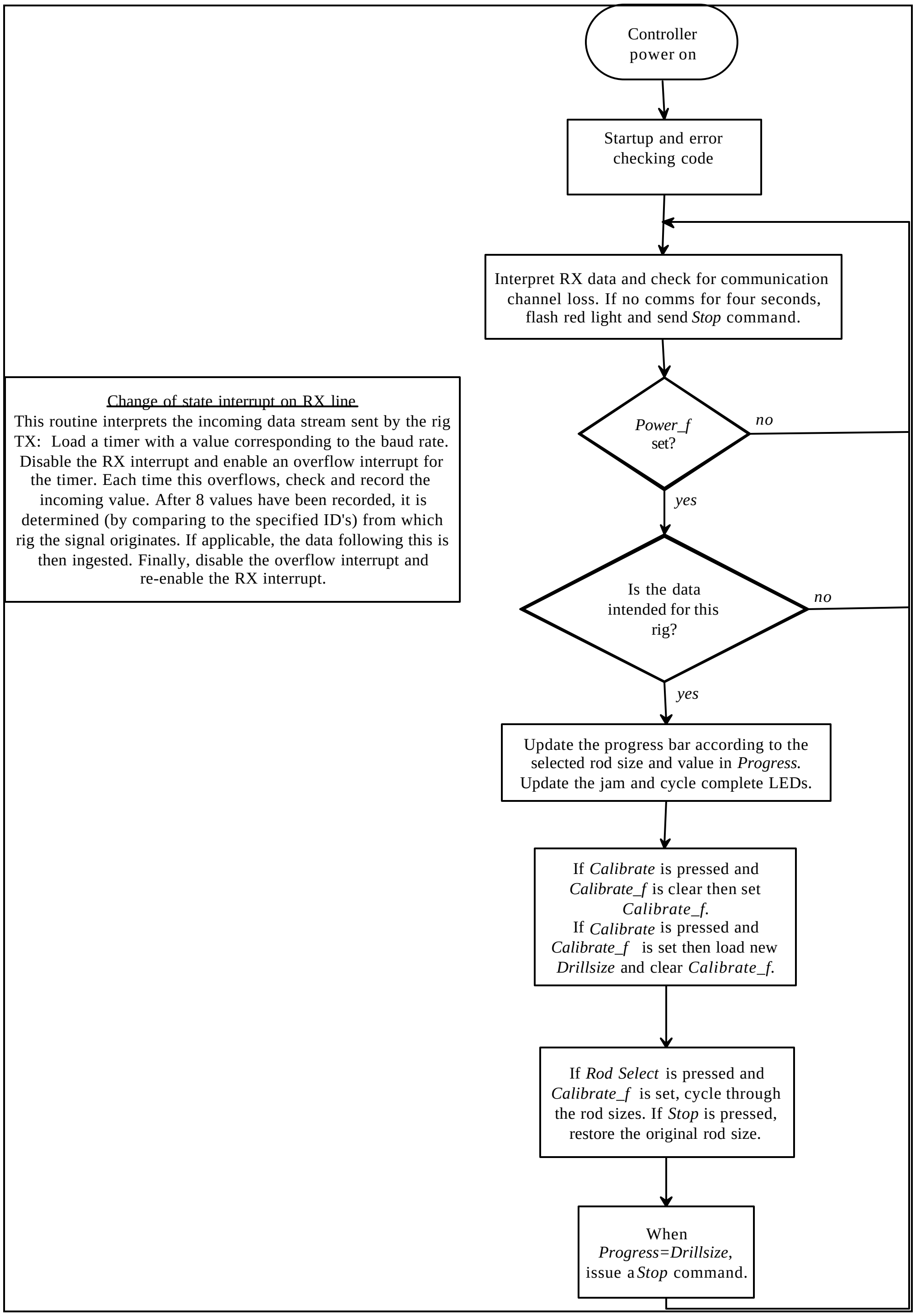


Figure 6. Main program loop for one of the microprocessors in the portable controller

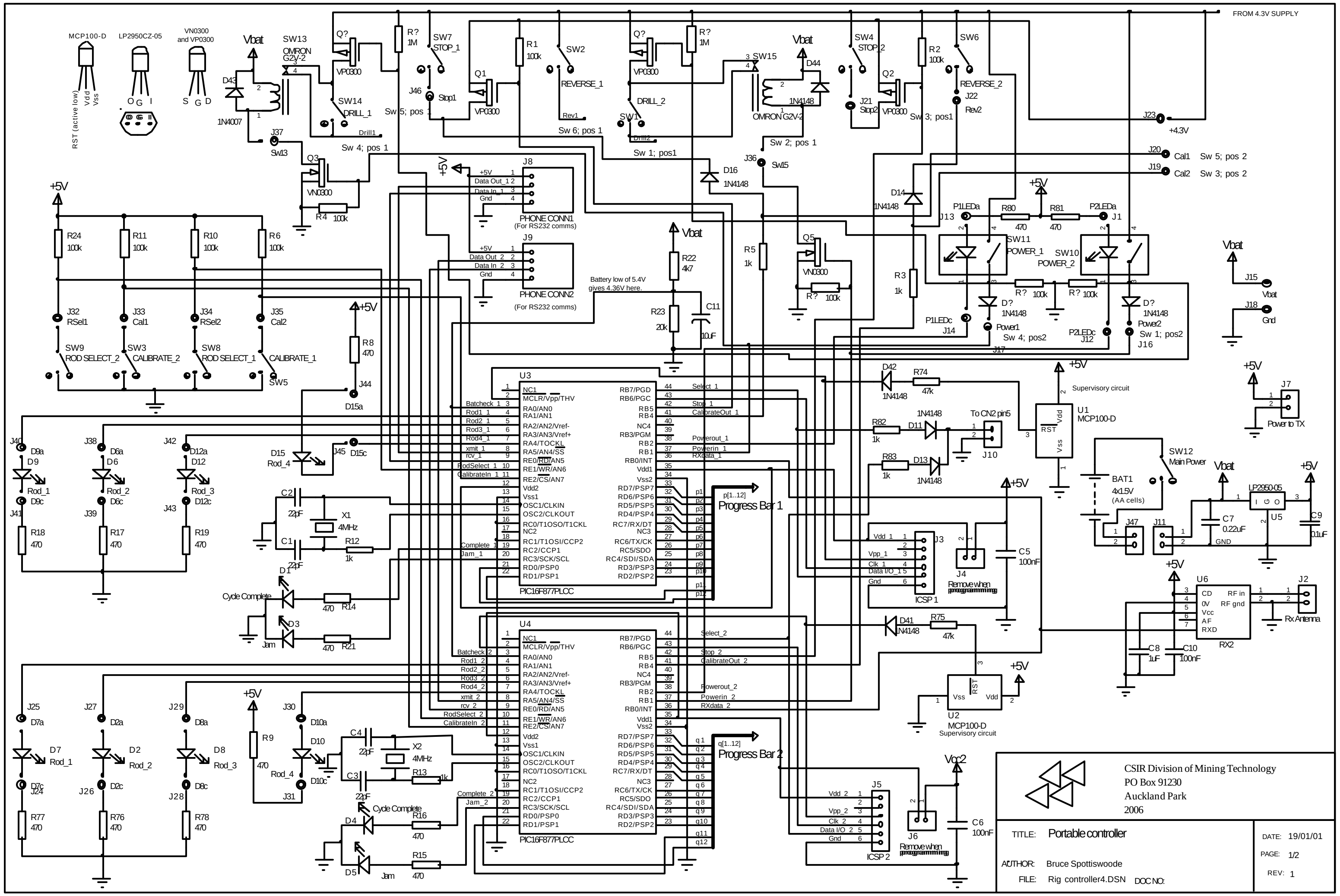


Figure 8. Schematic circuit diagram for the portable rig controller

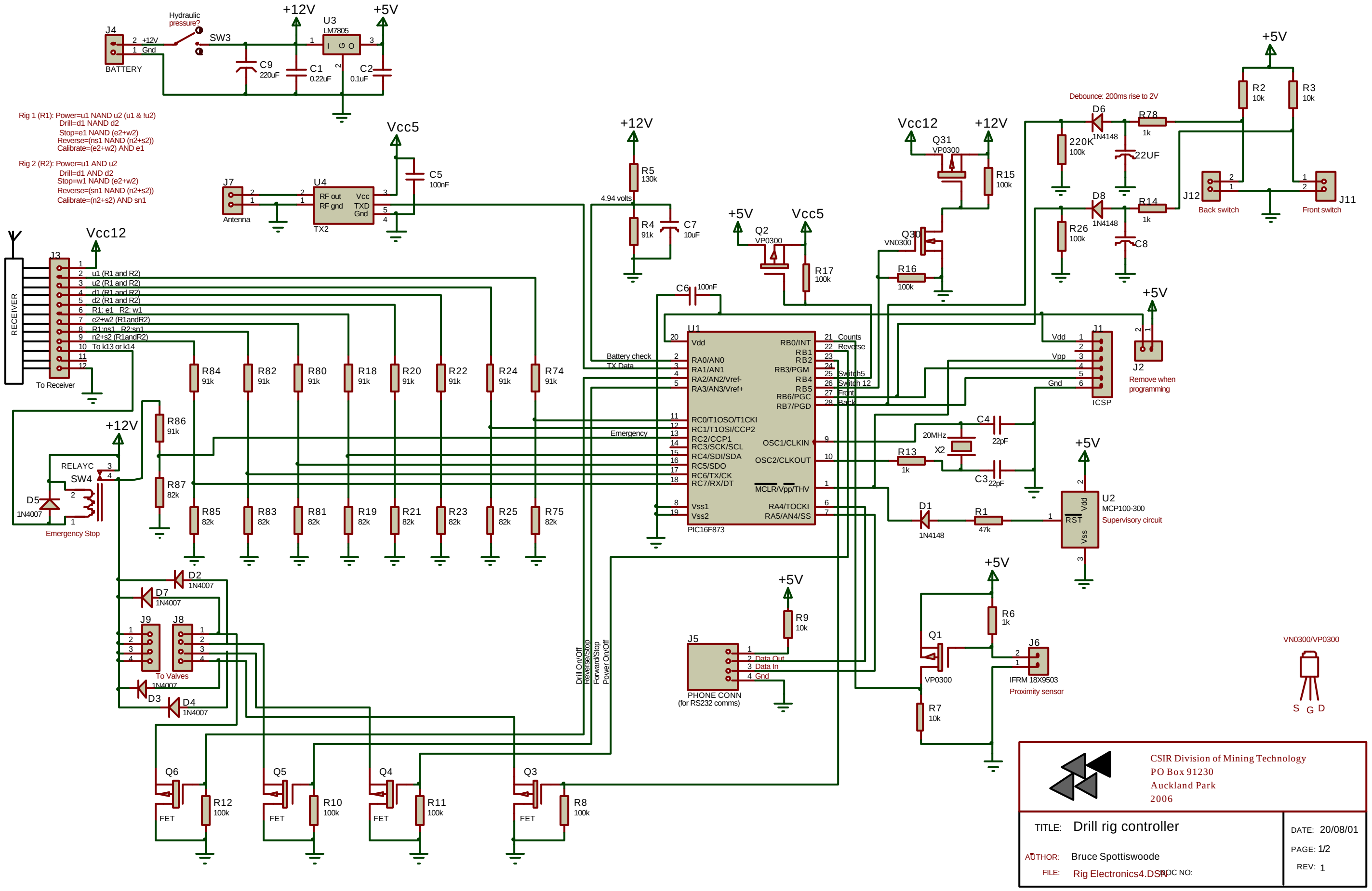


Figure 9. Schematic circuit diagram for the electronics housed in the rig