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The elimination of electrical power limitations in the Production Section of a South African Coal mine to facilitate additional production improvements.

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SUMMARY

Sasol Mining embarked on a renewal process during the beginning of 1998. The objective of this renewal process was based on a very clear case for change - Sasol Mining had to improve on its profitability as a coal mining company. The renewal process focussed on the following drivers:

- Q - The quality of coal delivered to the synthetic fuels plant (Sasol Synfuels) has to improve with respect to contamination.
- C - Production cost of coal/tonne must be contained, with an annual escalation of 1% less than the Producer Price Index (PPI).
- D - Delivery (tonne/continuous miner/shift) must improve.
- S – The health and safety of the operations has to be improved substantially, e.g. dust in ventilated areas.
- M - Morale of employees has to be raised substantially.

Referring to the above and specifically to `Delivery`, there was a potential threat that some of the underground (in-section) electrical equipment and infrastructure may be stressed beyond their design capacity and limits. A typical example was the question: Will the electric cutter motors on the continuous miner be able to cut continuously at the increased rate?

This study proactively investigated the matter and analysed the effect of the increased demand on certain equipment and infrastructure of the electrical in-section systems. The objective was to determine the production capacities (tonne/continuous miner/shift) that can be sustained by utilising present mining equipment and cables.

The power consumption of all the equipment in a standard section was measured to determine the present production capacity of various items of mining equipment used in a production section. The data was then evaluated to determine the limitations in the production section.

These results will assist Sasol Mining to determine the focus for upgrading different items of production equipment, taking into account the production potential of the in-section production equipment.

OPSOMMING

In die begin van 1998 het Sasol Mynbou begin met ‘n vernuwings proses. Die doel van die proses was gebaseer op ‘n noodroep vir verandering – Sasol Mynbou moes sy winsgewendheid as ‘n steenkoolmyngroep verbeter. Die vernuwings proses het gefokus op die volgende faktore:

- Q - Die kwaliteit van die steenkool wat aan die sintetiese brandstofaanleg (Sasol Synfuels) gelewer word moet verbeter in terme van kontaminasie.
- C - Produksiekoste van steenkool/ton moes beperk word tot ‘n jaarlikse eskalasie van 1% minder as die Verbruikersprysindeks (VPI).
- D - Lewering (ton/aaneendelwer /skof) moet verbeter.
- S – Die gesondheid en veiligheid van die bedryf moet verbeter, byvoorbeeld stof in geventileerde omgewings.
- M - Moraal van werknemers moet drasties verhoog word.

Met verwysing hierna, en veral ‘Lewering’ was daar ‘n potensiële bedreiging dat party van die toerusting en infrastruktuur van ‘n ondergrondse produksie seksies dalk bo die ontwerpvermoë en -limiete gedryf kon word. ‘n Tipiese voorbeeld is die vraag: Sal die snyermotors van die aaneendelwer aaneenlopend teen ‘n verhoogde snytempo kan produseer?

Hierdie studie het die probleem proaktief ondersoek en die uitwerking van verhoogde vraag op sekere toerusting en infrastruktuur in die elektriese stelsels van ‘n produksieseksie ontleed. Die doel van die studie was om die produksievermoë (ton/aaneendelwer /skof) te bepaal wat deurlopend gehandhaaf kan word deur bestaande toerusting en kabels te gebruik.

Die kragverbruik van alle toerusting in ‘n standaardseksie is gemeet om die huidige produksievermoë van verskeie items myntoerusting in ‘n produksieseksie te bepaal. Die data is daarna geëvalueer om die beperkings in die produksieseksie te bepaal.

Hierdie resultate sal Sasol Mynbou help om die fokus te bepaal vir die opgradeing van verskeie stukke produksietoerusting met inagneming van die potensiële produksievermoë van die toerusting wat nou gebruik word.

Vertrou volkome op die Here en

moenie op jou eie insigte staat maak nie – **Spreuke 3:5**

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SOS	=	Start of shift
EOS	=	End of shift
MSU	=	Mobile Switching Unit
GEB	=	Gate end boxes
CM	=	Continuous Miner
SC	=	Shuttle Car
FB	=	Feeder Breaker
RB	=	Roofbolter
RH	=	Right hand side
LH	=	Left hand side
LV	=	Low voltage
HV	=	High voltage
JNA	=	JOY Network Architecture
1 tonne	=	1 metric tonne = 1000 kg
m	=	meters

CHAPTER 1

INTRODUCTION

One of Sasol's values is "Continuous Improvement". A company needs to sustain constant growth in order to compete and survive in highly competitive markets. Sasol Mining is a global player competing in these markets and is thus continuously looking for ways to improve productivity and profitability.

1.1 BACKGROUND

The Renewal and Vuselela initiatives brought significant production improvements for Sasol Mining. It increased productivity from 900 tonnes/continuous miner/shift in 1997/98 to 2000 tonnes/continuous miner/shift in 2004/05. The maximum planned productivity figures are 2400 tonnes/continuous miner/shift, utilising present equipment and mining methods.

The Renewal initiative helped Sasol Mining to win the International Coal Company of the Year Award in the 2002 Platts/Business Week Global Energy Awards competition, and the Vuselela initiative will try to keep Sasol Mining in this position.

This improved production has an effect on the in-section electrical system. If production is increased, electricity consumption is increased, for example the cutter motors on the continuous miner (CM) work harder and the duty cycle of a shuttle car increases.

The threat at present is that further production improvements may exceed the production capacity of various pieces of equipment that are integral parts of the in-section electrical system. The in-section electrical system must be capable of sustaining further production improvements. Thus, the objective of this investigation was to determine which electrical components of the in-section power system were limiting the production capacity.

For example, just before this investigation started, there were a lot of breakdowns on the pump motors of the 16 tonne shuttle cars. The shuttle car used to be fitted with a

10 kW pump motor that powered the hydraulic systems. Increased production required this motor to work harder.

The investigations into these breakdowns after many motors were replaced revealed that the motors were too small for the increased workload. The average power consumption exceeded the motor's ratings, which caused the failures. The duty cycle imposed on the motor was a continuous S1 duty, whereas the motor was designed for S6 duty. The 10 kW motors have since been replaced with 15 kW, S1 duty type motors.

The data from the investigation pointed out that the duty cycle imposed on the motor exceeded the rated duty cycle of the motor. This meant that the duty cycle of the motor had to be changed. It is not clear from the data why a larger motor was needed for the application; a motor with a higher duty cycle would have been sufficient. This type of exercise was repeated on all the components of the in-section electrical network to determine possible limitations in the network before they were reached.

1.2 PURPOSE OF STUDY

Sasol Mining is increasing productivity, as stated already. This increase in productivity has an effect on the electrical system. The effect of this optimisation effort directly influences the power consumption of the in-section electrical system. The in-section electrical system may now become a bottleneck for increased production. The study was aimed at determining the limitations posed by the in-section electrical system as a consequence of the production improvements.

The in-section electrical system of the mine consists of various pieces of mining equipment and a distribution network. The equipment in turn consists of various subcomponents. The duty cycle and/or average power consumption of the equipment and subcomponents increase if the production rate is increased. All the equipment and subcomponents of the in-section electrical system will be discussed more thoroughly in Chapter 2.

Each subcomponent can sustain only a specific duty cycle or average power consumption. Therefore it influences the overall throughput. The limitations of the subcomponents limit the maximum capacity of the specific equipment. Equipment with a great production capacity is limited in its productivity by the production limitation of another piece of equipment or one of its own subcomponents. The equipment and the subcomponents that limit the overall production capacity must be pinpointed and replaced, or their capacity must be improved to be able to sustain a greater overall production capacity in the section.

The downside is that if, for example, the pump motor on a shuttle car is a limitation and a larger motor is installed to remove the limitation, it will put more pressure on the supply network, since the larger motor will consume more power. So by improving the capacity of the motor, the bottleneck will be shifted from the motor to another component in the network.

Next, the motor contactors must be tested to determine if they can still handle the load current of a larger motor. Then it must be determined if the trailing cable can still supply enough power to the shuttle car and if the gate end boxes, flameproof transformer and electrical supply network can still deliver enough power to the section.

This investigation will help Sasol Mining to react more proactively to these types of threats. Possible limitations in the production capacity of various items of mining equipment will be identified long before they become problems. Recommendations and suggestions on how to further improve or increase production were also made.

1.3 ISSUES TO BE ADDRESSED

The output of the investigation should provide answers to the following issues that would benefit Sasol Mining:

- The energy consumption points in a production section.
- The capacity, rating and duty cycle of currently used equipment and subcomponents.
- The capacity, rating and duty cycle of equipment and subcomponents limiting the production capacity.
- The effect on the life expectancy of subcomponents if continuously exposed to overload conditions.
- Suggestions on how to further improve the production capacity of a production section.

Challenges in executing this investigation included:

- Measuring the power consumption of individual components on every piece of mining equipment for various production rates.
- Obtaining measuring equipment for a flameproof environment.
- Simultaneous measurements of electrical energy on all major equipment and subcomponents in the in-section electrical system.
- Determining the influence of individual equipment and subcomponents on coal production.
- Accurately determining the maximum sustainable production capacity of a specific piece of equipment or subcomponent.

Only the electrically powered mining equipment used in a standard section was investigated. It included all the equipment that form part of the in-section electrical supply network, thus from the MSU (Mobile Switching Unit) towards the in-section. It also included all the equipment supplied with power from the in-section electrical distribution network.

All the equipment included in this investigation are intended for future use at Sasol Mining. This effectively means that mining equipment earmarked for replacement or already being phased out was excluded from this investigation. For example: Sasol Mining has 16 tonne and 20 tonne shuttle cars. All the 20 tonne cars will be replaced by 16 tonne cars, with most 20 tonne cars already having been replaced. The 20 tonne shuttle car, therefore, fell outside the scope of this investigation.

All equipment forming part of the conveyor belts were excluded from the investigation, except for the feeder breaker (crusher). It was assumed that the production capacity of the conveyor belts would not be a limitation to the production capacity of a production section. The mine’s electrical supply network towards the MSU was also excluded from this investigation.

1.4 RESEARCH METHODOLOGY

The investigation had four primary steps. The first step was to identify all the electrical energy consumption points (loads) in a section. The sections chosen for the study had to be typical and top producing sections of Sasol Mining. A typical section for the purpose of this investigation is defined as a section with an average coal seam height of between 3 m and 4 m. The production equipment used in such a “typical” section would be a JOY continuous miner with a JNA 1 controller and three 16 tonne shuttle cars.

The next step was to determine the ratings of these electrical loads and to identify which of them would change, either in capacity, power rating or duty cycle, if the production rate were increased.

The third step was to determine what coal production throughput in tonnes/continuous miner/shift could be sustained by utilising the current ratings on cables, motors, etc.

The last step was to determine at what point the motors, transformers or cables would become overloaded if higher production rates were encountered, and what the ratings for motors or cables should be. Problems addressed included the following:

- Obtaining the design production capacity of various pieces of mining equipment.
- Measuring the total electrical consumption of all the equipment used in a section and the consumption of each individual subcomponent forming part of the equipment.
- Determining the production capacity of the individual pieces of mining equipment through measurement.
- Processing the information to determine the maximum production capacity that could be sustained with the present in-section electrical system.
- Identifying which of these loads need to be changed either in capacity, power rating or duty cycle to improve production.
- Recommending new electrical components that can replace the present components to increase the production capacity of the overall system.
- Recommending improvements to the in-section power distribution system to provide the additional capacity to deal with the increased production.

Measuring equipment such as power, voltage, current, temperature and power factor meters were used to determine the different variables of all section equipment or subcomponents. The coal tonnage produced during each shift was measured with scales already installed on the conveyor belts.

Data was analysed using Microsoft® Excel and Matlab®, and the final results will be incorporated in the mine's load flow forecast to help with production planning.

1.5 BENEFICIARIES

Sasol Mining is the main beneficiary of this investigation. Equipment manufacturers such as JOY, ARO, Fletcher and Dimako would benefit indirectly. If they were provided with the results of this investigation, they could improve their products to sustain a higher production throughput.

Sasol Mining would benefit in the following ways, for example:

- The thorough investigation of the in-section production process.
- The true combined production capacity of a section was determined, as well as the production capacity and energy requirements of each component in the system.
- Equipment or components in the production system that limit production capacity were identified.
- Recommendations and suggestions were made on how to further improve production and production capacity.

CHAPTER 2
LITERATURE STUDY

Coal is sometimes called black gold. The reason for this is not always obvious, but if the uses for coal are investigated the meaning becomes clear. Coal is used for the generation of electricity, without which the world would not be the same place. Another application of coal that is unique to Sasol, is the conversion of coal to synthetic petrol and diesel fuels and chemicals.

The methods used for mining coal have changed drastically over the last number of decades. Coal was originally produced using picks and shovels, and later on explosives and drills were used. The coal mining process became mechanised as technology developed. Large electrical and diesel-powered machines automated the mining process and increased the production capacity considerably. Different mining methods were introduced, and these gave rise to the development of new equipment suited for each mining method.

2.1 BACKGROUND

South Africa's second largest domestic coal producer has, until recently, had very little to do with South Africa's largest coal consumer. The focus of Sasol Mining has always been the supply of coal for the production of synthetic fuels and petrochemicals. Through a careful strategy of matching and mixing, it will be beneficial to both the state-owned Eskom and the private sector company Sasol if Sasol Mining could sell coal to Eskom as well. Sasol Mining's first priority will always be the Synfuels plant at Secunda and the Infrachem factory at Sasolburg. Sasol Mining is free to exploit other markets once these obligations have been satisfied. Coal is also being exported, in addition to the coal that is supplied to Eskom.

Sasol Synfuels use two particle sizes – coarse coal between 6,3 mm and 75 mm for gasification and fine coal smaller than 6,3 mm for steam generation. Eskom generally needs fine coal with a low percentage of coarser coal, the production of which presents no insurmountable obstacles for Sasol Mining.

2.1.1 Production targets

The Renewal and Vuselela initiatives brought significant production improvements for Sasol Mining. It increased productivity from 900 tonnes/continuous miner/shift in 1997/98 to 1725 tonnes/continuous miner/shift in 2003/04. The maximum planned productivity figures are 2400 tonnes/continuous miner/shift. The Renewal initiative helped Sasol Mining to win the International Coal Company of the Year Award in the 2002 Platts/Business Week Global Energy Awards competition, and the Vuselela initiative will try to keep Sasol Mining in this position.

2.2 COAL MINING

There are two main types of coal mining used throughout the world. These types are surface and underground mining. Surface mining is more commonly known as strip mining. It is applied where the coal seams are close to the earth's surface and where the surface can be disturbed. A number of underground mining methods are used. These methods include longwall mining, either as retreating or advancing operations, board and pillar mining and pillar extracting mining.

Advancing longwalls are not used in South Africa, but have been widely used in European countries where relatively thin seams are extracted in deep mines (400 m to 1500 m). Retreating longwalls forms only about 5% of underground coal production in South Africa, as longwall equipment is very expensive and because conditions are not always suitable for the longwall layout.

Board and pillar methods are predominantly used in South Africa, as the coal seam is thick and close to the surface and because the surface should be protected. It is estimated that about 80% of underground coal production in South Africa is mined by the board and pillar method and 15% by pillar extraction.

Another estimation is that well above 90% of the coal mining industry in South Africa is mechanised. Huge diesel or electric powered equipment replaced the conventional manual mining methods. A short description of each mining method is given below.

2.2.1 Strip Mining

Strip mining is surface mining, where overburden or waste material is removed to reach the shallow coal seam. This coal is then removed and the overburden replaced and rehabilitated to its original state. Strip mining can only be used if the area's surface can be disturbed.

To effectively use this type of mining, huge mining machinery is needed. Draglines (Figure 2.2-1), shovels, trucks and bucket-wheel excavators are used to dig and load the trucks. The sizes of the trucks vary, and some of them are capable of conveying more than 150 tonnes at a time. The selection of strip mining equipment is based on a number of factors, such as the surface topography, the nature, extent and shape of the coal seam, production requirements, the nature and depth of the overburden and reclamation considerations.

Figure 2.2-1: Dragline used to remove overburden [1].

The coal seams in the Witbank coalfield are relatively close to the surface, which makes strip mining cheaper than underground mining. Board and pillar methods have been replaced by strip mining in this area. Underground mining is used only where the surface may not be disturbed when removing the coal.

2.2.2 Board and pillar

The most common underground coal mining method in South Africa is board and pillar mining. This method leaves coal pillars to support overlying strata. The method is normally used where coal seams are thick, relatively close to the surface and where the surface may not be disturbed. The board and pillar method can be seen in Figure 2.2-2.

Roads are mined in a checkerboard fashion, leaving pillars to provide support to the overlying strata as mentioned in the previous paragraph. Five or more headings are developed for operations with shuttle cars. The size of the pillars depends on the local strength or quality of the strata. The risk of rock falls and cave-ins are higher in low-quality strata, normally called dykes. In such cases the roads are lower and narrower to provide bigger and stronger pillars. This leaves more support for the roof to withstand the mass of the overlying strata.

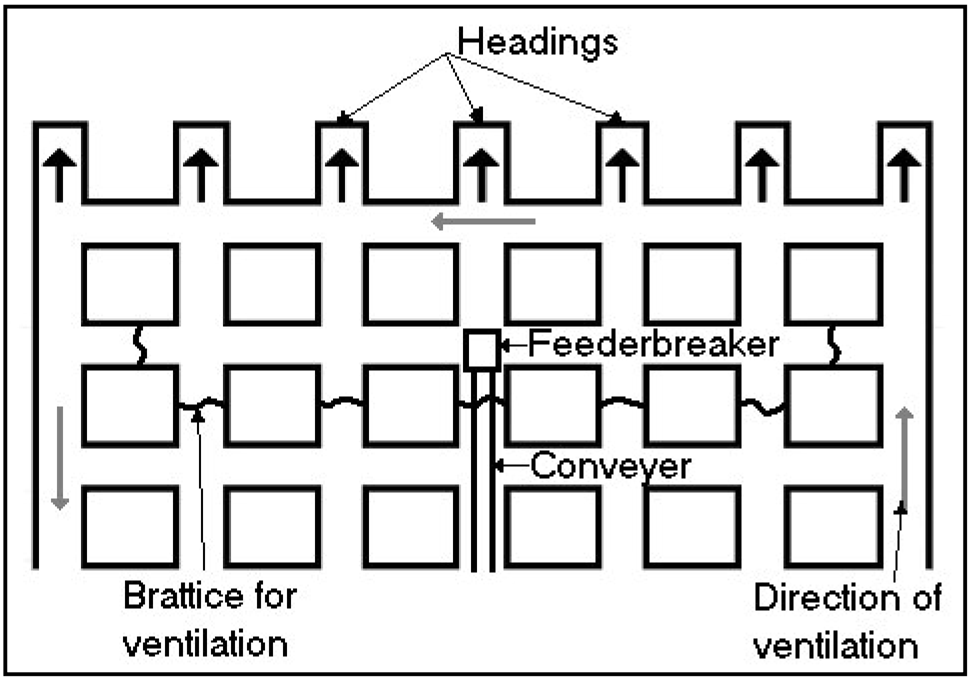


Figure 2.2-2 Board and Pillar mining method [2].

The conventional board and pillar mining method uses a coal cutter and a coal drill. The mechanised board and pillar mining method uses a continuous miner. The continuous miner is a single, self-tramming, electrically powered machine that cuts coal from a solid face and loads it simultaneously onto a conveyor system. Depending on the quality of the strata, the following procedure is normally used (see Figure 2.2-3):

- The board is advanced on one side of the roadway for about 4 m (#1).
- The board is advanced on the other side for about 8 m (#2).
- The “first” side is then advanced for another 4 m (#3).
- The heading is then squared with the “first” side by advancing the “second” side for a further 4 m (#4).

The roads are advanced parallel to each other. The continuous miner must be turned through 90° to cut the crossroads. It is not possible to turn a continuous miner through 90° in one simple operation, as a continuous miner is about 10 m long. For this reason the cross-board is cut at a 60° angle to the main road (see steps 17,18 and 19 in Figure 2.2-3) after which the rest of the crossroad is cut perpendicular to the main road.

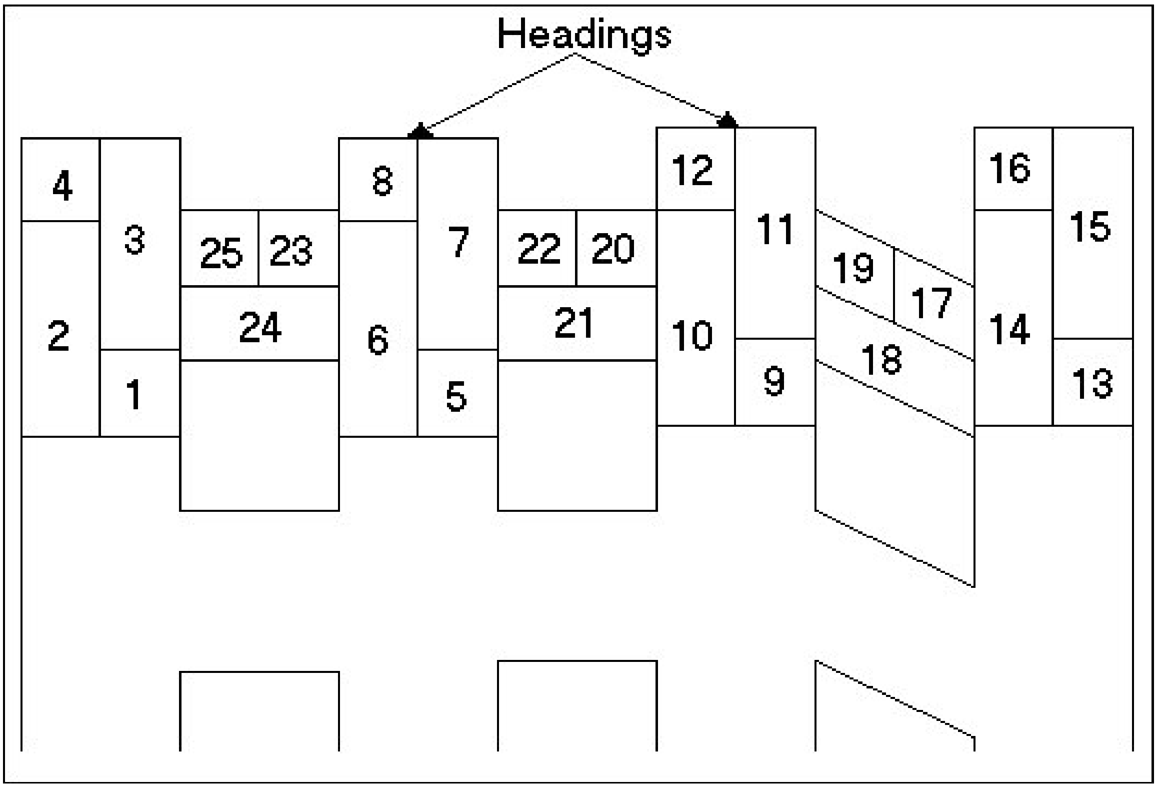


Figure 2.2-3: Mining procedure used for the board and pillar method [2].

This mining procedure is used for two important reasons. The first is to ensure that the cutting drum of the continuous miner is well ventilated at all times. The second is to prevent exposing too much roof without installing roof support.

Ventilation is essential in the heading of a conventional, mechanised board and pillar mine. The continuous miner and the conventional coal cutter create large amounts of coal dust. Water sprayers are used to suppress the dust. However, good ventilation is still necessary to ensure that all the airborne dust is eliminated to create a safe working environment and to ensure that the machines are well ventilated. Any of the following methods are used for ventilation:

Air enters on one side of the section. It sweeps all the headings and is exhausted on the other side of the section (see Figure 2.2-2). Air is taken in at the middle of the section and is exhausted on both sides of the section. This method is normally used for a double-header section. Each machine receives the same amount of air, but only half that of the previous method.

Auxiliary ventilation may be installed to remove air from the machine and to exhaust it towards the return path with fans. Brattice curtains and brick walls are used to control the direction of airflow (see Figure 2.2-2). As a section advances, the brattice curtains are replaced with more permanent brick walls.

This mining method requires excessive equipment manoeuvring because of the multi-road layout. A continuous miner mines the coal and dumps it onto a shuttle car. The shuttle car dumps the coal onto a feeder breaker that loads the coal onto a conveyor that removes the coal to the surface. Heavy maintenance is required as a result of the excessive manoeuvring. The ventilation structures must also be moved regularly to adhere to ventilation requirements.

A continuous haulage system can be used in the place of shuttle cars or battery haulers. Coal is loaded directly from the continuous miners conveyor onto the continuous haulage system, which transfers the coal to the section conveyor belt. This is a continuous system in the true sense of the word, as there are no stoppages while waiting for shuttle cars to get loaded.

The continuous haulage system is able to move on its own tracks as the section advances. Continuous haulage systems have not found favour in South Africa because frequent breakdowns resulted in low availability of the systems. More robust types are now available, which makes continuous haulage a viable alternative for shuttle cars.

2.2.3 Longwall mining

The production of a board and pillar section using continuous miners could not really be classified as continuous. Roof support must be installed and the continuous miner must sometimes wait for the shuttle cars to get into position, all of which lead to stoppages. A mechanised longwall system can be described as continuous, as it overcomes all the drawbacks of a board and pillar system.

Coal is cut, loaded and transported almost continuously, while roof support is installed at the same time. A longwall system extracts all the coal contained in a wide rectangular block, called a panel (see Figure 2.2-4), which is about 150 m wide and typically 2000 m to 3000 m deep.

A longwall miner, called a shearer in South Africa, is used to mine the whole width of the coalface. The shearer travels up and down along the face of the panel, making a cut from the whole face length called a web or shear. The web depth is 0.6 m to 1.0 m, depending on local conditions.

Hydraulic powered supports (called chocks or shields) are needed on the full length of the face to prevent the roof from collapsing on the face area. An armoured flexible conveyor (AFC) removes the coal as the shearer cuts the coal. The coal is then loaded onto a stage loader (shorter scraper conveyor), which in turn loads the coal on the first conveyor belt to remove the coal from the mine.

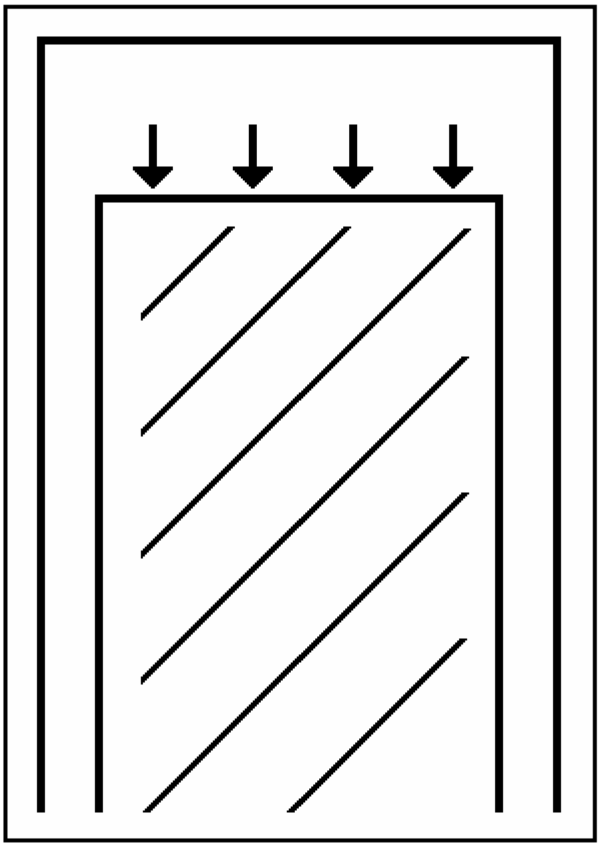


Figure 2.2-4: Linear mining method [2].

This process continues until the whole panel has been mined out. A small pillar is normally left to protect the access roadways. There are far less manual tasks and mechanical support needed for this method. Sasol Mining used longwall mining in the 1980's, but all the longwalls had been phased out by 1996.

2.2.4 Environmental Hazards in Coal Mining

Explosive methane gas (CH_4) and coal dust are produced during coal cutting. Sparks can ignite methane gas if the concentration of methane gas in a mine exceeds 5%. Sparks can be produced by electrical equipment or by cutter picks striking rock. The area around and near the mining face is thus classified as a hazardous area.

A methane explosion or underground fire can ignite the coal dust, causing a dust explosion. A coal dust explosion will spread trough the whole mine if no precautions are taken. There are strict laws and regulations for underground coal mining operations to prevent such explosions. The laws and regulations focus on ventilation and dust suppression, and then control of methane and dust concentrations in the mine. Certain electrical safety standards must also be adhered to.

2.3 STANDARD SECTION

This investigation will focus on the equipment used in conjunction with the mechanised board and pillar mining method (see Mining Methods, Section 2.2.2). A mine may have two or more sections, depending on the coal reserves and the desired demand. A section is actually a team of mining personnel with its electrical supply network and mining equipment, making it almost a complete mine on its own. The in-section electrical distribution network of a section consists of the following equipment:

- MSU (Mobile Switching Unit – 11 kV).
- 1250 kVA flameproof transformer (11 kV to 1000 V).
- Gate end boxes (1000 V switches).
- Supply cables and trailing cables.

A number of variations exist in the mining equipment used in sections of Sasol Mining, although they are all used for the board and pillar mining method. The mining equipment most commonly used in a section consists of a JOY continuous miner, three shuttle cars, a roofbolter, feeder breaker and four to six jetfans. Battery haulers can be used instead of shuttle cars, and the number of shuttle cars or Battery haulers can vary. Normally there are three cars for each section.

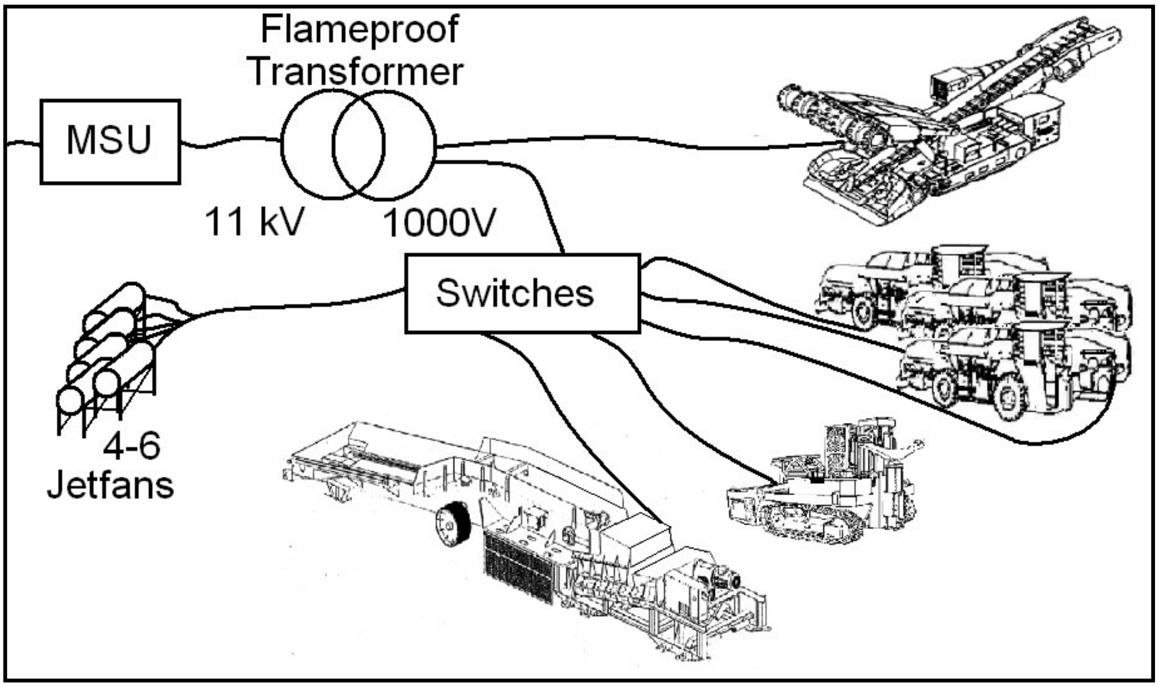


Figure 2.3-1: In-section electrical distribution network.

All the mining equipment in a section are electrically powered and connect to the gate end boxes, except for the continuous miner which is connected directly to the flameproof transformer. There are also ventilation fans, lights and pumps connected to the gate end boxes. A standard section for the purpose of this study will be defined as a section containing the following equipment:

- One continuous miner.
- Three shuttle cars.
- Two single-boom roofbolters.
- One feeder breaker.

2.3.1 Operational description

This section will provide background on how all the mining equipment in a production section fit together. Figure 2.3-2 shows a continuous miner on the left hand side and a shuttle car on the right hand side. The head of the continuous miner (cylindrical drum) turns at high speed. This turning drum has picks (sharp points) mounted at different angles, which do the actual cutting. The drum is moved into the coalface to cut coal, called sumping. While cutting coal, the head of the continuous miner is moved downwards, called shearing.

The cut coal falls on the spade at the front end of the continuous miner. There are two gathering heads that load all the coal onto a conveyor with a circular movement. At the end of the continuous miner the tail conveyor unloads the coal onto the waiting shuttle car (see Figure 2.3-2).

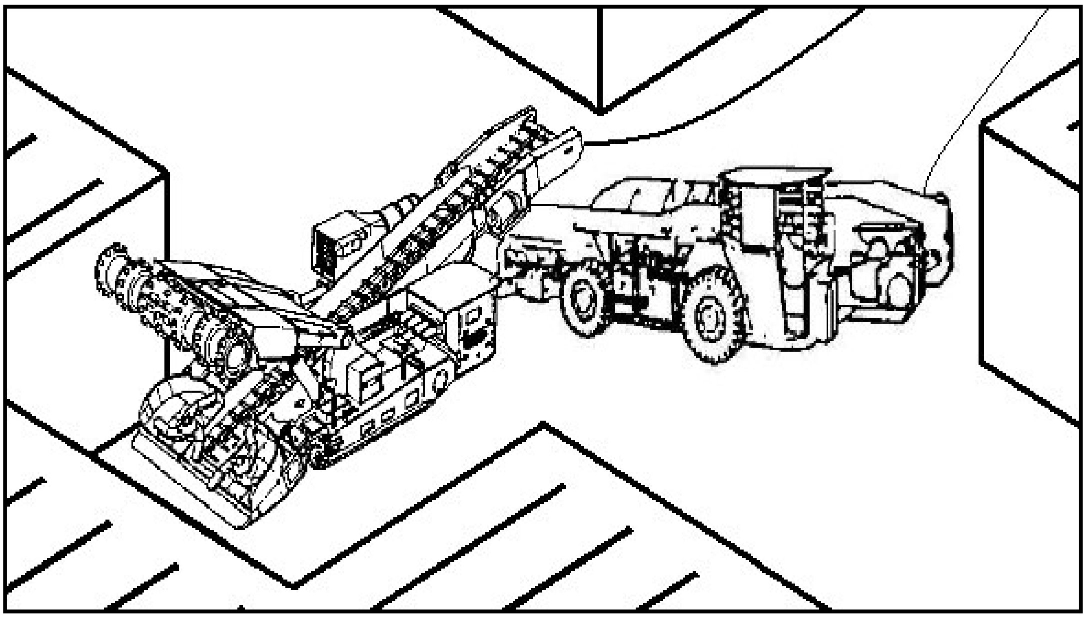


Figure 2.3-2: CM unloading coal onto a shuttle car [3], [4].

Figure 2.3-3 shows two shuttle cars and a feeder breaker. A feeder breaker is also known as a crusher. The shuttle car transports the coal between the continuous miner and the feeder breaker. The shuttle car has its own conveyor belt with which the coal is unloaded onto the feeder end of the feeder breaker.

The feeder end conveys the coal to the breaker of the feeder breaker, where the coal is crushed into smaller pieces before being dumped unto the section belts that conveys the coal out of the mine.

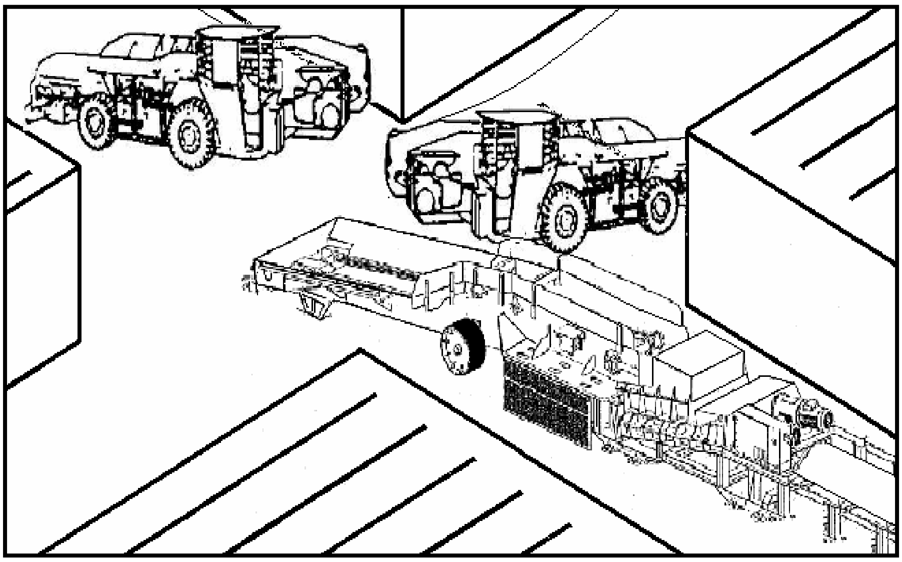


Figure 2.3-3: Shuttle cars waiting to unload coal on the feeder breaker [4], [5].

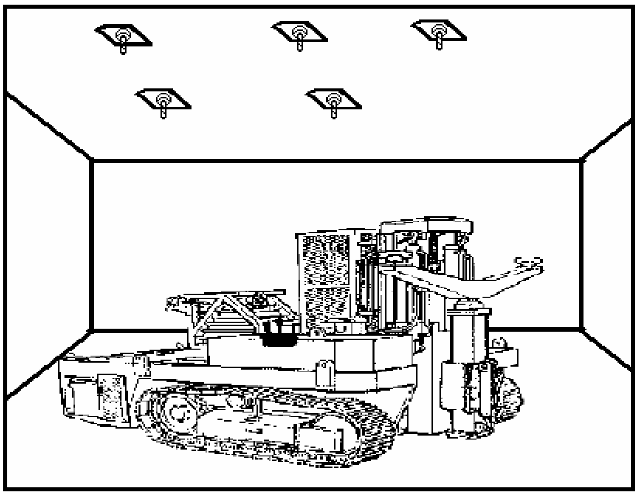


Figure 2.3-4: A forklift type roofbolter [10].

When the continuous miner has cut a maximum of 24 m from the last row of roofbolts, it must retreat. The roofbolter (see Figure 2.3-4) has to secure the roof by inserting roofbolts before cutting can be continued in the specific road. The roofbolter drills a hole in the roof and inserts resin and a bolt into the hole. Once mixed, the resin sets hard through a chemical reaction and will prevent the bolt from sliding out of the hole. This adds support to the roof.

Each piece of mining equipment is made up of a number of smaller subcomponents, for example motors, traction transformers, hydraulic systems, trailing cables and contactors. If they are not matched, any of these subcomponents can limit the total production capacity of the section.

2.4 ELECTRICAL DISTRIBUTION NETWORK

The function of the in-section electrical distribution network is to supply power to the mining equipment in the section. The in-section electrical distribution network is supplied with power from the mine’s distribution network, which is fed from surface substations. The distribution networks consist of an MSU, section 1250 kVA flameproof transformer, gate end boxes and cables.

2.4.1 Mobile Switching Unit

An MSU (Mobile Switching Unit) is the HV switch of the in-section distribution network and is connected to the 11 kV supply network of the mine. It is also used to protect the flameproof transformer and LV equipment. The power is usually interrupted at the MSU if there is an electrical fault in the section.

The MSU normally supplies power to the flameproof transformer and one belt transformer. In some cases it may supply power to more than one belt transformer, depending on the network layout. The MSU is rated to carry 630 A continuous current at 11 kV. In normal operation a section can consume up to 85 A at an average of between 35 A to 40 A at 11 kV. This means that the MSU has adequate spare capacity.

2.4.2 Flameproof Section Transformers

The flameproof transformer supplies power to all the mining equipment in the section. It supplies power directly to the continuous miner and the gate end boxes. The gate end boxes in turn supply power to all the other mining equipment used in a section. The flameproof transformer does not supply power to the conveyor belt motors nor to the conveyor belt transformers.

Normally Dimako flameproof air-cooled, three phase, 11 000 V to 1100 V, 1250 kVA transformers are used. They are rated at 65 A on the primary and 656 A on the secondary side. A section consumes about 300 A on average on the 1100 V side of the transformer. The average current consumed by the transformer is a direct function of the work done in the section during the shift, meaning that the higher the production levels, the higher the average current consumed.

2.4.3 Gate end boxes

The gate end boxes are the LV switches in the section. All the mining equipment except the continuous miner are individually connected or disconnected to or from the network at the gate end boxes. The gate end boxes are ten 1000 V switches that are connected to a single busbar. The busbar is rated at 300 A.

The switches supply power to three shuttle cars, the feeder breaker, one or two roofbolters and four to six jetfans. A more powerful fan is also used periodically. The electric circuit of the equipment connected to the switch can be isolated from the network at the switch if work needs to be done on the circuit.

2.4.4 Cables and flameproof couplers

The supply and trailing cables form the actual in-section distribution network and supply power to the various pieces of mining equipment. The supply cables and trailing cables will at some time in the future be a limiting factor in the distribution network if they have not reach that point already. The current carrying capability and the ease with which the cables can be handled must be considered. Handling is an important consideration, as the cables are regularly moved when machines tram from one point to another or when the gate end boxes are moved closer to the coal face.

A number of different cables and cable size are used in a section, as can be seen in Table 2-1. The cable used on the 11 kV network is normal 3 core, XLPE insulated, steel wire armoured and PVC sheated. The trailing cables are used in applications where the cable will be handled, stretched, bent or even manhandled. These are extra-heavy-duty cables and are normally used on self-propelled electrically driven machines and portable electric apparatus in hazardous areas.

Table 2-1: Supply and trailing cables used in a section.

From	To	Cable Type	Size (mm2)	Current rating (A)*
11 kV network	MSU	PEX	95 / 185	290 / 410
MSU	Flameproof transformator	HV trailing cable	95	295
Flameproof transformator	CM	Trailing cable	95	295
Flameproof transformator	GEB	Trailing cable	95	295
GEB	Shuttle Car	Trailing cable	16	100
GEB	Feeder breaker	Trailing cable	16	100
GEB	Roofbolter	Trailing cable	16	100
GEB	Jetfans	Trailing cable	4	45

* Maximum conductor temperature 90 ℃, ambient temperature 30 ℃

Cable damage results in excessive downtime in the production section, because cables are often abused. Mining equipment like shuttle cars, continuous miners and roofbolters may occasionally drive over cables or bump cables against the walls, which may result in an earth fault. Production must be halted to replace the damaged cable. Other reasons for cable damage include overload conditions and the general moving and, it must be said, abuse of cables.

JOY Mining Machinery investigated the trailing cable of the continuous miner. The investigation revealed that the trailing cable was too cumbersome to be handled. They decided to switch to a 3,3 kV supply voltage to take advantage of smaller cables and to deliver more power to the section and the mining equipment. Dimako shared this view, as cables are becoming a limitation.

2.5 MINING EQUIPMENT

The mining equipment consists of subcomponents, such as electric motors, traction transformers, cables, overload relays and contactors. The electric motors are generally the main energy consumption points. This section will discuss the energy of each electric powered machine used in a section for production.

2.5.1 Continuous Miner

Sasol Mining uses Voest and JOY continuous miners. The JOY machines (see Figure 2.5-1) are much more common than the Voest machines. The Voest machines are normally used in conjunction with a Long Airdox continuous haulage system and can cut the whole road width in one pass, while the JOY machines are smaller and can only cut half the road width at a time.

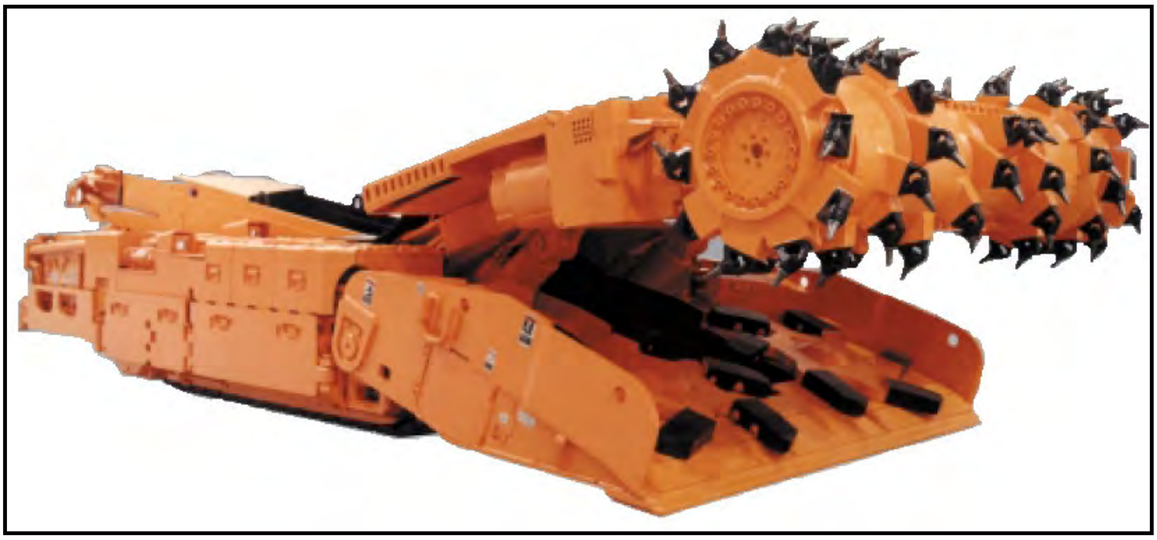


Figure 2.5-1: A JOY continuous miner [12].

Sections where Voest machines are used, have an MSU and gate end boxes, the same as sections using JOY machines, but these sections use two flameproof transformers to supply power to the mining equipment. The Voest machine does the roofbolting while cutting, so there is no need for additional roofbolters in these sections.

Sasol Mining has a number of different models and versions of the JOY continuous miners. Older HM9 and HM21 machines are still being used, but the HM 31 machines are more common. Different cutting drum specifications are used for different conditions, for example on mega head and mini mega head machines. The mega heads are more robust for tougher conditions.

Various control standards are used on JOY continuous miners, for example JNA (JOY Network Architecture), JNA 1 and JNA 2. The JOY Network Architecture automates the mining cycle and gives fast diagnostic and troubleshooting capabilities. Most of the continuous miners at Sasol Mining have JNA 1 controllers. A few continuous miners are equipped with the newer JNA 2 controllers.

The difference between a JNA 1 and a JNA 2 continuous miner affects the control of the cutting cycle. The speed of the cutting cycle is controlled with JNA 1. The cutting speed is fixed and independent of the hardness of the coal. The cutter motors will only consume full load current if the coal is very hard. The motors will, therefore, not work to there full capacity if the coal is moderately hard. The JNA 2 controls the energy consumption of the motors, driving them to consume full load current as consistently as possible. The cutting cycle is faster when the coal is softer and slower when the coal is harder. This investigation will focus on the continuous miners with JNA 1 controls. The main energy consumption points on a 12HM31B continuous miner are:

- Two 175 kW AC cutter motors – these motors drive the cutter head drums which actually do the cutting. Figure 2.5-2 shows the location of the cutter motors.

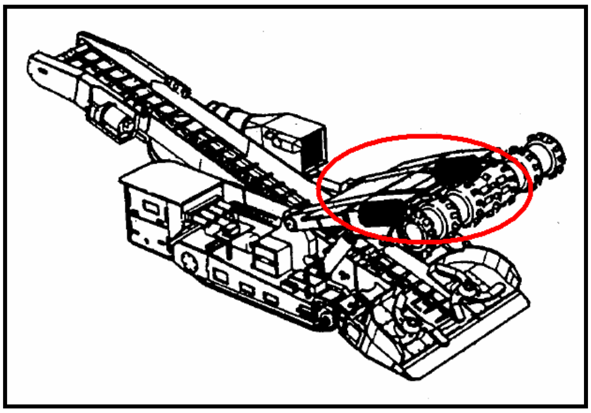


Figure 2.5-2: Location of cutter motors on continuous miner [3].

- Two 40 kW AC gathering head motors – these motors drive the gathering arms on the spade of a continuous miner through a reduction gearbox to load the coal onto the conveyor. Figure 2.5-3 shows the location of the gathering head motors.

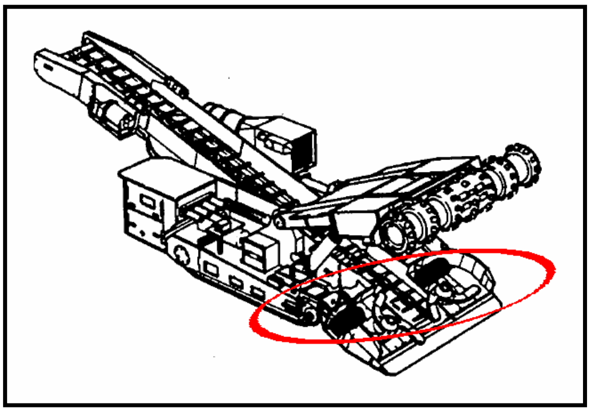


Figure 2.5-3: Location of gathering head motors on continuous miner [3].

- One 116 kW AC pump motor – this motor drives the hydraulic pump that powers all the hydraulic systems on a continuous miner. Figure 2.5-4 shows the location of the pump motor.

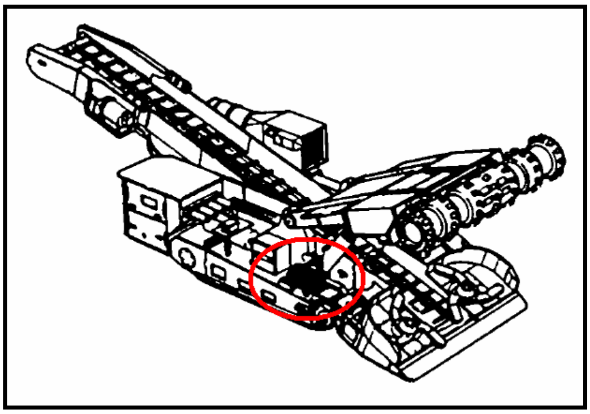


Figure 2.5-4: Location of pump motor on continuous miner [3].

- One 37 kW AC conveyor motor – this motor drives the conveyor on the continuous miner that removes coal from the spade of the continuous miner and loads the coal onto waiting shuttle cars. Figure 2.5-5 shows the location of the conveyor motor.

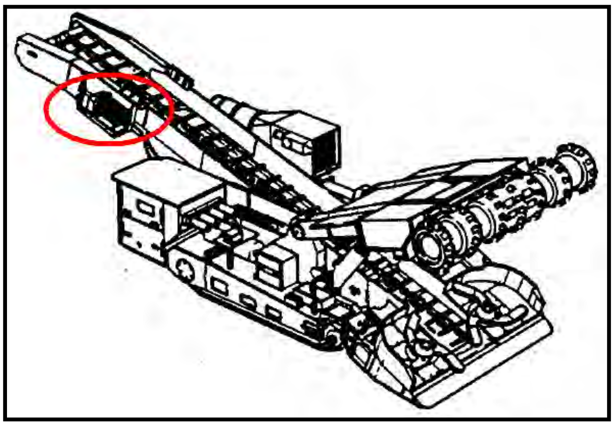


Figure 2.5-5: Location of conveyor motor on continuous miner [3].

- One 34 kW AC scrubber motor – this motor drives a fan on the continuous miner that removes dust from the coalface. Figure 2.5-6 shows the location of the scrubber motors. The process of replacing these motors with 45 kW motors has already started.

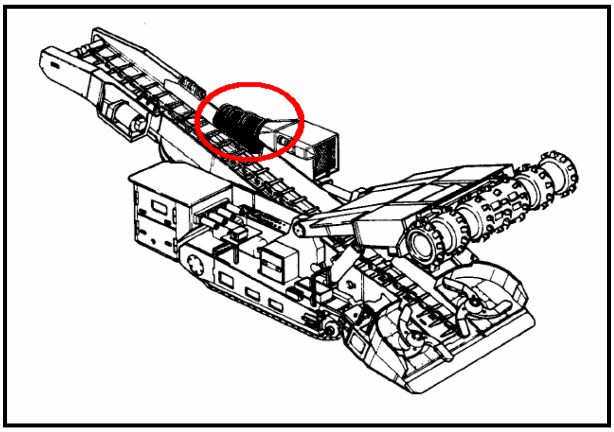


Figure 2.5-6: Location of the scrubber motor on a continuous miner [3].

- Two 37 kW or 50 kW DC traction motors – these motors are used for tramming (moving forward, backwards and turning) a continuous miner. Figure 2.5-7 shows the location of the traction motors. A number of the traction motors have already been upgraded to 50 kW motors.

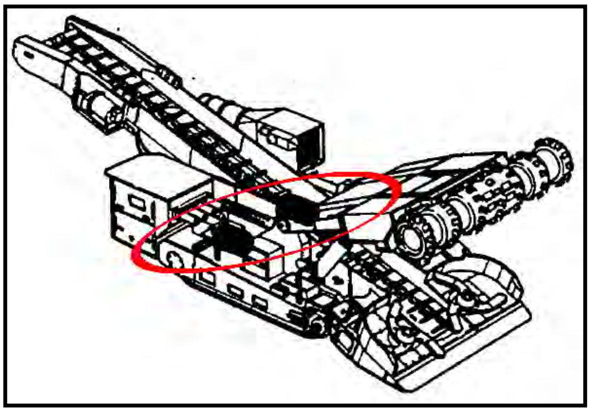


Figure 2.5-7: Location of traction motors on a continuous miner [3].

2.5.2 Shuttle car

Shuttle cars haul coal haulage in production sections of Sasol Mining. A number of battery haulers and Long Airdox continuous haulage systems are also used, but not as widely as shuttle cars.

Figure 2.5-8: A JOY shuttle car [13].

Battery haulers look like ordinary shuttle cars, but they have no electricity supply cables limiting their movement, which is a big advantage. Battery cars outperform shuttle cars initially, but their performance decreases as the batteries wear out, whereas the performance of shuttle cars is constant. The Long Airdox is a moving conveyor, which links the continuous miner, normally a Voest machine, with the conveyor belts. This combination forms a true continuous coal producing system.

Sasol Mining uses specially made 16 tonne and 20 tonne shuttle cars, produced by Sasol Mining's Central Workshop. The 20 tonne shuttle cars are used for thicker seams (4 m to 5 m) and the 16 tonne cars are used for the thinner seams (3 m to 4 m). Sasol Mining is replacing the 20 tonne cars with 16 tonne cars.

The installed electrical capacity on the 20 tonne shuttle car is 110 kW compared to the 16 tonne shuttle car which uses only 73 kW. The 16 tonne cars were originally 12 tonne cars of which the coal carrying capacity was upgraded. However, the electric motors stayed the same as were used on the 12 tonne cars.

The major subcomponents of the shuttle car include:

- One 15 kW AC pump motor – this motor drives the hydraulic pump that powers all the hydraulic systems. Figure 2.5-9 shows the location of the pump motor. Until recently a 10 kW motor powered the hydraulic system.

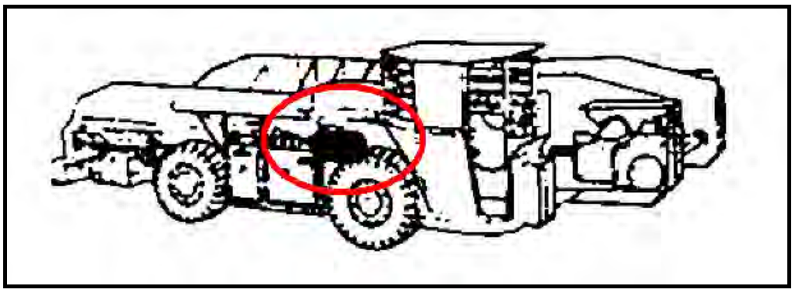


Figure 2.5-9: Location of the pump motor on a shuttle car [4].

- One 19 / 9.5 kW conveyor motor – this motor drives the conveyor on the Shuttle car. Figure 2.5-10 shows the location of the conveyor motor. It is a two speed motor, but it is normally configured operate at the higher speed only.

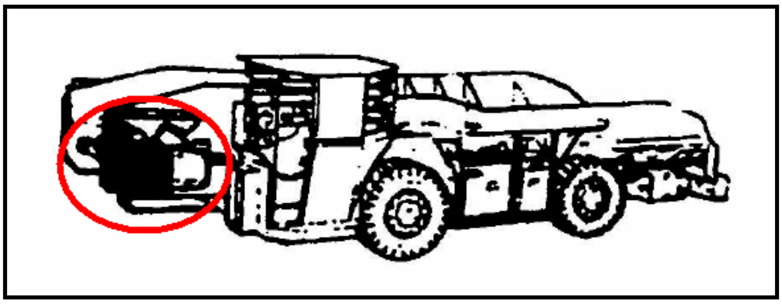


Figure 2.5-10: Location of the conveyor motor on a shuttle car [4].

- One 22 kW DC traction motor – this motor is used for tramming (moving forward and backwards) a shuttle car. Figure 2.5-11 shows the location of the traction motors.

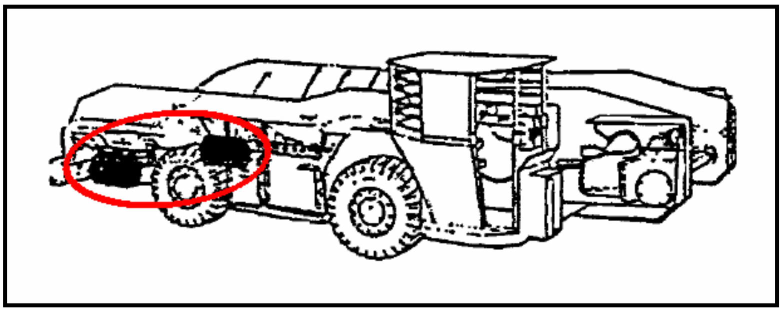


Figure 2.5-11: Location of the traction motors on a shuttle car [4].

2.5.3 Feeder breaker

Sasol Mining uses feeder breakers from a number of different manufacturers, and there are an even greater number of variations of these breakers. The variations exist especially as a result of the size and number of motors on the feeder as well as the breaker part of the feeder breaker. A Buffalo feeder breaker from FFE Minerals can be seen in Figure 2.5-12.

The feeder breaker consists of two parts, the feeder and the crusher or breaker. Shuttle cars unload the coal on the feeder of the feeder breaker. A conveyor feeds the coal to the breaker of the feeder breaker, which crushes the coal into smaller particles to prevent chutes on the conveyor belts from blocking. The crushed coal is dumped onto the section belts that remove the coal from the mine.

Figure 2.5-12: A Buffalo feeder breaker [14]

The major subcomponents of the Buffalo m800 feeder breaker are:

- One 55 kW AC motor to drive the conveyor of the feeder which transports coal dumped by the shuttle cars to the breaker of the feeder breaker.

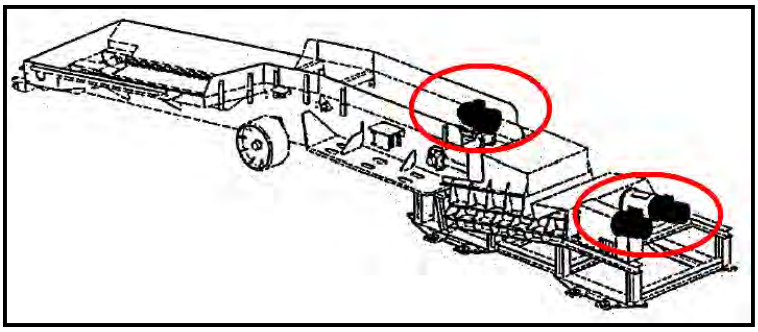


Figure 2.5-13: Location of the conveyor and crusher motors on a feeder breaker [5].

- Two 55 kW AC crusher motors that drive the breaker of the feeder breaker to crush coal into smaller particles before it is dumped on conveyor belts.

2.5.4 Roofbolter

Roofbolters are used in production sections to give added support to the roof by inserting bolts into the roof. The roofbolts will hold the roof together, and if a roof is sagging, roofbolts will act as a telltale of a collapsing roof. Roofbolters have a significant effect on the productivity of a section; if they function effectively, there will be no unnecessary stoppages to limit production.

Sasol Mining uses three basic designs of roofbolters – onboard, single-boom and double-boom roofbolters (see Figure 2.5-14). The Voest machines each have an onboard roofbolter that does the roofbolting while the coal is being mined. In the sections that use JOY equipment, however, additional roofbolters have to be used. The single-boom roofbolters can insert 70-80 roofbolts per shift, and the double-boom ARO roofbolters can insert 222 roofbolts per shift [25]. Two single-boom roofbolters are used together, each operating in a different part of the section, to keep up with production, while only one double-boom roofbolter needs to be used in a section.

The difference between single-boom and double-boom roofbolters is that single-boom roofbolters can only insert one roof bolt at a time and must reposition before it can insert the next roofbolt. In contrast, double-boom roofbolters can insert two roofbolts at the same time, and they do not have to reposition to insert other roofbolts in the same row, as their arm is merely extended.

Figure 2.5-14: A JOY double boom Roofbolter [16].

Single-boom roofbolters are the most numerous type at Sasol Mining, and two designs are used, namely RHAM and Fletcher. Sasol Mining's Central Workshop builds the RHAM roofbolter. Only one double-boom roofbolter, the ARO roofbolter, is used at Sasol Mining. The major subcomponent of the RAM roofbolter is:

- One 30 kW AC pump motor which drives the hydraulic pump.

2.6 ELECTRIC MOTORS

Electric motors are the workhorses of industry. There are a wide variety of motor types with a huge difference in motor sizes and capacities. Electric motors are used for any imaginable application.

Sasol Mining generally uses DC motors as well as AC induction motors. DC motors are generally used for tramming, while induction motors are used to power cutting, pumping, conveying and ventilation systems.

Electric motors are designed for a number of applications and for a wide spectrum of possible environments, for example flameproof or very wet environments. The load characteristics and environmental conditions should be determined accurately before specifying a motor's ratings to ensure that the motor will be able to handle the applied load and the environmental conditions.

Various factors influence the efficiency and expected life of an electric motor. Voltage regulation at the motor, the load applied to the motor and the duty cycle at which the load is applied and the cooling of the motor are all factors that will influence the performance of motors.

2.6.1 Motor ratings

The IEC has standards for motor ratings, e.g. IEC60034 [18, 20 & 21]. Motors are designed for a specific power requirement and an operational duty cycle relevant to the specific application. These ratings are specified to ensure that the temperature rise of the motor is kept within limits to prevent damage to the motor.

- Enclosure Protection indexes

  The IEC have indexes for the degree of protection that the motor's enclosure affords against solid objects and liquids [17], [18]. These ratings are based on a two-digit numbering scheme. The digits follow the letters IP.

  The first digit indicates how well the motor is protected against solid objects for example dust, wire or tools. The second digit indicates protection from the ingress of liquids. Figure 2.6-1 shows the degrees of protection against solid objects (hands, tools and dust), and Figure 2.6-2 shows the enclosure's protection against liquids such as for example water.

#	Definition
0	No protection.
1	Protected against solid objects of over 50mm (e.g. accidental hand contact).
2	Protected against solid objects of over 12mm (e.g. finger).
3	Protected against solid objects of over 2.5mm (e.g. tools, wire).
4	Protected against solid objects of over 1mm (e.g. thin wire).
5	Protected against dust.
6	Totally protected against dust. Does not involve rotating machines.

Figure 2.6-1: Protection against solid objects [17], [18].

#	Definition
0	No protection.
1	Protected against water vertically dripping (condensation).
2	Protected against water dripping up to 15° from the vertical.
3	Protected against rain falling at up to 60° from the vertical.
4	Protected against water splashes from all directions.
5	Protected against jets of water from all directions.
6	Protected against jets of water comparable to heavy seas.
7	Protected against the effects of immersion to depths of between 0.15 and 1.0 m.
8	Protected against the effects of prolonged immersion at depth.

Figure 2.6-2: Protection against liquids [17], [18].

- Insulation classes

  The material used to insulate windings is categorised in 4 classes. These classes are based on the highest temperature that the insulation material can withstand continuously without degrading or reducing the expected life of the motor. A rule of thumb suggests that a 10℃ rise in winding temperature cuts the insulation system’s useful life in half and a 10℃ decrease doubles the insulation system’s life. This, however, does not mean that a motor will last forever if it is kept cool enough, because a motor is more than just windings.

Table 2-2 shows the temperatures for each class. The motors used in the production sections at Sasol Mining are generally class F and H motors.

Table 2-2: Insulation classes and their thermal ratings [19].

Insulation class	Maximum winding temperature in ℃
A	105 ℃
E	120 ℃
B	130 ℃
F	155 ℃
H	180 ℃
* maximum ambient temperature of 40°	

- Cooling

The IEC uses a letter and digit code to designate how a motor is cooled [20]. There is a letter for any type of coolant and a digit for every known cooling method. The designation used for cooling motors is shown in Figure 2.6-3.

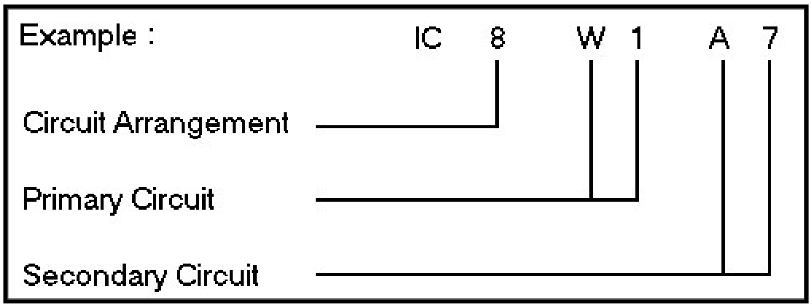


Figure 2.6-3: Designation of the IC code [20].

The circuit arrangement referred to, is shown in Table 2-3. The cooling code for the primary circuit and the secondary circuit consists of a letter and a digit. The letter refers to the coolant used; see Table 2-4, whereas the digit refers to the method by which the coolant is moved through or over the motor, see Table 2-5.

Table 2-3: Circuit arrangement for IC cooling code [20].

Characteristic numeral	Brief description	Definition
0 (see note 1)	Free circulation	The coolant is freely drawn directly from the surrounding medium, cools the machine, and then freely returns directly to the surrounding medium (open circuit)
1 (see note 1)	Inlet pipe or inlet duct circulated	The coolant is drawn from a medium remote from the machine, is guided to the machine through an inlet pipe or duct, passes through the machine and returns directly to the surrounding medium (open circuit)
2 (see note 1)	Outlet pipe or outlet duct circulated	The coolant is drawn directly from the surrounding medium, passes through the machine and is then discharged from the machine through an outlet pipe or duct to a medium remote from the machine (open circuit)
3 (see note 1)	Inlet and outlet pipe or duct circulated	The coolant is drawn from a medium remote from the machine, is guided to the machine through an inlet pipe or duct, passes through the machine and is then discharged from the machine through an outlet pipe or duct to a medium remote from the machine (open circuit)
4	Frame surface cooled	The primary coolant is circulated in a closed circuit in the machine and gives its heat through the external surface of the machine (in addition to the heat transfer via the stator core and other heat conducting parts) to the final coolant which is the surrounding medium. The surface may be plain or ribbed, with or without an outer shell to improve the heat transfer.
5 (see note 2)	Integral heat exchanger (using surrounding medium)	The primary coolant is circulated in a closed circuit and gives its heat via a heat exchanger, which is built into and forms an integral part of the machine, to the final coolant which is the surrounding medium
6 (see note 2)	Machine-mounted heat exchanger (using surrounding medium)	The primary coolant is circulated in a closed circuit and gives its heat via a heat exchanger, which is mounted directly on the machine, to the final coolant which is the surrounding medium
7 (see note 2)	Integral heat exchanger (using remote medium)	The primary coolant is circulated in a closed circuit and gives its heat via a heat exchanger, which is built into and forms an integral part of the machine, to the secondary coolant which is the remote medium
8 (see note 2)	Machine-mounted heat exchanger (using remote medium)	The primary coolant is circulated in a closed circuit and gives its heat via a heat exchanger, which is mounted directly on the machine, to the secondary coolant which is the remote medium
9 (see note 2 and 3)	Separate heat exchanger (using surroundings or remote medium)	The primary coolant is circulated in a closed circuit and gives its heat via a heat exchanger, which is seperated from the machine, to the secondary coolant which is either the surrounding or the remote medium

Notes

1 Filters or labyrinths for seperating dust, supressing noise, etc., may be mounted in the frmae or ducts. Characteristic numerals 0 to 3 also apply to machines where the cooling medium is drawn from the surrounding medium through a heat exchanger in order to provide cooler medium than the surrounding medium, or blown out through a heat exchanger to keep the ambient temperature lower.

2 The nature of the heat exchanger is not specified (ribbed or plain tubes, etc.)

3 A separate heat exchanger may be installed beside the machine or in a location remote from the machine. A gaseous secondary coolant may be the surrounding medium or a remote medium (see also annex A, table A.3).

Table 2-4: Possible coolants used to cool electric motors [20].

Characteristic letter	Coolant
A	Air
F	Freon
H	Hydrogen
N	Nitrogen
C	Carbon dioxide
W	Water
U	Oil
S	Any other coolant
Y	Coolant not yet selected

Various ways are used to cool motors, as can be seen in Table 2-3, Table 2-4 and Table 2-5. There are a number of methods for cooling motors. Motors at Sasol Mining are normally cooled with air, water or a water and anti-freeze mixture. Various factors influence the effectiveness of the different coolants, for example the flow rate of the coolant, the initial temperature of the coolant and the ability of the coolant to conduct heat away from the motor. Cooling with water, for example, is much more effective than cooling with air, as water is a better conductor of heat than air.

Table 2-5: Different coolant circulation methods [20].

Characteristic numeral	Brief description	Definition
0	Free convection	The coolant is moved by temperature differences. The fanning action of the rotor is negligible
1	Self-circulation	The coolant is moved dependent on the rotational speed of the main machine, either by the action of the rotor alone or by means of a component designed for this purpose and mounted directly on the rotor of the main machine, or by a fan or pump unit mechanically driven by the rotor or the main machine
2, 3, 4		Reserved for future use
5 (see note)	Integral indepen-dent component	The coolant is moved by an integral component, the power of which is obtained in such a way that it is independent of the rotational speed of the main machine, e.g. an internal fan or pump unit driven by its own electric motor
6 (see note)	Machine-mounted independent component	The coolant is moved by a component mounted on the machine, the power of which is obtained in such a way that it is independent of the rotational speed of the main machine, e.g. a machine-mounted fan unit or pump unit driven by its own electric motor
7 (see note)	Separate and independent component or coolant system pressure	The coolant is moved by a separate electrical or mechanical component not mounted on the machine and independent of it or is produced by the pres-sure in the coolant circulating system, e.g. supplied from a water distribution system, or a gas main under pressure
8 (see note)	Relative displacement	The movement of the coolant results from relative movement between the machine and the coolant, either by moving the machine through the coolant or by flow of the surrounding coolant (air or liqiud)
9	All other	The movement of the coolant is produced by a method other than defined above and shall be fully described
Note - The use of an independent component as a principal source for movement does not exclude the fanning action of the rotor or the existence of a supplementary fan mounted directly on the rotor of the main machine.		

- Duty cycle

The duty cycle of an electric motor is defined as the degree of regularity at which a motor is submitted to a specific load. The number of start-stop cycles per hour can accelerate heating dramatically. Most motors used in a mining section are designed for continuous operation and not for regular starting and stopping.

There are 10 categories of duty cycles [21], [22], and each is referred to with a letter S and a digit between 1 and 10. See appendix A for a more comprehensive and graphic explanation of the different types of duty cycles.

S1 – Continuous duty. Motor works at constant load for long enough to reach temperature equilibrium.

S2 – Short-time duty. The motor works at constant load, but not long enough to reach temperature equilibrium, followed by a period of rest which is long enough for the motor to cool down to ambient temperature.

S3 – Intermittent periodic duty. A sequence of identical cycles, each one including a running period at constant load and a period of rest. Thermal equilibrium is not achieved.

S4 – Intermittent periodic duty with starting. A sequence of identical duty cycles, but each duty cycle includes a significant starting time, a time of operation at constant load and then a rest and de-energized period. Thermal equilibrium is not achieved.

S5 – Intermittent periodic duty with electric braking. A sequence of identical duty cycles, but each cycle consists of a starting period, a running period at constant load, a period of electric braking and then a rest and de-energized period. Thermal equilibrium is not achieved.

S6 – Continuous operation periodic duty. Sequence of identical duty cycles, each consisting of a running period at constant load and a running period at no load, with no periods of rest.

S7 – Continuous operation periodic duty with electric braking. A sequence of identical duty cycles, each cycle consisting of a starting period, a running period at constant load and a period of electric braking. There is no period of rest.

S8 – Continuous operation periodic duty with related speed/load changes. A sequence of identical duty cycles, each cycle consisting of a starting period, a running period at constant load corresponding to a predetermined speed of rotation. This is followed by one or more running periods at different constant loads corresponding with different speeds of rotation. There is no time at rest.

S9 – Duty with non-periodic load and speed variations. Load and speed vary non-periodically within the permissible operating range. The duty type includes frequently applied overloads that may greatly exceed the reference load.

S10 – Duty with discrete constant loads. This duty type consists of up to four discrete values of load. Each load value must be maintained for sufficient time to allow the machine to reach thermal equilibrium.

2.6.2 Effect of voltage regulation on motors

As mines get older, the sections in the mine are situated further from the main substation of the mine. As the distances between the main supply of the mine and the sections become longer, voltage drops in the cables can become a limiting factor in the efficiency of the electrical equipment.

Power factor correction units are installed in the network, not only to improve the power factor, but also to raise the voltage level at the farthest reaches of the mine. This, however, could lead to overvoltages, especially during non-production periods. The overvoltages can significantly reduce the life expectancy of motors if the overvoltages exceed the insulation ratings of the windings.

The rotor current and the load-dependent component of the stator current will drop approximately inversely to the voltage. However, the magnetising current, flux density and the core losses are increased. The efficiency will drop if the voltage increases above 10% due to saturation of the core. Sustained or excessive overvoltages will thus saturate a motor’s core.

Undervoltage conditions are much more dangerous than overvoltages, as electrical motors can withstand larger overvoltages than undervoltages [22]. The efficiency of a motor will decreases if undervoltage conditions are experienced, and the current will rise in an attempt to provide the power necessary to drive the load. The current capacity of the motor will now become a limitation and excessive heat will be produced in the motor, which could cause permanent damage to the motor's windings or motor burnout. The increased current consumption can also cause excessive strain on the electrical distribution network.

Powerful cutter motors on a continuous miner can cause significant voltage drops when the motors are started. When an induction motor is started, it typically consumes 6 times the full-load current. Although it is just for a short period, it can have a considerable effect on the network voltages, as one 175 kW cutter motor would consume double the section's apparent power during this period. In addition, these motors are not designed to be started repeatedly, but to run continuously. Repeated starting of these motors should thus be avoided if at all possible.

Another consideration is the voltage drop in cables that are reeled on the cable drum of a shuttle car. There are considerable differences in the current-carrying capacity of a deployed cable, compared to that of a cable coiled on a drum. The voltage drops in these cables will thus also differ. On average there will be three layers on the cable drum of a shuttle car. According to Aberdare [23], the derating factor for the current-carrying capacity of a cable with one layer coiled on the drum is 0.84, and it decreases to 0.45 when there are three layers on the drum. Three layers thus reduces the current-carrying capacity of the cable by half.

2.6.3 Thermal models for electric motors

Current flowing in a conductor will always generate heat in the conductor as a result of resistance and other factors in the circuit that create losses. Electric motors will thus heat up due to these losses. A motor is designed for a specific full-load current, which will cause a rise in temperature depending on the class of insulation material used on the windings.

Even a motor operating under normal conditions will suffer a rise in temperature, especially when the motor is frequently started before it has acquired enough thermal capacity through cooling off. A typical starting current of 6 times the full-load current will cause 36 times the normal heat in the motor. The heat damages and weakens the insulation of the winding. The motor has to be cooled to prevent it from exceeding the rated temperature of the insulation system.

Starting a motor, even under normal starting conditions, will cause a temperature rise if it is started frequently before acquiring enough thermal capacity by cooling off, the motor's capability to withstand increased temperatures will be exceeded, resulting in damage to the insulation and premature failure.

- Internal motor temperatures [22]

  Good heat dissipation in the case of air-cooled motors depends on the efficiency of the ventilation system, the total dissipation area of the frame and the temperature difference between the external surface and the ambient air temperature ($t_{ext} - t_a$).

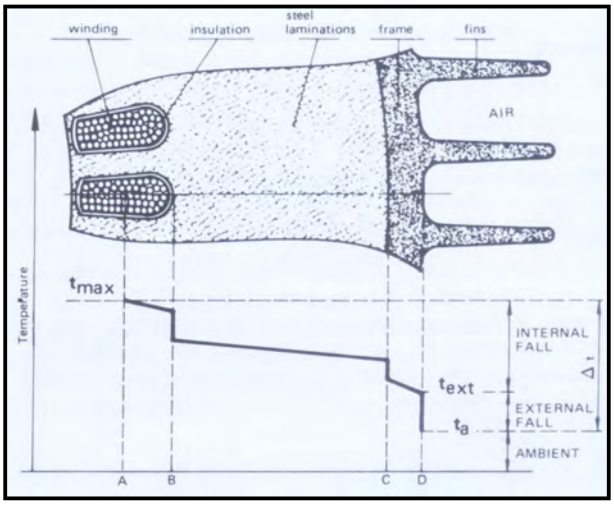


Figure 2.6-4: Electric motor internal temperature drops [22].

Figure 2.6-4 shows the drop of temperature inside a motor. The objective is to reduce the internal temperature through improving heat transfer, in order to obtain a larger drop in external temperature necessary for good heat dissipation. The sum of the internal and external drops in temperature are generally called the rise in temperature (Δt). The heat dissipation will thus be better with a lower ambient temperature.

The temperature of important points in a motor is shown in Figure 2.6-4. The points are:

A – Hottest point of the winding.

AB – Temperature drop due to heat being transferred from hottest point to outer wiring.

B – Temperature drop through slot insulation, from the conductors on the inner surface to the core laminations on the outer surface.

BC – Temperature drop by transmission through lamination material.

C – Temperature drop trough contact between the laminations of the stator and the frame of the motor.

CD – Temperature drop by heat transmission through the frame thickness.

D – External temperature.

- Thermal model

A motor's temperature can be calculated with the help of equation 1. It shows that a motor will heat exponentially, fast at first and slower on as time passes. Thermal equilibrium will be reached after a certain time depending on the thermal time constant (T_{th}) of the motor.

$$\theta = \theta_{\max}(1 - e^{(-t/T_{th})}) \qquad (1)$$

$$\theta = 1 - (\theta_{\max}(1 - e^{(-t/T_{th})})) \qquad (2)$$

The cooling of a motor can be calculated with the help of equation 2. A motor that is switched off will take a lot longer to cool than a motor that is switched on, but running at a reduced load. This is because the rotor of a motor that is still switched on is still turning, thereby circulating air or water through the motor. When the motor is switched off, this circulation is also stopped and radiation is the only way by which the motor will cool.

The first order model [24] of a motor's temperature (see equation 3) gives a better representation of a motor's temperature than the formulas in equation 1 and 2. This equation forms the basis for determining the temperature of a motor. The first part of the equation calculates the contribution that the present load current has on the temperature of the motor.

$$U_n = \frac{I^2}{T_{th}}\Delta t + (1 - \frac{\Delta t}{T_{th}})U_{n-1} \qquad (3)$$

U_n = Temperature at sample n
U_{n-1} = Temperature at the previous sample
T_{th} = Thermal time constant
Δt = Sampling interval
I = Load current of motor

The second part of the equation gives the combined exponential effect, as is done in equations 1 and 2. This part of the equation takes into account the temperature of the motor at the end of the previous sampling period. Depending on the load current of the motor, the temperature of the motor will either increase or slowly decrease over the next time period.

The temperature will decrease if the motor is consuming less current, with the rate of cooling dependent on the thermal time constant of the motor. The motor will start heating again if the load current is increased.

This is, however, just a theoretical model of a motor's temperature, as there are numerous factors influencing the thermal time constant of a motor. The thermal time constant of the motor should be determined under the same conditions and in the same environment for this model to be accurate. Coal dust on the motor will increase a motor's temperature and will slow the cooling of a motor drastically. Higher ambient temperatures than assumed, undervoltage or overvoltage conditions and motors situated in a closed panel or using a different coolant with different flow rates than specified will also change the thermal reaction of a motor considerably.

2.7 WORK-STUDY

Work-studies are used to determine the activities and the duration of the activities in a production section related to production. The information from these studies is used to determine what the average duty cycle of, for example, a shuttle car is. This duty cycle includes the time that the shuttle car is being loaded at the continuous miner, tramming to and from the continuous miner, unloading the coal at the feeder breaker and a little waiting time at the continuous miner and the feeder breaker. All the information gathered on all the mining equipment and activities are then combined to theoretically determine what the maximum sustainable production capacity of a section could be if all downtimes are excluded.

Work-studies are also used to determine the percentage availability of each piece of equipment and the maximum production capacity it can sustain on a standard shift. This investigation will, however, show if the electrical distribution network and other electrical components on the equipment can sustain such a theoretical production capacity and whether there are electrical limitations that could prevent sections from reaching such production levels.

Table 2-6 shows a typical work-study done for a section with a JOY 12HM31 continuous miner and three 16 tonne shuttle cars mining in an area with seam height between 3.3 m and 3.7 m.

In order to sustain production of 2400 tonne/continuous miner/shift requires:

- A maintenance shift for regular machine maintenance, belt extensions, stone dusting and preparing for the next shift, such as changing picks and sleeves, tramming the continuous miner to the next face, cable handling, etc.
- Total in section time of 525 minutes excludes the 60 minutes/shift travelling time.
- Production to start no later than 10 minutes after the official travelling time to the face and production to stop no earlier than 5 minutes before official travelling time out. Hot seat changes should not to exceed 10 minutes. (This equates to the 25 minutes allowed).
- Total availability of conveyors (trunk + section) to be at least 97%.

- Total availability of in-section machines to be 94% (CM ~ 95%).
- The non-measured time to be ~ 85% of the cutting time (sump and shear).
- The non-cutting part of the cutting cycle includes pulling back the continuous miner, lifting the cutter boom and moving forward, and some error correction time. This time is usually 40% of the total cutting time.
- The average continuous miner cutting rate is 11.5 tonnes/minute (sump and shear).

Table 2-6: Work study for JOY 12HM31 CM, 3 x 16t shuttle cars at mining height of 3.3 m to 3.7 m.

	Time per shift: Typical (minutes)	Time per shift: Potential (minutes)
Infrastructure	**24**	**16**
Conveyor belts	20	13
Other	4	3
Essentials	**35**	**30**
Change picks	25	22
Tramming	10	8
SOS, HSC, EOS	**43**	**25**
Statutory	**6**	**5**
Geological	**0**	**0**
Operational delays	**39**	**32**
CM sweep	11	10
Cable handling	13	12
Other (fan,blockages,etc)	15	10
Planned downtime	**0**	**0**
Breakdowns	**37**	**30**
CM		
Other		
CM Cutting	**176**	**209**
Non-measured	**165**	**178**
CM in-face manoeuvring	42	41
Non-cutting part of cutting cycle	69	84
S/car change out	48	47
Other(obstructions, etc)	6	6
Total in-section time	**525**	**525**
Cutting rate (ton/minute)	**10.5**	**11.5**
Ton/shift	**1850**	**2400**

Work-studies will be done while measurements are taken at the sections to be investigated. This information will help to determine in what cycle a certain piece of equipment was while being measured. The work-study will also help to determine what could be classified as normal activities for all the equipment and the average period that these activities last. Any unusual activity that increases the duty cycle of equipment or the load on equipment will not be classified as usual and normal and would not influence the results of the investigation.

2.8 CONCLUSION

Sasol Mining is increasing production throughput with the help of motivation schemes like Renewal and Vuselela. The whole objective of these initiatives is to increase production while at the same time limiting expenditure. Increased production, however, leads to increased electrical energy consumption. This has an effect on all the components that form the electrical in-section system. All of these components have a limitation in the production capacity that it can sustain. These limitations need to be determined and suitable replacement components need to be identified.

This chapter gave a summary of the different coal mining methods used in the world and the equipment used for each specific mining method. Sasol Mining uses the board and pillar mining method with continuous miners, continuous haulage systems, shuttle cars, battery haulers, feeder breakers and roofbolters, thus fully mechanised.

All the equipment used in a production section at Sasol Mining and the specific task of each piece of equipment in the overall production of coal was discussed. The energy consumption points (electric motors) on the mining equipment and factors influencing the efficiency of the electric motors were determined. The different ratings and characteristics of motors were also explained.

CHAPTER 3

MEASURING STRATEGY

Measurement equipment are the eyes of an electrical engineer, and without them he would just be a gambler when making decisions. All the variables that may be important or have an influence must be measured so that informed decisions can be made.

There are a number of variables that have to be measured for the purpose of this investigation. Measuring in normal circumstances is not an obstacle. However, in a flameproof environment it becomes tricky. Measuring equipment must either be flameproof or have to fit inside a flameproof enclosure. These difficulties were a challenge, as there were a lot of variables to be measured and space was very limited in the flameproof enclosures, as there are no flameproof measuring equipment.

3.1 PROPOSED MEASURING STRATEGY

The investigation was divided into two parts. The first was to determine the consumption of the in-section electrical distribution network, and the second was to determine the consumption of the mining equipment. The in-section electrical distribution network was investigated to determine the production capacity of the electrical network and whether any were being overloaded.

The actual energy consumption points in a section are the electric motors located on the mining equipment. The piece of mining equipment was thus investigated to determine the production capacity of its subcomponents. Subcomponents included electric motors, contactors, couplers and controllers. The capacity can be determined if it can be proven that the different subcomponents on the equipment are only just handling the workload or if they still have spare capacity. The bottlenecks limiting the production capacity of the mining equipment can be determined from this information.

3.1.1 In-section electrical distribution network

The main components in the in-section electrical distribution network were identified in chapter 2. It was important that all the main production equipment be measured at the same time as the distribution network. These measurements must give an accurate representation of the power consumed and distributed through the in-section electrical network. Data would be virtually worthless if some important variable was not measured and all the power consumed in a section could not be accounted for.

The main components of the in-section electrical network were also discussed in the previous chapter. The in-section electrical network with the proposed measuring points can be seen in Figure 3.1-1. Table 3-1 shows a summary of the measuring points and the variables that had to be measured at each point.

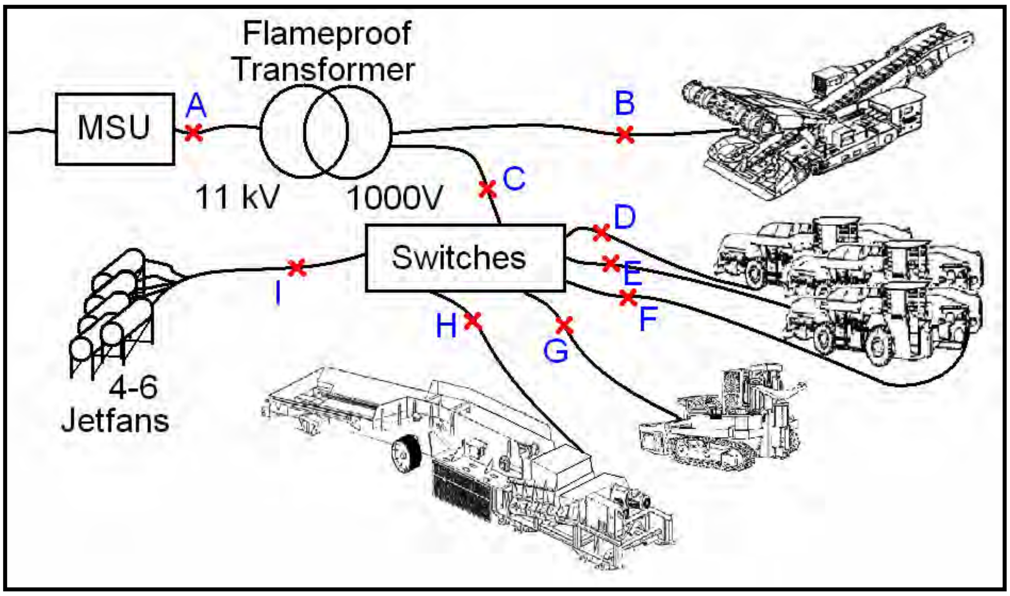


Figure 3.1-1: In-section electrical system with proposed measuring points indicated.

Table 3-1: Measuring points in the distribution network as indicated in Figure 3.1-1 as well as the variables to be measured at each point.

Measuring Point	Description	Number of phases to be measured	Variables to be measured for each phase
A	MSU	3	Voltages, Currents, kVA, kW and kVAr
B	CM	3	Voltages, Currents, kVA, kW and kVAr
C	1000 V switches	3	Voltages, Currents, kVA, kW and kVAr
D, E, F	Shuttle Car	3	Voltages, Currents, kVA, kW and kVAr
G*	Roofbolter	3	Voltages, Currents, kVA, kW and kVAr
H	Feeder Breaker	3	Voltages, Currents, kVA, kW and kVAr
I**	Jet fan	3	Voltages, Currents, kVA, kW and kVAr

* One or two Roofbolters to be measured.

** Six jetfans to be measured.

From Table 3-1 it can be seen that there were numerous points to be measured on the distribution network, with an even greater number of variables at each point. In each case three phase voltage, current and power have to be measured. The measurements at all the points should be taken simultaneously if at all possible, which would require a number of measuring instruments. This will ensure that a complete time-capsule snapshot of the load consumption and distribution through the in-section electrical distribution network can be produced.

The equipment in the electrical distribution network was manufactured by a variety of manufacturers. This practice will probably continue, at least for the immediate future. Dimako manufactures most of the MSUs and 1250 kVA flameproof transformers, but other suppliers include Yorkshire, Reyrolle and Steelcor for the MSUs and G&H for the flameproof transformers. Sasol Mining's Central Workshop and Emis are suppliers of the gate end boxes.

Although there are numerous equipment suppliers, there is not a great difference in the capacity of the various pieces of equipment. The differences among suppliers are more obvious in the protection schemes and protection equipment used than in the ratings of the equipment.

The total supply to a production section (voltage, current and power) can be measured at point A (see Figure 3.1-1). These measurements will, however, include power consumed by the conveyor belt transformers, which are not included in this investigation. The measurements will show if the main supply network of the mine might become a limitation if sections progress far from the main substation on the surface.

Points B and C (Figure 3.1-1) will measure the total load consumed by the continuous miner and the gate end boxes respectively. The sum of these measurements will give the total load consumed by the flameproof transformer and will reveal whether the flameproof transformer or the cables supplying power to either the flameproof transformer, the continuous miner or the gate end boxes might become a limitation in future. Special attention should be given to the cables supplying power to the continuous miner and the gate end boxes from the flameproof transformer, as well as the busbars in the gate end boxes. Some of the manufacturers already classified these components as limitations or potential limitations in a production section.

Measurements at points D to I will measure the total load consumed by each item of equipment. The measurements at each switch can be analysed to calculate if the cables supplying each item of equipment is still loaded within its rating or whether it might become a limitation in future. It will also show the contribution of each item of mining equipment to the total consumption through the gate end boxes.

3.1.2 Mining Machinery

Many measurements had to be taken on the mining equipment. The reason for this is that each machine consists of a number of smaller energy consumption points, i.e. mainly motors. The motors are the workhorses of the section, and if not limited by the distribution network, they will determine the actual production capacity.

The power consumed by each motor must be measured to determine if a specific motor is overloaded or whether it could become a limitation if the production is further increased. A motor that is overloaded has the potential to limit the total production capacity of the specific piece of equipment and, therefore, the total production capacity of a section.

The main subcomponents of the mining equipment were discussed in the previous chapter. Voltage, current and power (or power factor) measurements are needed for only one phase of a motor, as it is assumed that the phases of a motor are balanced. Table 3-2 shows the mining equipment and the individual motors on every piece of equipment for which measurements must be made. The variables measured at each motor are also indicated. See chapter 2 for more information in general on the mining equipment and the motors on each piece of equipment.

Table 3-2: Measuring points on the mining equipment and the variables to be measured.

Equipment	Component	Phases to be measured	Variables to be measured
CM			
	Cutter motor 1	1	Voltage, Current and Power
	Cutter motor 2	1	Voltage, Current and Power
	Gathering motor 1	1	Voltage, Current and Power
	Gathering motor 2	1	Voltage, Current and Power
	Pump motor	1	Voltage, Current and Power
	Conveyer motor	1	Voltage, Current and Power
	Dust motor	1	Voltage, Current and Power
	LH Traction motor	1	Voltage, Current and Power
	RH Traction motor	1	Voltage, Current and Power
Shuttle Car*			
	Pump motor	1	Voltage, Current and Power
	Conveyer motor	1	Voltage, Current and Power
	Traction motor LH	1	Voltage, Current and Power
	Traction motor RH	1	Voltage, Current and Power
Feeder Breaker			
	Conveyer motor	1	Voltage, Current and Power
	Crusher motor 1	1	Voltage, Current and Power
	Crusher motor 2	1	Voltage, Current and Power
Roofbolter**			
	Pump motor	1	Voltage, Current and Power
Fans			
	Fan motor	1	Voltage, Current and Power

* Three Shuttle cars
** One or two Roofbolters

- Continuous miner –The contactors of each motor is split between two flameproof panels. The space in the DC panel is limited as a result of the bridge rectifier and the firing pack taking up a lot of space. The measuring instruments could fit into the AC panel. Spare wires between the AC and DC panels were used to measure the consumption of motors situated in the DC panel.

  The traction motors were generally 37 kW motors. However, after several breakdowns, the motors were upgraded to 50 kW. Most continuous miners are however still using 37 kW traction motors.

- Shuttle car – Some shuttle cars have small flameproof panels that could make it difficult to install measuring instruments. Those with the larger flameproof panels should offer not difficulties.

- Feeder breaker – The more general configuration for feeder breakers at Sasol Mining are one feeder motor and two breaker motors. Space is available in the flameproof enclosures of feeder breakers, although the width of the measuring instrument could make it difficult to fit the instrument into the enclosure.

- Roofbolter – The flameproof enclosure where the measuring instruments must be inserted is very small, and a very small measuring instrument will have to be used. Practicability problems could be experienced.

3.1.3 Measurement schedule

At least two sections must be investigated. The first part of the measurement schedule would be on the in-section electrical distribution network, whereafter the individual energy consumption points on the mining equipment must be measured. Table 3-3 shows the proposed measuring schedule. It can be repeated at each section that has to be investigated.

Measurements on the distribution network should be done for 5 days at each measuring point proposed. The consumption of each of the motors on the mining equipment should then be measured for a total of five days. The total measuring period will cover ten shifts.

Table 3-3: Proposed measurement schedule for a section.

Meter	Mo	Tu	We	Th	Fri
Week 1					
Meter	**Mo**	**Tu**	**We**	**Th**	**Fri**
MAS	In-section Distribution network	In-section Distribution network	In-section Distribution network	In-section Distribution network	In-section Distribution network
ION 7700	Section MSU	Section MSU	Section MSU	Section MSU	Section MSU
Flashcard Recorder	Section CM	Section CM	-	-	-
Week 2					
Meter	**Mo**	**Tu**	**We**	**Th**	**Fri**
ION 7700	Section FB Crusher motor 1 Crusher motor 2 Conveyor motor	Section FB Crusher motor 1 Crusher motor 2 Conveyor motor	Section FB Crusher motor 1 Crusher motor 2 Conveyor motor	Section CM Cutter motors X 2 Pump motor Traction motors X 2	Section CM Cutter motors X 2 Pump motor Traction motors X 2
MA	-	-	-	-	-
Week 3					
Meter	**Mo**	**Tu**	**We**	**Th**	**Fri**
ION 7700	Section CM Cutter motors X 2 Pump motor Traction motors X 2	Section CM Gathering head motors X 2 Conveyor motor Traction motors X 2	Section CM Gathering head motors X 2 Conveyor motor Traction motors X 2	Section CM Gathering head motors X 2 Conveyor motor Traction motors X 2	Section CM Gathering head motors X 2 Dust motor Traction motors X 2
MA	SC Pump motor	SC Pump motor	SC Conveyor motor	SC Conveyor motor	-
Week 4					
Meter	**Mo**	**Tu**	**We**	**Th**	**Fri**
ION 7700	Section SC Pump motor Conveyor motor Traction motors X 2	Section SC Pump motor Conveyor motor Traction motors X 2	Section SC Pump motor Conveyor motor Traction motors X 2	Jetfans	Jetfans
MA	FB Crusher motor 1	FB Crusher motor 2	FB Conveyor motor	-	-

3.2 MEASURING INSTRUMENTATION

Voltage, current and power or power factor measurements must be taken at a number of points on the in-section electrical distribution network as well as on the motors on the mining equipment. These measurements will be analysed to determine the production capacity of each item of the equipment used in a production section. The measuring instruments should comply with the following requirements:

- Measure and store voltages and currents and if possible power or power factor in real time.
- Sampling interval of 2 seconds or less.
- Capacity to store this data for a period of at least two shifts (20 hours).
- Instruments must be robust, small and compact. It should preferably be flameproof.

The instruments must either be able to measure currents and voltages simultaneously, or the instruments must be able to synchronise with other instruments if only one variable can be measured at a time. The measuring instrument must be able to store more than 36 000 sampled values (2 second sampling interval, recording for 20 hours) for each voltage or current variable measured, as well as 36 000 time values.

The investigations were performed in a flameproof environment that makes measuring difficult. The measuring instruments must thus either be placed within a flameproof panel or the instruments must be flameproof. Space is very limited inside the flameproof panels for instruments.

3.2.1 Available measuring instruments

Sasol Mining has a variety of measuring instruments with recording capabilities that could be used for the investigation. The instruments are:

- 6 X Brymen TBM 515 multimeters
- 1 X Fluke 43 power quality meter
- 1 X ION 7730 power quality meter
- 1 X ION 7700 power quality meter

The Brymen multimeters were not suitable, because they cannot record for 20 hours at a sampling interval of 2 seconds or less. The sampling interval is selectable between 0.05, 1, 20, 40, 60, 120, 240 and 480 seconds. They can only record for 35 minutes at a 0.05 second sampling interval and for 12 hours at a 1 second sampling interval. Another disadvantage is that the multimeters can only record one variable against time, either a voltage or a current, and they cannot be synchronised with the other Brymen multimeters.

The Fluke 43 power quality meter can record one voltage and one current for periods ranging from 4 minutes to 16 days. The recording capacity, however, does not meet the requirements, as only 240 variables, can be stored compared to the required 36 000.

The ION 7330 can measure three AC voltages and three AC currents simultaneously. If three voltages and three currents are measured every two seconds together with the active power or power factor of each phase, it can record for only three hours, which also does not meet the requirements.

The ION 7700 is the larger and more sophisticated model of the ION range of meters. It is a highly advanced digital power meter. The programming of the ION 7700 is done in the same way as the ION 7330, but it comes standard with a number of extra features. The data storage memory is much larger, and it has four analog inputs that can be used to measure DC voltages and currents of the two traction motors via transducers.

Three phase voltages and currents can be measured or single-phase measurements of three different motors can be made simultaneously. The sampling interval is adjustable between hundredths of a second and hours. The ION 7700 can record three AC voltages and three AC currents and either the power factor or active power for each phase, together with four analog values at a two second sampling interval for more than 20 hours. It is the only measuring instrument that satisfies the requirements, although its not really robust or compact. The ION 7700 has the following specifications:

- Power 85 V - 240 V_{ac} or 100 V to 300 V_{dc}
- Voltage input 120 V_{LN} or 208 V_{LL}
- Current input 5 A
- Analog inputs (A1 to A4) 0 mA – 20 mA

The ION 7700 has three clip-on current transformers (CTs), adjustable between 1000/5 or 250/5 or 100/5. A three-phase 1000 V / 110 V transformer was used to transform the 1000 V voltages in a section to the input level of the instrument. Two DC voltage transducers and two current transducers were used for the measurements on the DC traction motors of either a shuttle car or a continuous miner. The transducers convert the DC voltage or current to 0 mA - 20 mA DC current, which can be recorded by the ION 7700 meter through its 0 mA - 20 mA analog inputs. The specifications of the transducers are:

- Voltage Transducers - Danntech

DC Voltage Input to DC Current Output		
DC Voltage input	Min:	0 V
	Max:	500 V
DC Current Output	Min:	0 mA
	Max:	20 mA
Supply		115 Vac

- Current Transducers – RS Components

Split Core Hall Effect Current Transducers		
DC Voltage input	Min:	0 A
	Max:	500 A
DC Current Output	Min:	4 mA
	Max:	20 mA
Supply		± 15 Vdc

3.2.2 Additional measuring instruments

The ION 7700 meter could be used for the measurements on the mining equipment. Sasol Mining, however, did not have enough instruments to simultaneously measure all the points in the in-section electrical distribution network. MAS Condition Monitoring was approached for a quotation to do the measurements on the in-section electrical distribution network. They use measuring instruments that can record at a sampling interval of less than 1 second and their instruments can record for more than 20 hours at this sampling rate. The instruments can only record one variable at a time, but all the instruments can be synchronised.

The MA series of motor protection relays are the standard protection relay used for motors on mining equipment since January 2005. These MA protection relays of NewElec have a recording capability. However, these relays don't have any data storing capacity. A laptop must be connected to the relay for the duration of the recordings. The laptop serves as the storage medium for the recordings from the relay and is placed inside the panel with the relay. Another drawback of the relays is that they can only record the currents and voltages consumed, not the power factor or active power of the motor.

The sections selected for the studies do not have any MA protection relays yet in the panels. The relays will only be installed as the equipment is taken in for mayor overalls and repairs. An MA100 relay and an old Pentium 1 laptop from NewElec were used for this study, and an MA50 relay was obtained from Sasol Mining's Central Workshop. The MA50 is used for motors with currents from 5 A – 50 A and the MA100 for larger motors (10 A to 100 A). These two relays were used in conjunction with the laptop from NewElec.

A flashcard recorder from JOY Mining Machinery was used for additional measurements on the continuous miner. The flashcard recorder can be used only on the JNA 1 continuous miners. It will automatically record the consumption of all the motors, except that of the pump and dust motors on the continuous miner. This data is recorded on a flashcard and can be downloaded to a computer with the help of a card reader. The flashcard measures the line voltage and current for one phase as well as the current for each motor, except the two motors mentioned above. The DC voltage and current for both traction motors were also measured.

There were only two flash cards and each card could only record a single day's data. After two days of recording, the disks had to be taken to JOY to download the data. The flashcards were not always reliable which caused some remeasuring.

3.3 SECTIONS TO BE STUDIED

There were a number of sections at each mine, with each section having different combinations of mining equipment. Some production sections have two Fletchers roofbolters, while other sections use a single ARO double boom roofbolter. The same applies to shuttle cars and continuous miners. Some sections have three shuttle cars and others four, while some even use battery haulers or continuous haulage systems. There are also significant differences in the continuous miners used at all the Sasol mines.

A number of variables were taken into account when deciding on the sections to be investigated. These included considerations such as the equipment being used in a section, whether a section was developing or stoping, seam height and environmental conditions. It was important for the purpose of this investigation to keep most of these considerations constant. The results of this investigation, if at all possible, should be applicable to most of the “standard” sections at Sasol Mining.

The sections to be studied must use equipment that will still be in use at Sasol Mines for some time to come. At least two sections should be studied. The more sections measured, the more applicable and universal the data will be.

It was decided that the coal haulage method should be three shuttle cars and that JNA 2 continuous miners will not form part of the investigation, as Sasol Mining feels that the future still lies with the JNA 1 continuous miners. Sections to be measured must therefore have a JNA 1 continuous miner and three shuttle cars, and at least two section must be investigated. The sections also had to be in a developing phase instead of pillar extraction phase.

Another requirement for the sections to be investigated was that they had to be selected from the better producing sections at Sasol Mining (see Table 3-4). The down time is far less at these top sections and they are more consistently produce high tonnages. The capabilities or limitations of a section’s equipment will clearly indicate if measurements were taken at a top section producing high tonnes. Higher production will also make it easier to forecast what can be expected if the production is further increased.

A critical factor in deciding on the sections to be investigated was the flameproof enclosures on the shuttle cars. There are two sizes of flameproof enclosures on the shuttle cars. One type has a large flameproof enclosure with a traction transformer next to the driver’s cab. The other type has a smaller flameproof enclosure with a traction transformer right next to the enclosure. The measuring instruments used for the investigation could only fit into the large enclosures. This requirement limited the sections that could be used for the study, as only 20% of the shuttle cars used at Sasol Mining have large flameproof enclosures. This, coupled with the requirement that the section has to be a top producing one, made it very difficult to find suitable sections to study.

Table 3-4: Production sections with highest to lowest cumulative production.

Section	Mine	Continuous Miner	TONNE	T/CM/S	Cumulative in-section cost		NO of
			YTD	YTD AVG	R 000	R/TON	SC
61	**Twistdraai**	**Joy 12HM31**	**493,687**	**2,082**	**9,721**	**19.69**	**3**
15	Twistdraai	Joy 12HM31	419,043	1,821	7,899	18.85	3
21	**Twistdraai**	**Joy 12HM31**	**418,965**	**1,767**	**8,867**	**21.16**	**3**
16	Brandspruit	Joy 12HM31	407,394	1,738	8,349	20.49	3
30	Brandspruit	Joy 12HM31	392,761	1,707	7,555	19.24	3
32	Brandspruit	Joy 12HM31	388,520	1,641	7,208	18.55	3
46	Brandspruit	Joy 12HM31	385,915	1,694	8,182	21.20	3
20	Twistdraai	Joy 12HM31	385,238	1,688	8,528	22.14	3
40	Bosjesspruit	Joy 12HM31	382,499	1,651	7,413	19.38	3
68	Bosjesspruit	Joy 12HM31	374,598	1,659	7,050	18.82	3
51	**Twistdraai**	**Joy 12HM31**	**369,991**	**1,601**	**7,506**	**20.29**	**3**
59	Bosjesspruit	Joy 12HM31	368,961	1,620	6,293	17.06	3
45	Bosjesspruit	Joy 12HM31	361,380	1,594	7,760	21.47	3
85	Export Mine	Joy 12HM31	344,979	1,570	8,647	25.07	3
55	Bosjesspruit	Joy 12HM31	343,030	1,500	7,230	21.08	3
81	Export Mine	Joy 12HM31	335,305	1,551	8,183	24.40	3
50	Twistdraai	Joy 12HM31	333,917	1,464	8,151	24.41	3
29	Brandspruit	Joy 12HM31	330,039	1,446	7,592	23.00	3
19	Bosjesspruit	Joy 12HM9	327,854	1,472	6,171	18.82	3
82	Export Mine	Joy 12HM31	324,204	1,507	6,207	19.15	3
76	Export Mine	Joy 12HM31	315,510	1,463	5,810	18.41	3
83	Export Mine	Joy 12HM31	304,473	1,405	7,144	23.46	3
56	Bosjesspruit	Joy 12HM31	293,551	1,311	7,487	25.50	3
86	Export Mine	Joy 12HM31	284,988	1,315	7,580	26.60	3
74	Export Mine	Joy 12HM31	283,998	1,335	6,177	21.75	3
91	Bosjesspruit	Joy 12HM31	283,236	1,260	7,156	25.27	3
58	Bosjesspruit	Joy 12HM31	281,404	1,258	8,362	29.72	3
39	Twistdraai	Joy 12HM31	278,739	1,311	9,505	34.10	3
78	Export Mine	Joy 12HM31	276,244	1,293	6,674	24.16	3
25	Bosjesspruit	Joy 12HM31	274,665	1,222	9,048	32.94	3
75	Export Mine	Joy 12HM31	244,695	1,150	6,900	28.20	3

* YTD - Year to date
* S/C - Shuttle Cars

Production sections using equipment such as Voest miners, JNA 2 continuous miners or continuous coal haulage systems, battery haulers or more than three shuttle cars in a section were not considered. The following sections complied with most of the requirements to form part of the study:

- Twistdraai Central, Section 21
- Twistdraai Central, Section 51
- Twistdraai Central, Section 61

Section 61 did not meet all the requirements. It was the best section at Sasol Mining using a JOY 12HM31 continuous miner, but it does not have shuttle cars with large flameproof panels. It was decided that the network measurements should be done at section 61, because it was the top section, with the measurements on the mining equipment to be done at section 51.

Section 21, 51 and 61 are all sections that produced more than 1 million tonnes per year in recent years, with sections 21 and 61 having reached this milestone again this year (2005). Section 51 did not produce as much the previous year, but it was doing well at the time of the investigation. Mining conditions were limiting the performance as there is a lot of rock in the coal seam.

Figure 3.3-1 shows a simplified representation of the 11 kV distribution network supplying the sections with power. Power factor correction units have been installed in the lines supplying sections 21, 51 and 61 (see Figure 3.3-1). Several other loads and transformers supplying power to the mine’s conveyor belts are also supplied from this distribution network. Section 21 was almost 12 km from the shaft at the time of the investigation, with section 61 about 10 km from the shaft. Section 51 was about 6 km from the shaft.

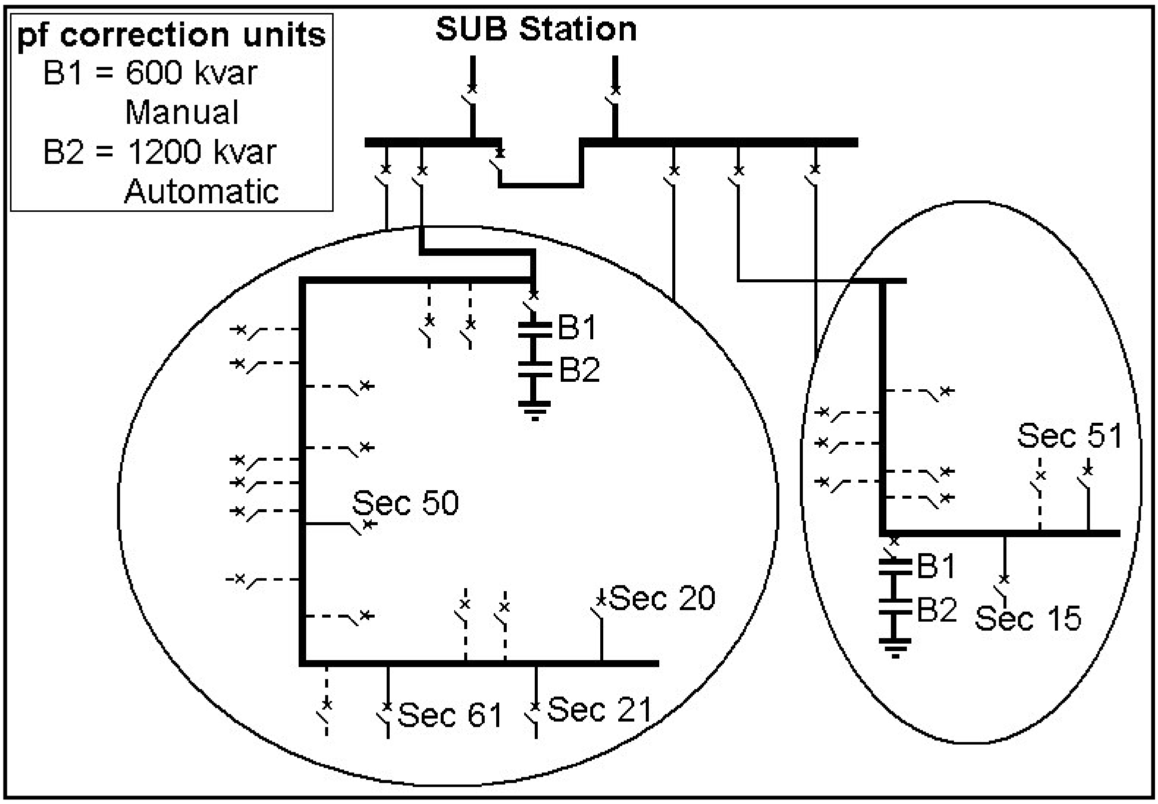


Figure 3.3-1: Simplified representation of the Twistdraai Central 11 kV distribution network.

The equipment forming part of sections 21, 51 and 61 can be seen in Table 3-5, Table 3-6 and Table 3-7. All the sections were using the same equipment. The most striking difference between the equipment used in these three sections was that the continuous miner of section 21 still uses 37 kW traction motors, while the continuous miners of the other two sections use 50 kW motors. The only other differences between the equipment of these sections are that the protection relays and the layout of the contactors, relays and instrument transformers in the flameproof enclosures differ.

Table 3-5: Mining equipment of section 21.

#	Equipment	Manufacturer	Components	Rating
1	MSU	Dimako		630 A @ 11 kV
1	Flameproof Transformer	Dimako		1250 kVA
1	Gate end boxes	Sascoal		
1	Continuous Miner	JOY		
			Cutter motors X 2	175 kW
			Gathering head motors X 2	40 KW
			Pump motor	116 kW
			Conveyor motor	37 kW
			Scrubber motor	35 kW
			Traction motors X 2	37 kW
3	16 tonne Shuttle Car	Sascoal		
			Traction motors X 2	22 kW
			Pump motor	15 kW
			Conveyor motor	19/9.5 kW
1	Feeder Breaker	McCarthy		
			Crusher motors X 2	55 kW
			Conveyor motor	55 kW
2	Roofbolters	RHAM/		
		Sascoal	Pump motor	30 kW

Looking at the practical execution of the investigation it was easier with all the sections being in one mine. Variables having an effect on production would be more constant than if a section from another mine was included in the selection. Although mining conditions can differ significantly even in the same mine, the equipment was in similar condition. One mine will usually use the same type of feeder breaker; flameproof transformer and gate end box, for example, whereas the equipment will differ more if sections from different mines were investigated.

Table 3-6: Mining equipment of section 51.

#	Equipment	Manufacturer	Components	Rating
1	MSU	Dimako		630 A @ 11 kV
1	Flameproof Transformer	Dimako		1250 kVA
1	Gate end boxes	Sascoal		
1	Continuous Miner	JOY		
			Cutter motors X 2	175 kW
			Gathering head motors X 2	40 KW
			Pump motor	116 kW
			Conveyor motor	37 kW
			Scrubber motor	35 kW
			Traction motors X 2	50 kW
3	16 tonne Shuttle Car	Sascoal		
			Traction motors X 2	22 kW
			Pump motor	15 kW
			Conveyor motor	19/9.5 kW
1	Feeder Breaker	McCarthy		
			Crusher motors X 2	55 kW
			Conveyor motor	55 kW
2	Roofbolters	RHAM/		
		Sascoal	Pump motor	30 kW

Table 3-7: Mining equipment of sections 61.

#	Equipment	Manufacturer	Components	Rating
1	MSU	Dimako		630 A @ 11 kV
1	Flameproof Transformer	Dimako		1250 kVA
1	Gate end boxes	Sascoal		
1	Continuous Miner	JOY		
			Cutter motors X 2	175 kW
			Gathering head motors X 2	40 KW
			Pump motor	116 kW
			Conveyor motor	37 kW
			Scrubber motor	35 kW
			Traction motors X 2	50 kW
3	16 tonne Shuttle Car	Sascoal		
			Traction motors X 2	22 kW
			Pump motor	15 kW
			Conveyor motor	19/9.5 kW
1	Feeder Breaker	McCarthy		
			Crusher motors X 2	55 kW
			Conveyor motor	55 kW
2	Roofbolters	RHAM/		
		Sascoal	Pump motor	30 kW

3.4 ACTUAL MEASURING STRATEGY

The previous sections describe what needed to be measured if possible, what measuring instruments satisfied the requirements and what instruments had to be hired or borrowed. The variables to be measured and the measuring instruments were matched and a decision was made on the actual measuring strategy.

The idea was to measure everything over the same time period. This included all the measuring points in the in-section electrical distribution network as well as all the motors on the mining equipment. There were not enough instruments to do just that, and it would have been too expensive to hire enough instruments. The measuring strategy needed to be adapted.

All the measuring points were reconsidered and the most critical points determined. Only the most important variables would be measured. Most of the variables not measured were not crucial to the investigation. The cost for hiring measuring equipment was kept to a minimum through adapting the strategy.

3.4.1 In-section electrical distribution network

The measurements on the in-section electrical distribution network were contracted out to MAS Condition Monitoring. The number of measuring points and variables was reduced to save money.

The supply to only one of the three shuttle cars and one of the roofbolters was measured. Single-phase measurements were done instead of three-phase measurements to further reduce cost, as all the important loads were three-phase motors and in theory the phases should be balanced. The supply to the jet fans was not measured as they form a constant load that will not increase as production is increased.

The proposed strategy was to do measurements for a week in each section, but the period was reduced to three days, with an extra day if required. The extra day could be used if production had been below average on the previous three days, or if a number of large breakdowns occurred during the measuring period. Table 3-8 shows the points that were measured as indicated in Figure 3.4-1.

Table 3-8: Actual measuring points for in-section electrical distribution network.

Measuring Point	Description	Number of phases to be measured	Variables to be measured for each phase
A	MSU	3	Voltages, Currents and kW ṡ
B	CM	1	Voltage and Current
C	GEB	1	Current
D	Suttle Car	1	Voltage and Current
E	Roofbolter	1	Current
F	Feeder Breaker	1	Current

Only one voltage was measured at the 1250 kVA flameproof transformer. The voltage measured at that point can be used for other points, as long as the measurements were synchronised and the voltage drop was small. The ION 7700 measuring instrument was used to measure at point A, and the other seven variables were measured by MAS Condition Monitoring. MAS used seven measuring instruments that were synchronised to measure the seven variables at the five different points, with each instrument recording only one variable. Measurements were also done on the continuous miner with the flashcard recorder from JOY.

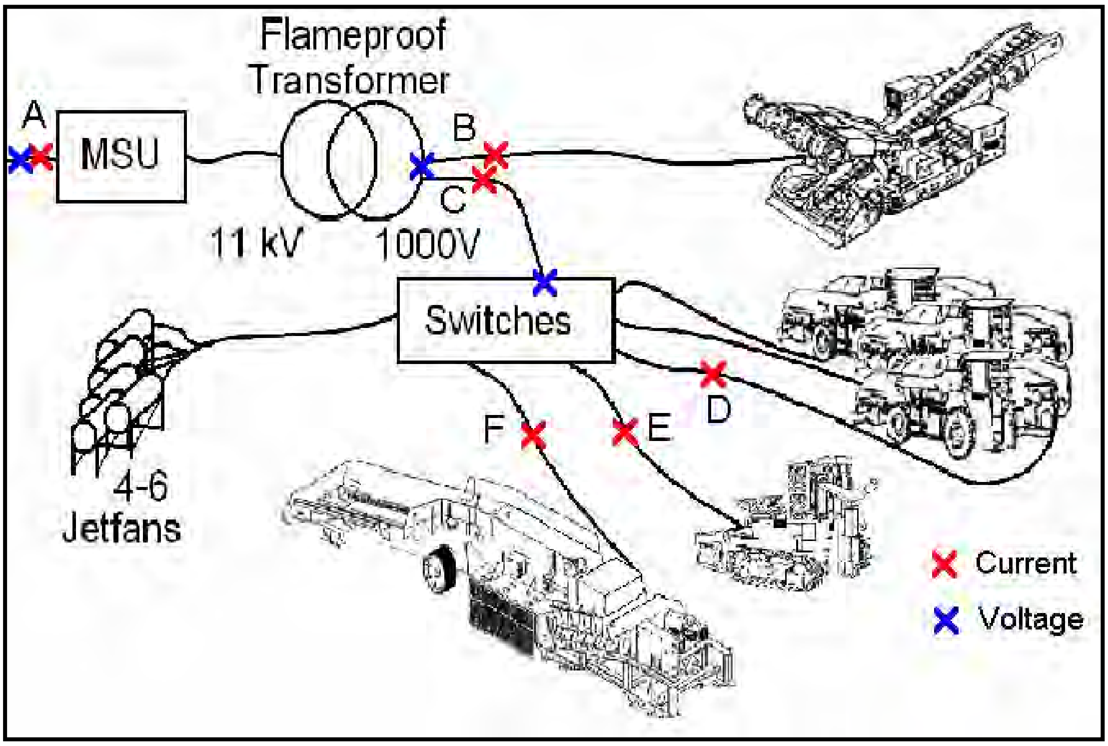


Figure 3.4-1: In-section electrical system with actual measuring points indicated.

3.4.2 Mining equipment

All the energy consumption points in a section had to be measured. Only the consumption on the dust motor of the continuous miner was not measured, the reason being that the consumption profile of these motors would not change if production were increased. Single-phase measurements were done as the motor loads were theoretically balanced.

Difficulties experienced with the measurements on the mining equipment relate more to the practicalities of performing these measurements. There was only one measuring instrument (ION 7700) that satisfied the requirements and this instrument had to fit inside the flameproof enclosures of the different pieces of mining equipment.

Doing measurement directly on the roofbolter was not possible, because the flameproof enclosure was too small for the measuring instruments to fit inside. Consumption of the roofbolter could only be measured at the gate end boxes, which could not provide a precise representation of the consumption of the roofbolter's pump motor. Although not a considerable contribution, voltage drops in the cables and power used on the control circuits and by the lights would be included in the measured consumption.

No measurements were possible on any shuttle car. The shuttle car needs to have a large flameproof enclosure to be able to fit the measuring instruments into the panel. Shuttle cars with large flameproof enclosures were in the minority and this was one of the factors that were considered in deciding on which sections to measure.

The aim was to measure simultaneously on the different equipment, but because of a shortage in measuring instruments and their capabilities, it was not possible. Only three AC motors and two DC motors could be measured simultaneously. The measuring points on every piece of equipment can be seen in Table 3-9.

The ION 7700 can measure three AC currents, so the consumption of three AC motors could be measured simultaneously. The DC motors were measured simultaneously with the three AC motors by using transducers in conjunction with the analog inputs of the ION 7700. Only one voltage was measured for the three AC motors, as all the AC motors on each machine are connected in parallel, and therefore the voltage on each motor is the same.

Table 3-9: Actual measuring points on mining equipment.

Machine	Component	Phases to be measured	Variables to be measured
CM			
	Cutter motor 1	1	Voltage and Current
	Cutter motor 2	1	Current
	Gathering motor 1	1	Current
	Gathering motor 2	1	Current
	Pump motor	1	Current
	Conveyer motor	1	Current
	LH Traction motor	1	Voltage and Current
	RH Traction motor	1	Voltage and Current
Shuttle Car			
	Pump motor	1	Voltage and Current
	Conveyer motor	1	Current
	Traction motor LH	1	Voltage and Current
	Traction motor RH	1	Voltage and Current
Feeder Breaker			
	Conveyer motor	1	Voltage and Current
	Crusher motor 1	1	Current
	Crusher motor 2	1	Current

Additional measurements were made with the MA relays. These measurements only showed the current consumption profiles of the motors when the active power and power factor were not available. The relays were, however, not used often, because the data storage medium was not reliable. Each time a power failure of longer than 5 minutes occurred, the laptop switched off and data recording stopped. Not much useful data was obtained using the MA relays.

3.4.3 Measurement schedule

The plan was to perform the measurements on the in-section electrical distribution network and then the mining equipment at one section before moving to the next section. This did not happen.

It suited the contractors better to measure one section's distribution network the first week and the next section's distribution network the following week. Table 3-10 shows the schedule for measurements on the distribution network of section 21 and 61.

Table 3-10: Measurement schedule for in-section electrical distribution networks.

Week 1 - Section 21					
Meter	**Mo**	**Tu**	**We**	**Th**	**Fri**
MAS	-	In-section Distribution network	In-section Distribution network	In-section Distribution network	Extra day
ION 7700	-	Section MSU	Section MSU	Section MSU	Extra day
Flashcard Recorder	-	Section CM	Section CM	Section CM	-
Week 2 - Section 61					
Meter	**Mo**	**Tu**	**We**	**Th**	**Fri**
MAS	In-section Distribution network	In-section Distribution network	In-section Distribution network	Extra day	Extra day
ION 7700	Section MSU	Section MSU	Section MSU	Extra day	Extra day
Flashcard Recorder	Section CM		-	-	-

Section 61 has shuttle cars with small flameproof enclosures. Even so, section 61 was still used to measure the in-section electrical distribution network because it is the top-producing section at Sasol Mining. The measurements on the mining equipment of section 61 were done on the mining equipment of section 51. The measurement schedule for measuring the mining equipment of section 21 can be seen in Table 3-11, and that of section 51 in Table 3-12.

Table 3-11: Mining equipment measurement schedule for section 21.

Week 1					
Meter	**Mo**	**Tu**	**We**	**Th**	**Fri**
ION 7700	-	Section FB Crusher motor 1 Crusher motor 2 Conveyor motor	Section FB Crusher motor 1 Crusher motor 2 Conveyor motor	Section FB Crusher motor 1 Crusher motor 2 Conveyor motor	-
Week 2					
Meter	**Mo**	**Tu**	**We**	**Th**	**Fri**
ION 7700	Section CM Cutter motors X 2 Pump motor	Section CM Cutter motors X 2 Pump motor	Section CM Cutter motors X 2 Pump motor	Section CM Gathering head motors X 2 Conveyor motor	Section CM Gathering head motors X 2 Conveyor motor Traction motors X 2
Week 3					
Meter	**Mo**	**Tu**	**We**	**Th**	**Fri**
ION 7700	Section CM Gathering head motors X 2 Conveyor motor Traction motors X 2	Section CM Gathering head motors X 2 Scrubber motor Traction motors X 2	-	-	-

Measurements on the shuttle cars in section 21 could not be taken. The only shuttle car with a large flameproof enclosure in section 21 was taken to the surface for major repairs during the second week of measurements at section 21. This happened before measurements on the shuttle car could be done. Measurements were immediately done on the shuttle cars of section 51 to ensure that data on a shuttle car was obtained.

Table 3-12: Mining equipment measurement schedule for section 51.

Week 4					
Meter	**Mo**	**Tu**	**We**	**Th**	**Fri**
ION 7700	Section SC Pump motor Conveyor motor Traction motors X 2	Section SC Pump motor Conveyor motor Traction motors X 2	-	Section CM Cutter motors X 2 Pump motor	-
Week 5					
Meter	**Mo**	**Tu**	**We**	**Th**	**Fri**
ION 7700	-	Section CM Cutter motors X 2 Pump motor	Section CM Gathering head motors X 2 Conveyor motor Traction motors X 2	Section CM Gathering head motors X 2 Conveyor motor Traction motors X 2	-
MA 100	-	Section FB Conveyor motor	Section FB Crusher motor 1	Section FB Crusher motor 2	-

The measurement period on the equipment of section 51 was curtailed from three days to two days on each motor. The reason was that the shuttle car of section 21 would have been returned to production in the second week of measurements at section 51. If measurements at section 51 were shortened, it would mean that there would be a week left to do measurements on the shuttle car of section 21 before section 21 moved from Twistdraai Central to Twistdraai West Colliery. It was not possible to get the shuttle car back in section 21 before the section moved to Twistdraai West, as a there was a shortage in transportation. The shuttle car was therefore not measured.

Problems were also experienced with measurements on the pump motor of a shuttle car. No useable data could be obtained for a pump motor's consumption at section 51. Measurements were taken for one day on a shuttle car in section 50 to obtain data of the consumption of a shuttle car's pump motor.

Measurements were also not performed on the feeder breaker of section 51 with the ION 7700 meter. Although the feeder breaker models were the same and the flameproof enclosures were the same, the layout of the protection equipment differed so much that the meter just could not fit inside. The MA 100 relay was used to do measurements on the feeder breaker, as can be seen in Table 3-12. The only useful data obtained were for the day that measurements were made on the conveyor motor.

Problems were also experienced with the active power measurements on the mining equipment. There were almost no useful power measurements on any of the motors. The instrument did not always correctly measure the active power, because the phases measured did not always correlate. The voltage of phase A was measured, but what should have been the current of phase A was the current of phase B, for example, because the colour coding on the cables was wrong. This meant that the active power was calculated incorrectly. In the post-processing of data this phase-shift was corrected.

3.5 WORK STUDY

Time studies were performed at the test sections on certain days while measurements were being made on the distribution network and the mining equipment. This information helped to correlate the measured data with what was actually happening in the section. It was thus possible to tell at what time during the measuring a roofbolter was drilling or installing a roofbolt and when a shuttle car was being loaded or offloading.

Time studies on the continuous miner and the feeder breaker were performed simultaneously with measurements on the distribution network. Studies were either performed on the continuous miner or the feeder breaker when measurements were done on the mining equipment, depending on the equipment being measured. The information helped to determine the “normality” of operations in the section. The average loading time of a shuttle car could be determined and compared to the actual measurements, for example. If something were out of the ordinary, it would be detected.

3.6 SUMMARY

The sections to be investigated had to satisfy a number of requirements, e.g. the seam height had to be between 3 m and 4 m, and three 16 tonne shuttle cars had to be used for coal haulage. The sections that satisfied the requirements of the investigation, were sections 21, 51 and 61 at Twistdraai Central Colliery.

Measurements on the in-section distribution network were performed at section 61. The measurements on the mining equipment were performed at section 51.

An obstacle experienced in performing measurements was the number of measuring instruments that Sasol Mining owned and the available functions on these measuring instruments. The budget did not allow for hiring a lot of measuring instruments or to let a contractor do most of the measurements. The general limitation was the storage capacity of the instruments at the proposed sampling interval. The ION 7700 was the only measuring instrument owned by Sasol Mining that satisfied all the measuring requirements. The ION 7700 was therefore used to perform measurements on the energy consumption points on the mining equipment.

MAS Condition Monitoring was contracted to do the measurements on the in-section electrical distribution network, as there was not enough measuring instruments to measure at all the points simultaneously. The proposed measuring points on the in-section electrical distribution network were reduced and the measurement period shortened to three days to reduce cost.

The space in the flameproof enclosures of the equipment was very limited. Measurements could not be performed on the pump motors of the roofbolters. The feeder breaker of section 51 could also not be measured with the ION 7700, because there was not enough space to fit the instrument inside the flameproof enclosure.

Problems were experienced with measurements on the shuttle cars. Measurements could only be performed on shuttle cars with large flameproof enclosures, because the measuring instrument could only fit into these enclosures. The shuttle car of section 21 that had a large flameproof enclosure was taken out of the section for repairs before it could be measured. The shuttle car in section 51 was measured, but the data on the consumption of the pump motor could not be used. Measurements were then made for an additional day on the shuttle car of section 50 to obtain useable data on the pump motor of a shuttle car.

CHAPTER 4
IN-SECTION ELECTRICAL DISTRIBUTION NETWORK

The investigation was divided into two parts. The first part consisted of measuring the in-section electrical distribution network, and for the second part the energy consumption points on the various pieces of mining equipment used in a production section was measured.

This chapter summarises the results obtained from the measurements on the in-section electrical distribution network. The analysed data showed which equipment and supply cables in the distribution network are already being overloaded and could become limitations in the future. The CD attached to the end of the report has more detailed results, as this chapter provides only a summary of the results and highlights only a few cases and extreme conditions that were measured.

4.1 MEASURING SUMMARY

Measurements were made at the points indicated on Figure 4.1-1. The measurements were then used to determine the total energy consumption at specific points in the distribution network to determine whether cables or equipment still have spare capacity or whether they are already overloaded.

Problems were experienced with measurements done in both sections. The measuring instrument that was recording the consumption of the continuous miner in section 21 did not record during the first two days. The same instrument had a problem on the first day of measurements in section 61 when its range was set too low to record the consumption of the continuous miner. The consumption of the continuous miner was clipped at 315 A. Other problems experienced with the instruments were that their storage capacity was regularly insufficient. Sometimes they stopped recording at 22:00 at night while the sections were still producing.

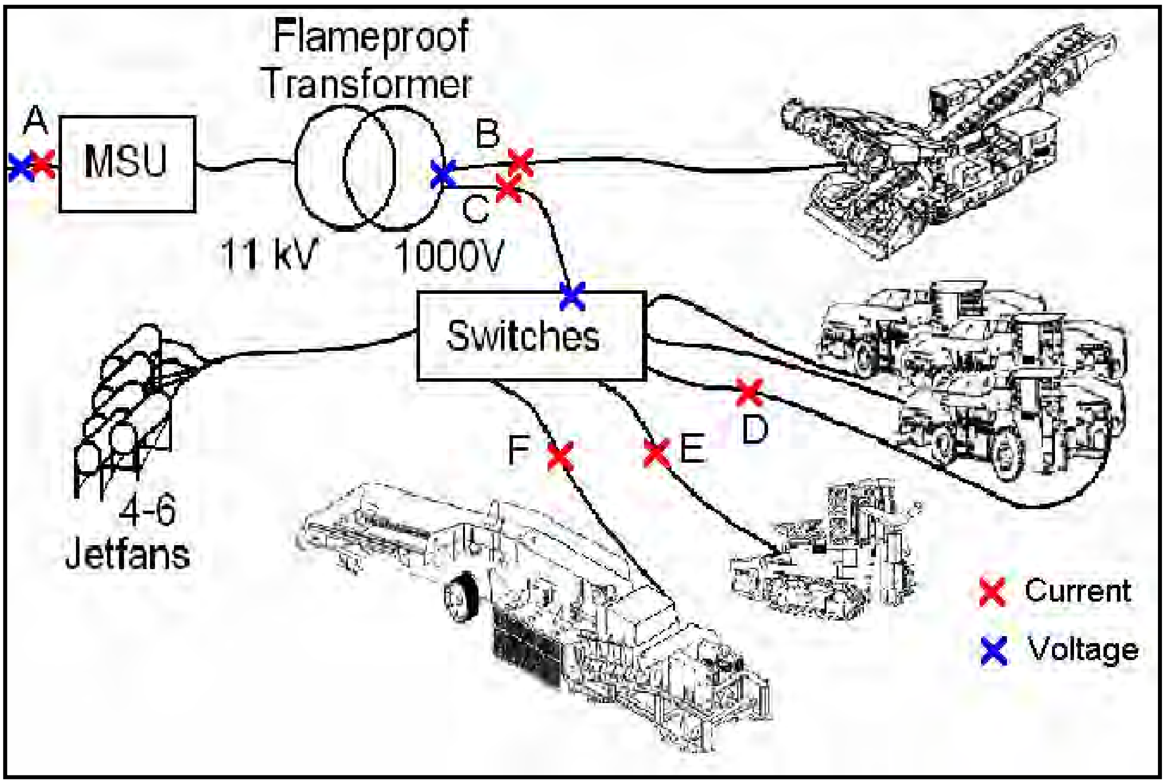


Figure 4.1-1: Measuring points for in-section electrical distribution network.

Measurements on the shuttle cars and roofbolters were also problematic. The measuring instrument was placed in a switch that was supplying power to a specific shuttle car or roofbolter. The supply switch of the shuttle car or roofbolter was then sometimes changed right after the shift started for unknown reasons, normally after repeated tripping on earth fault. This left the instrument recording nothing. Problems were also experienced with breakdowns on especially the shuttle cars. The cars suffered numerous lengthy breakdowns, sometimes not producing for a full shift, while waiting for new trailing cables.

4.2 PRODUCTION RESULTS

Table 4-1 shows the production of section 21 and 61 during the period that measurements were performed on the in-section electrical distribution network of these sections. The afternoon shifts of both sections performed better than the morning shifts.

Both sections had two shifts that produced poorly, two average shifts and two shifts that performed good or better than the rest. A summary is given in this chapter of the data obtained, if any, during the two average and good shifts of each section.

Table 4-1: Production (tonnes/CM/shift) for section 21 and 61 during measuring period on the in-section electrical distribution networks.

Date	Sect 21		Sect 61	
	Morning	Afternoon	Morning	Afternoon
17-May-2005	858	**2145**	-	-
18-May-2005	1320	**2112**	-	-
19-May-2005	**1716**	**2013**	-	-
23-May-2005	-	-	**1740**	**2030**
24-May-2005	-	-	1450	**2320**
25-May-2005	-	-	**2320**	1160

4.3 MOBILE SWITCHING UNIT

The total consumption of the MSU was measured at the MSU in the main substation of each section. The MSU supplies power to the section conveyor belts as well as all the equipment used in the production sections. MSUs receive their power from the main distribution network of the mine via either a 95 mm^2 or 185 mm^2 XLPE cable. The 95 mm^2 cable is rated for a current of 290 A at 11 kV and the 185 mm^2 cable is rated for a current of 410 A at 11 kV at an ambient temperature of 25°C. The MSUs are rated for a current of 630 A at 11 kV.

Figure 4.3-1 and Figure 4.3-2 show the consumption of the MSUs at 11 kV, during two shifts in sections 21 and 61 respectively. There were marked differences between the average consumption and the maximum consumption of a section; the maximum consumption being more than double the average consumption. The three phases were very well balanced and it can be seen that the consumption was not constant, but cyclic.

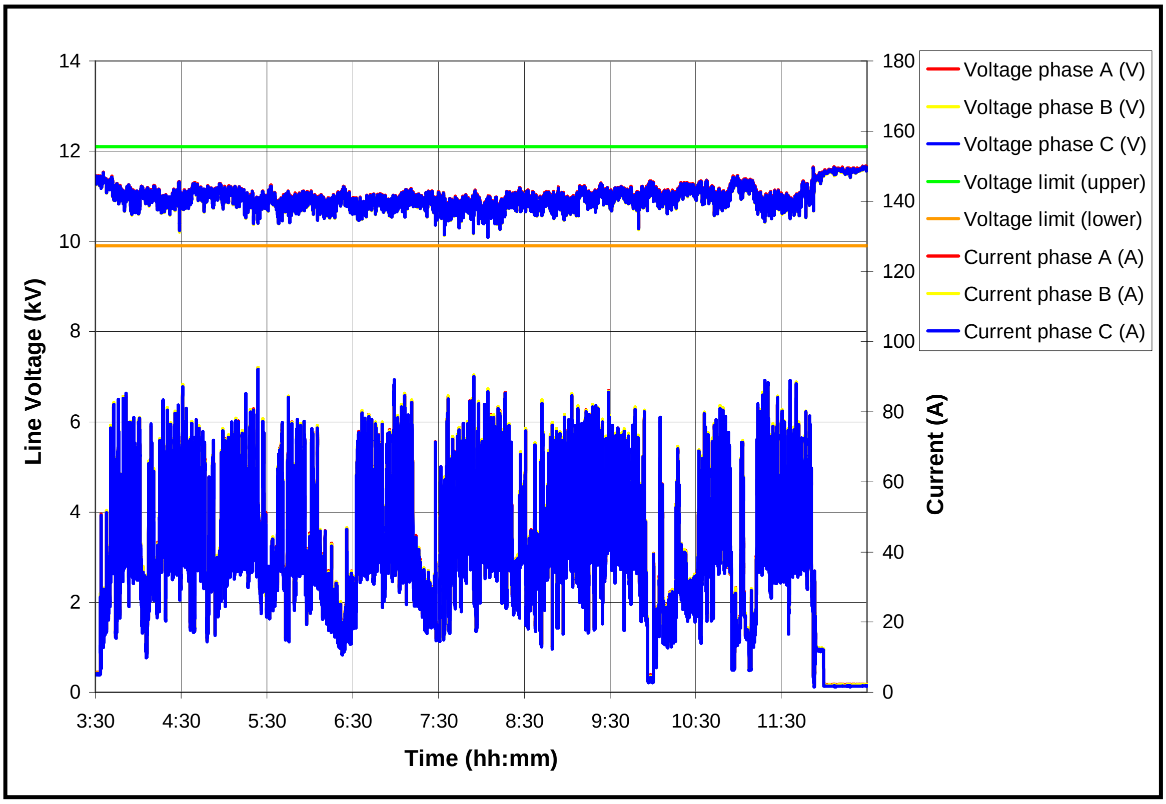


Figure 4.3-1: Load current and voltage for an MSU – Afternoon shift 18 May 2005.

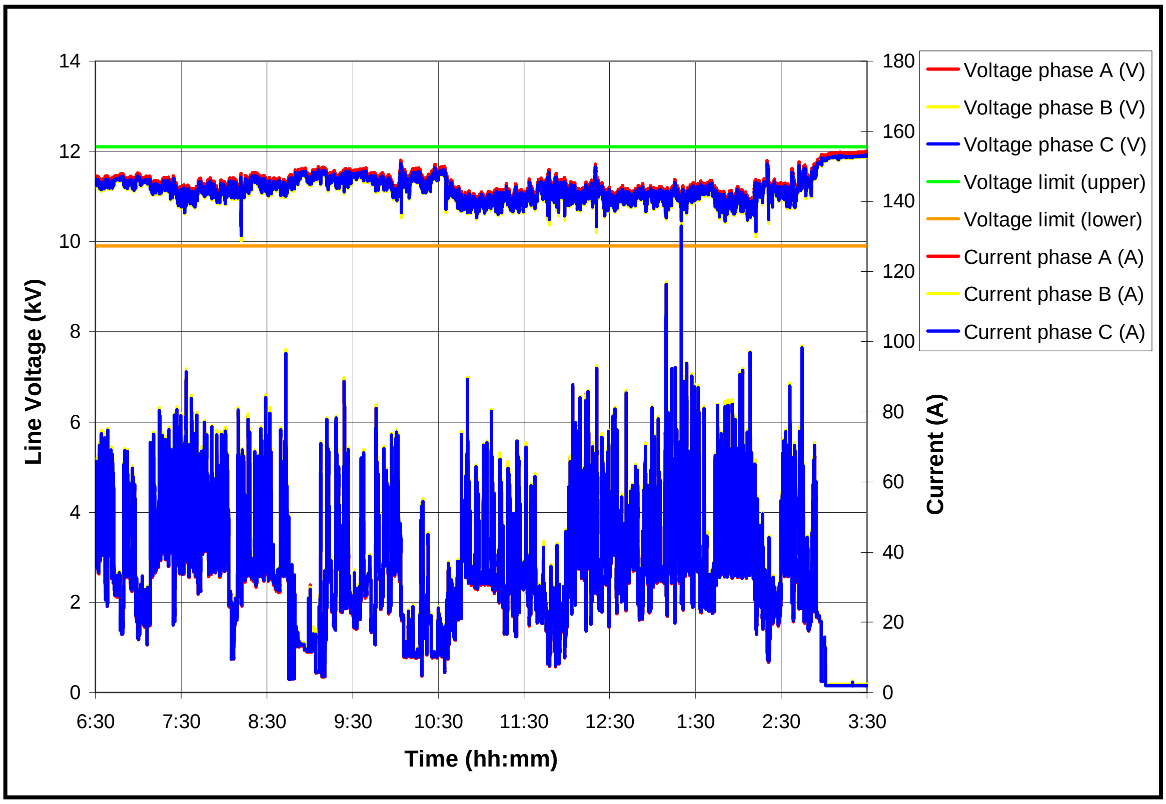


Figure 4.3-2: Load current and voltage for an MSU – Morning shift 23 May 2005.

Table 4-2 shows the production of section 21 during the measuring period with Figure 4.3-3 showing a histogram of the currents consumed during these shifts. From Figure 4.3-3 it can be seen that the average consumption of section 21 was between 30 A and 40 A per phase with a small peak between 60 A and 70 A per phase. The consumption profile of all the shifts at section 21 was quite similar.

Table 4-2: Section 21 - Data for the total consumption of an MSU.

	Morning	Afternoon	Afternoon	Afternoon
	19-May-05	17-May-05	18-May-05	19-May-05
Tonnes/CM/Shift	1716	2145	2112	2013

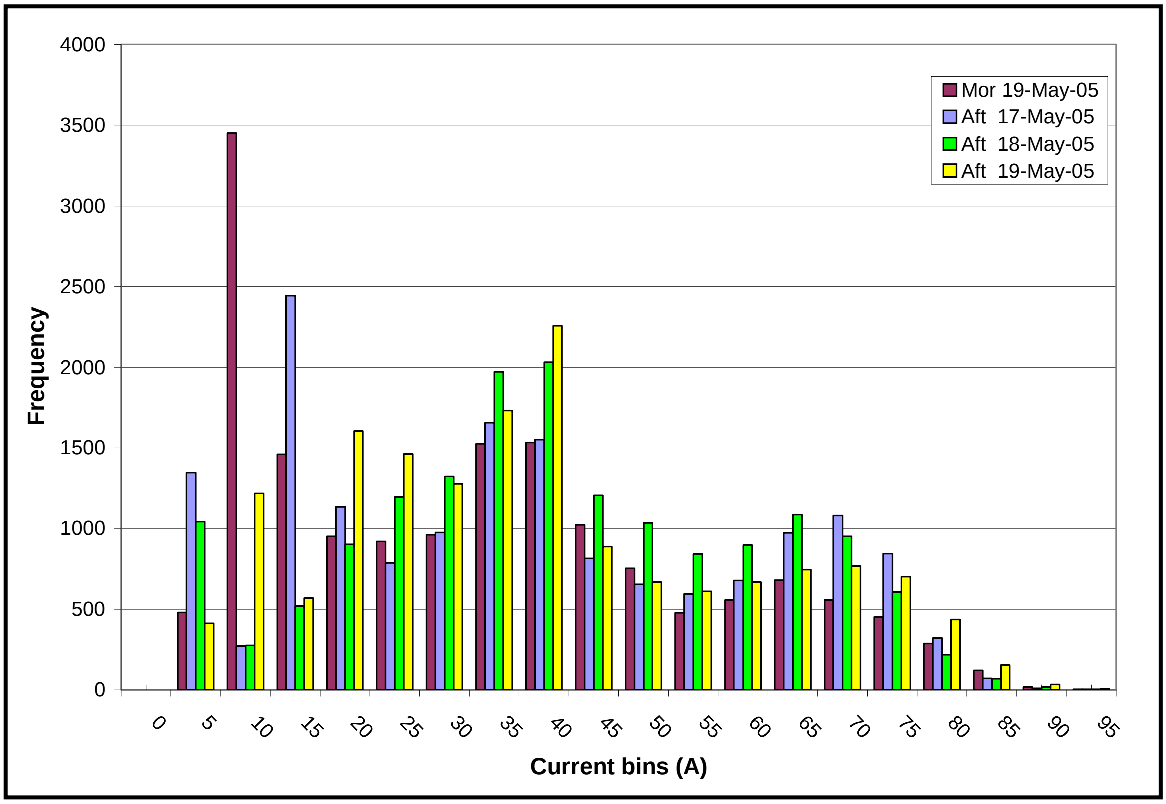


Figure 4.3-3: Section 21 - Histogram for current consumed by an MSU.

Table 4-3 shows the production of section 61 during the measuring period with Figure 4.3-4 showing a histogram of the currents consumed during these shifts. From Figure 4.3-4 it can be seen that the average consumption of section 61 was also between 30 A and 40 A, except for the morning shift of 25 May 2005 that had its average between 45 A and 50 A.

Table 4-3: Section 61 - Data for the total consumption of an MSU.

	Morning	Morning	Afternoon	Afternoon
	23-May-05	25-May-05	23-May-05	24-May-05
Tonnes/CM/Shift	1740	2320	2030	2320

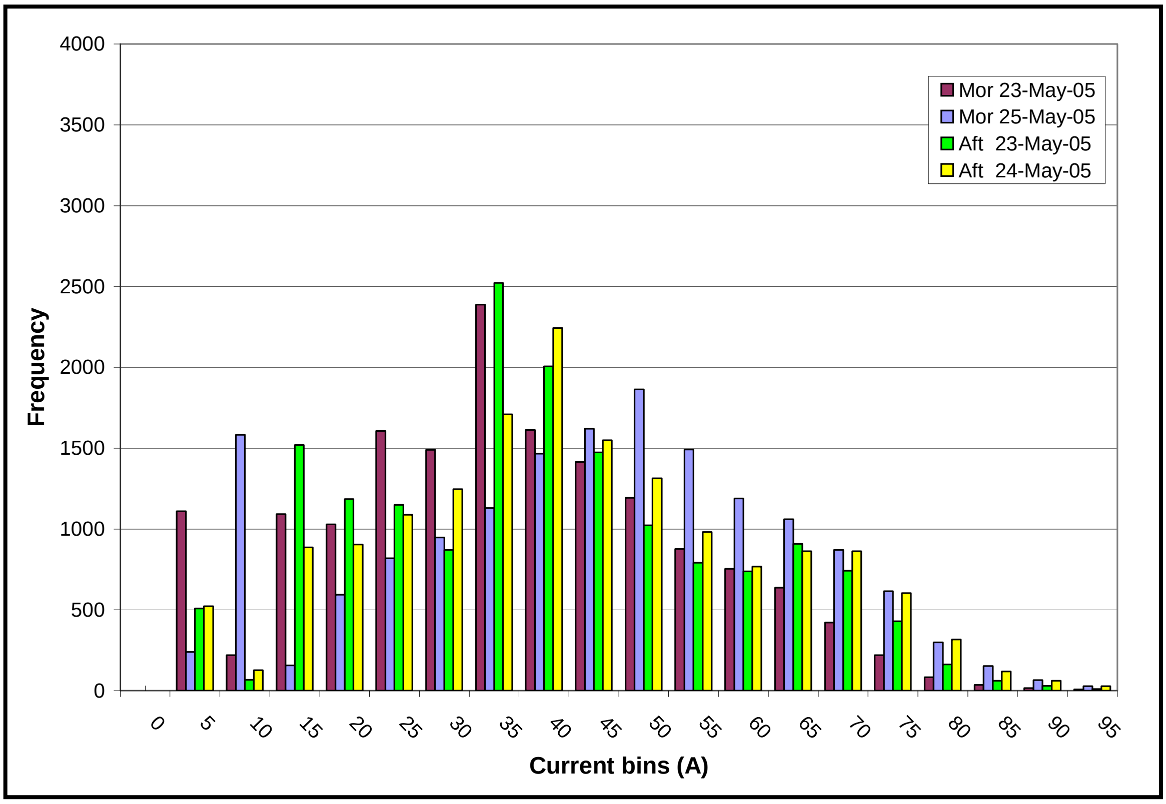


Figure 4.3-4: Section 61 - Histogram for current consumed by an MSU.

The current consumed during the shifts in both sections correlate well with the tonnes produced during the shift. The average consumption per phase was approximately 40 A for a good shift, while it drops for worst-producing shifts. Section 61 did not experience a distinctive small peak at the higher currents as did section 21. Section 21 consumed higher currents for longer periods, whereas section 61 only consumed higher currents for short periods and was consuming the average current more consistently.

From the data it can be seen that a single MSU was able to supply power to almost ten sections without being overloaded. Neither the cables supplying the MSU with power nor the MSU itself was a limitation and should not become a limitation unless drastic changes are made to the number of equipment used in sections or the size of the motors on the equipment. The 95 mm^2 cables still have vast spare capacity.

4.4 FLAMEPROOF TRANSFORMER

The total consumption of the 1250 kVA flameproof transformer was measured on the 1000 V side of each section's flameproof transformer. Flameproof transformers were supplied with power from the MSU by a 95 mm^2 trailing cable. The cable is rated for a current of 295 A at 11 kV at an ambient temperature of 30℃.

The derating factor for an ambient temperature of 25℃ is 1.1, which gives a current rating of 325 A at 11 kV for the cable. The 1250 kVA flameproof transformer itself is rated for 65.6 A on the 11 kV side and 656 A on the 1100 V side. The limitation at this point in the distribution network is thus the capacity of the flameproof transformer and not the supply cable. Measurements were made on 1100 V side of the flameproof transformer.

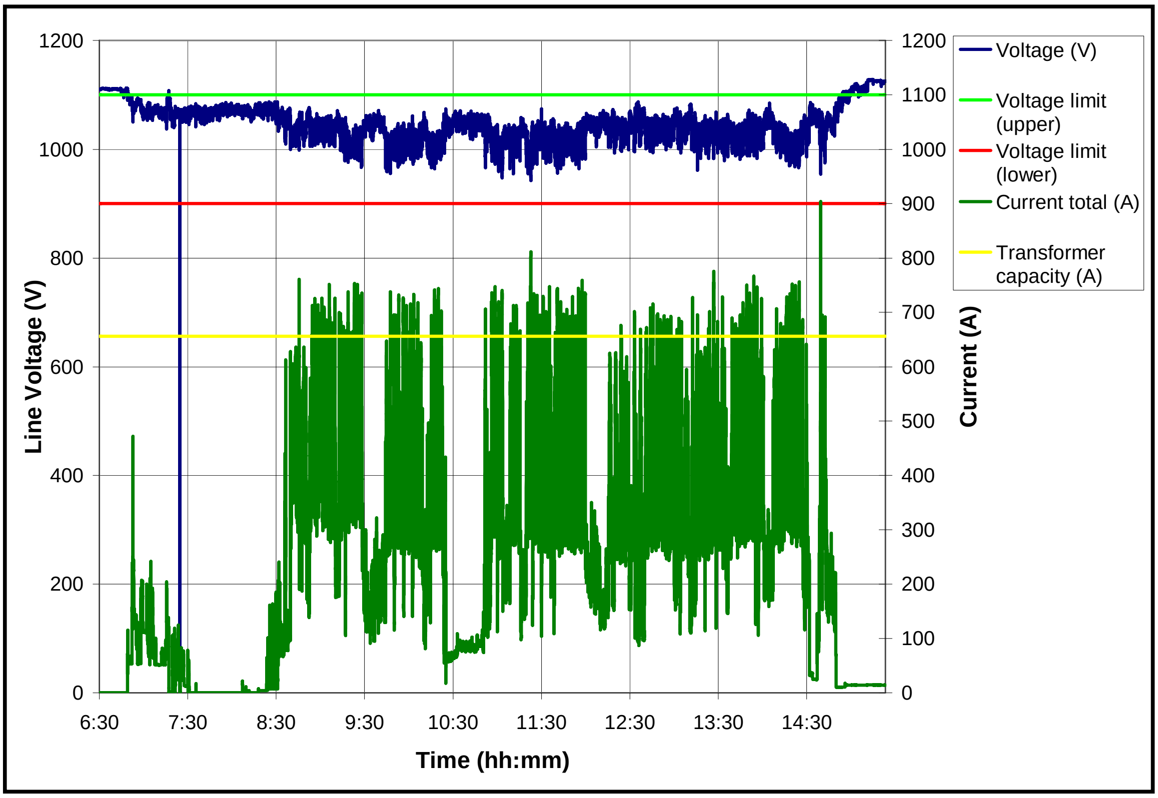


Figure 4.4-1: Load current and voltage for a 1250 kVA flameproof transformer – Morning shift 19 May 2005.

Figure 4.4-1 and Figure 4.4-2 show the total consumption of the sections' 1250 kVA flameproof transformers during a shift in section 21 and section 61 respectively. Figure 4.4-3 shows the consumption of the flameproof transformer in section 61 for a period of 30 minutes during the same shift as in Figure 4.4-2. It can be seen that the peak currents consumed by the flameproof transformers were quite high and the load consumed was very cyclic.

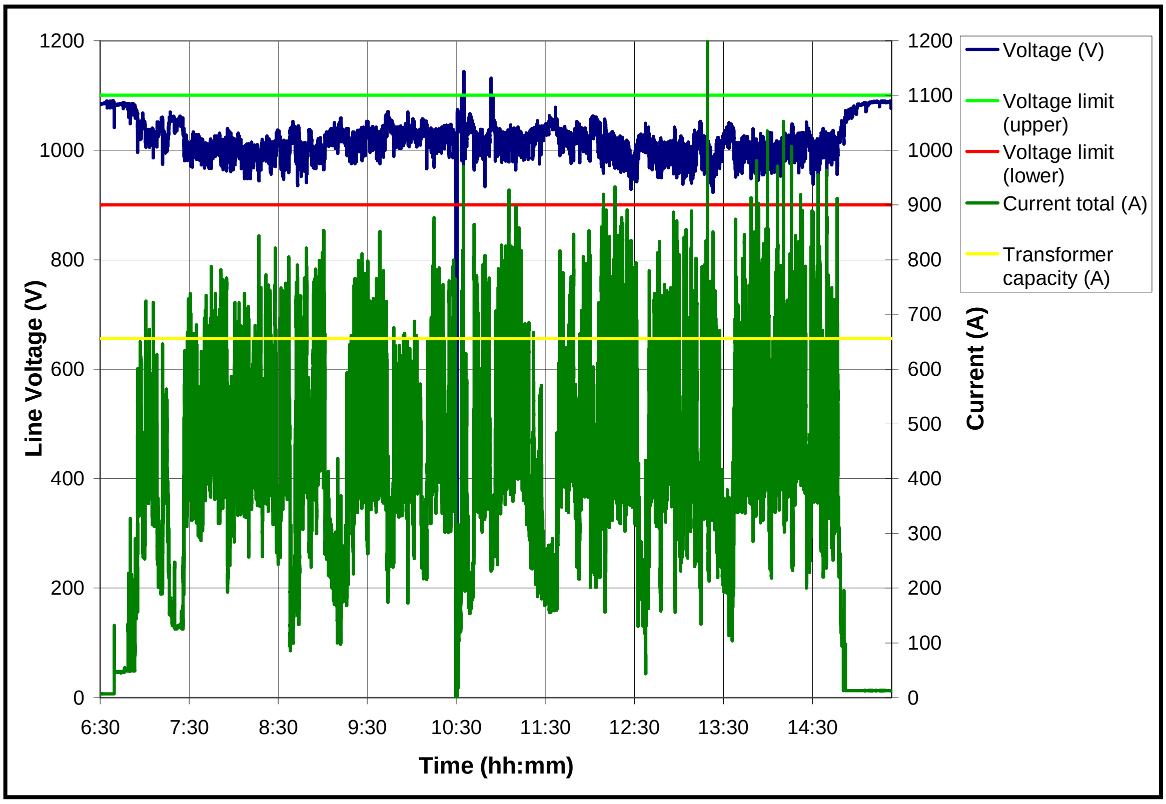


Figure 4.4-2: Load current and voltage for a 1250 kVA flameproof transformer – Morning shift 25 May 2005.

Figure 4.4-3 shows how the total load consumed by the flameproof transformer was divided between the continuous miner and the gate end boxes. The continuous miner is clearly the largest contributor to the total load at the flameproof transformer and thus the largest consumer of the total load of a section. The load consumed by the gate end boxes was reasonably constant, whereas the load consumed by the continuous miner was very cyclic with large peaks.

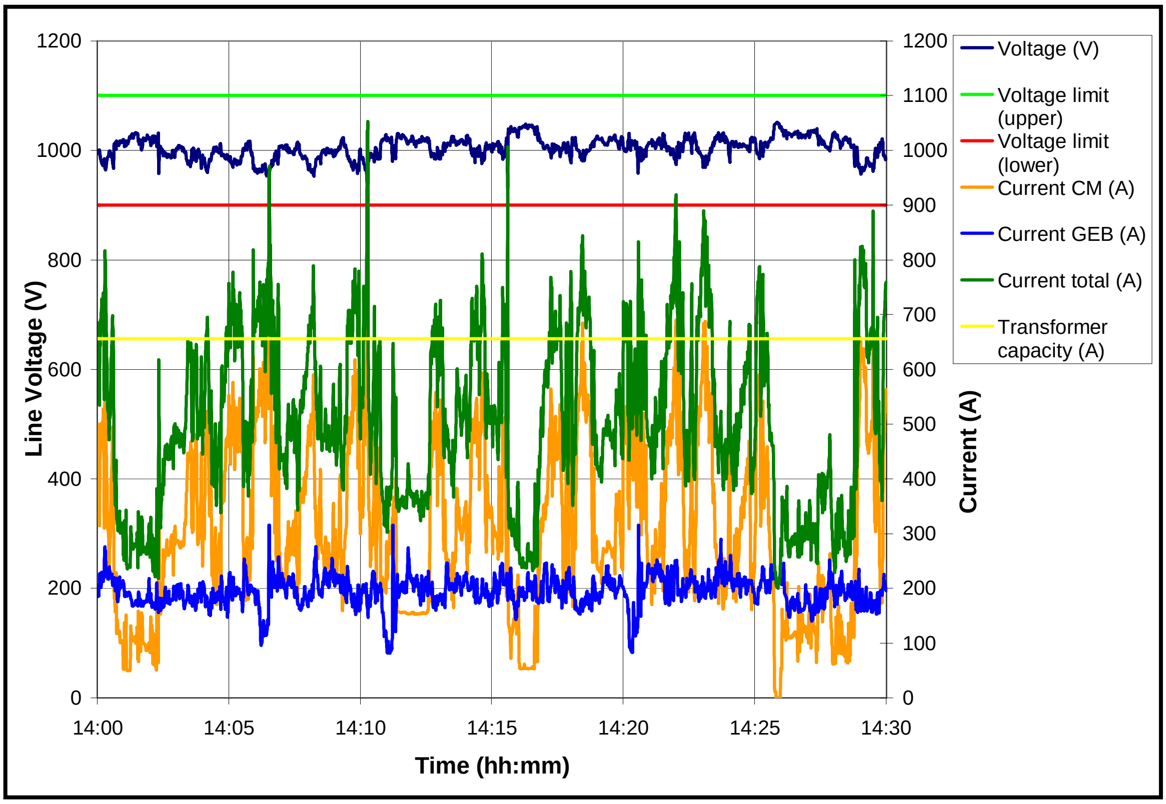


Figure 4.4-3: Load current and voltage for a 1250 kVA flameproof transformer – Morning shift 25 May 2005 (30 minute period).

Table 4-4: Sections 21 & 61 - Data for the total consumption of a 1250 kVA flameproof transformer.

	Morning	Afternoon	Morning	Afternoon
	19-May-05	19-May-05	25-May-05	24-May-05
Tonnes/CM/Shift	1716	2013	2320	2320
% Time of shift producing	87.58%	97.74%	99.79%	98.29%
% of Production time underloaded	97.19%	97.25%	91.44%	95.02%
% of Production time overloaded	2.81%	2.75%	8.56%	4.98%

Table 4-4 shows the data for the total consumption of the flameproof transformers of sections 21 and 61. The flameproof transformer of section 61 was being overloaded a little more than that of section 21. Figure 4.4-4 shows a histogram of the current consumed by the flameproof transformers.

The current consumed during the two shifts measured at section 21 were following a trend, whereas the two shifts measured at section 61 differed significantly, even though the production was the same over these two shifts. The flameproof transformers at section 21 experienced peak consumption between 270 A and

300 A and again a smaller peak between 480 A and 570 A. The afternoon shift of 19 May frequently consumed currents between 90 A and 180 A.

The morning shift of 25 May in section 61 consumed the most current, between 420 A and 480 A, while the afternoon shift of 24 May experienced a lower average current consumption between 300 A and 330 A. The afternoon shift of 24 May also experienced frequent lower currents of between 150 A and 240 A.

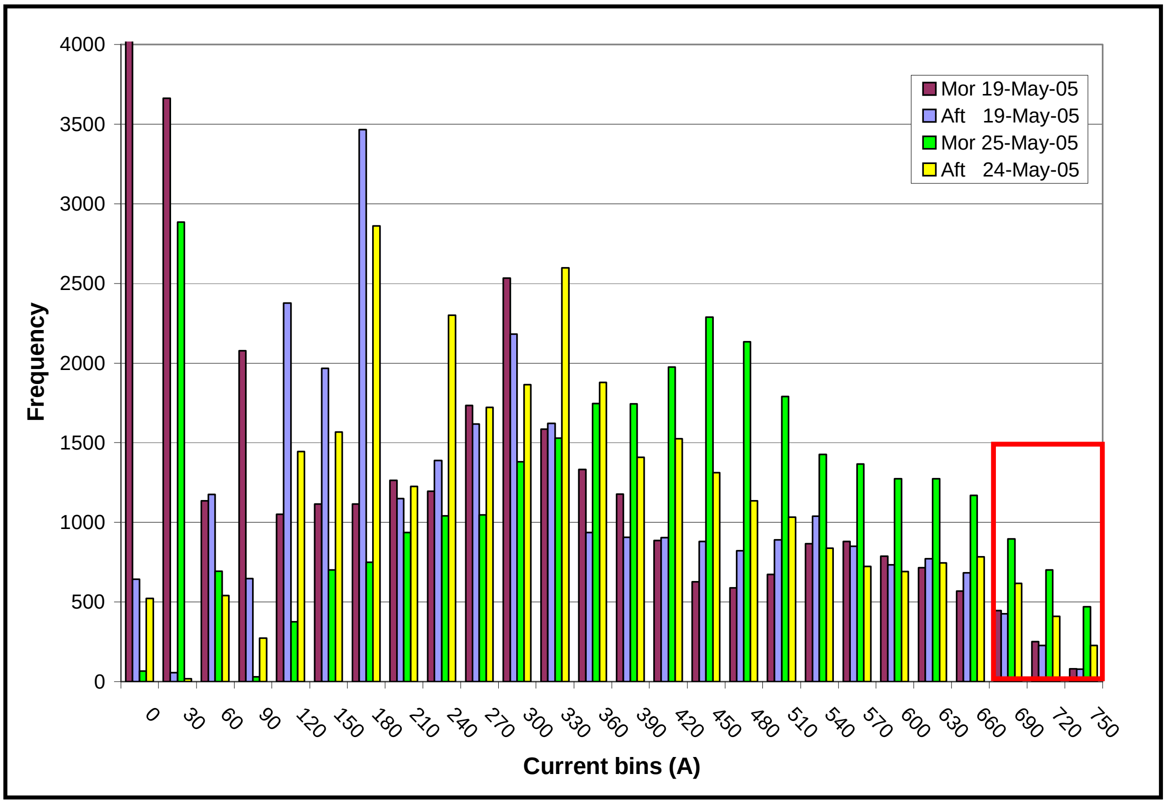


Figure 4.4-4: Section 21 & 61 - Histogram for current consumed by a 1250 kVA flameproof transformer.

The trends measured in the two sections were a repeat of what was seen at the MSU. Section 21 had a peak at the average current consumed and then a smaller peak for the peak currents that were consumed. The frequency of the currents consumed in section 61 in contrast did not have a distinctive smaller peak at the higher currents consumed. Section 21 thus consumed higher currents for longer periods of time, whereas section 61 consumed the average current more constantly. The average and peak currents consumed by section 61 were much higher than that consumed in section 21.

A transformer can handle larger overloads for longer periods than, for example, motors. A transformer can be overloaded up to 200% for a certain period of time. The average current consumed by a flameproof transformer was in the range of 300 A per phase with a less frequent consumption at 480 A per phase. The flameproof transformer and the trailing cable supplying power to the transformer was not a limitation and should not become a limitation in future if no drastic changes are made to the power requirements of the equipment used in a section. There was still spare capacity at the 1250 kVA flameproof transformer.

4.5 GATE END BOXES

The total consumption of the gate end boxes was measured at the supply from each section's 1250 kVA flameproof transformer. Gate end boxes were supplied with power from the 1250 kVA flameproof transformer by means of a 95 mm^2 trailing cable. The cable is rated for a current of 295 A at 1000 V at an ambient temperature of 30℃. The derating factor for an ambient temperature of 25℃ is 1.1, which gives a current rating of 325 A for the cable. The busbars of the gate end boxes are rated for 300 A.

Figure 4.5-1 and Figure 4.5-2 show the total consumption of the gate end boxes during a shift in sections 21 and 61 respectively. Figure 4.5-3 shows the consumption of the gate end boxes of section 61 for a period of 30 minutes during the same shift as in Figure 4.5-2. It is clear that the gate end boxes in section 61 were on average consuming much larger currents than the gate end boxes of section 21.

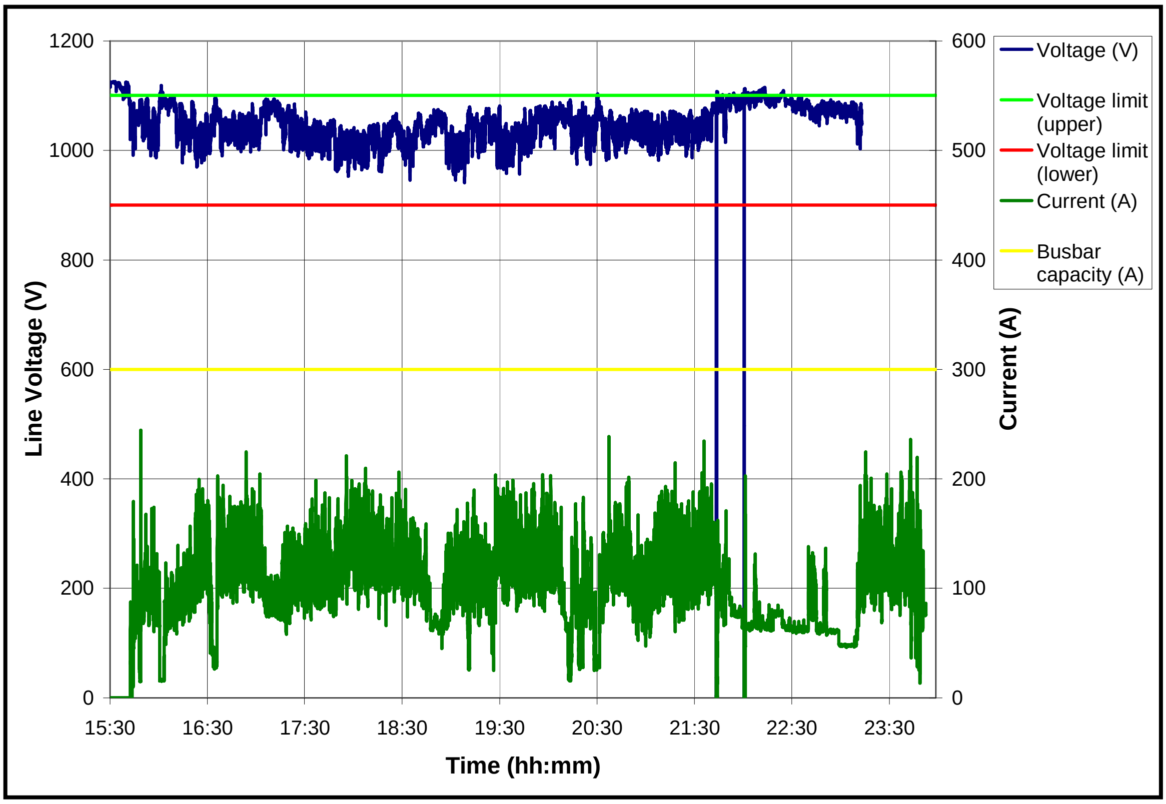


Figure 4.5-1: Load current and voltage for a GEB – Afternoon shift 17 May 2005.

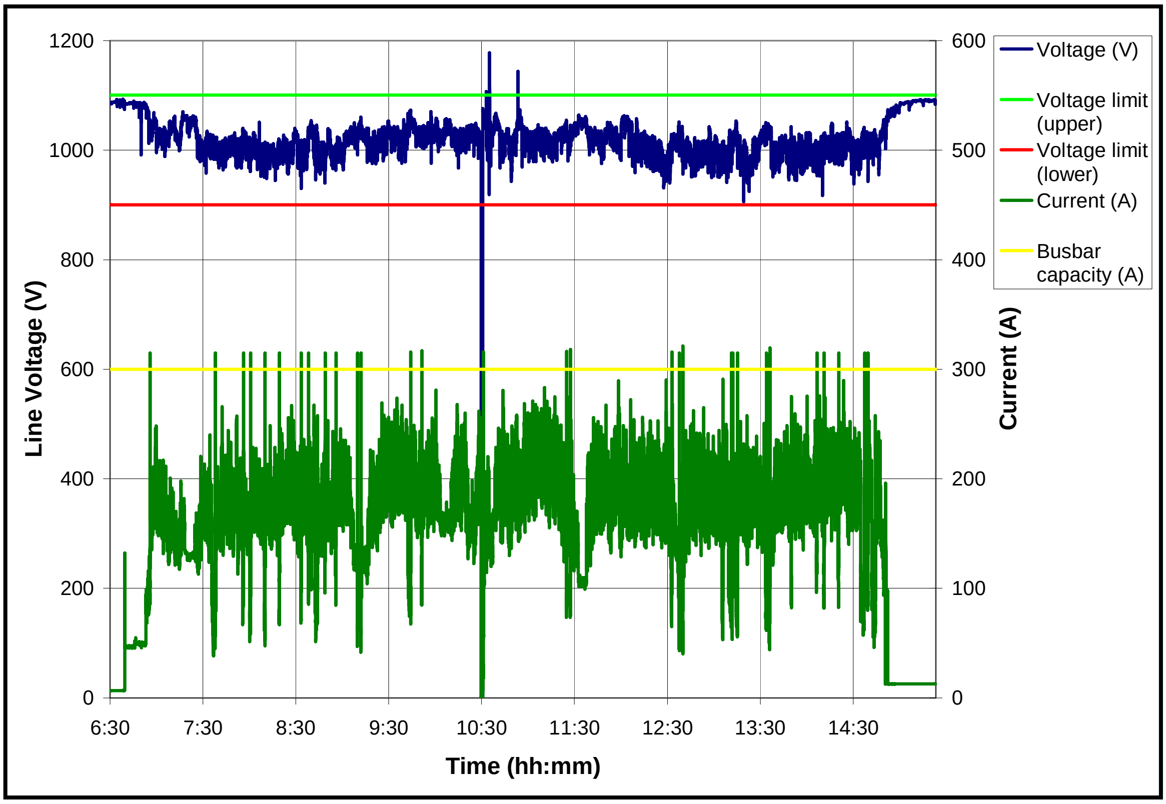


Figure 4.5-2: Load current and voltage for a GEB – Morning shift 25 May 2005.

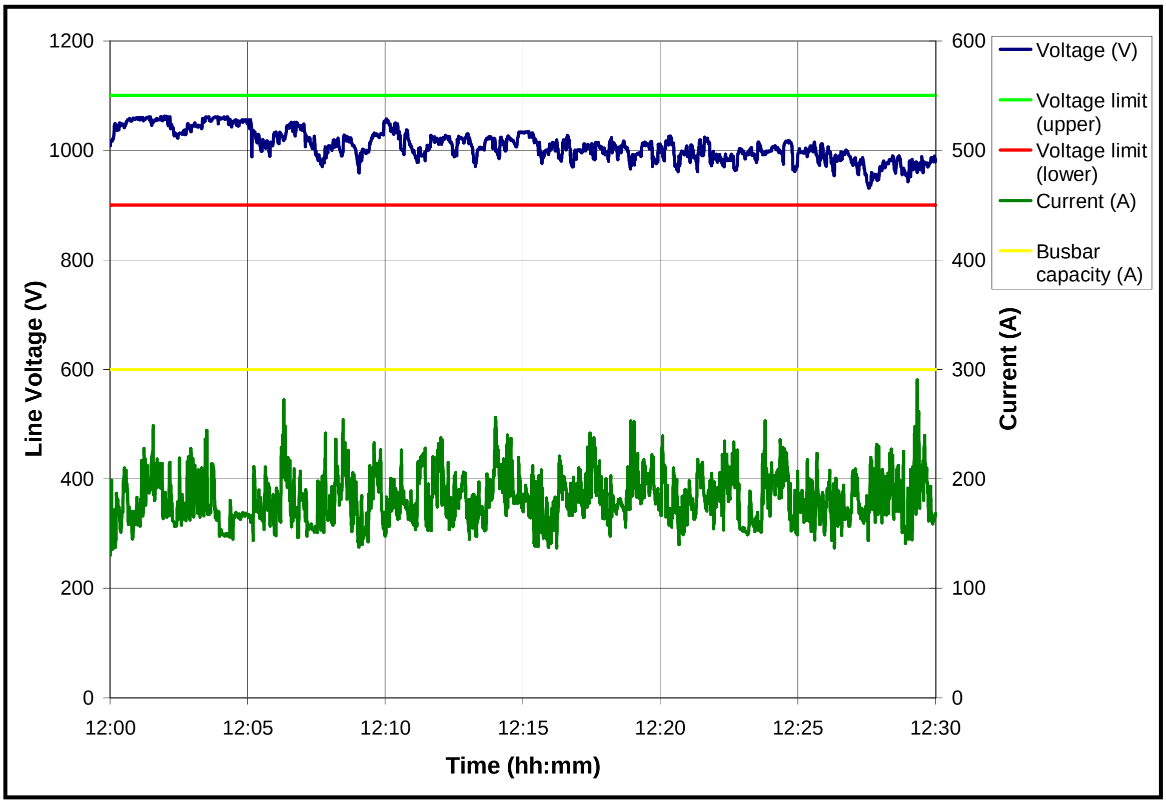


Figure 4.5-3: Load current and voltage for a GEB – Morning shift 25 May 2005 (30 minute period).

Table 4-5 shows the data for the total consumption of the gate end boxes in section 21. The busbars of the gate end boxes were never overloaded. Figure 4.5-4 shows a histogram of the current consumed by the gate end box. The consumption trends were almost the same, especially those of the afternoon shifts of 18 and 19 May. The average current consumed was between 90 A and 130 A.

Table 4-5: Section 21 - Data for the total consumption of a GEB.

	Morning	Afternoon	Afternoon	Afternoon
	19-May-05	17-May-05	18-May-05	19-May-05
Tonnes/CM/Shift	1716	2145	2112	2013
% Time of shift producing	84.11%	97.12%	98.72%	100.00%
% of Production time underloaded	100.00%	100.00%	100.00%	100.00%
% of Production time overloaded	0.00%	0.00%	0.00%	0.00%

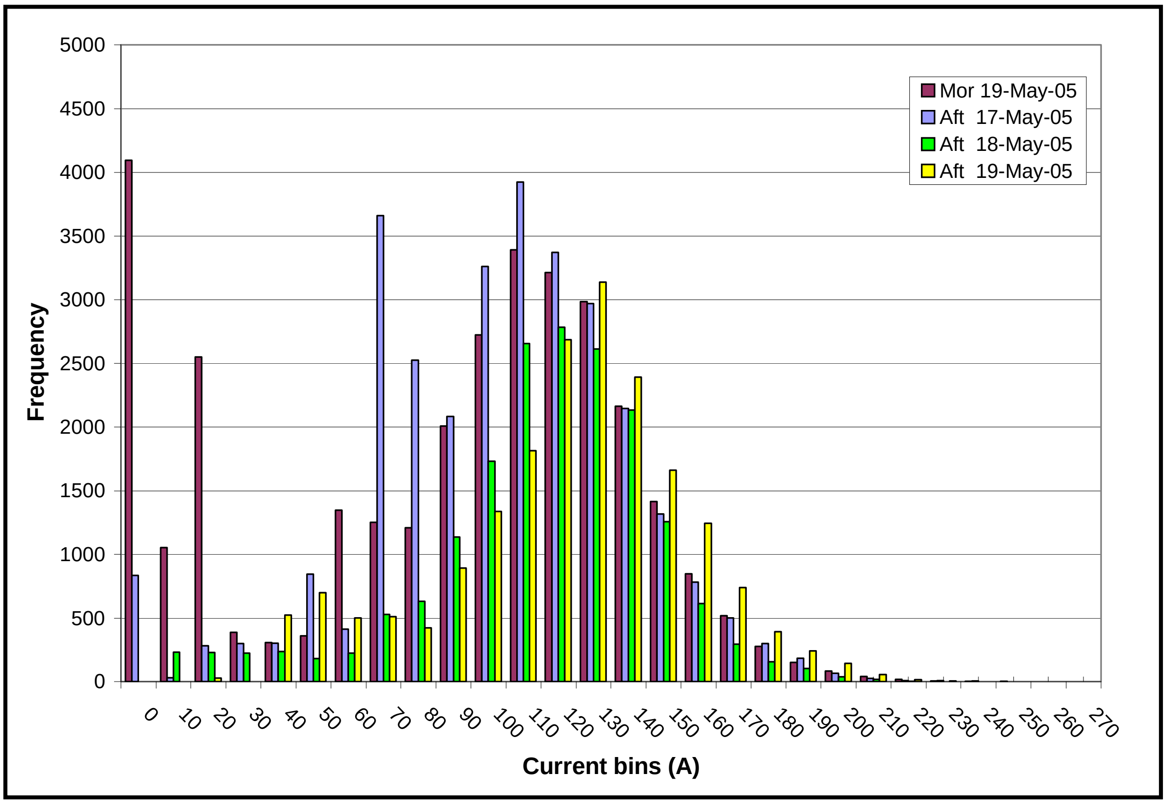


Figure 4.5-4: Section 21 - Histogram for current consumed by a GEB.

Table 4-6: Section 61 - Data for the total consumption of a GEB

	Morning	Morning	Afternoon	Afternoon
	23-May-05	25-May-05	23-May-05	24-May-05
Tonnes/CM/Shift	1740	2320	2030	2320
% Time of shift producing	98.95%	98.00%	99.14%	100.00%
% of Production time underloaded	99.97%	99.83%	99.96%	99.79%
% of Production time overloaded	0.03%	0.17%	0.04%	0.21%

Table 4-6 shows the data for the total consumption of the gate end boxes in section 61. The busbar of the gate end boxes were underloaded more than 99.8% of the time, although consuming much larger currents than the gate end box of section 21. Figure 4.5-5 shows a histogram of the current consumed by the gate end box. The consumption trends differ more than those in section 21. The average current consumed differs among shifts, but it was in the range of 140 A to 190 A.

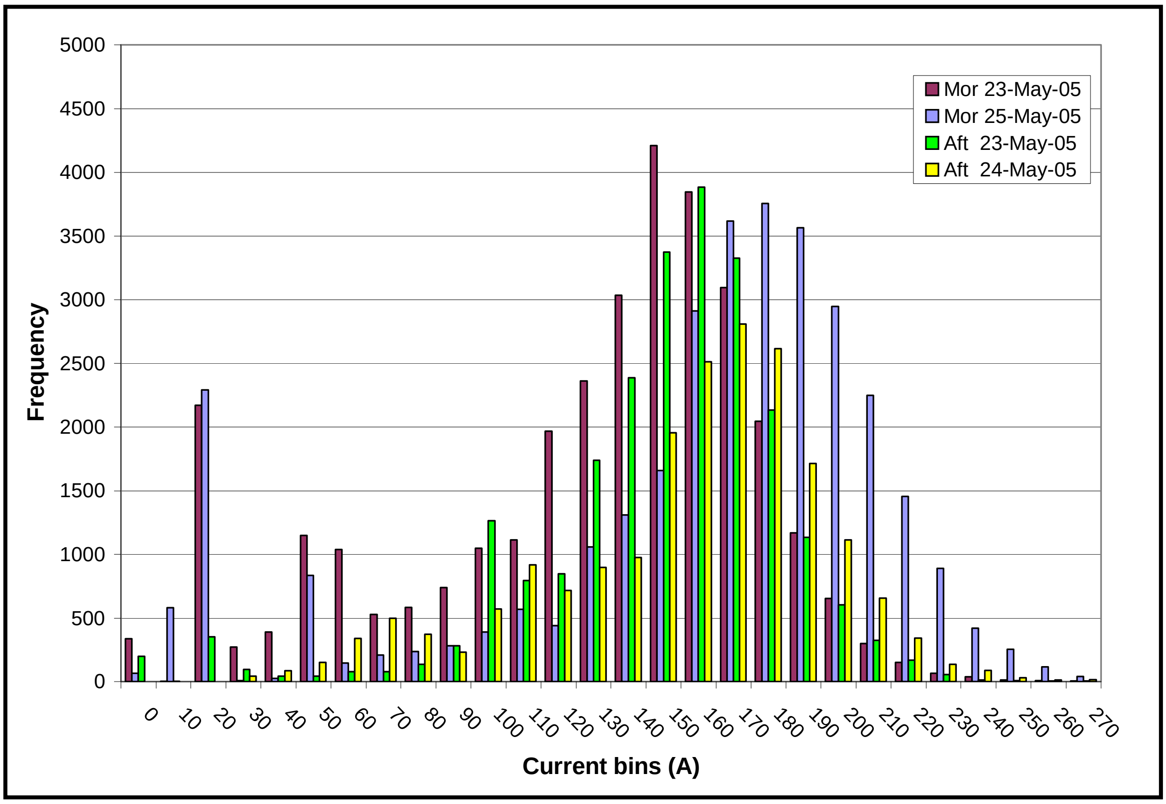


Figure 4.5-5: Section 61 - Histogram for current consumed by a GEB.

There was a considerable difference in average current consumed at the gate end boxes in section 21 and in section 61. Section 61 consumed approximately 50 A per phase more on average than in section 21. A possible reason for this marked difference in consumption is that the shuttle cars or feeder breaker was consuming more power in section 61 than in section 21. Another possibility is that submersible water pumps were powered from the gate end boxes to pump excess water from the section.

The gate end boxes and the trailing cables supplying them with power were not a limitation, not even where the average consumption of section 61 was a good representation of what is happening in the other sections at Sasol Mining.

4.6 CONTINUOUS MINER TRAILING CABLE

The total consumption of a continuous miner was measured at each section's 1250 kVA flameproof transformer, which supplies the continuous miner with power. A continuous miner is supplied with power from the 1250 kVA flameproof transformer by means of a 95 mm^2 trailing cable that is generally 250 m long. The cable is rated for a current of 295 A at an ambient temperature of 30℃. The derating factor for an ambient temperature of 25℃ is 1.1, which gives a current rating of 325 A for the cable.

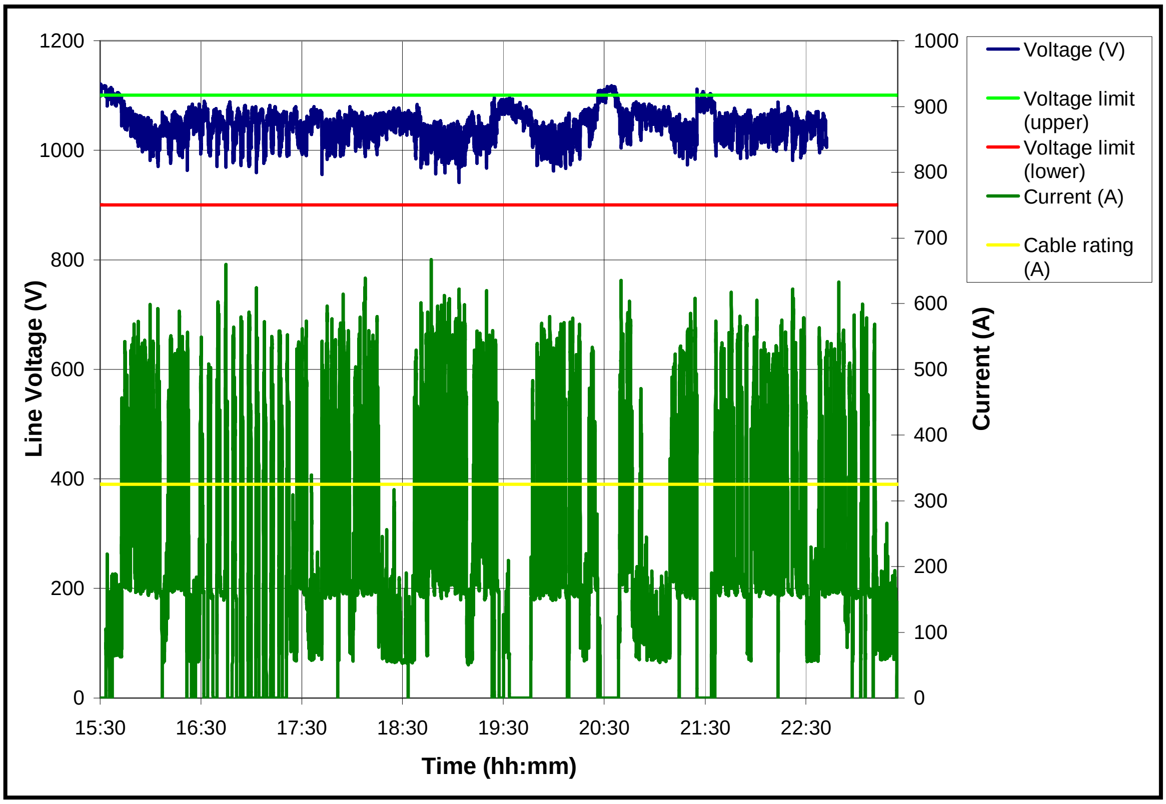


Figure 4.6-1: Load current and voltage for a CM – Afternoon shift 19 May 2005.

Figure 4.6-1 and Figure 4.6-2 show the total consumption of a continuous miner during a shift in sections 21 and 61 respectively. The consumption of the continuous miner in section 61 exceeds the consumption of the continuous miner in section 21. Figure 4.6-3 shows the consumption of the continuous miner in section 61 for a period of 30 minutes during the same shift as in Figure 4.6-2. It is clear from the figure that the load consumed by a continuous miner changes frequently, depending on, for example, whether the continuous miner is cutting only or cutting while loading a shuttle car.

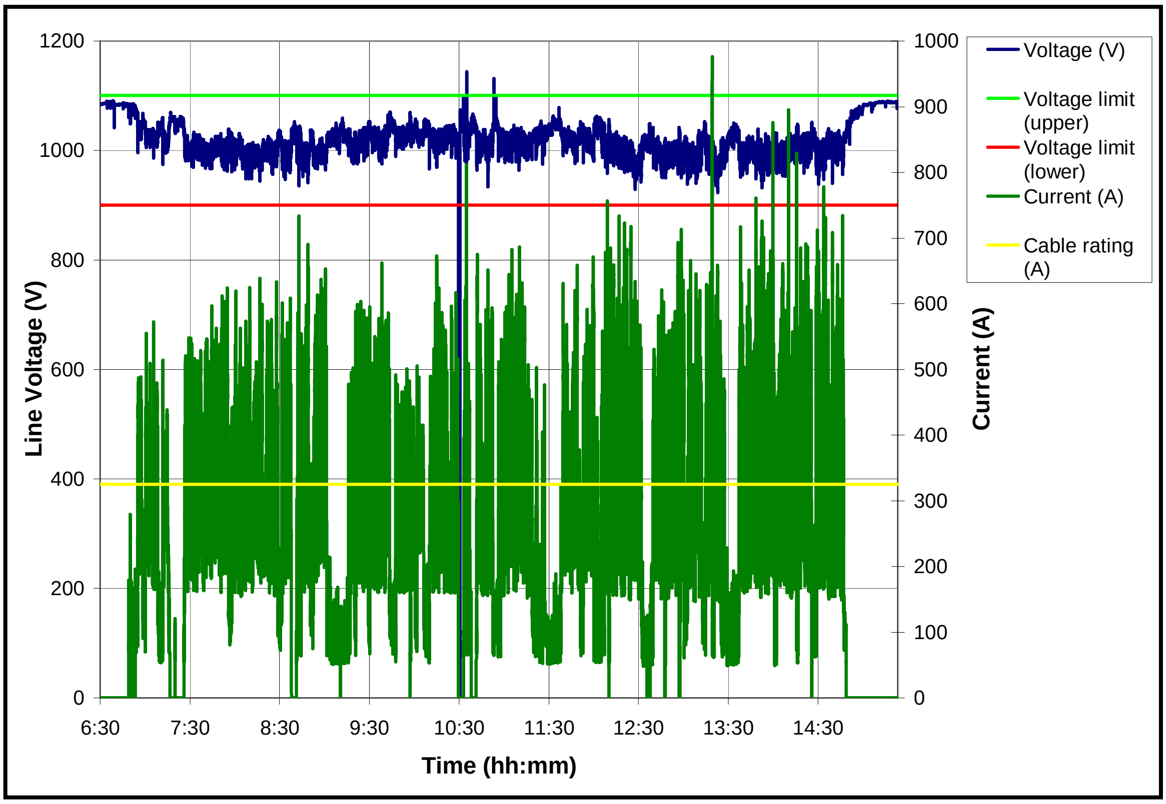


Figure 4.6-2: Load current and voltage for a CM – Morning shift 25 May 2005.

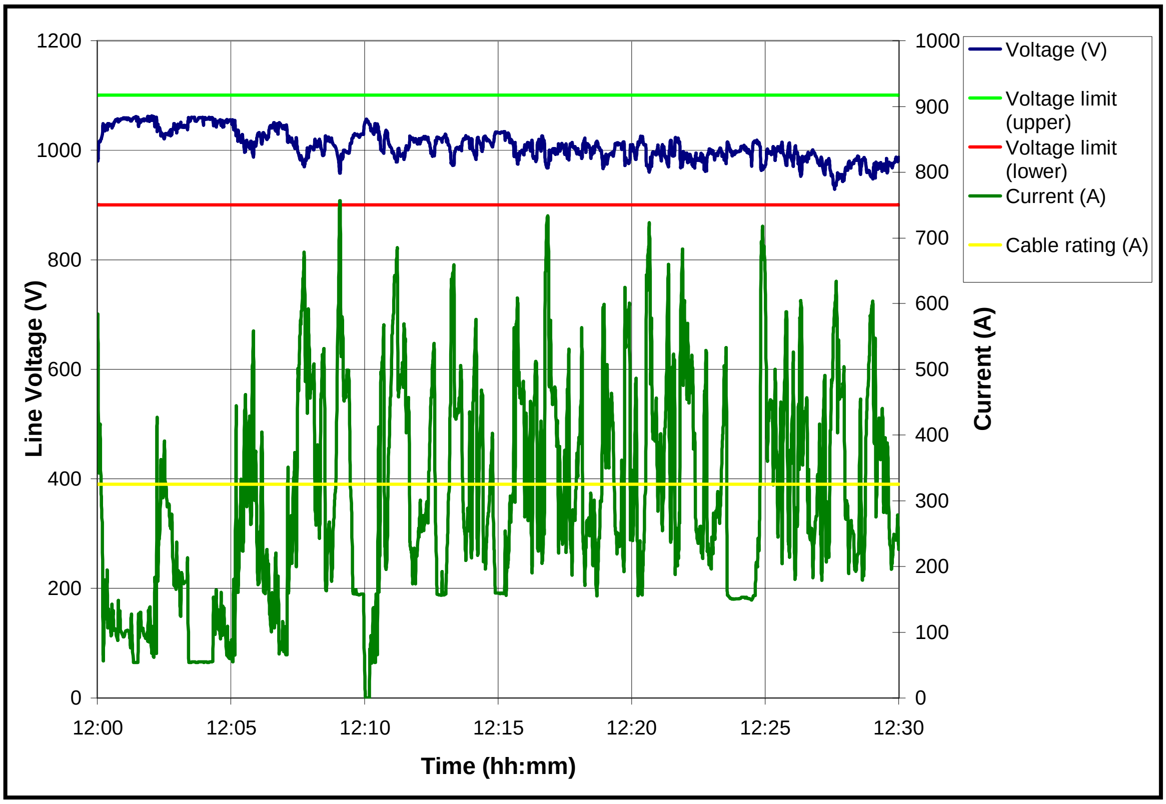


Figure 4.6-3: Load current and voltage for a CM – Morning shift 25 May 2005 (30 minute period).

Table 4-7 shows the data for the total consumption of the continuous miners in sections 21 and 61. The data gives a constant trend for all the shifts, as the trailing cables of the continuous miners were overloaded for an average of 30% of the time.

Table 4-7: Sections 21 & 61 - Data for the total consumption of a CM.

	Morning	Afternoon	Morning	Afternoon
	19-May-05	19-May-05	25-May-05	24-May-05
Tonnes/CM/Shift	1716	2013	2320	2320
% Time of shift producing	63.74%	84.80%	84.28%	92.90%
% of Production time underloaded	72.01%	69.07%	65.87%	72.14%
% of Production time overloaded	27.99%	30.93%	34.13%	27.86%

Figure 4.6-4 shows a histogram of the current consumed by the continuous miners. The average current consumed by the continuous miner in section 21 was between 150 A and 180 A, with section 61 consuming on average between 90 A and 300 A, excluding the range between 180 A and 210 A. Higher currents were, however, constantly consumed over the range of 300 A to 540 A.

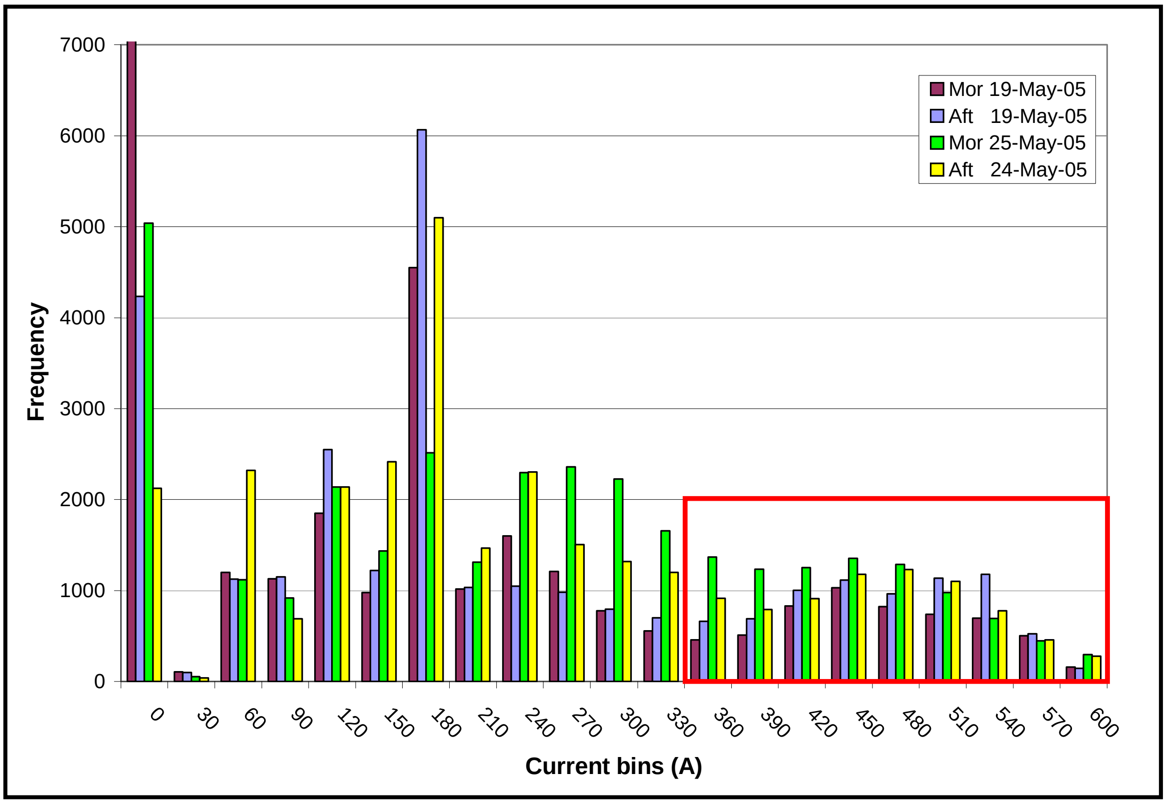


Figure 4.6-4: Section 21 & 61 - Histogram for current consumed by a CM.

The continuous miner in section 61 was consuming on average far more power than the continuous miner in section 21. The peak consumption of the continuous miner in section 61 was also almost 100 A higher than that of the continuous miner in section 21.

The measurements in both sections gave consistent overload trends. The cables were being overloaded for 30% of the time that the continuous miner was utilised. The cables are rated for a continuous current of 325 A and the flameproof couplers are designed for a current rating of 425 A. These ratings were, however, consistently exceeded.

The cable of the continuous miner gets very hot when the continuous miner was being used. Temperature measurements made on the trailing cable of the continuous miner indicate that the outside temperature of the cable sometimes exceeded 55℃. The trailing cable of the continuous miner is thus already a limitation. If the number of stop/starts of the cutter motors could be reduced, it will reduce the thermal load on the cable of the continuous miner.

4.7 SHUTTLE CAR TRAILING CABLE

The total consumption of a shuttle car was measured at the gate end box of each section, which supplies the shuttle car with power. Shuttle cars are supplied with power through a 16 mm^2 trailing cable that is generally 200 m long. The cable is rolled on a drum and is coiled or uncoiled as the shuttle car trams from one point to another.

The drum can hold 12 coils on each layer and a maximum of six layers on the drum. There should be six coils on the drum at all times and this is enforced by the use of a limit switch. This prevents the cable of being pulled out of the flameproof socket at the shuttle car when the shuttle car is tramming too far from the supply switch.

The cable is rated for a current of 105 A at an ambient temperature of 30℃. The derating factor for an ambient temperature of 25℃ is 1.1, which gives a current rating of 115 A for the cable. The derating factor for one layer is 0.84, which gives a current rating of 97 A. For three layers it has a derating factor of 0.45, which gives a current rating of 52 A, and for 5 layers the derating factor is 0.05 which gives a current of 6 A.

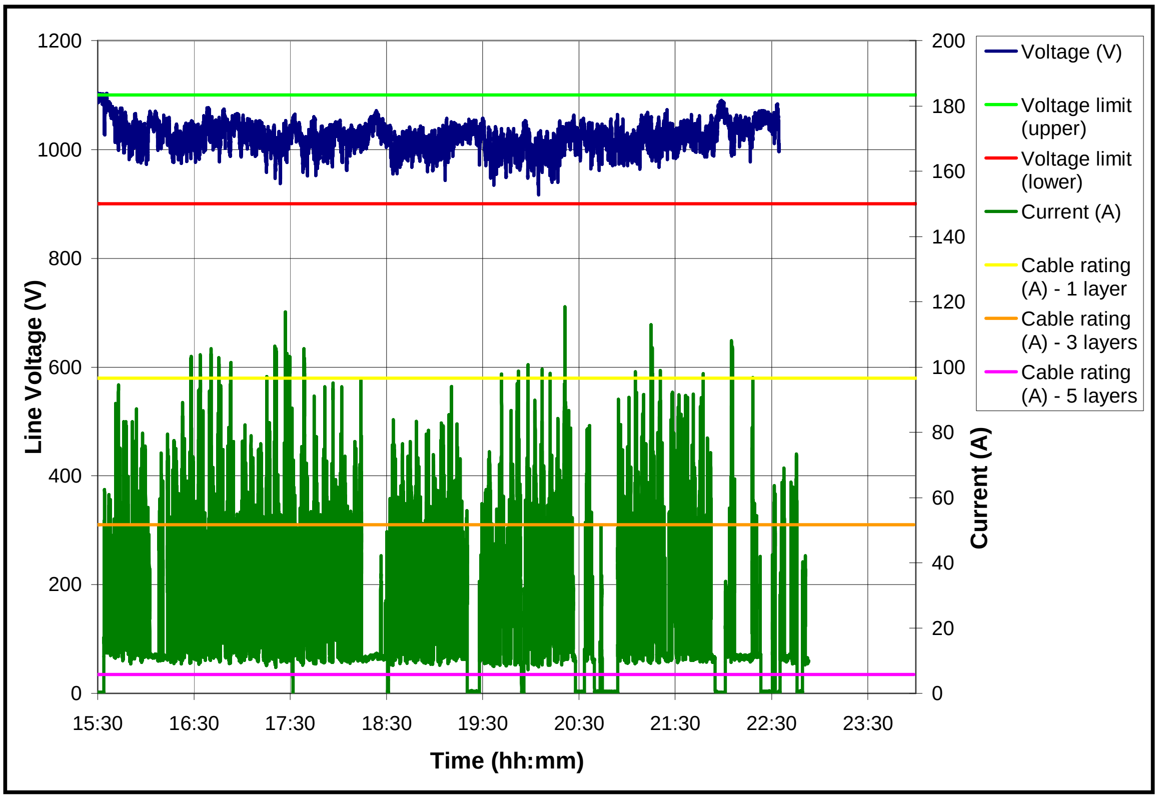


Figure 4.7-1: Load current and voltage for a SC – Morning shift 18 May 2005.

Figure 4.7-1 and Figure 4.7-3 show the total consumption of a shuttle car during a shift in sections 21 and 61 respectively. The largest consumption of the shuttle car is between the cable's 3 layer and 5 layers rating. The 1 layer current rating of the cable was almost never exceeded, while the 5 layer current rating was exceeded all the time. Figure 4.7-2 shows the consumption of the shuttle car in section 21 for a period of 30 minutes during the same shift as in Figure 4.7-1.

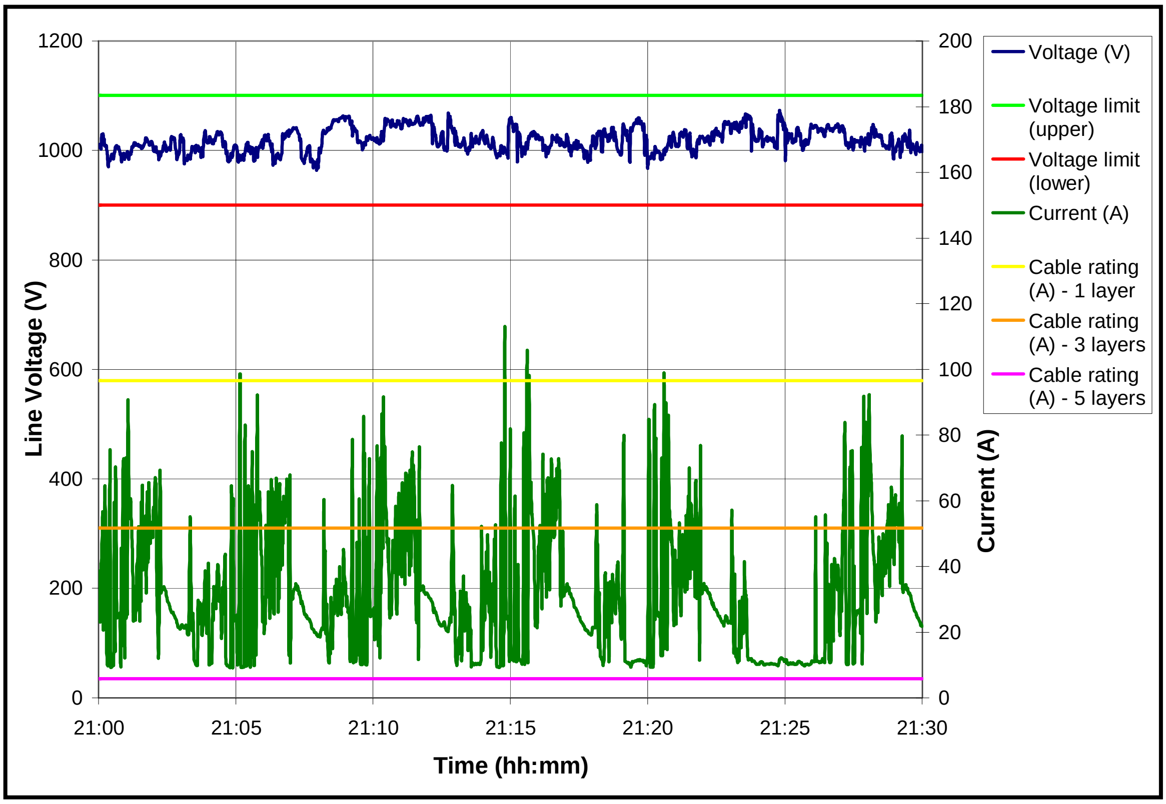


Figure 4.7-2: Load current and voltage for a SC – Morning shift 18 May 2005 (30 minute period).

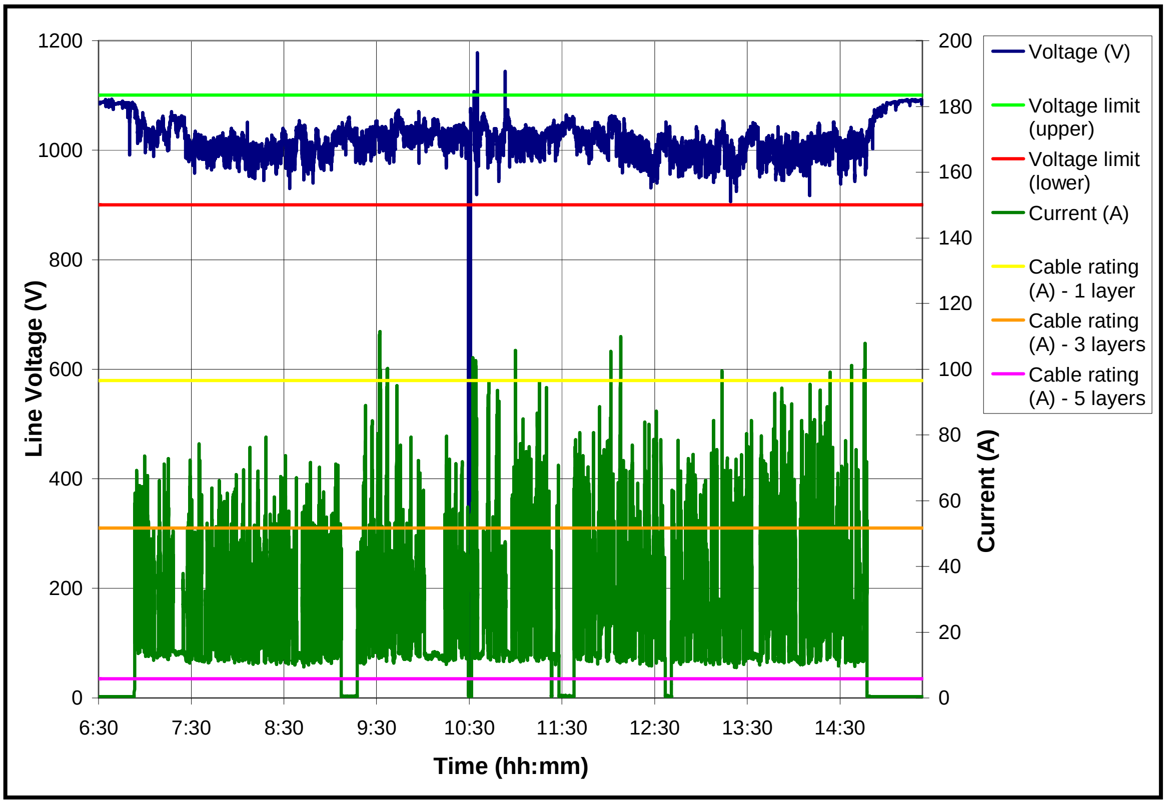


Figure 4.7-3: Load current and voltage for a SC – Morning shift 25 May 2005.

Table 4-8 shows the data for the total consumption of the shuttle cars in sections 21 and 61. The 3 layer cable rating was exceeded more often in section 21 than in section 61. Figure 4.7-4 shows a histogram of the current consumed by the shuttle cars. The average current consumed by the shuttle cars in both sections was between 10 A and 15 A, with another peak between 20 A and 30 A. The shuttle cars were probably using the conveyor motor and pump motor at the average between 10 A and 15 A, and the pump motor and traction motors were most likely used during the 20 A to 30 A consumption periods.

Table 4-8: Sections 21 & 61 - Data for the total consumption of an SC.

	Afternoon	Afternoon	Morning	Afternoon
	18-May-05	19-May-05	25-May-05	24-May-05
Tonnes/CM/Shift	2112	2013	2320	2320
% Time of shift producing	88.18%	86.97%	82.98%	89.35%
% of Production time over cable rating - 1 layer	0.35%	0.17%	0.06%	0.07%
% of Production time over cable rating - 3 layers	12.94%	7.88%	5.62%	5.02%
% of Production time over cable rating - 5 layers	100.00%	100.00%	100.00%	100.00%

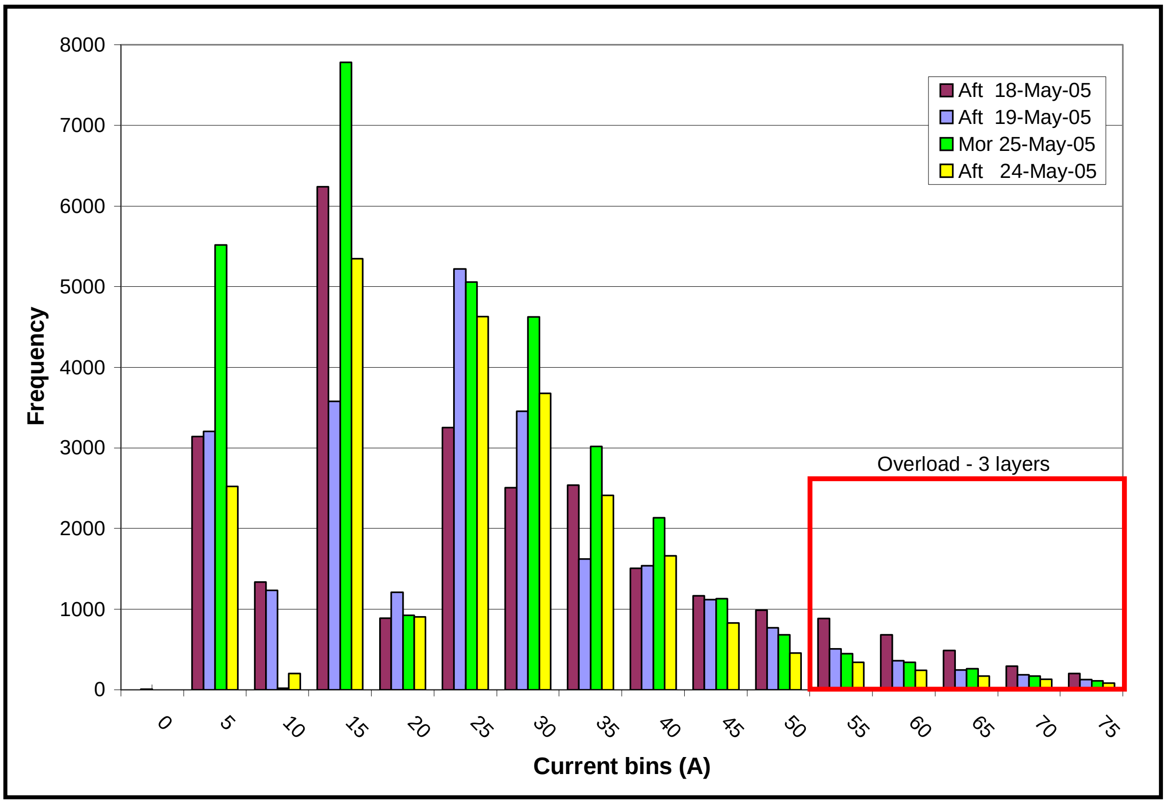


Figure 4.7-4: Sections 21 & 61 - Histogram for current consumed by an SC.

The average consumption and peak consumption of the shuttle cars in both sections were almost the same. The trailing cable as such was not a limitation at all. However, a problem does exist when the cable is coiled on a cable drum. This derates the current-carrying capacity of the cable considerably.

It was assumed that on average 3 layers of cable were left coiled on the drum, which derates the cable to only 52 A. This current rating of the cable was exceeded between 8% and 13% of the time a shuttle car was utilised in section 21. This rating was exceeded only 5% of the time for a shuttle car utilised in section 61.

4.8 FEEDER BREAKER TRAILING CABLE

The total consumption of a feeder breaker was measured at the gate end box of each section, which supplies the feeder breaker with power. Feeder breakers are supplied with power from the gate end boxes by means of a 16 mm^2 trailing cable that is generally 200 m long. The cable is rated for a current of 105 A at an ambient temperature of 30℃. The derating factor for an ambient temperature of 25℃ is 1.1, which gives a current rating of 115 A for the cable.

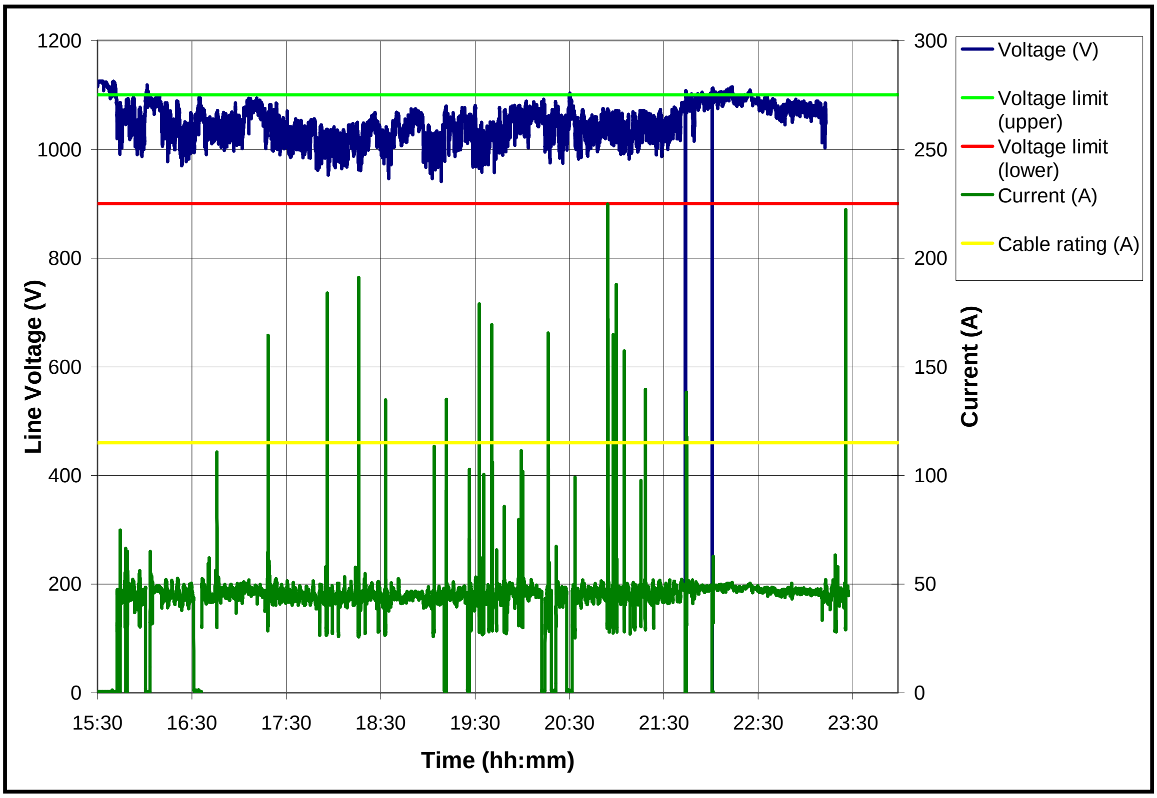


Figure 4.8-1: Load current and voltage for an FB – Afternoon shift 17 May 2005.

Figure 4.8-1 and Figure 4.8-2 show the total consumption of a feeder breaker during a shift in sections 21 and 61 respectively. Figure 4.8-3 shows the consumption of the feeder breaker in section 61 for a period of 30 minutes during the same shift as in Figure 4.8-2. The consumption of the feeder breaker was very consistent, except for the peaks that were consumed periodically. The peaks were normally caused when the feeder breaker was switched on and had to overcome the initial inertia of a conveyor loaded with coal. This can be clearly seen in Figure 4.8-3.

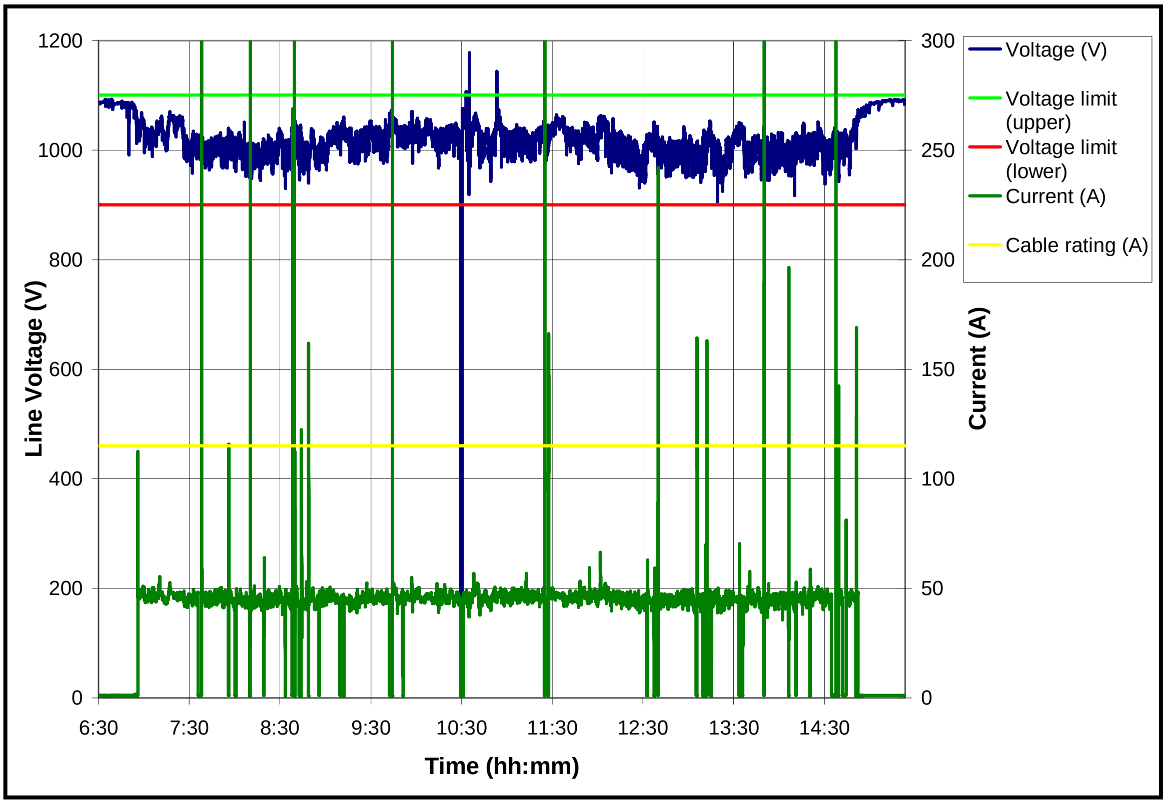


Figure 4.8-2: Load current and voltage for an FB – Morning shift 25 May 2005.

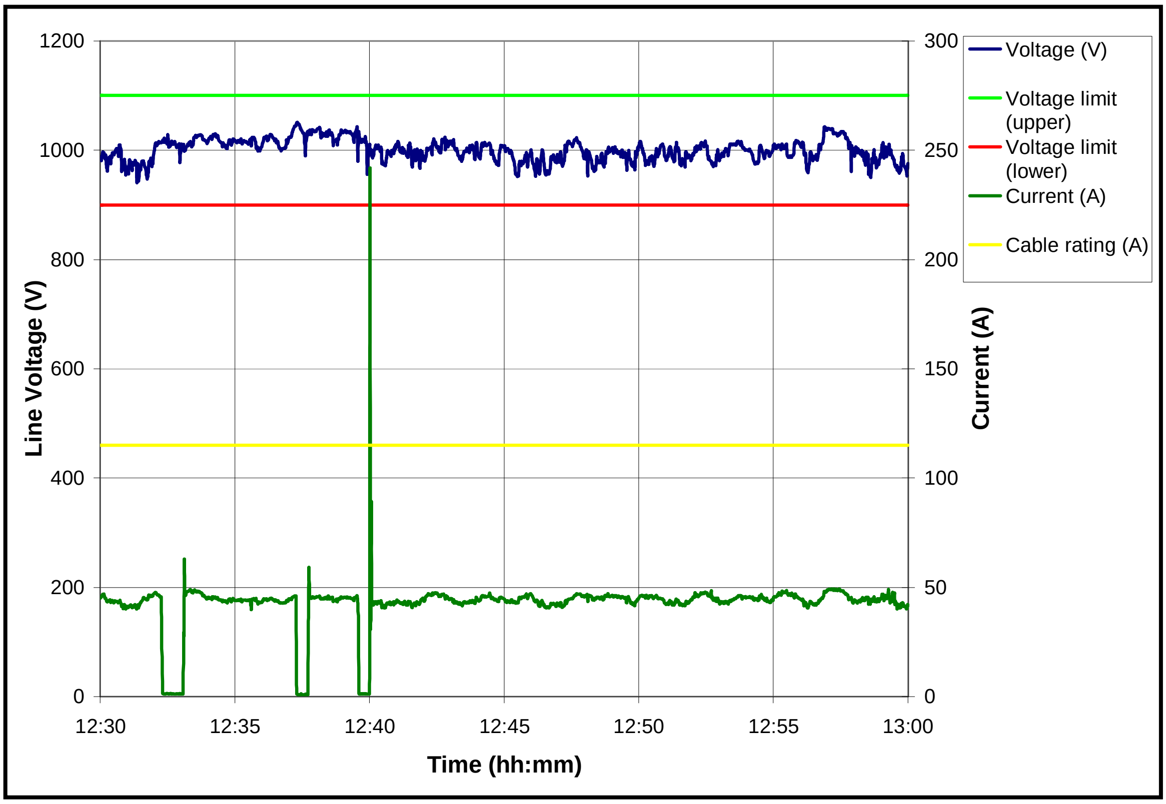


Figure 4.8-3: Load current and voltage for an FB – Morning shift 25 May 2005 (30 minute period).

Table 4-9 shows the data for the total consumption of the feeder breaker in section 21. The trailing cable of the feeder breaker was underloaded for more than 99.9 % of the time. Figure 4.8-4 shows a histogram of the current consumed by the feeder breaker in section 21. It can clearly be seen that the consumption was very constant and the average was between 40 A and 50 A.

Table 4-9: Section 21 - Data for the total consumption of an FB.

	Morning	Afternoon	Afternoon	Afternoon
	19-May-05	17-May-05	18-May-05	19-May-05
Tonnes/CM/Shift	1716	2145	2112	2013
% Time of shift producing	70.71%	92.61%	86.05%	90.48%
% of Production time underloaded	99.98%	99.92%	99.96%	99.99%
% of Production time overloaded	0.02%	0.08%	0.04%	0.01%

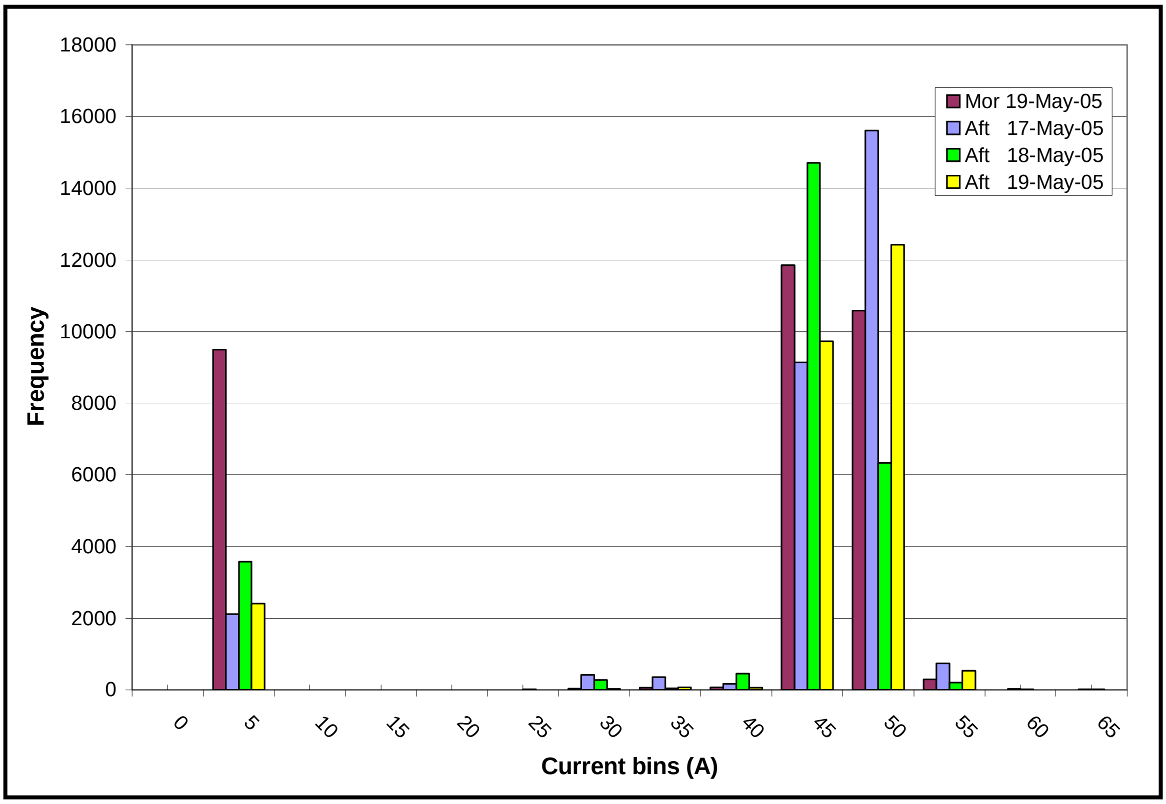


Figure 4.8-4: Section 21 - Histogram for current consumed by an FB.

Table 4-10 shows the data for the total consumption of the feeder breaker in section 61. The trailing cable of the feeder breaker was also underloaded for at least 99.9% of the time. Figure 4.8-5 shows a histogram of the current consumed by the feeder breaker in section 61. The consumption was also constant and the average was between 40 A and 50 A.

Table 4-10: Section 61 - Data for the total consumption of an FB.

	Morning	Morning	Afternoon	Afternoon
	23-May-05	25-May-05	23-May-05	24-May-05
Tonnes/CM/Shift	1740	2320	2030	2320
% Time of shift producing	76.04%	82.66%	95.06%	89.54%
% of Production time underloaded	99.90%	99.90%	99.93%	99.85%
% of Production time overloaded	0.10%	0.10%	0.07%	0.15%

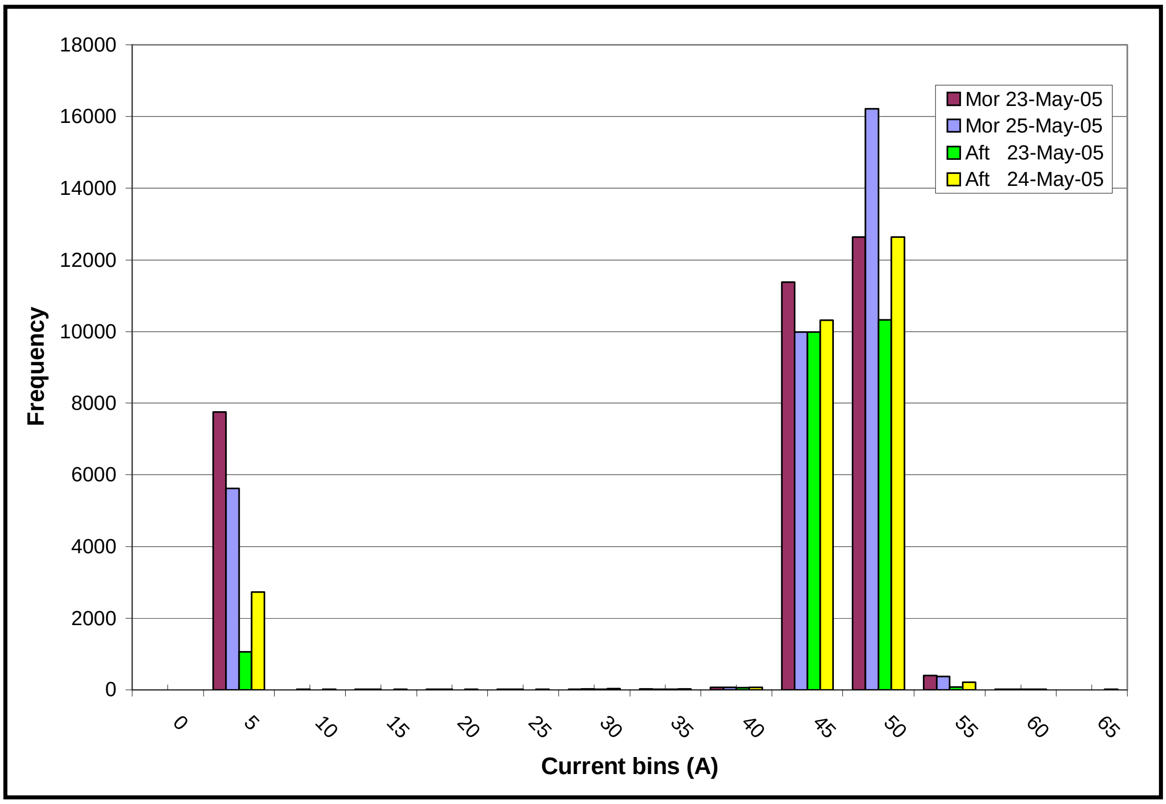


Figure 4.8-5: Section 61 - Histogram for current consumed by an FB.

The average consumption of a feeder breaker was between 40 A and 50 A in both sections for the full period that measurements were taken. The trailing cable of the feeder breaker was also not a limitation and should not become a limitation in future. Mechanical limitations in the feeder breaker's design put a limit on the electrical load that can be applied on a feeder breaker. The current consumption of the motors increased only slightly when the feeder breaker was fully loaded with coal. The mechanical limitations of the feeder breaker was also dependant on the loading capacity of the section conveyor belts.

4.9 ROOFBOLTER TRAILING CABLE

The total consumption of a roofbolter was measured at the gate end boxes in each section from where the Roofbolter is supplied with power. Roofbolters were supplied with power from the gate end boxes via a 16 mm^2 trailing cable that is generally 200 m long. The cable is rated for a current of 105 A at an ambient temperature of 30℃. The derating factor for an ambient temperature of 25℃ is 1.1, which gives a current rating of 115 A for the cable.

Figure 4.9-1 and Figure 4.9-3 show the total consumption of a roofbolter during a shift in sections 21 and 61 respectively. Figure 4.9-2 shows the consumption of the roofbolter in section 21 for a period of 30 minutes during the same shift as in Figure 4.9-1. The consumption of the roofbolters vary significantly as it depends on whether the roofbolter was tramming or drilling, for example.

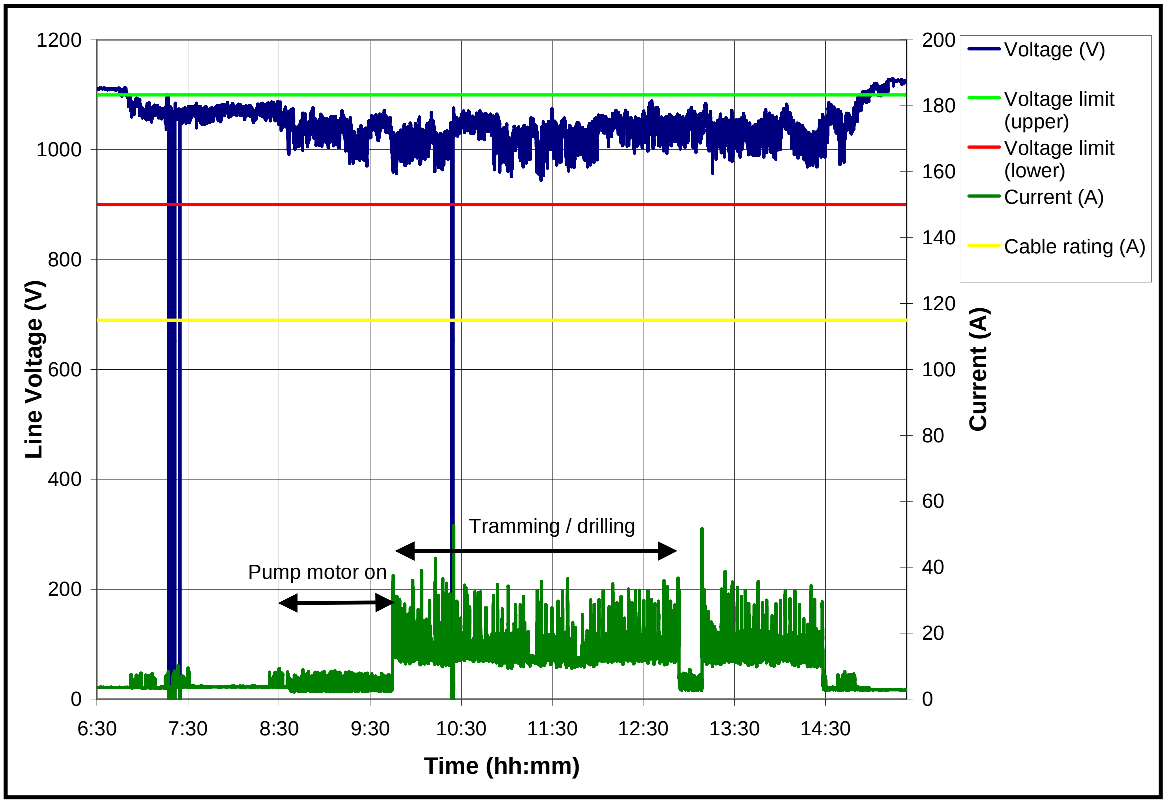


Figure 4.9-1: Load current and voltage for an RB – Morning shift 19 May 2005.

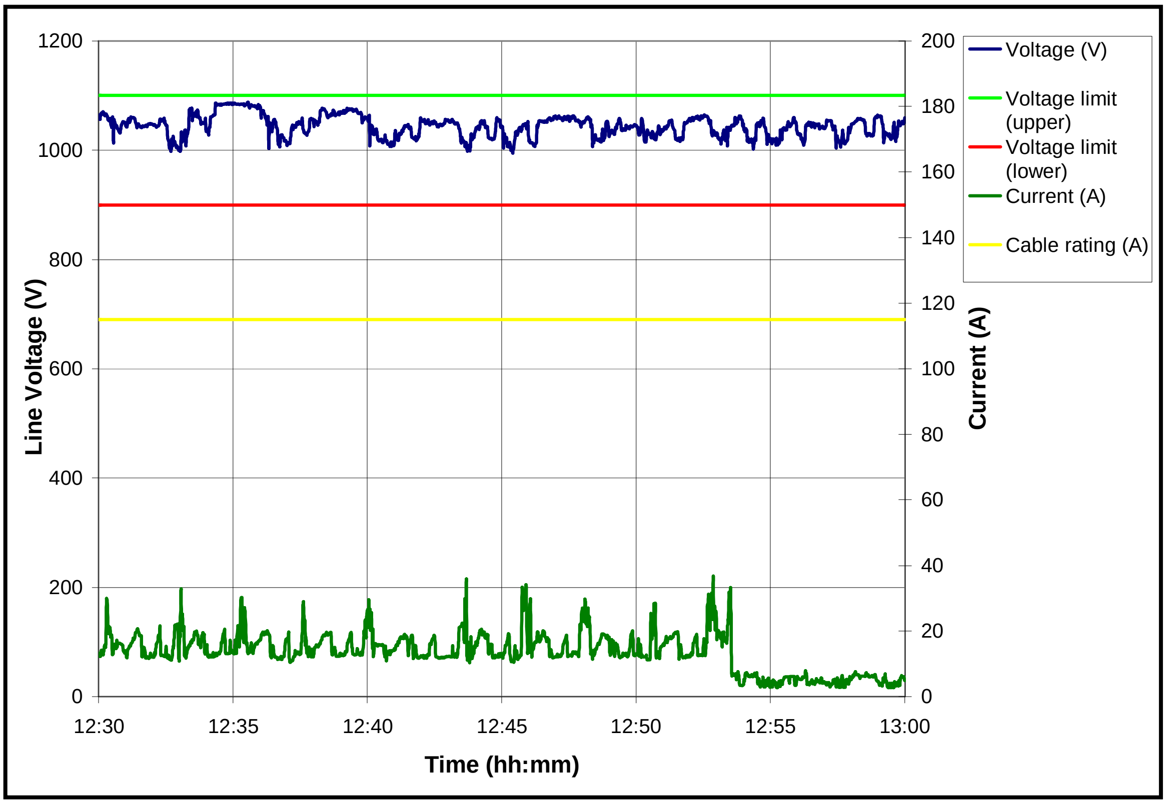


Figure 4.9-2: Load current and voltage for an RB – Morning shift 19 May 2005 (30 minute period).

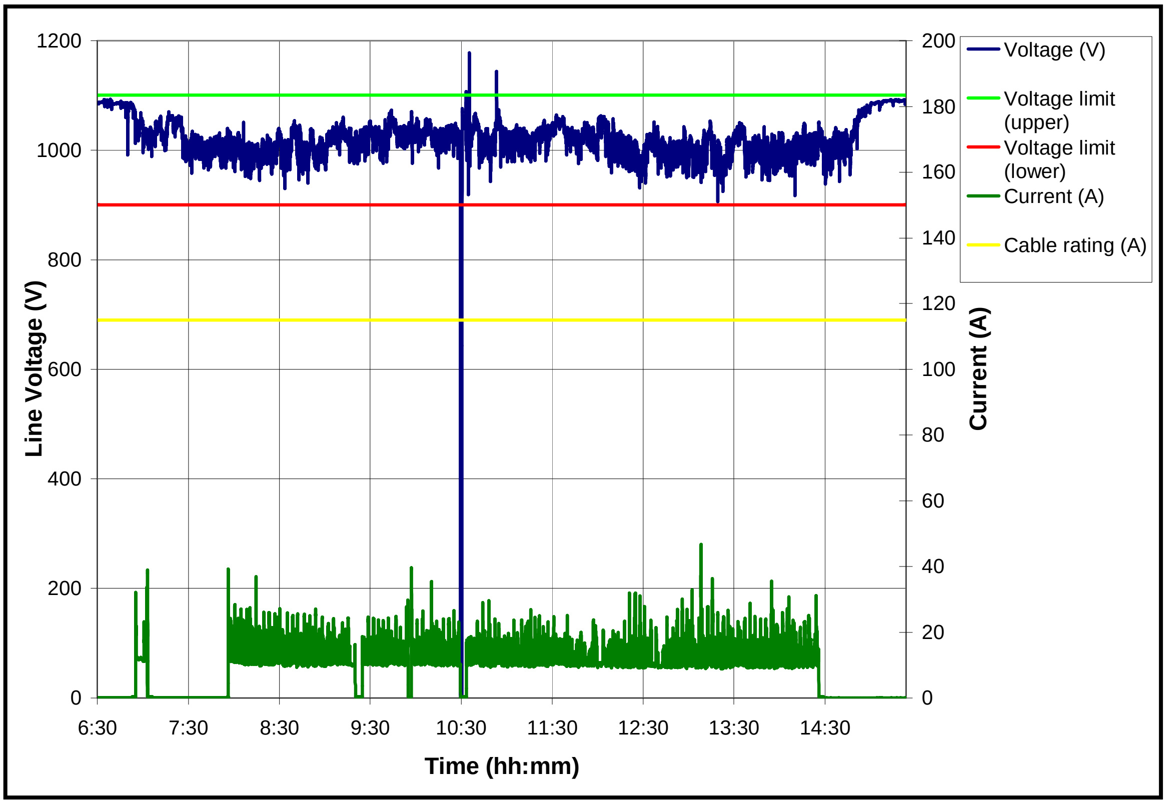


Figure 4.9-3: Load current and voltage for an RB – Morning shift 25 May 2005.

Table 4-11: Section 21 & 61 - Data for the total consumption of an RB.

	Morning	Afternoon	Morning	Afternoon
	19-May-05	19-May-05	25-May-05	24-May-05
Tonnes/CM/Shift	1716	2013	2320	2320
% Time of shift producing	49.63%	80.38%	71.58%	30.12%
% of Production time underloaded	100.00%	100.00%	100.00%	100.00%
% of Production time overloaded	0.00%	0.00%	0.00%	0.00%

Table 4-11 shows the data for the total consumption of the roofbolters in sections 21 and 61. Figure 4.9-4 shows a histogram of the current consumed by the roofbolters. The average for the roofbolter in section 21 was between 12 A and 13 A, but according to the histogram the roofbolters in section 61 consumed between 9 A and 11 A. The consumption of the roofbolters was very constant whether used for 30% or 80% of a shift.

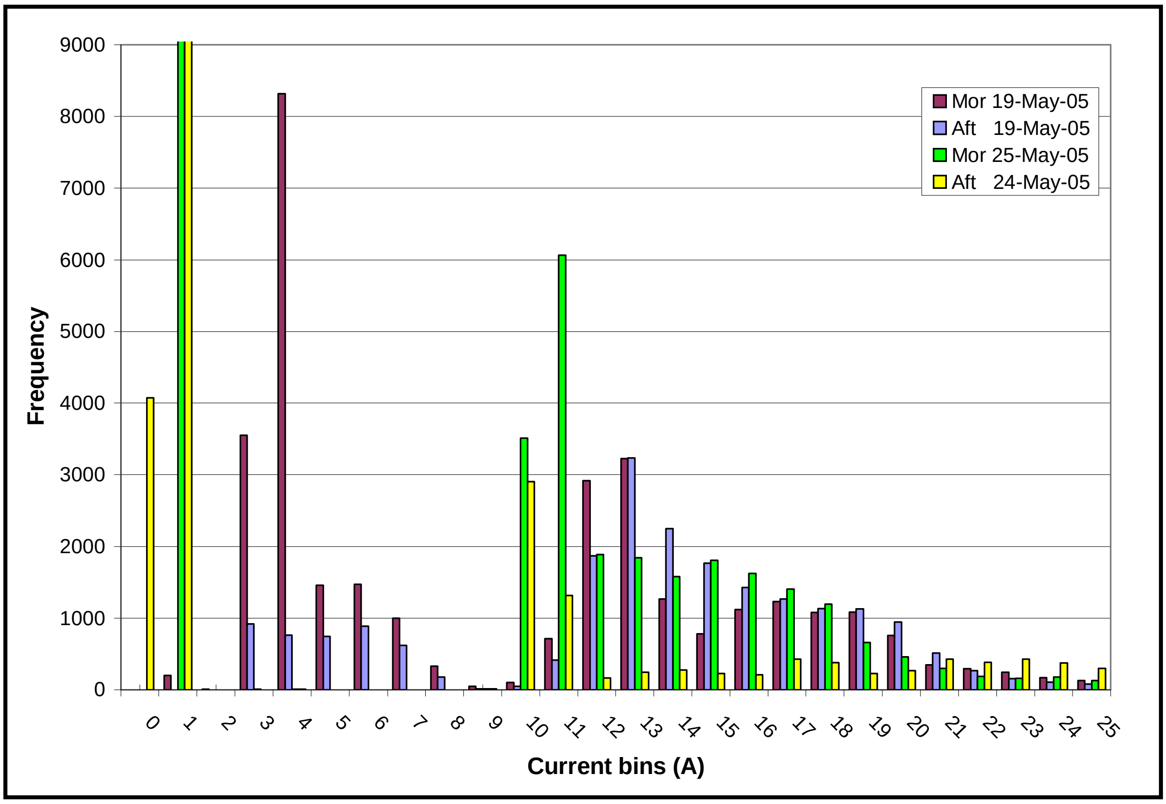


Figure 4.9-4: Section 21 & 61 - Histogram for current consumed by an RB.

Problems were experienced with measurements on the supply to the roofbolter, the reason being that only one roofbolter could be measured at a time and this was not necessarily the roofbolter that was used during the shift. The average consumption of a roofbolter while working was about 13 A if the roofbolter was used for a large part of the shift. This means that the trailing cable was nowhere near being a limitation.

A 4 mm^2 trailing cable would have been more than sufficient to supply power to the roofbolter.

A roofbolter is used for only short periods in a section, as there are two roofbolters in a section and the duty cycle of a roofbolter is entirely dependent on the production of a section. If production is increased, the duty cycle of a roofbolter will increase, but not the size of the load.

4.10 NETWORK VOLTAGES

The distribution network of the mine is at 11 kV. This is then transformed to 1000 V at the section flameproof transformers. The voltage levels should be regulated within ± 10% from the nominal value to prevent undervoltage and overvoltage conditions. If the voltage levels are regulated within these levels, the voltage in the sections should then be between 900 V and 1100 V.

Sections 21 and 61 are supplied from the same section of the distribution network, as can be seen in chapter 2. A power factor correction unit was connected to the network before sections 21 and 61 were supplied with power to improve the power factor and to increase the voltage levels in the sections. Section 21 is slightly farther from the main substation on surface than section 61.

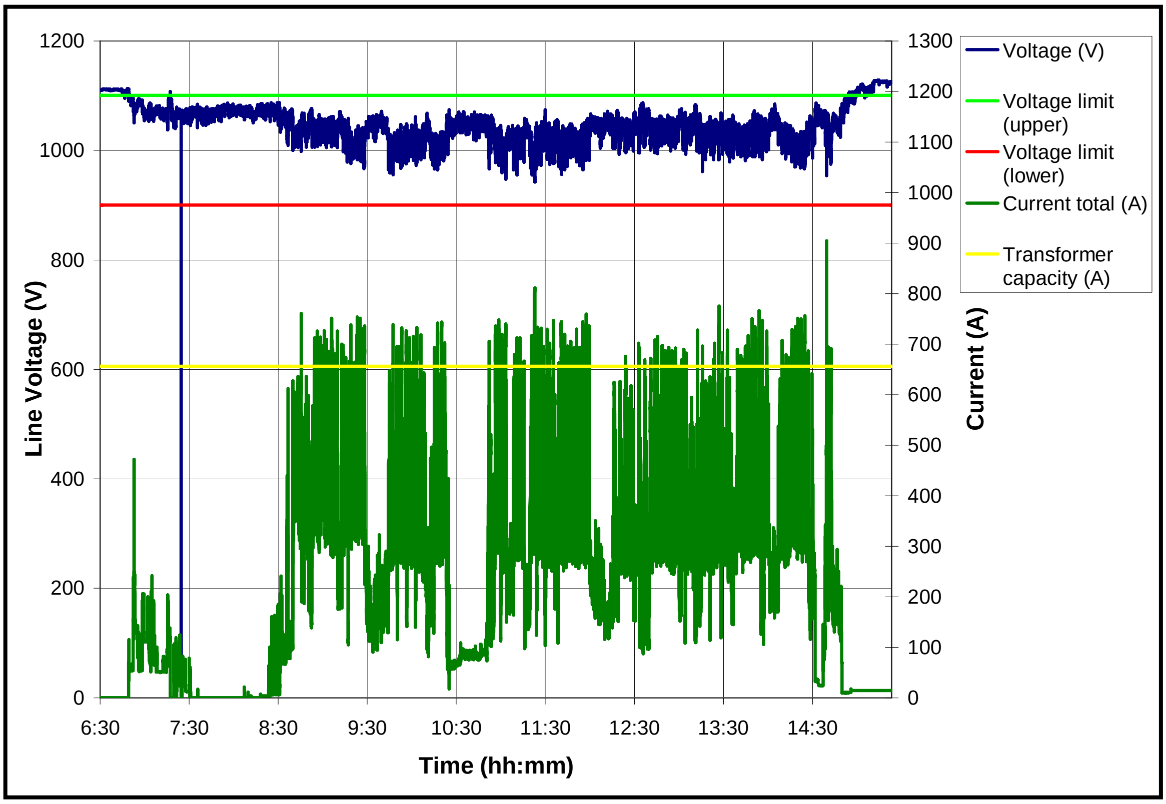


Figure 4.10-1: Load current and voltage for a 1250 kVA flameproof transformer – Morning shift 19 May 2005.

Figure 4.10-1 and Figure 4.10-2 show the voltages for a shift recorded at the 1250 kVA flameproof transformers of section 21 and section 61 respectively. The voltages in both sections were close to the upper limit for the voltages. As soon as production starts, the voltages drop to around 1000 V and fluctuate at that level depending on the size of the load in the section measured as well as other section in the area.

Figure 4.10-3 shows the voltages at the continuous miner of section 51 during night shift when coal was not being produced. The voltages become constant until the section starts producing coal the next morning.

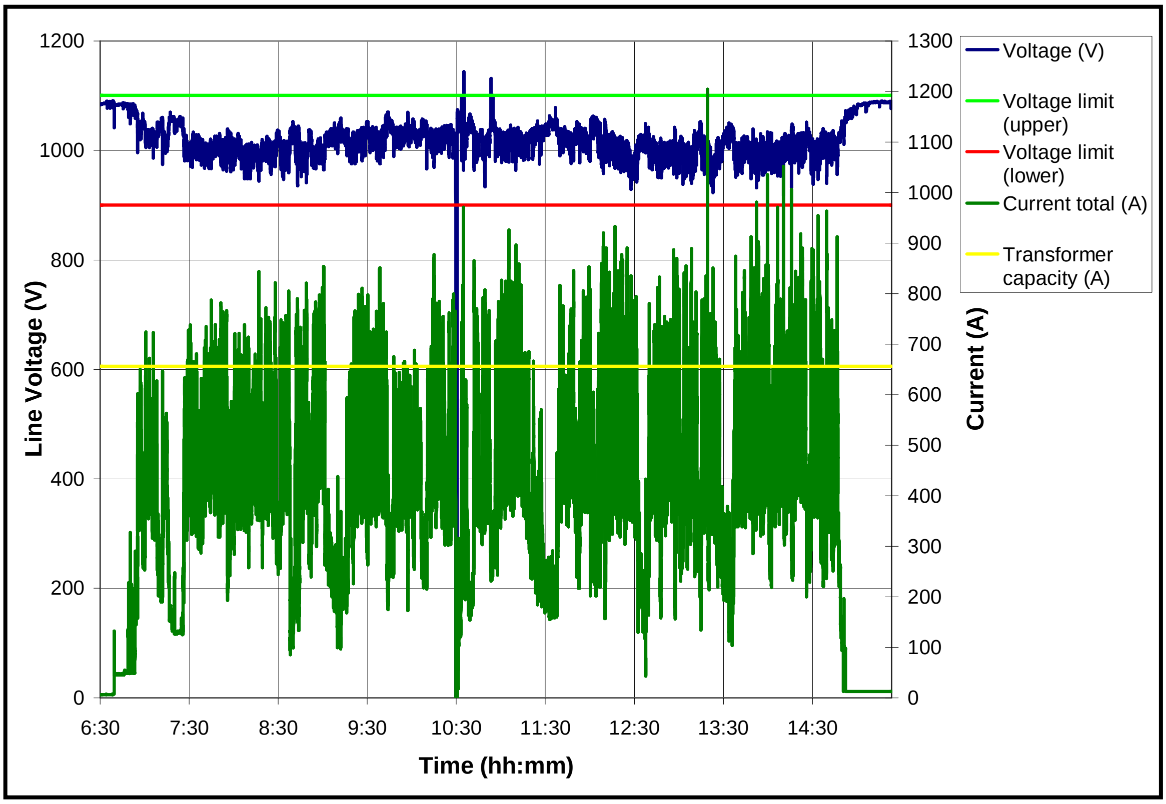


Figure 4.10-2: Load current and voltage for a 1250 kVA flameproof transformer – Morning shift 25 May 2005.

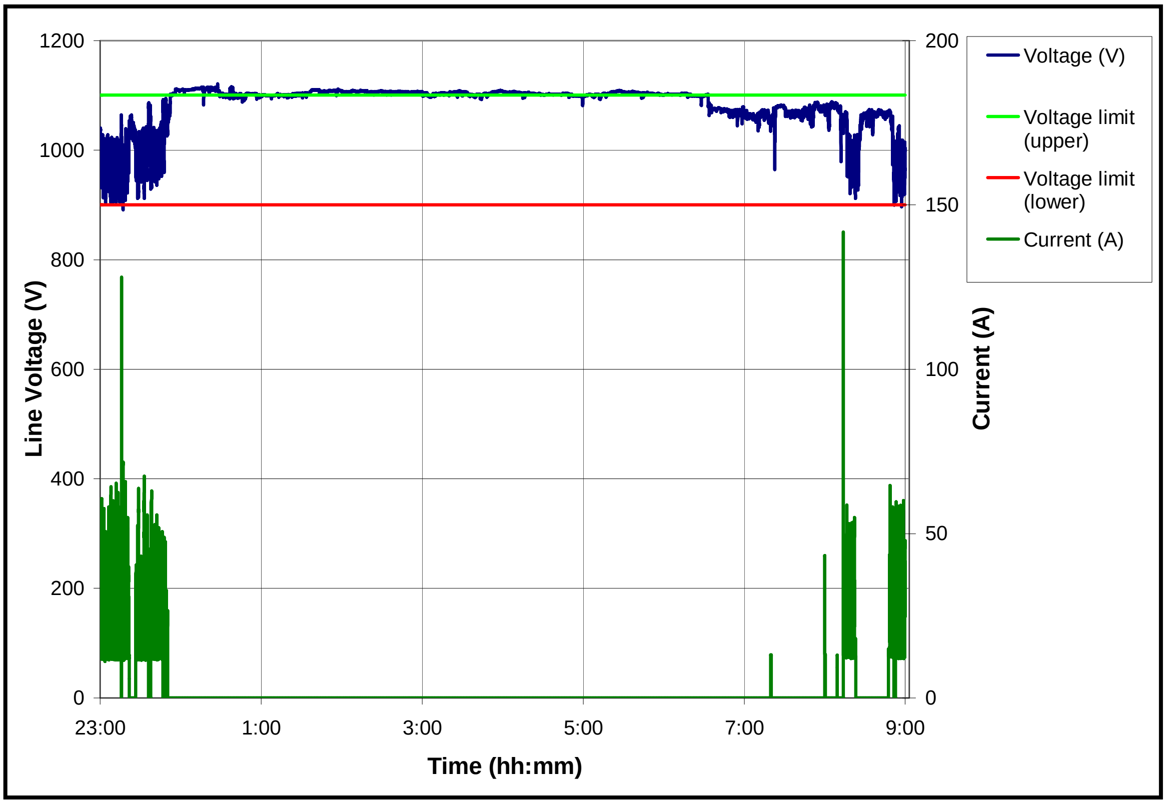


Figure 4.10-3: Section 51 CM: RH cutter motor current and voltage – Afternoon shift 23 June 2005 to morning shift 24 June 2005.

Table 4-12 shows the time of the shift, as a percentage, that the voltages were within a specific range in section 21. The voltages were within ± 5% of the nominal voltage for at least 50 % of the time and for another long period it was between 1050 V and 1100 V. Figure 4.10-4 shows the histogram for the voltages in section 21. The voltages were normally between 1000 V and 1080 V. The red block shows the period when the voltage exceeded the upper voltage limit.

Table 4-12: Section 21 - Data for the voltages at the 1250 kVA flameproof transformer.

	Morning	Afternoon	Afternoon	Afternoon
	19-May-05	17-May-05	18-May-05	19-May-05
Tonnes/CM/Shift	1716	2145	2112	2013
Voltages between limits as %:				
900 V to 950 V	0.02%	0.02%	0.01%	0.00%
950 V to 1050 V	53.48%	52.34%	84.49%	53.29%
1050 V to 1100 V	36.72%	43.39%	14.89%	42.59%
> 1100 V	9.79%	4.25%	0.49%	4.11%

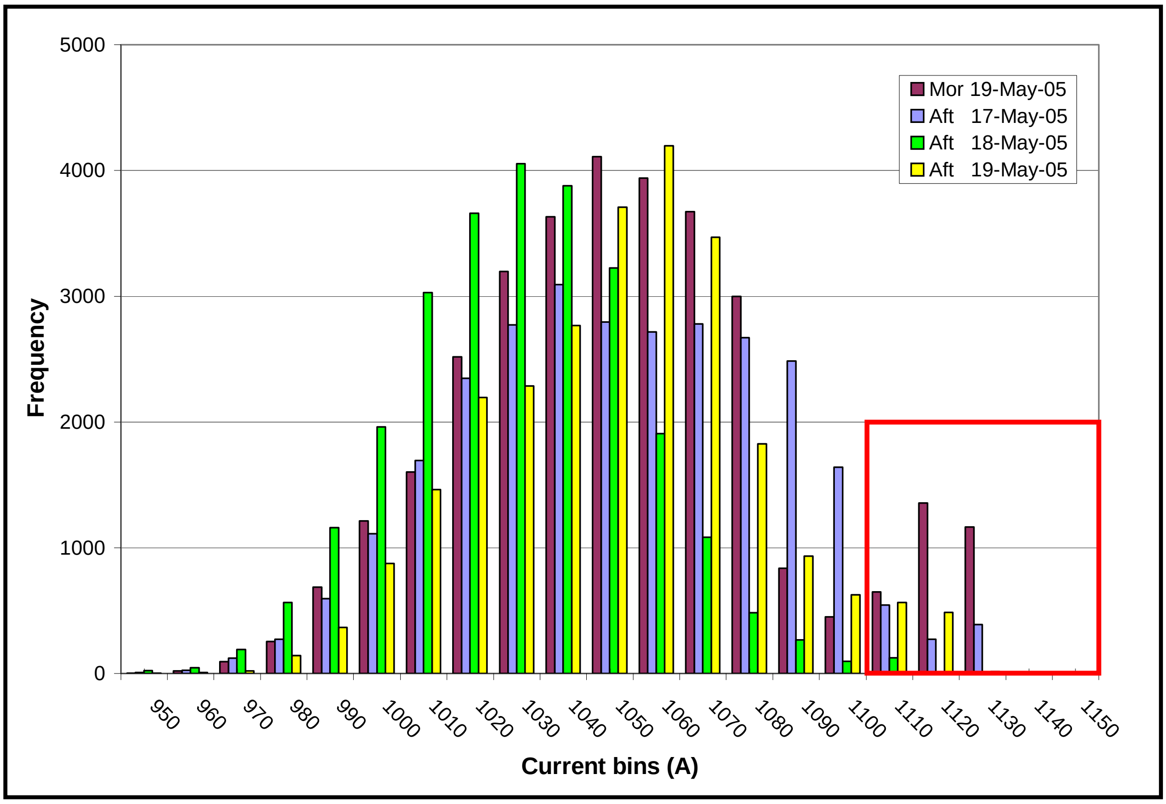


Figure 4.10-4: Section 21 - Histogram for voltages at the 1250 kVA flameproof transformer.

Table 4-13 shows the time of the shift, as a percentage, that the voltages were within a specific range in section 61. The voltages were within ± 5% of the rated voltage most of the time and for a short period it was between 1050 V and 1100 V. Figure 4.10-5 shows the histogram for the voltages in section 61. The voltages were normally between 980 V and 1060 V.

Table 4-13: Section 61 - Data for the voltages at the 1250 kVA flameproof transformer.

	Morning	Morning	Afternoon	Afternoon
	23-May-05	25-May-05	23-May-05	24-May-05
Tonnes/CM/Shift	1740	2320	2030	2320
Voltages between limits as %:				
900 V to 950 V	0.15%	0.24%	0.18%	0.30%
950 V to 1050 V	76.66%	83.15%	89.98%	90.78%
1050 V to 1100 V	18.09%	16.59%	9.18%	8.58%
> 1100 V	5.10%	0.00%	0.66%	0.34%

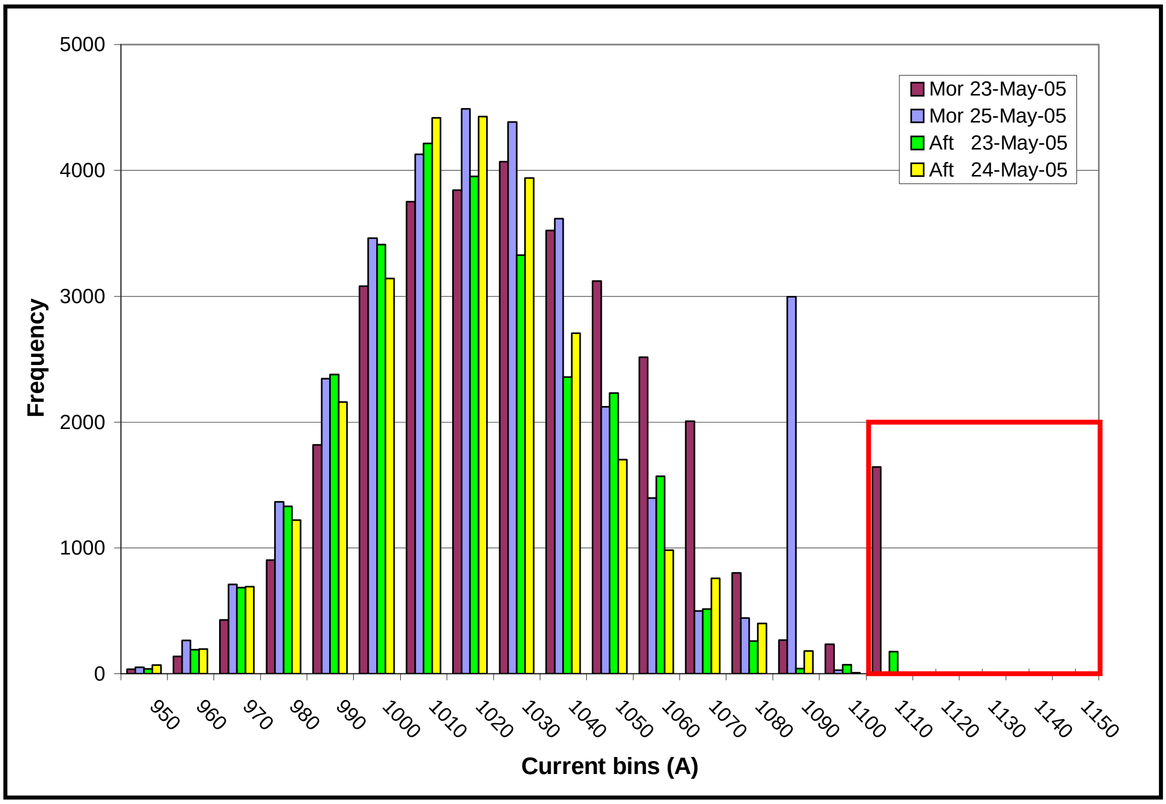


Figure 4.10-5: Section 61 - Histogram for voltages at the 1250 kVA flameproof transformer.

The voltages were lower in section 61 because the consumption was much higher than in section 21 due to higher production. It was not only the specific section measured that has an influence on the voltages in that section, but also the sections supplied from the same branch of the network. The combined effect of all the sections being started up contributes to the drop in voltage levels.

Constant undervoltages were not experienced in any of the sections. If the voltages exceeded the lower voltage limits, it would only be for a few seconds. The control of the power factor correction unit was not optimal, although undervoltage problems were prevented. The power factor correction unit also causes the overvoltages experienced in the sections. The unit's control system must remove the capacitor banks when the load consumed by the sections decreases drastically to prevent the voltage levels from rising too high, as voltages that rise too high can damage motors.

4.11 SUMMARY

Measurements were made on the in-section electrical distribution networks of sections 21 and section 61 at Twistdraai Central for three continuous days in each section. Problems were experienced with the measuring equipment from MAS Condition Monitoring and with mining equipment that was moved to different supply switches than those being measured. Breakdowns on the equipment, especially on the shuttle cars of both sections, had a marked influence on the amount of useful data obtained over the measuring period.

Neither the MSU, the 1250 kVA flameproof transformer and the gate end boxes in both the sections nor the cables supplying these equipment with power were a limitation or could easily become one. The MSU was consuming on average 30 A to 40 A per phase for a shift producing in excess of 2000 tonnes. The flameproof transformer experienced large peaks that overloaded the transformer slightly, but because a transformer can be overloaded by up to 200% it did not cause a problem. Average consumption of the transformer was about 300 A per phase, with 480 A also being consumed regularly.

Section 61 was on average consuming more power than section 21 and also created larger peaks. There was, however, a marked difference in the average consumption of the gate end boxes of both sections that could not be explained. The gate end box of section 21 consumed between 90 A and 130 A on average per phase, whereas that of section 61 consumed between 140 A and 190 A. This meant a difference of almost 50 A on the average consumption. Initially it was thought that the shuttle cars and feeder breaker of section 61 consumed more power than that of section 21. This was, however, not the case as can be seen in this chapter.

A possible explanation for the difference in consumption is that all the equipment used in section 61 more consistently consumed the average current which would then not be the case at section 21. For example, all three cars in section 61 were continuously consuming their average currents, while in section 21 only one car and sometimes two were consuming their average current at a time. The total effect resulted in a difference of 50 A. Another possibility could be that submersible water pumps were powered from the gate end boxes to remove excess water from the section. This could be clarified by simultaneously measure all the equipment that was supplied with power from the gate end boxes.

Section 61 uses much more power on average than section 21. The difference could not be explained by a corresponding difference in the production (tonnes/CM/shift). The continuous miner of section 61, for example, was being worked much harder than the continuous miner of section 21, but its production was only 200 tonnes higher at the end of the shift. Only the duty cycle of the equipment should change if more coal is being produced and not how hard the equipment has to work at a specific time.

The continuous miner contributes to almost two thirds of the total load consumed by a section. The continuous miner of section 21 consumed between 150 A and 180 A on average, with the continuous miner of section 61 consuming anything between 90 A and 300 A on average. Currents between 300 A and 540 A were also frequently consumed.

The trailing cable supplying a continuous miner with power was a limitation, as it was on average overloaded for 30 % of the time that a continuous miner was being utilised. The cable's temperature sometimes exceeded 55℃. However, it is not practical use larger cables for the continuous miners because it will provide additional problems. The cable was already difficult to handle. If a larger cable were used, it would make it impossible to handle, which in turn will have a negative effect on production. Another option is to convert the section voltages from 1000 V to 3.3 kV. The cost will be huge, but the option should be investigated. Trailing cables will be smaller, and voltage drops will be less. There will also be capacity for improvements on the size and number of loads used in a section.

The cable of the shuttle car was not a limitation by itself, but because it was coiled on a drum its current rating was derated considerably. It is assumed that 3 layers of cable are left on the drum on average, which derates the cable to only 52 A. Longer cables will have more layers on the drum more frequently, which could mean that the trailing cable of a shuttle car will overheat.

The trailing cables supplying the roofbolters and the feeder breakers with power have more than sufficient spare capacity. A 4 mm^2 trailing cable can be used to supply power to the roofbolter and still provide more than enough spare capacity. Roofbolters only consume 9 A to 13 A on average, and the 4 mm^2 cable is rated for 50 A at 25℃. The load on the feeder breaker can almost be doubled, as it consumes only between 45 A and 50 A per phase, while the cable was rated for 115 A at 25℃.

The voltage levels in the sections were a little high at times, especially in non-production periods. This can be corrected by improving control on the power factor correction units. The voltage levels decrease when the sections in the mine start to produce. The voltage level varies according to the size of the load consumed by the sections. Section 21 had higher voltages on average than section 61, because section 61 was consuming more power.

CHAPTER 5

PRODUCTION EQUIPMENT

The investigation was divided into two parts. The first part consisted of measuring the in-section electrical distribution network, and for the second part the motors on the mining equipment used in a production section were measured.

This chapter gives a short summary of the results obtained from the measurements on the motors. The analysed data show which motors are already being overloaded on specific equipment and which of the motors could become limitations in future. The CD attached to back of report has more extensive results, as this chapter gives only a summary of the results and only highlights a few cases and extreme conditions that were measured.

5.1 MEASURING SUMMARY

All motor loads (see Table 5-1) were measured, except the dust motor and the pump motor on the continuous miner. The load on the dust motor of the continuous miner will not change if production is increased. It was not practically possible to measure the consumption of the roofbolter's pump motor, because the flameproof enclosure was too small to fit the measuring instrument into it.

Measurements were taken on the mining equipment in section 21 and in section 51. The strategy was to do measurements for three days on each motor, but unfortunately problems were experienced and it was not always possible. The measuring instrument could only fit into the flameproof enclosures of the shuttle cars, which are fitted with a large flameproof enclosure. There was only one shuttle car with a large flameproof enclosure in section 21 and one in section 51. Measurements could not be taken on the shuttle car in section 21, because it was removed for major maintenance before measurements could be taken.

The shuttle car in section 51 was measured for two days, but the pump motor could not be measured due to differences in the wiring diagrams of the pump motor and the actual wiring. The only other shuttle car with a large flameproof enclosure in

Twistdraai Central was a car in section 50. This car was measured for a day to obtain data on the consumption of the pump motor of a shuttle car.

Table 5-1: Actual measuring points on mining equipment.

Equipment	Component	Phases to be measured	Variables to be measured
CM			
	Cutter motor 1	1	Voltage, Current and Power
	Cutter motor 2	1	Current and Power
	Gathering motor 1	1	Current and Power
	Gathering motor 2	1	Current and Power
	Pump motor	1	Current and Power
	Conveyer motor	1	Current and Power
	LH Traction motor	1	Voltage and Current
	RH Traction motor	1	Voltage and Current
Shuttle Car			
	Pump motor	1	Voltage, Current and Power
	Conveyer motor	1	Current and Power
	Traction motor LH	1	Voltage and Current
	Traction motor RH	1	Voltage and Current
Feeder Breaker			
	Conveyer motor	1	Voltage, Current and Power
	Crusher motor 1	1	Current and Power
	Crusher motor 2	1	Current and Power

Sometimes measurements could be taken for only three days in a week. The reason was that there was not always transport to the section or artisans on night shift to assist with the installation and or removal of the measuring equipment or with the downloading of the data. Active power measurements were also made on each of the motors.

Motors should be derated to 92% of the rated output or operated at a maximum ambient temperature of 32℃ as the coal mines of Sasol Mining are situated at an altitude above 1000 m above sea level. The motors are, however, normally operated at an ambient temperature of 25℃. It was thus assumed that the altitude and temperature rating changes would cancel each other out, leaving the motor rated as indicated on the nameplate of the motor.

5.2 CONTINUOUS MINER

Several different motors are used on a continuous miner. All the motors are induction motors except for the two DC motors used for tramming. The motors on the continuous miners of the different sections use the same size motors except for the DC traction motors. The traction motors of the continuous miner in section 21 were only 37 kW, while the continuous miner in section 51 uses 50 kW motors.

All the motors on a continuous miner are water cooled. The cutter motors and traction motors are, however, the only motors cooled with water through an open loop system. The other motors are cooled in a closed loop system using antifreeze as the coolant. This is not as effective as the open loop water system, because the antifreeze has to be cooled before being reused.

5.2.1 Conveyor Motor

The conveyor motor is located on the tail of the continuous miner (see Chapter 2) and it powers the conveyor that runs from the spade in the front, which is filled with coal by the gathering head motors. The only purpose of the conveyor motor is to load coal onto the waiting shuttle cars. The motor does not normally run continuously. It has to wait either for a shuttle car to position itself under the tail of the continuous miner to be loaded or for the continuous miner to cut coal so that the gathering head motors can load the coal onto the conveyor.

The conveyor motor measured in both sections were 37 kW induction motors with a full-load current rating of 30 A (see Table 5-2 for details).

Table 5-2: Nameplate data of the conveyor motor on a CM.

CM Conveyor Motor					
Power	37	kW	Voltage	1000	V
Duty	S1 - HR		Current	30	A
Ins class	H		RPM	1380	
			pf	0.77	

Table 5-3: Production figures for shifts where the conveyor motor was monitored.

Date	Sect 21		Sect 51	
	Morning	Afternoon	Morning	Afternoon
9-Jun-2005	1225	1400	-	-
10-Jun-2005	1575	**2695**	-	-
13-Jun-2005	**2310**	**2520**	-	-
29-Jun-2005	-	**-**	1305	**2175**
30-Jun-2005	-	-	1740	**2320**

Table 5-3 shows the production at the respective sections when the consumption of the conveyor motors was measured. Figure 5.2-1 and Figure 5.2-2 show the voltage and load current consumed by the conveyor motor for two shifts over a 30-minute period. It can be seen that the duty cycle of the conveyor motor was quite short with a large peak at the start of each cycle and again at the end of each cycle. The waiting time between two successive cycles was normally dependent on the shuttle cars, as the continuous miner has to wait for another car to come into position before loading again.

The peak current was measured at the start of the second cycle, because the conveyor was filled with coal when it stopped loading the previous car. The motor then has to overcome the inertia of the loaded conveyor, which results in the peak. The peak at the end of the cycle was the result of suddenly stopping the motor with a fully loaded conveyor.

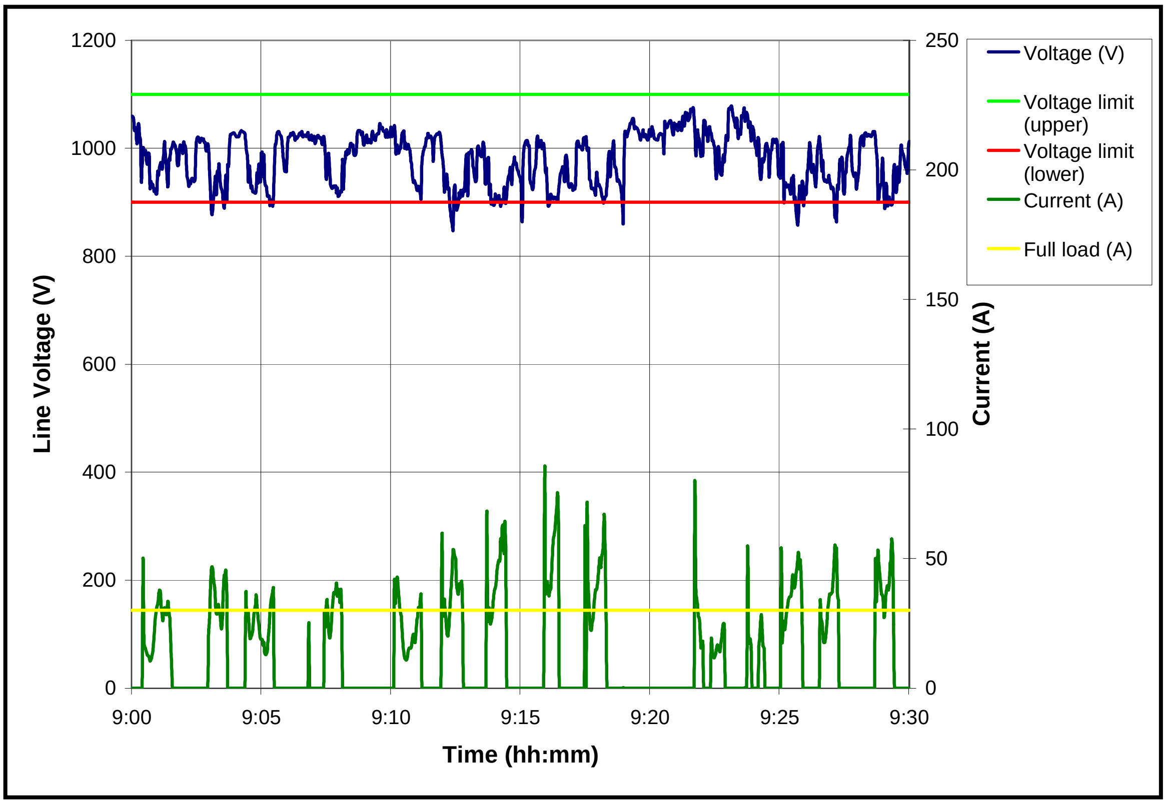


Figure 5.2-1: Load current and voltage for the conveyor motor – Afternoon shift 13 June 2005 (30 minute period).

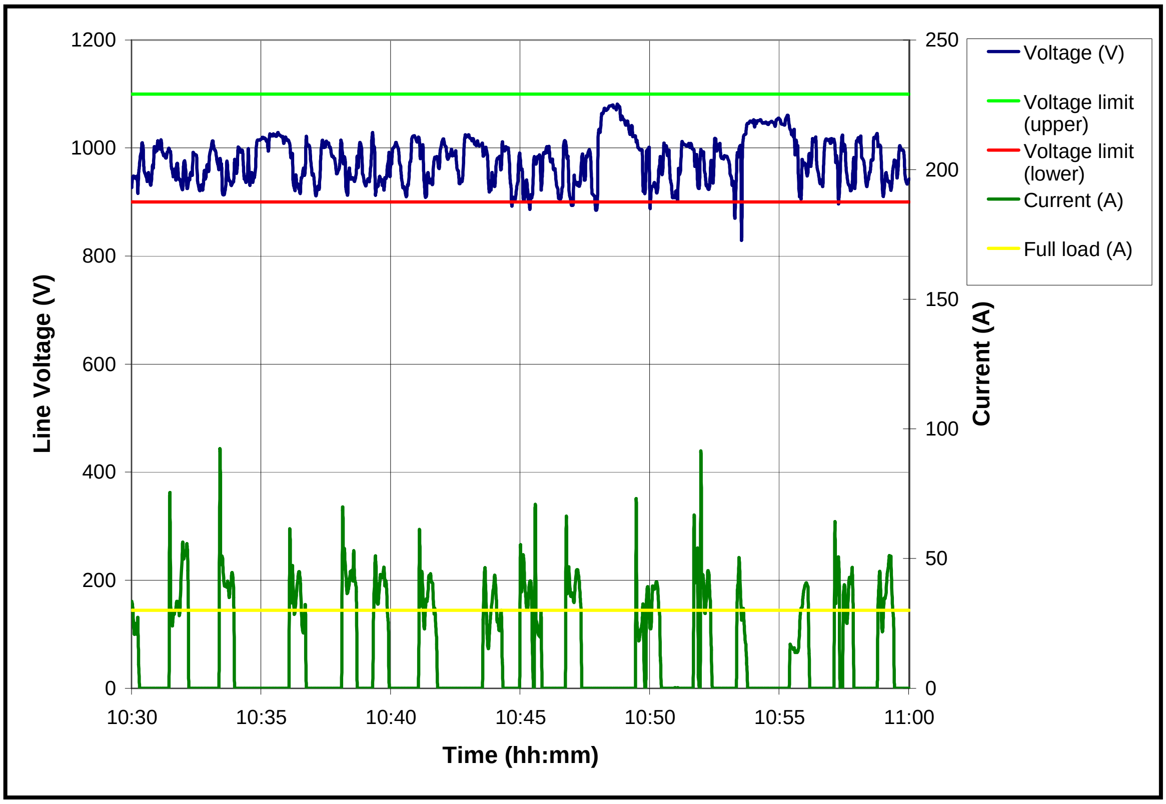


Figure 5.2-2: Load current and voltage for the conveyor motor – Afternoon shift 29 June 2005 (30 minute period).

The amplitude of the peaks, the average consumption over a cycle and the duration of a cycle also differ. It can be seen that the duty cycle of the conveyor motor on the afternoon shift of 29 June 2005 was much more consistent than on the afternoon shift of 13 June 2005. The reason for this was the human factor. The second operator was much more consistent.

Table 5-4: Data for the total current consumption of the conveyor motor.

	Afternoon	Afternoon	Afternoon	Afternoon
	10-Jun-05	13-Jun-05	29-Jun-05	30-Jun-05
Tonnes/CM/Shift	2695	2520	2175	2320
% Time of shift producing	23.63%	36.10%	24.09%	27.07%
% of Production time underloaded	44.92%	52.17%	35.81%	38.05%
% of Production time overloaded	55.08%	47.83%	64.19%	61.95%

Table 5-4 shows the percentage time that a motor was utilised during a shift as well as the percentage time that the motor was overloaded and underloaded while being used. It can be seen that the conveyor motor was overloaded considerably in both sections, anything from 45 % to 65 % of the time.

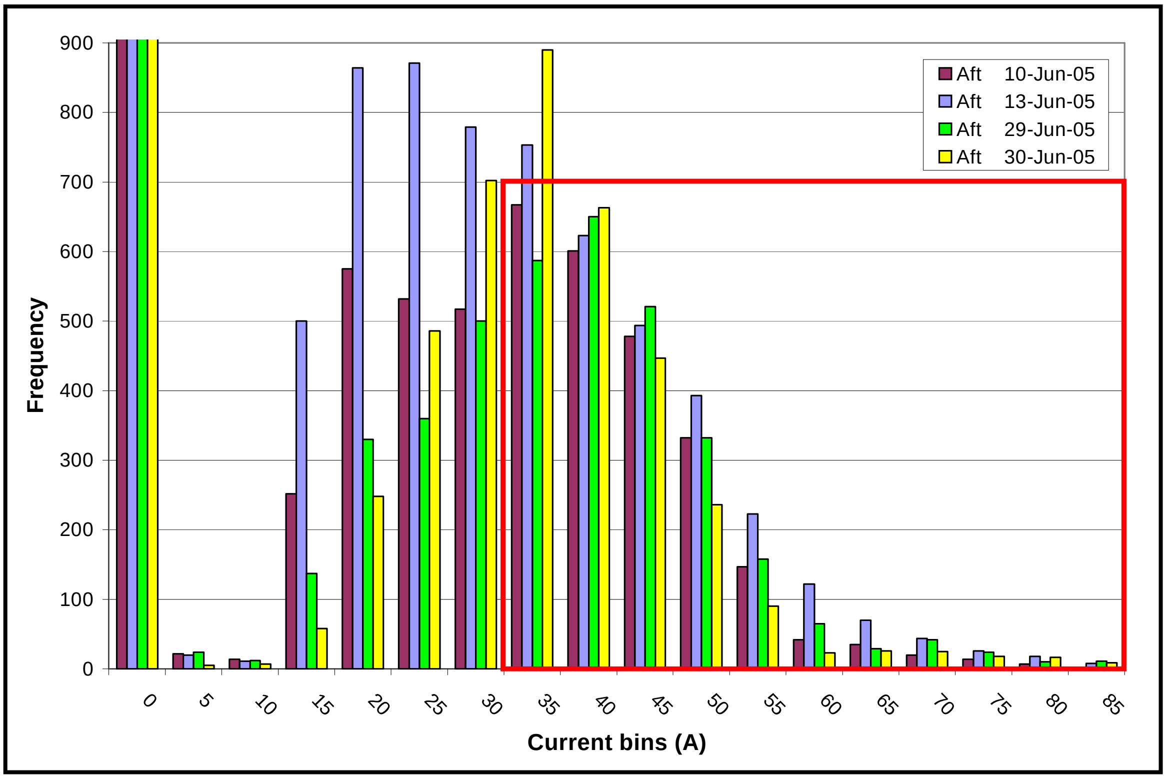


Figure 5.2-3: Histogram for current consumed by the conveyor motor. The red block indicates the overload area.

Figure 5.2-3 and Figure 5.2-4 show respectively the current and power consumed by the conveyor motor. The average current consumption of the conveyor motor was between 30 A and 40 A with the average power consumption between 35 kW and 40 kW. The conveyor motor in section 21 consumed on average lower currents during the afternoon shift of 13 June 2005 than during the other shifts. It is clear that the motor is being overloaded.

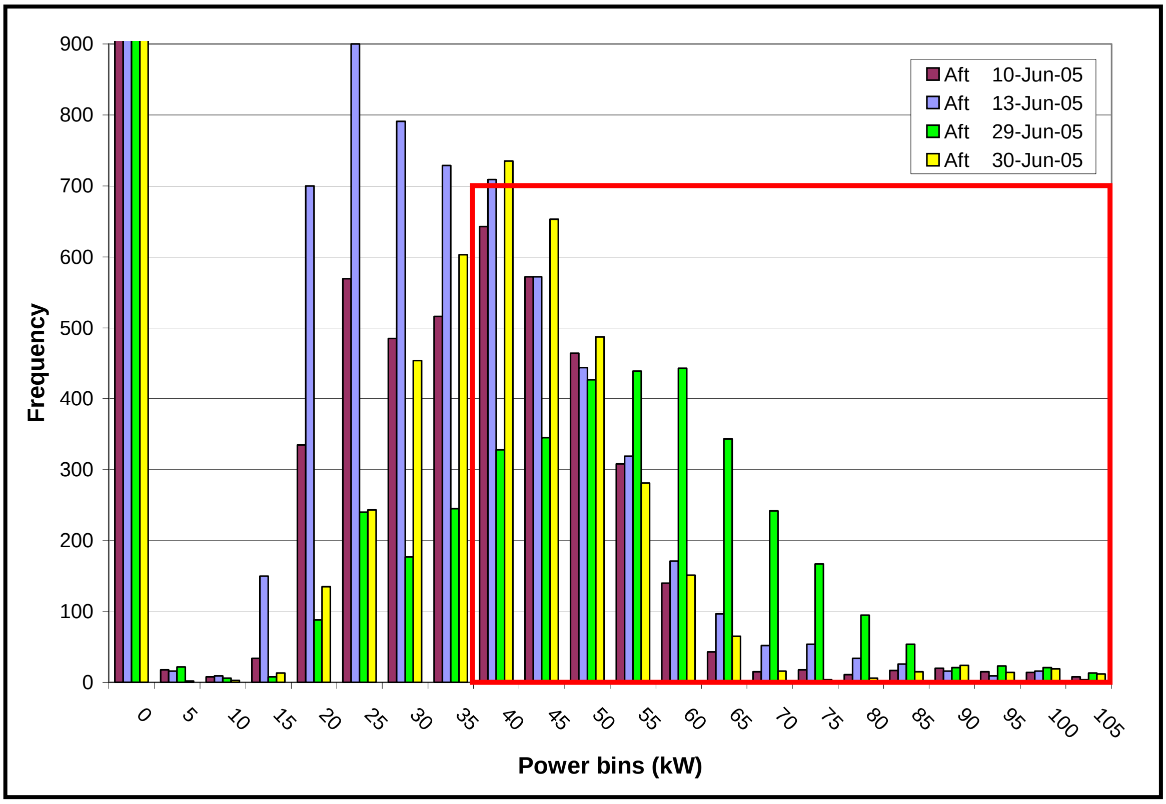


Figure 5.2-4: Histogram for power consumed by the conveyor motors. The red block indicates the overload area.

Accurate information about the thermal time constants of the motors could not be obtained from the suppliers of the motors. Assumptions were thus made for these values. A number of factors influence the thermal time constants of the motors, for example dust on the motor, whether the motor is housed in an enclosure and the cooling method used.

The thermal time constant for the conveyor motor was estimated at 45 minutes and the conductor temperature should stabilise at 155°C if operated at full load for a long period. The ambient temperature was 24°C. Figure 5.2-5 shows the load current and motor winding temperature for a conveyor motor over a shift. The estimated winding temperature was calculated with different time constants (see figure 5.2-5). This illustrates the effect that thermal time constants have on the actual motor temperature. A class H insulation system is rated for a winding temperature of 180℃.

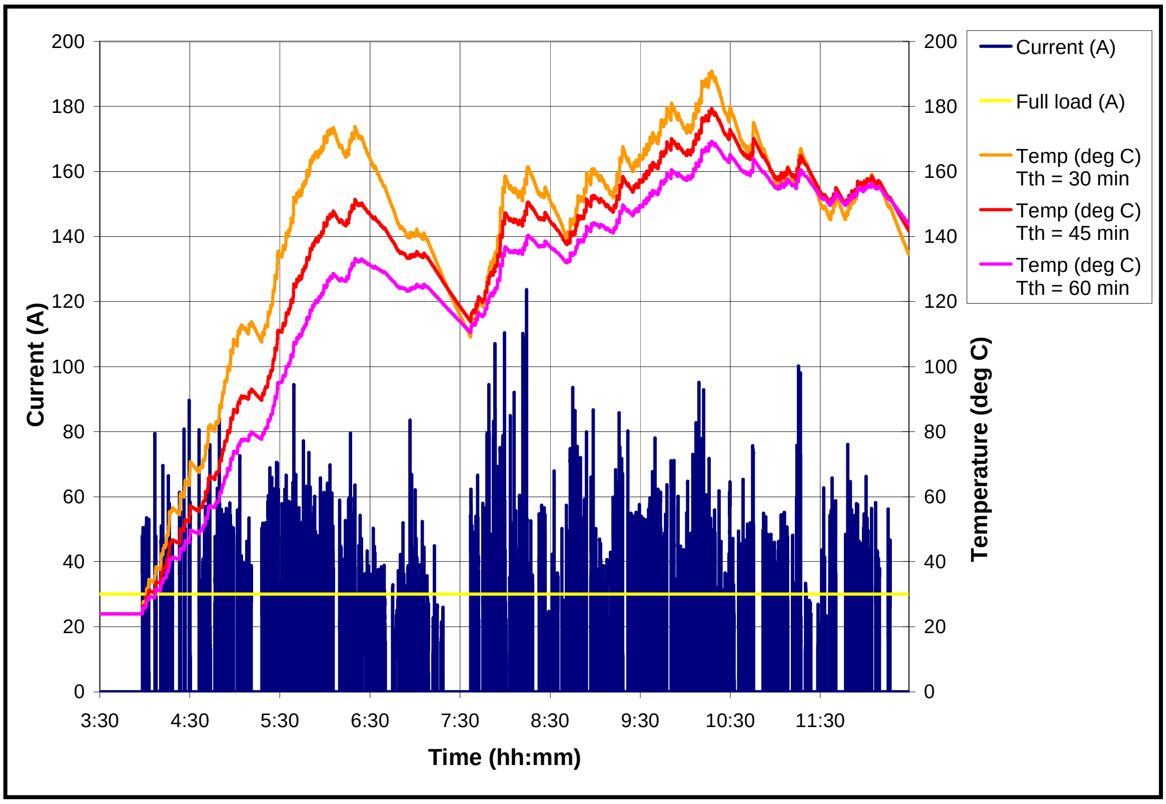


Figure 5.2-5: Load current and motor temperature for the conveyor motor – Afternoon shift 13 June 2005.

The temperature increases as a result of higher duty cycles and increased consumption during these cycles. The higher duty cycle means that the motor has less time to cool down.

It is clear from the figure that the conveyor motor is working too hard. The motor winding temperature reaches and exceeds the maximum temperature for class H insulation, which is 180℃. The motor will easily exceed the temperature continuously if the duty cycle is increased or if the motor is worked harder. The conveyor motor was thus overloaded and is a limitation if the productivity is increased even more. A 55 kW motor is ideally suited for the application.

5.2.2 Pump motor

The pump motor is used to power the hydraulics on the continuous miner (see Chapter 2). This motor runs continuously as long as the continuous miner is being utilised. The pump motors measured in both sections were 116 kW induction motors with full-load current ratings of 91 A (see Table 5-5 for details).

Table 5-5: Nameplate data of the pump motor on a CM.

CM Pump Motor					
Power	116	kW	Voltage	1000	V
Duty	S1		Current	91	A
Ins class	H		RPM	1477	
			pf	0.77	

Table 5-6 shows the production rates in the respective sections when the consumption of the pump motors were measured. Figure 5.2-6 and Figure 5.2-7 show the voltage and load current consumed by the pump motor for two shifts over a 30-minute period. The consumption of the pump motor fluctuates considerably and large peaks were recorded.

Table 5-6: Production figures for shifts when the pump motor was monitored.

	Sect 21		Sect 51	
Date	Morning	Afternoon	Morning	Afternoon
6-Jun-2005	**2079**	1485	-	-
7-Jun-2005	**1925**	1435	-	-
8-Jun-2005	1750	**2240**	-	-
23-Jun-2005	-	**-**	1856	1566
28-Jun-2005	-	-	**2204**	1740

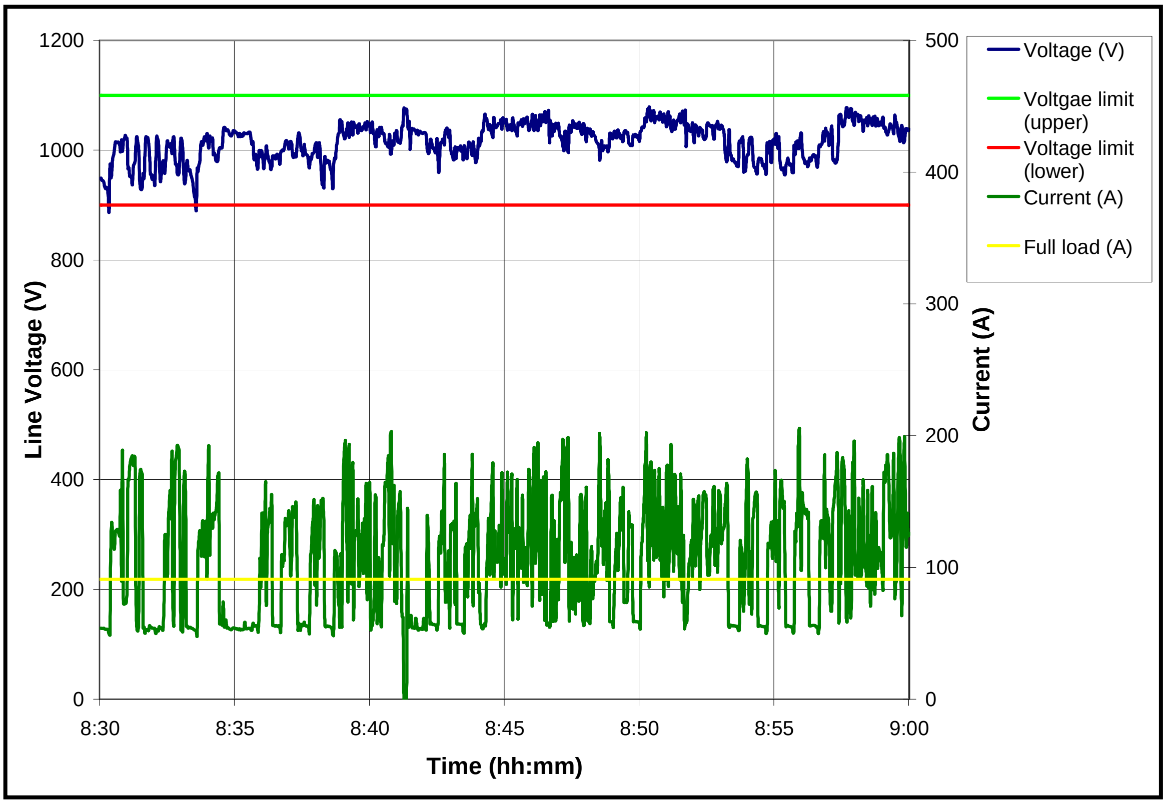


Figure 5.2-6: Load current and voltage for the pump motor – Afternoon shift 8 June 2005 (30 minute period).

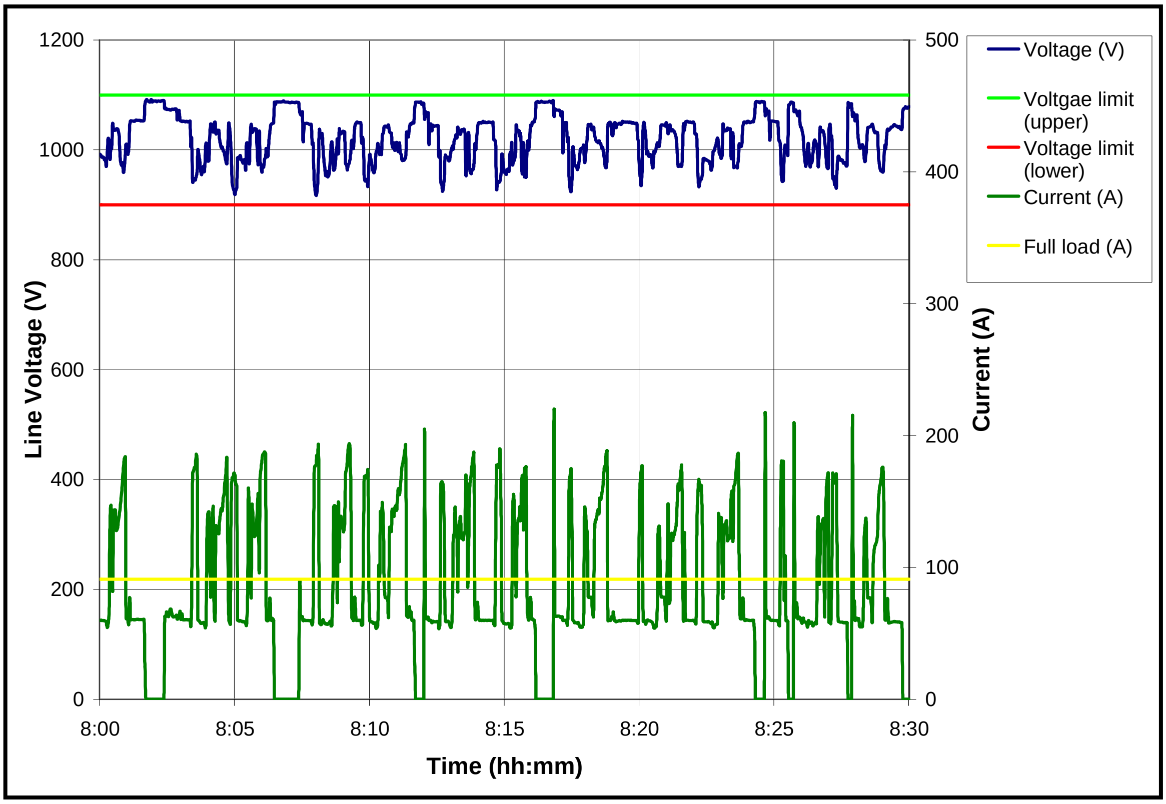


Figure 5.2-7: Load current and voltage for the pump motor – Afternoon shift 28 June 2005 (30 minute period).

Table 5-7 shows the percentage of time that the pump motor was utilised during a shift, as well as the percentage of time that the motor was overloaded and underloaded while being utilised. The motor was overloaded for 50 % of the time that the continuous miner was running.

Table 5-7: Data for the total current consumption of the pump motor.

	Morning	Morning	Afternoon	Morning
	6-Jun-05	7-Jun-05	8-Jun-05	28-Jun-05
Tonnes/CM/Shift	2079	1925	2240	2204
% Time of shift producing	78.14%	58.06%	77.40%	79.22%
% of Production time underloaded	51.83%	52.29%	52.49%	49.05%
% of Production time overloaded	48.17%	47.71%	47.51%	50.95%

Figure 5.2-8 and Figure 5.2-9 show the current and power consumed by the pump motor as histograms. The average current consumption of the pump motor was between 50 A and 60 A on the continuous miner in section 51 (morning shift 28 June 2005), the current often varying between 90 A and 180 A.

The average power consumption was between 70 kW and 80 kW for the continuous miner in section 21, but the continuous miner in section 51 consumed power between 80 kW and 90 kW. The power consumption was between 120 kW and 240 kW on a number of occasions.

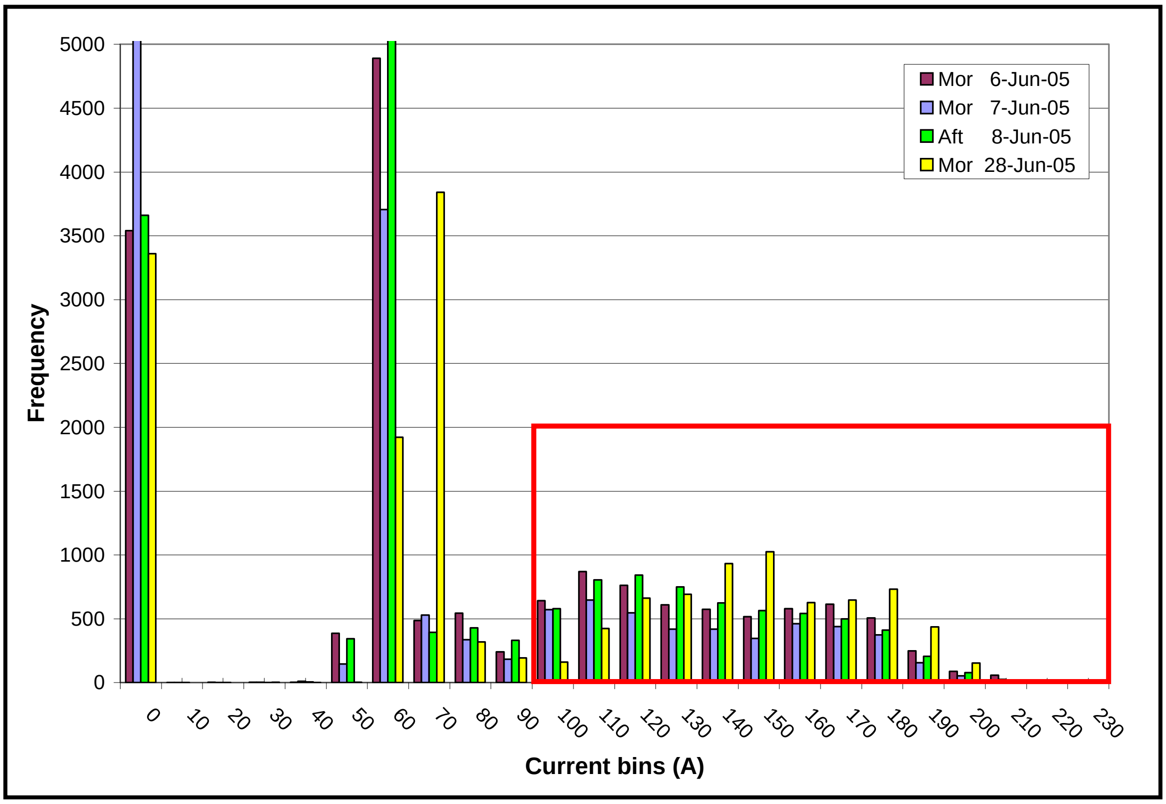


Figure 5.2-8: Histogram for current consumed by the pump motors.

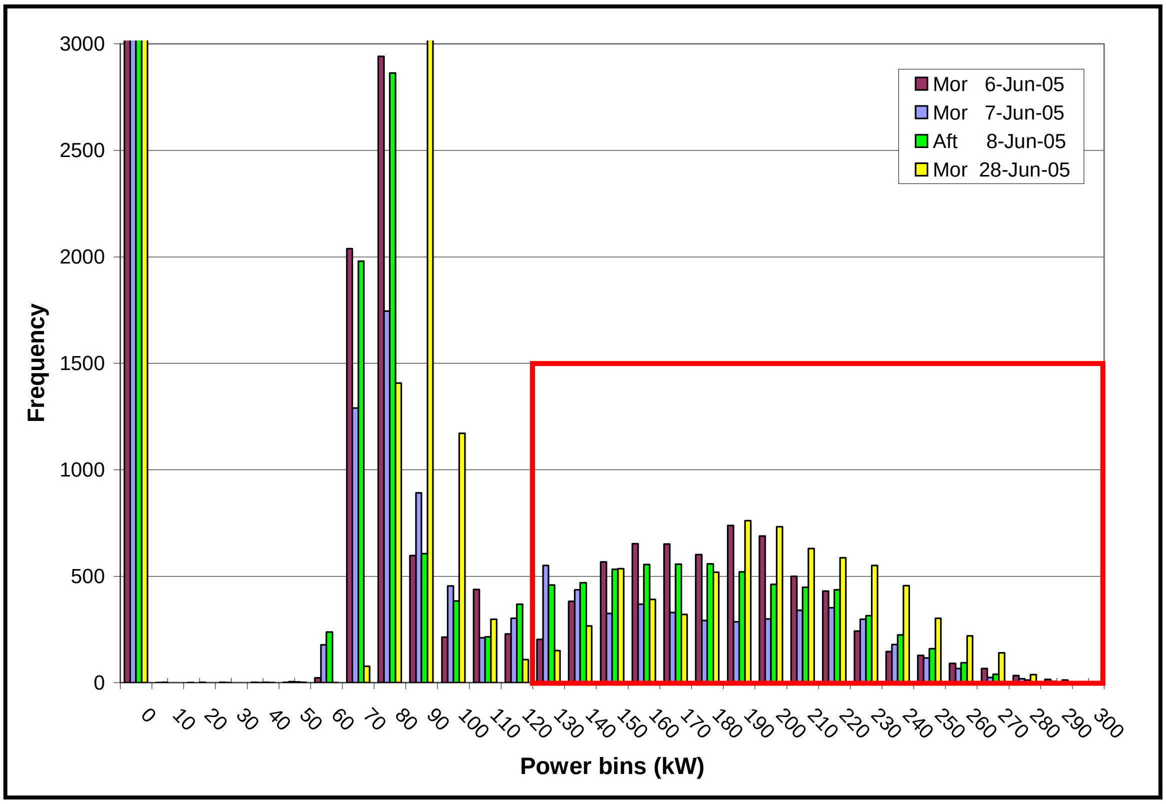


Figure 5.2-9: Histogram for power consumed by the pump motors.

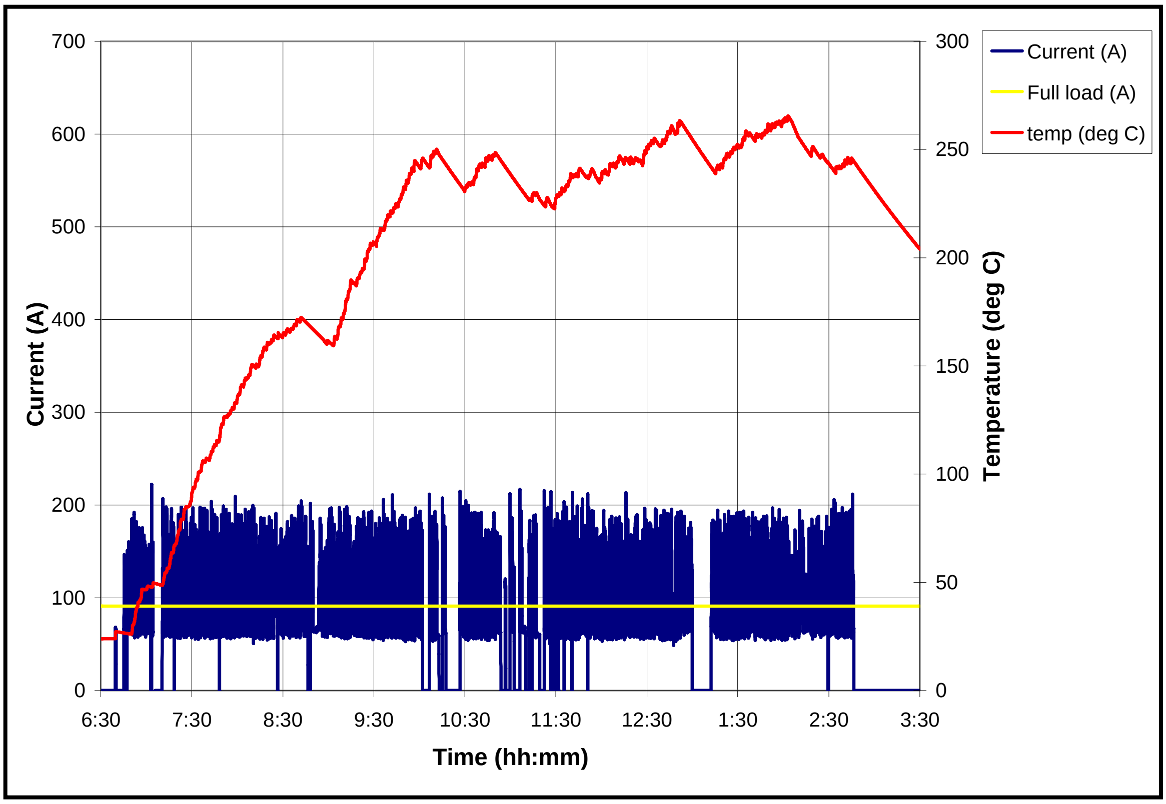


Figure 5.2-10: Load current and motor temperature for the pump motor – Morning shift 28 June 2005.

The thermal time constant for the pump motor is 60 minutes and it should stabilise at 155℃ if operated at full-load for a period long enough to reach thermal equilibrium. The ambient temperature is 24℃. Figure 5.3-10 shows the load current and motor winding temperature for a pump motor over a shift. Changes in the thermal time constant, as was done with the conveyor motor of the continuous miner, do not drastically change the temperature reached by the motor.

From the graph it is clear that the pump motor is exceeding the maximum temperature for a class H insulation of 180℃ continuously. This motor is already a limitation and should be replaced with a larger motor. Ideally a 175 kW motor is needed for this application.

An increase in production will only reduce the expected life of the motor even further. The motor normally experiences the overload condition when the continuous miner is cutting. A possible reason for the overloading is that the operator of a continuous miner uses the pump motor to speed up the cutting time of a continuous miner by forcing the cutter drum down.

5.2.3 Gathering head motors

The gathering head motors are located on the spade of the continuous miner (see Chapter 2) and are used to load the coal onto the conveyor of the continuous miner so that the shuttle cars can be loaded. These motors only work when the conveyor is switched on and shuttle cars are being loaded.

The gathering head motors measured in both sections were 40 kW induction motors with full-load current ratings of 33 A (see Table 5-8 for details).

Table 5-8: Nameplate data of the gathering head motor on a CM.

CM Gathering head Motors					
Power	40	kW	Voltage	1000	V
Duty	S1 - HR		Current	33	A
Ins class	H		RPM	1390	
			pf	0.76	

Table 5-9: Production figures for shifts when gathering head motors were monitored.

Date	Sect 21		Sect 51	
	Morning	Afternoon	Morning	Afternoon
9-Jun-2005	1225	1400	-	-
10-Jun-2005	1575	**2695**	-	-
13-Jun-2005	**2310**	**2520**	-	-
29-Jun-2005	-	**-**	1305	**2175**
30-Jun-2005	-	-	1740	**2320**

Table 5-9 shows the production in the respective sections when the consumption of the gathering head motors were measured. Figure 5.2-11 and Figure 5.2-12 show the voltage and load current consumed by the RH gathering head motor for two shifts over a 30-minute period. There were small fluctuations in consumption of the gathering head motors. Peaks were normally recorded at the start of the duty cycle to overcome the initial inertia of the coal on the spade of the continuous miner. The consumption decreased after the peak and was then fairly constant for the rest of the cycle.

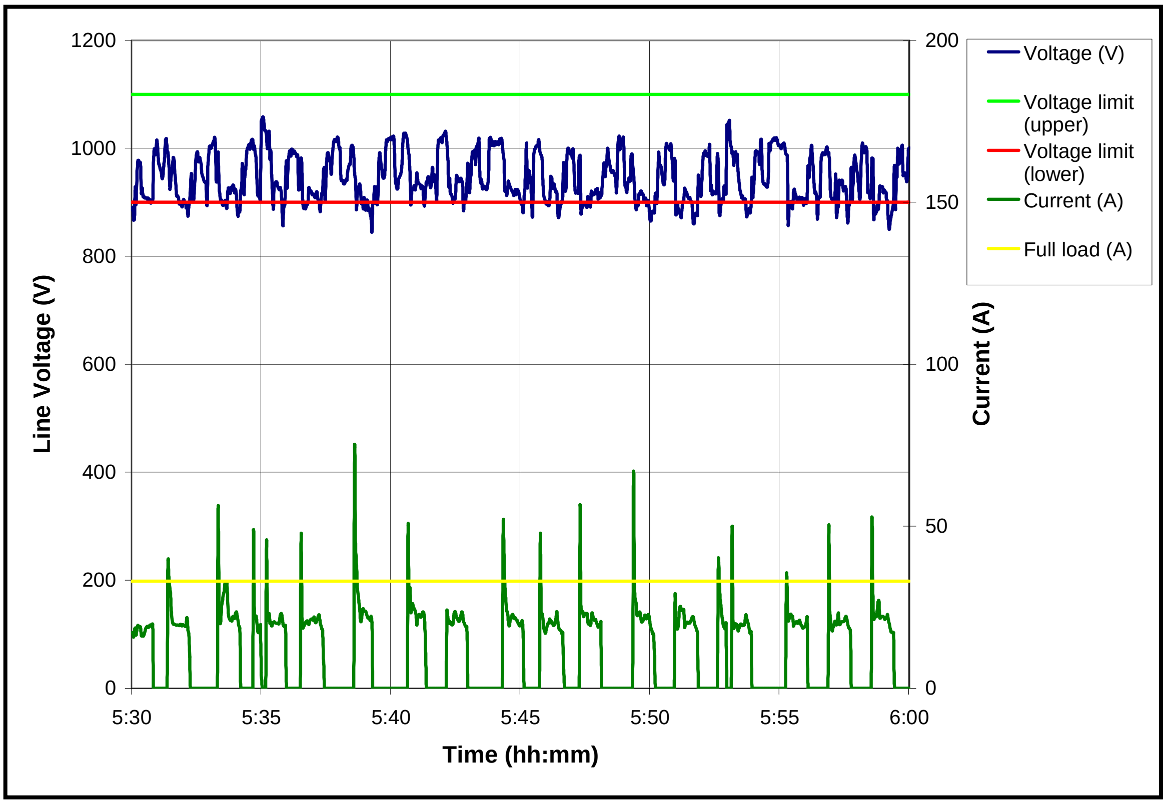


Figure 5.2-11: Load current and voltage for the RH gathering head motor – Afternoon shift 13 June 2005 (30 minute period).

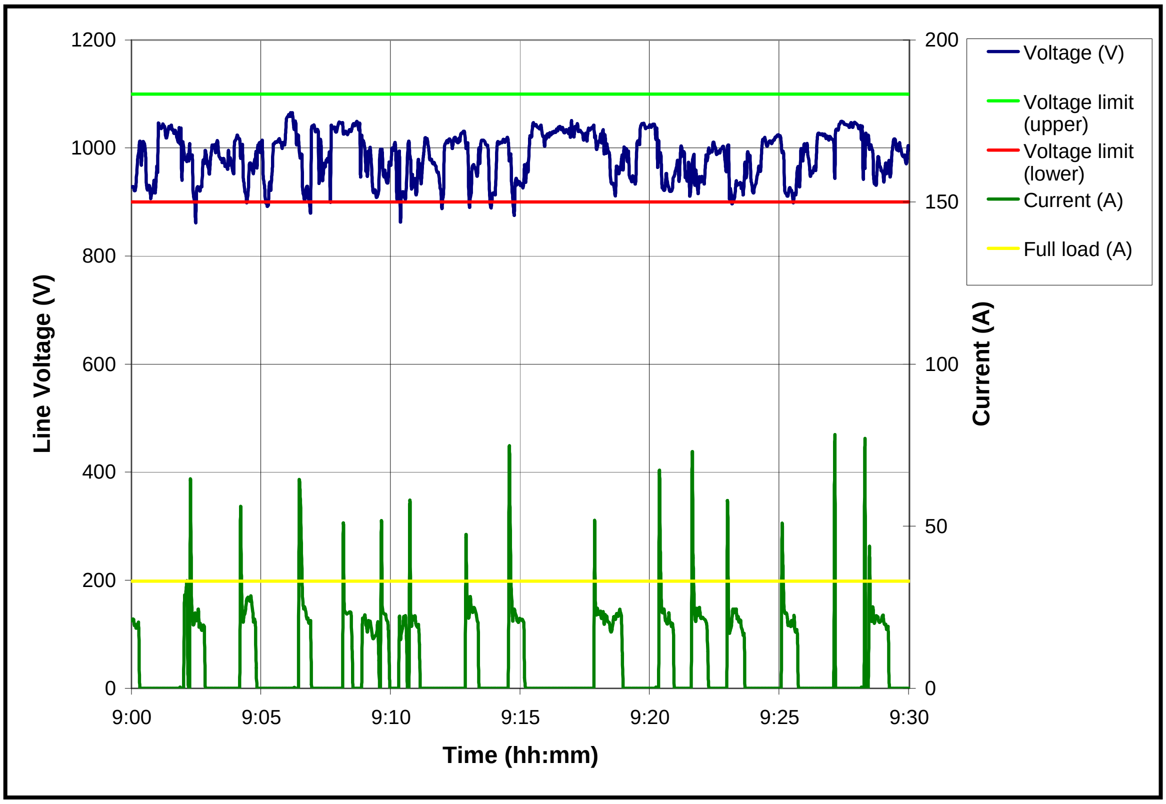


Figure 5.2-12: Load current and voltage for the RH gathering head motor – Afternoon shift 29 June 2005 (30 minute period).

Table 5-10 shows the percentage of time that the RH gathering head motors were utilised during a shift as well as the percentage of time that the motors were overloaded and underloaded while being utilised. The motors were underloaded for more than 90% of the time that they were used. From these figures it is clear that the overload was a result of the peaks experienced at the start of each cycle.

Table 5-10: Data for the total current consumption of the RH gathering head motors.

	Afternoon	Afternoon	Afternoon	Afternoon
	10-Jun-05	13-Jun-05	29-Jun-05	30-Jun-05
Tonnes/CM/Shift	2695	2520	2175	2320
% Time of shift producing	22.55%	34.66%	23.74%	29.00%
% of Production time underloaded	92.69%	95.15%	91.01%	93.14%
% of Production time overloaded	7.31%	4.85%	8.99%	6.86%

Figure 5.2-13 and Figure 5.2-14 show respectively a histogram of the current and power consumed by the RH gathering head motor. The average current consumption of the gathering head motors was between 20 A and 25 A. The average power consumption was between 20 kW and 35 kW. The consumption of the motors was very constant and well below the full-load capacity of the motors.

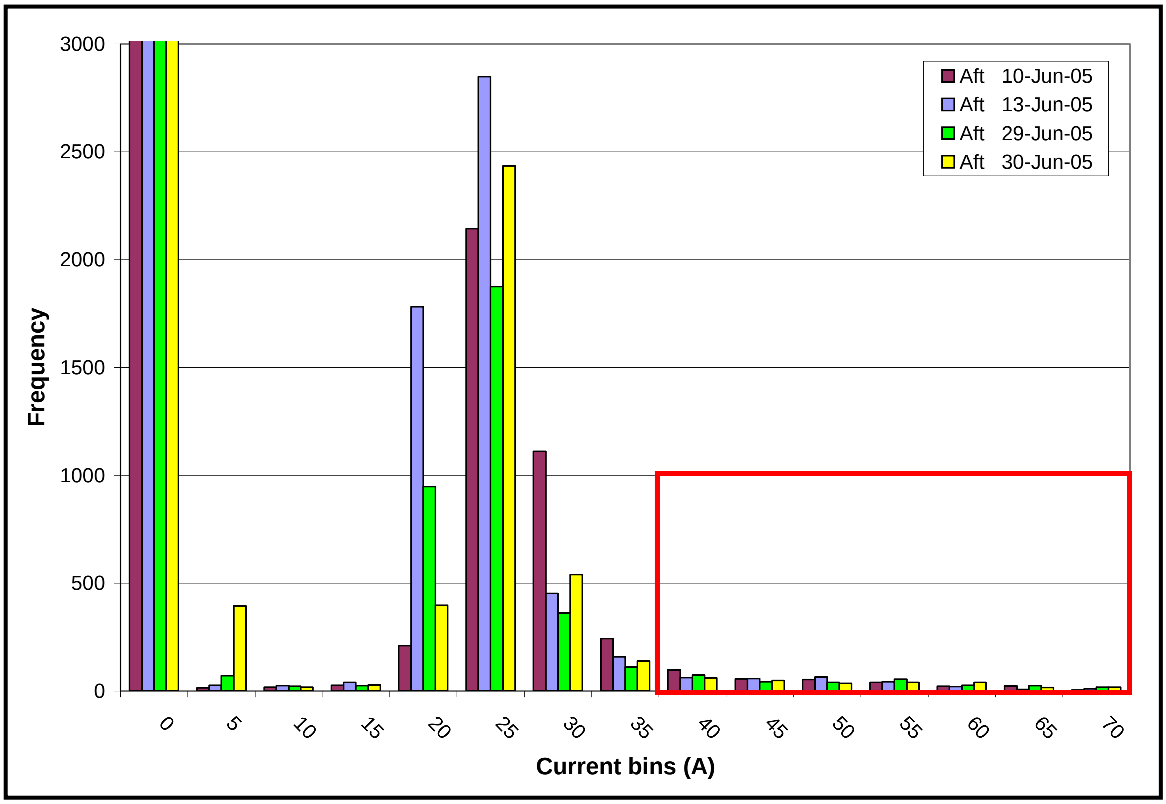


Figure 5.2-13: Histogram for current consumed by the RH gathering head motors.

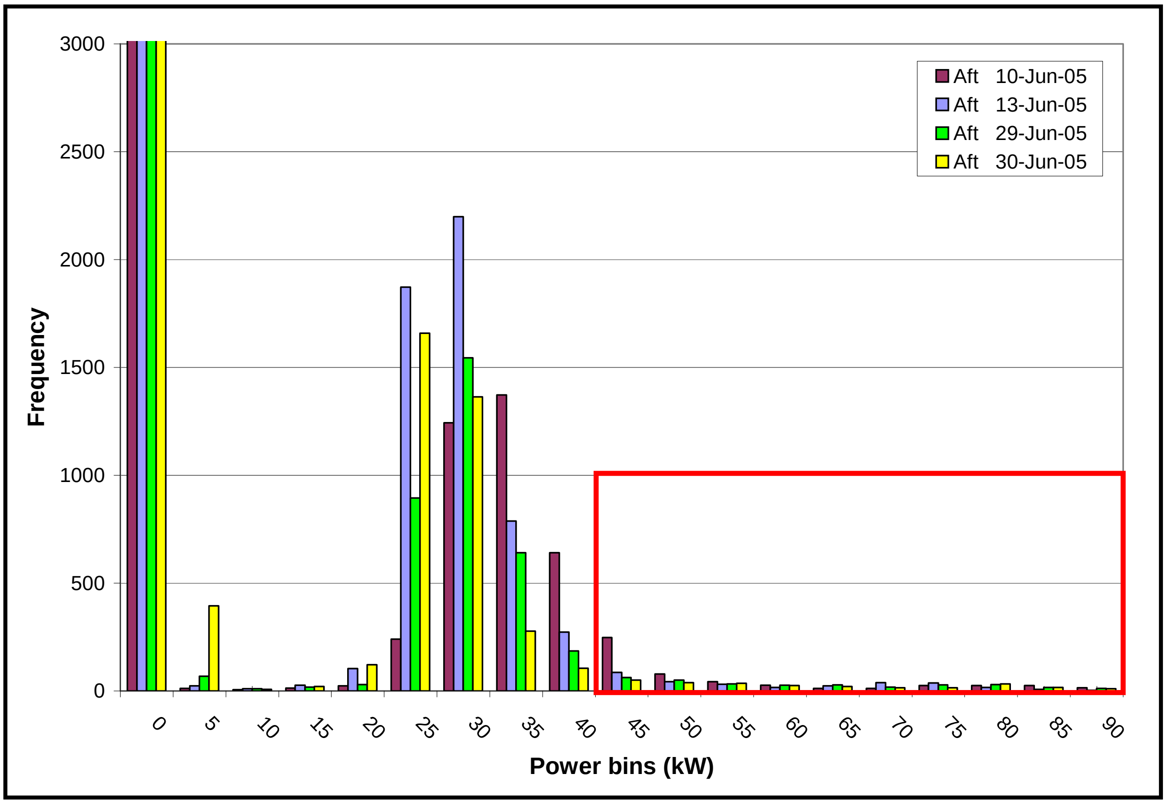


Figure 5.2-14: Histogram for power consumed by the RH gathering head motors.

The thermal time constant for the gathering head motors is 45 minutes and it should stabilise at 155℃ if operated at full load for a period long enough to reach thermal equilibrium. The ambient temperature was 24℃. Figure 5.2-15 shows the load current and motor winding temperature for the RH gathering head motor over a shift. The temperature of the windings, although running relatively cool, was almost purely a result of the peaks consumed by the motors.

The winding temperatures of the gathering head motors in section 21 were much lower than those in section 51 (see Figure 5.2-15). The gathering head motors in section 51 recorded higher peak currents than the motors of section 21. The reason for this could be that there was rock in the coal seam in section 51. With rock being heavier than coal, it would have meant that the motors had to work harder to overcome the initial inertia of the rocks.

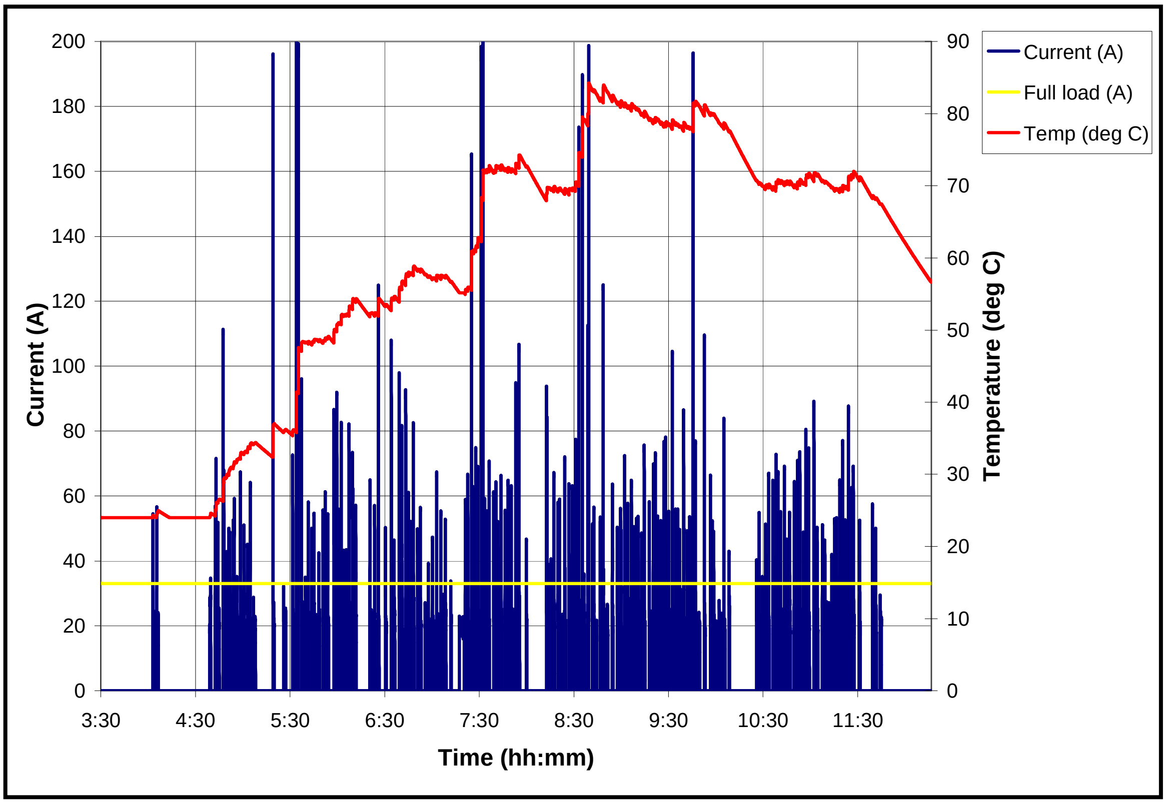


Figure 5.2-15: Load current and motor temperature for the RH gathering head motor – Afternoon shift 29 June 2005.

It is clear that the motor currently is not a limitation. It will become a problem only when changes are made to the loading capacity and thus the cutting capacity of the continuous miner. An increase in duty cycle as a result of an increase in production will also not stress the motor.

5.2.4 Cutter motors

The cutter motors are located on the cutting head of the continuous miner (see Chapter 2) and are used to actually cut the coal. The cutter motors measured in both sections were 175 kW induction motors with full-load current ratings of 133 A (see Table 5-11 for motor details).

Table 5-11: Nameplate data of the cutter motor on a CM.

CM Cutter Motors					
Power	175	kW	Voltage	1000	V
Duty	S1		Current	133	A
Ins class	H		RPM	1475	
			pf	0.79	

Table 5-12: Production figures for shifts when cutter motors were monitored.

Date	Sect 21		Sect 51	
	Morning	Afternoon	Morning	Afternoon
6-Jun-2005	**2079**	1485	-	-
7-Jun-2005	**1925**	1435	-	-
8-Jun-2005	1750	**2240**	-	-
23-Jun-2005	-	**-**	1856	1566
28-Jun-2005	-	-	**2204**	1740

Table 5-12 shows the production in the respective sections when the consumption of the gathering head motors were measured. Figure 5.2-16 and Figure 5.2-17 show the voltage and load current consumed by the RH cutter motor for two shifts over a 30-minute period. The load on the cutter motors fluctuates continuously, with large peaks measured regularly for relatively longer periods. The peaks on the cutter motor of section 21 (Figure 5.2-16) were higher than those on the cutter motor of section 51 (Figure 5.2-17).

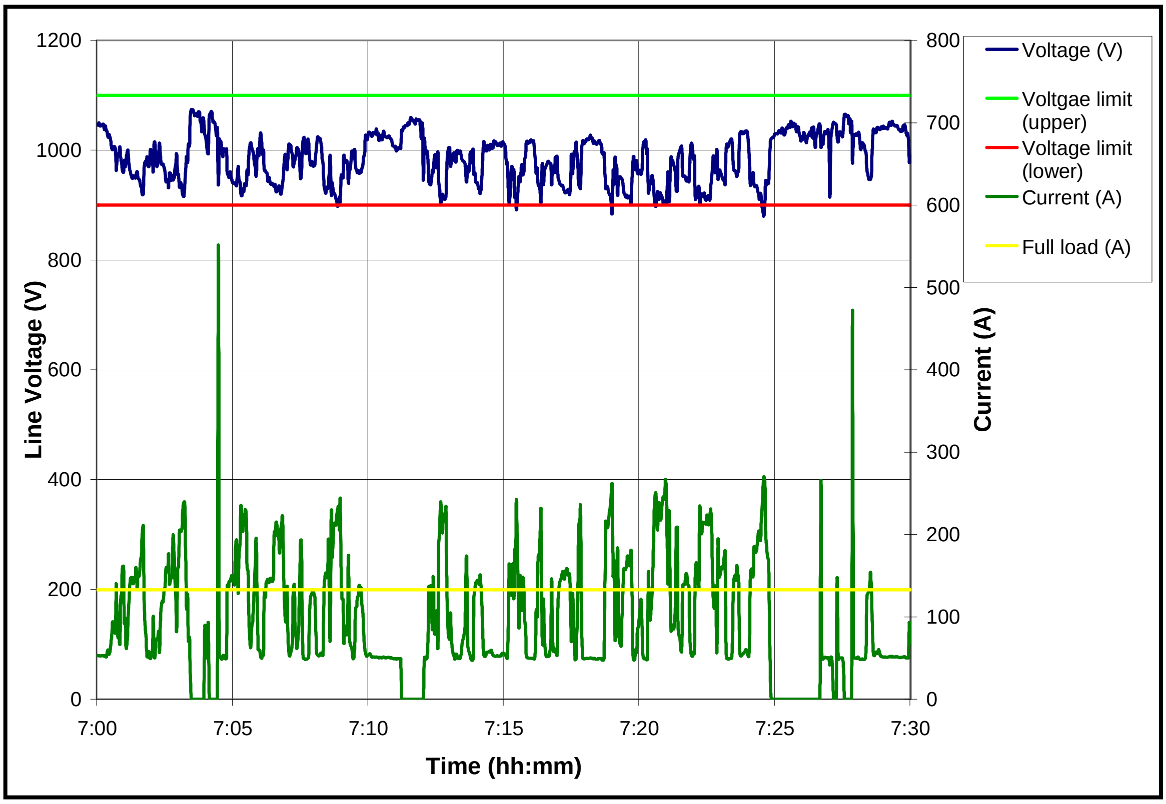


Figure 5.2-16: Load current and voltage for the RH cutter motor – Morning shift 7 June 2005 (30 minute period).

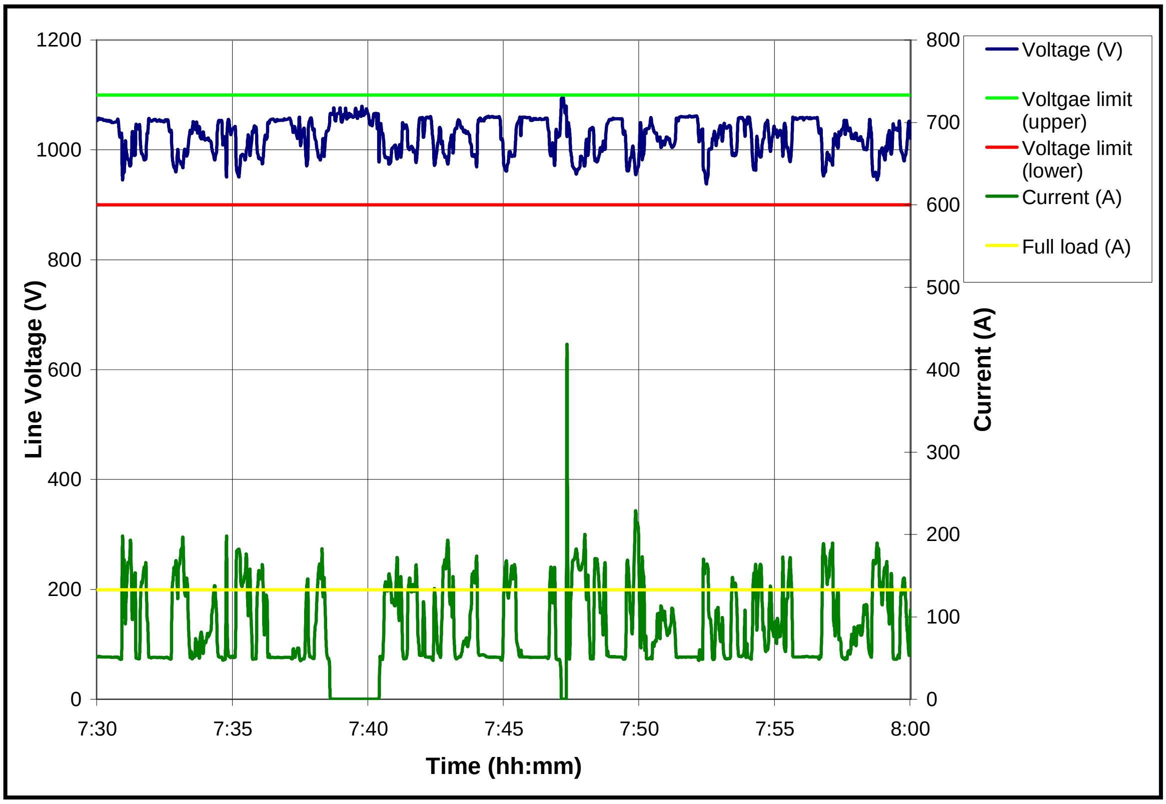


Figure 5.2-17: Load current and voltage for the RH cutter motor – Morning shift 28 June 2005 (30 minute period).

From the other measured data it was also quite clear that the load on the cutter motors was fully dependent on the operator of the continuous miner. Although the continuous miner on the morning shift of 7 June 2005 consumed higher peak currents (forced by the operator), it took out less coal than the continuous miner on the morning shift of 28 June 2005.

Table 5-13 shows the percentage of time that the RH cutter motors were utilised during a shift, as well as the percentage of time that the motors were overloaded and underloaded while being utilised. The motors were overloaded for between 25% and 35% of the time that the motors were utilised. It is clear from the table that the operator has a major influence on the overloading of the motor. The same operator was operating the continuous miner on the morning shifts of 6 and 7 June 2005. A different operator was operating the continuous miner during the afternoon shift of 8 June 2005. The effects of the different operators were seen a number of times in the measured data.

Table 5-13: Data for the total current consumption of the RH cutter motors.

	Morning	Morning	Afternoon	Morning
	6-Jun-05	7-Jun-05	8-Jun-05	28-Jun-05
Tonnes/CM/Shift	2079	1925	2240	2204
% Time of shift producing	54.73%	39.85%	59.32%	60.68%
% of Production time underloaded	66.92%	63.23%	75.02%	74.47%
% of Production time overloaded	33.08%	36.77%	24.98%	25.53%

Figure 5.2-18 and Figure 5.2-19 show respectively a histogram of the current and power consumed by the RH cutter motors. The average current consumption of the cutter motors was between 40 A and 60 A, with large peaks between 60 A and 240 A. The average current consumption was measured when the motors were not cutting and running on no-load. Typically, the motors consumed between 140 A and 160 A when cutting.

The average power consumption was between 60 kW and 80 kW. A smaller peak was measured between 160 kW and 180 kW, similar to the peaks noticed for current consumption.

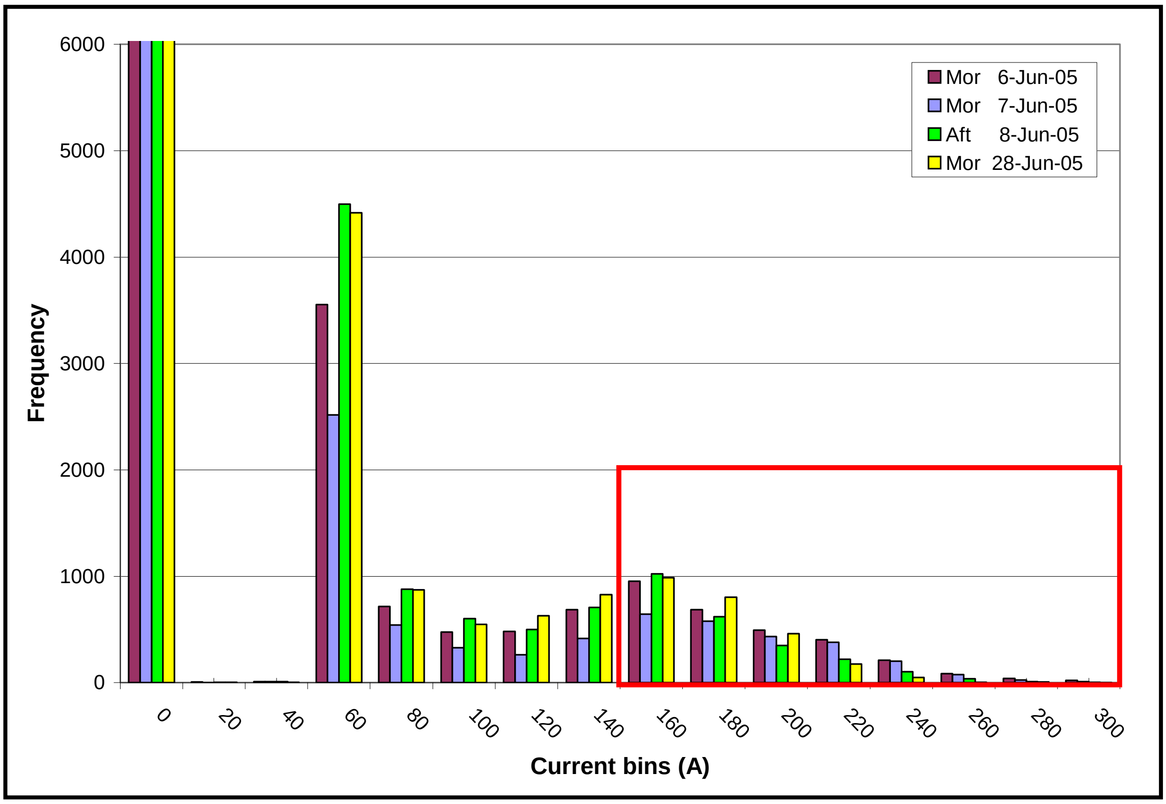


Figure 5.2-18: Histogram for current consumed by the RH cutter motors.

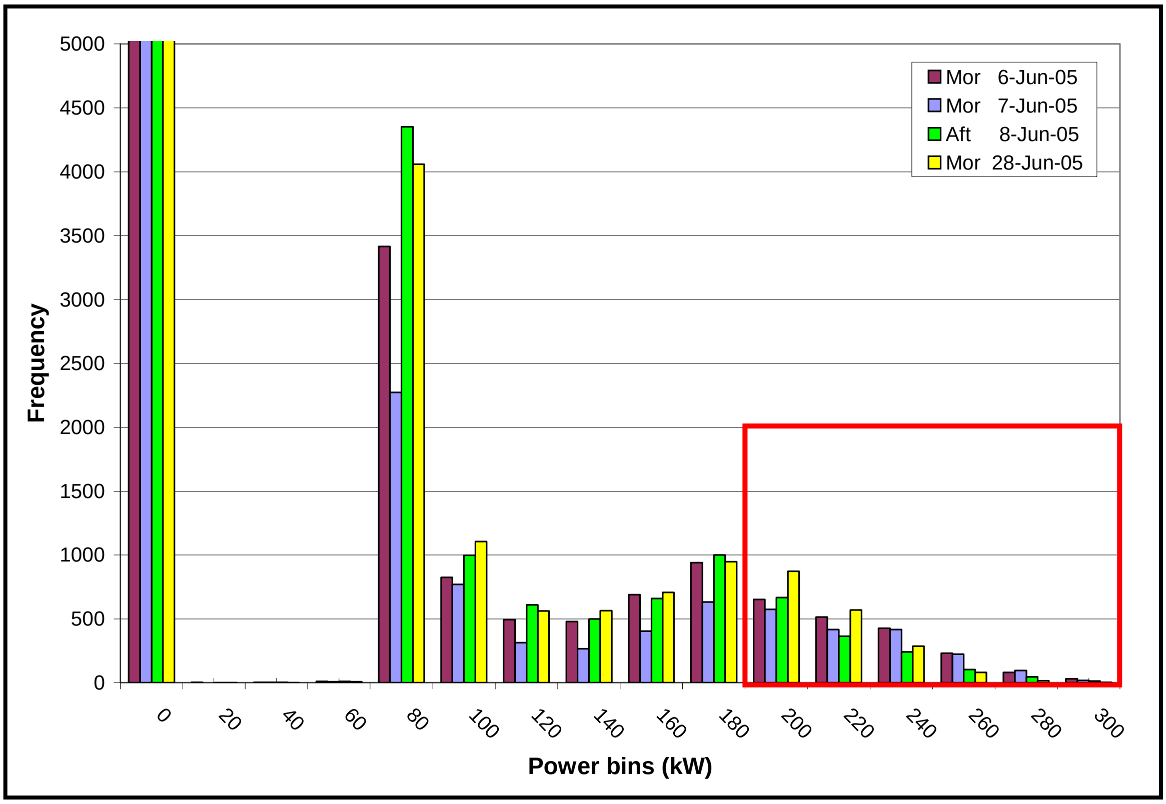


Figure 5.2-19: Histogram for power consumed by the RH cutter motors.

The thermal time constant for the cutter motors is 70 minutes and it should stabilise at 155℃ if operated at full-load for a period long enough to reach thermal equilibrium. The ambient temperature was 24℃. Figure 5.2-20 shows the load current and motor winding temperature for the RH cutter motors over a shift.

It was also found that the longer the motors worked, the higher the temperatures became. The maximum temperature was normally reached at the end of a shift. The motors will thus not reach the same high temperature during a short shift as is the case for a longer shift, as for example in the case of Lima shifts (longer shifts than normal). The start/stop operating mode of the cutter motors also has a considerable effect on the temperature of the motors.

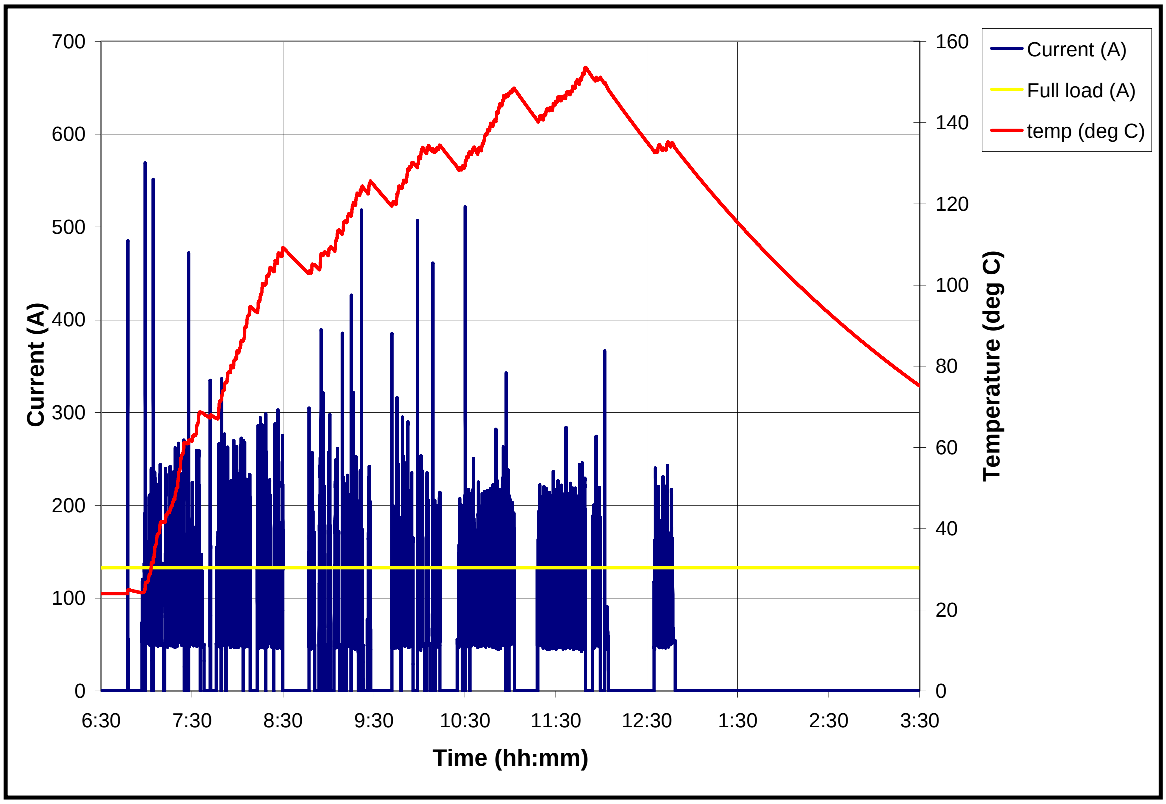


Figure 5.2-20: Load current and motor temperature for the RH cutter motor – Morning shift 7 June 2005.

The cutter motors may already be a limitation for longer shifts with high production, as the temperatures of the motors normally peaked at the end of the shifts. The motors will, however, become a limitation if production is increased, because the duty cycle of the motors will increase, which will increase the winding temperatures resulting in a decrease in life expectancy of the motors.

5.2.5 Traction motors

The traction motors on a continuous miner are used to move the continuous miner from one point to another or to move into or out of the coalface (see Chapter 2). The traction motors measured in section 21 were 250 V, 37 kW DC motors, with a full-load current rating of 167 A. The traction motors in section 51 were 250 V, 50 kW DC motors, with a full-load current rating of 226 A (see Table 5-13 for details).

Table 5-14: Nameplate data of the traction motors on a CM.

CM Traction Motors					
Power	37 / 50	kW	Voltage	250	V
Duty	S2 - 60		Current	167 / 226	A
Ins class	H		RPM	1650 / 1500	

Table 5-15: Production figures for shifts when the traction motors were monitored.

Date	Sect 21		Sect 51	
	Morning	Afternoon	Morning	Afternoon
10-Jun-2005	1575	**2695**	-	-
13-Jun-2005	**2310**	**2520**	-	-
14-Jun-2005	1610	1750	-	-
29-Jun-2005	-	**-**	1305	**2175**
30-Jun-2005	-	-	1740	**2320**

Table 5-15 shows the production rates in the respective sections when the consumption of the traction motors was measured. Figure 5.2-21 and Figure 5.2-22 show the power consumed by the RH traction motor for two shifts over a 30-minute period. The power consumed by the traction motors fluctuates a lot. It can be clearly seen that, although it is a larger motor, the average consumption of the motor in Figure 5.2-22 (section 51) is less than in Figure 5.2-21 (section 21). This again points to the influence the operator has on the performance of the continuous miner.

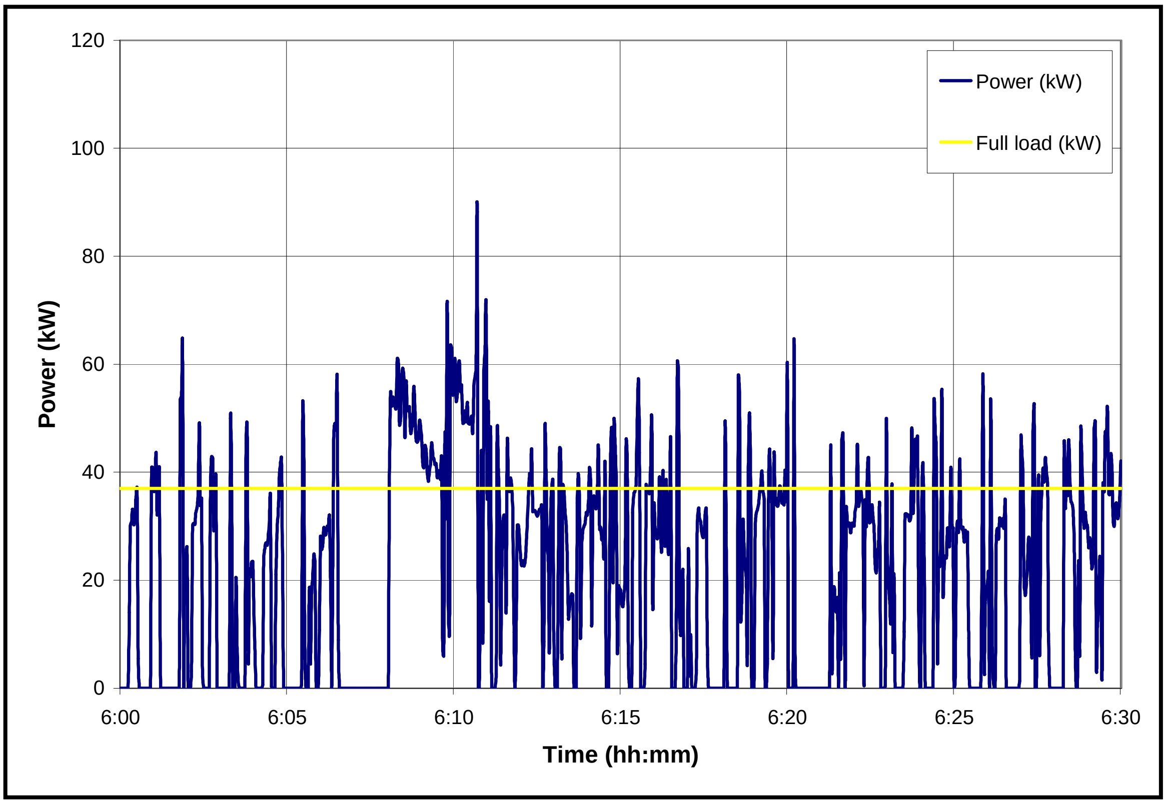


Figure 5.2-21: Power consumed by the RH traction motor – Afternoon shift 13 June 2005 (30 minute period).

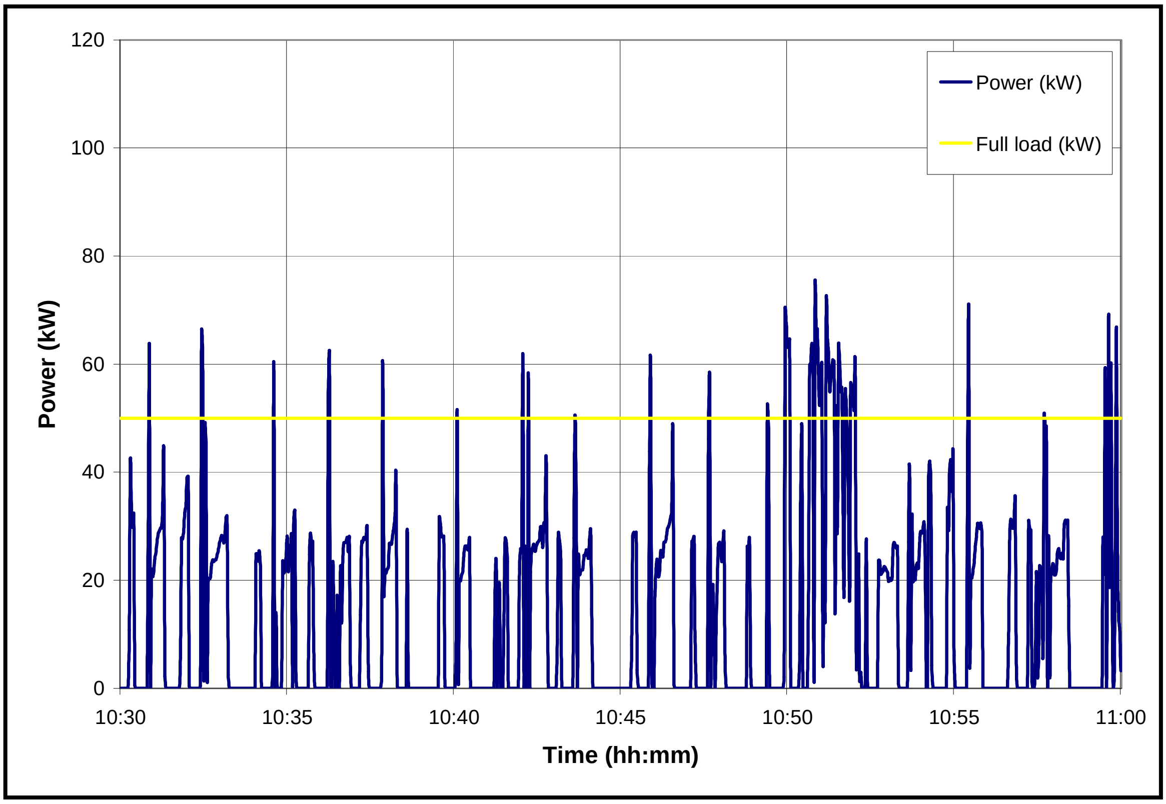


Figure 5.2-22: Power consumed by the RH traction motor – Afternoon shift 30 June 2005 (30 minute period).

Table 5-16 shows the percentage of time that the RH traction motor was utilised during a shift, as well as the percentage of time that the motor was overloaded and underloaded while being utilised. It must be remembered that section 51 (afternoon shift on 29 and 30 June 2005) have a 50 kW motor, while section 21 (afternoon shift on 10 and 13 June 2005) have a 37 kW motor. The RH traction motor in section 21 was overloaded for about 40% of the time that it was utilised, while the RH traction motor of section 51 was overloaded for only approximately 20% of the time.

Table 5-16: Data for the total current consumption of the RH traction motors.

	Afternoon	Afternoon	Afternoon	Afternoon
	10-Jun-05	13-Jun-05	29-Jun-05	30-Jun-05
Tonnes/CM/Shift	2695	2520	2175	2320
% Time of shift producing	37.56%	48.55%	41.95%	43.70%
% of Production time underloaded	64.63%	55.41%	82.16%	81.67%
% of Production time overloaded	35.37%	44.59%	17.84%	18.33%

Figure 5.2-23 and Figure 5.2-24 show respectively a histogram of the current and power consumed by the RH traction motor. The motors had the same loads to transport and thus consumed the same power, although the motors were of different sizes. The average current consumed ranged between 100 A and 140 A for section 21 and between 140 A and 160 A for section 51. The load current often varied between 170 A and 270 in both sections. The voltages applied to the DC motors also exceeded the 250 V rating of the DC motors on a regular basis with 400 V applied to the motors at stages.

The average power consumed ranged between 20 kW and 35 kW in both sections. The power consumption profile differs from the current consumption, because motor voltage can be adjusted.

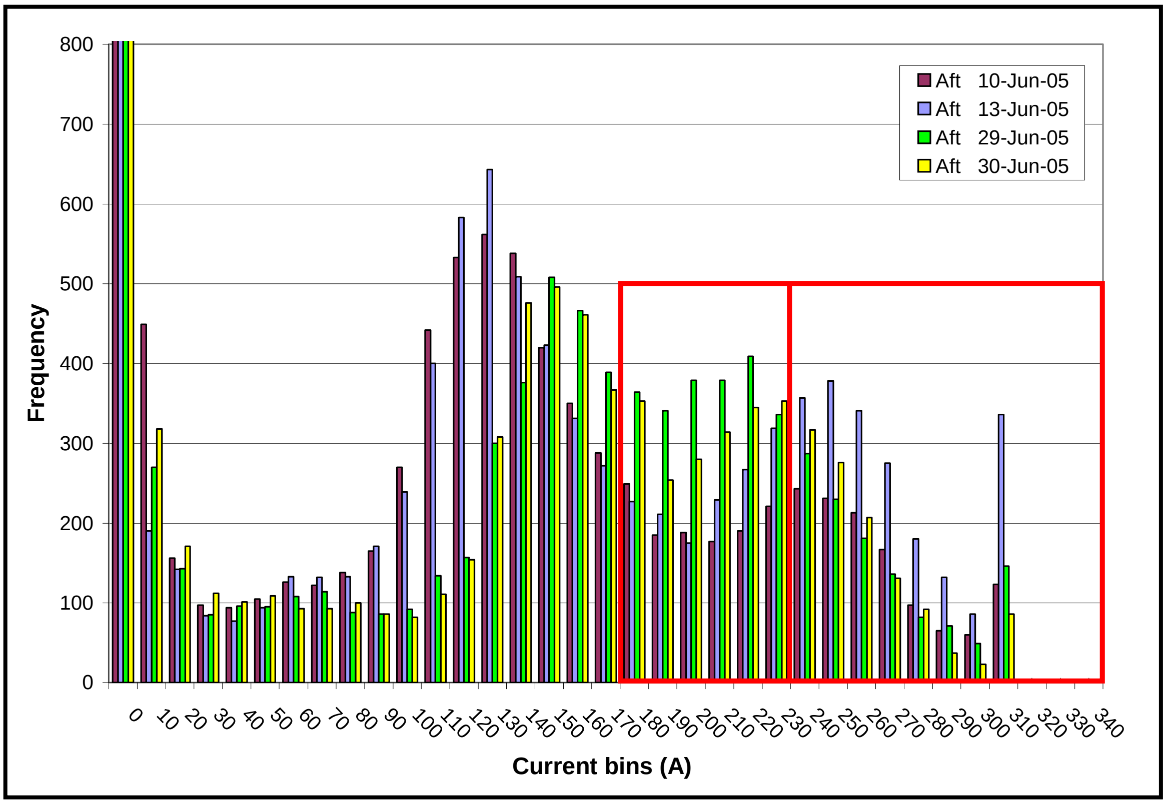


Figure 5.2-23: Histogram for current consumed by the RH traction motors.

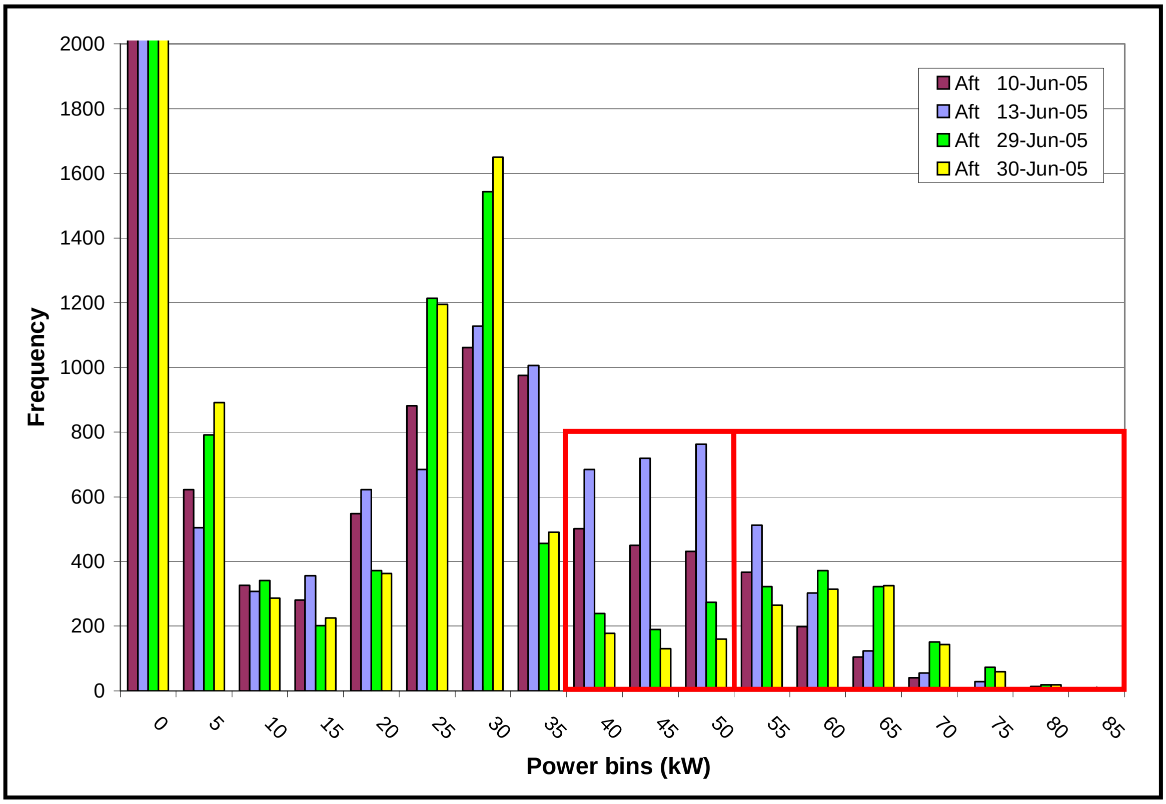


Figure 5.2-24: Histogram for power consumed by the RH traction motors.

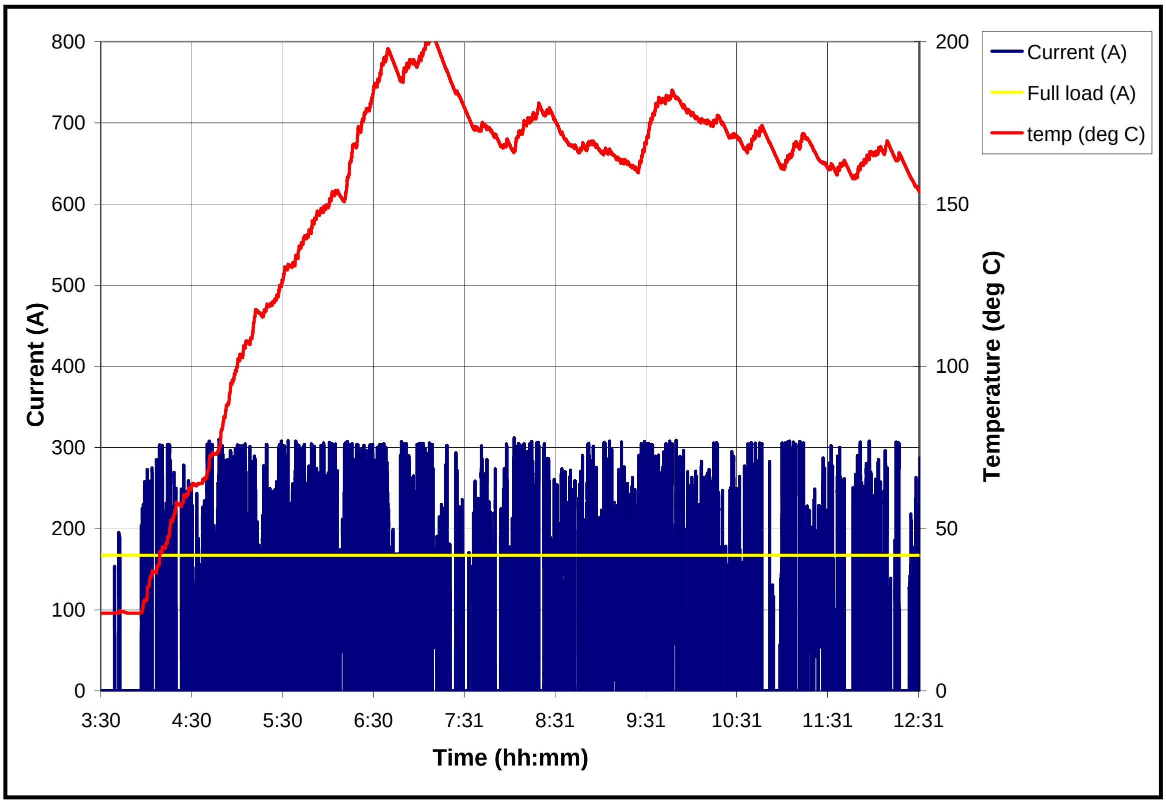


Figure 5.2-25: Load current and motor temperature for the 37 kW RH traction motor – Afternoon shift 13 June 2005.

The thermal time constant for the 37 kW traction motor of section 21 is 40 minutes, and 45 minutes for the 50 kW motor of section 51. Both motors should stabilise at 155℃ if operated at full-load for a period long enough to reach thermal equilibrium. The ambient temperature was 24℃. Figure 5.2-25 shows the load current and motor winding temperature for the 37 kW RH traction motor of section 21 over a shift. The temperature of the motor exceeds the maximum temperature (180 ℃) of a motor with class H insulation. The winding temperature of a 50 kW motor is almost constantly below 100 ℃ and was thus not a problem.

The 37 kW traction motor was already a limitation and it was the right option to start replacing the 37 kW motors with 50 kW motors, as can be seen from the results. The 50 kW motors should be monitored if production is further increased, because the traction motors will then be used more often, leaving less time for the motor to cool down between cycles.

5.3 SHUTTLE CAR

The shuttle car has a number of smaller motors which are all used for hauling coal. Problems were experienced in finding a shuttle car that could be measured, even though there are three shuttle cars in a section. The reason was that only cars with large flameproof enclosures could be measured, as explained in Chapter 3. A number of logistical problems were also experienced during the recordings. Measurements were made on only one shuttle car in section 51 and one in section 50 as a result of the problems that were experienced.

5.3.1 Conveyor motor

The conveyor motor is located on the tail of the shuttle car (see Chapter 2) and is used to drive the conveyor that dumps the coal on the shuttle car onto the feeder breaker. The motor is normally loaded only at the feeder breaker, but it is sometimes also loaded at the continuous miner while being loaded to make more space for coal to be loaded.

The conveyor motor measured in both sections was a 9.5 / 19 kW two speed induction motor (see Table 5-17 for details). The motor is normally operated at the higher speed.

Table 5-17: Nameplate data of the conveyor motor on a shuttle car.

Shuttle car Conveyer Motor					
Power	19 / 9.5	kW	Voltage	950	V
Duty	S1		Current	15	A
Ins class	H		RPM	1390 / 695	
			pf	0.86	

Table 5-18: Production figures for shifts when the conveyor motor was monitored.

Date	Sect 51		Sect 50	
	Morning	Afternoon	Morning	Afternoon
20-Jun-2005	1200	1890	-	-
21-Jun-2005	**2030**	**2320**	-	-
4-Jul-2005	-	**-**	1800	**2124**

Table 5-18 shows the production rates in the respective sections when the consumption of the conveyor motor was measured. Figure 5.3-1 and Figure 5.3-2 show the voltage and load current consumed by the conveyor motor for two shifts over a 30-minute period. The duty cycle of the conveyor motor of the shuttle car is longer than the duty cycle of the conveyor motor of the continuous miner. Large peaks are also experienced at the start of each cycle, but no peaks were experienced at the end of the cycle, because the conveyor was empty at the end of the cycle.

The short cycle between every long cycle occurred when the coal was being loaded at the continuous miner and the conveyor was used to make space for more coal to be loaded onto the car. The longer cycle was occurred when coal was being dumped onto the feeder breaker. The time between a long and short cycle was generally the time that the car travels between the continuous miner and the feeder breaker.

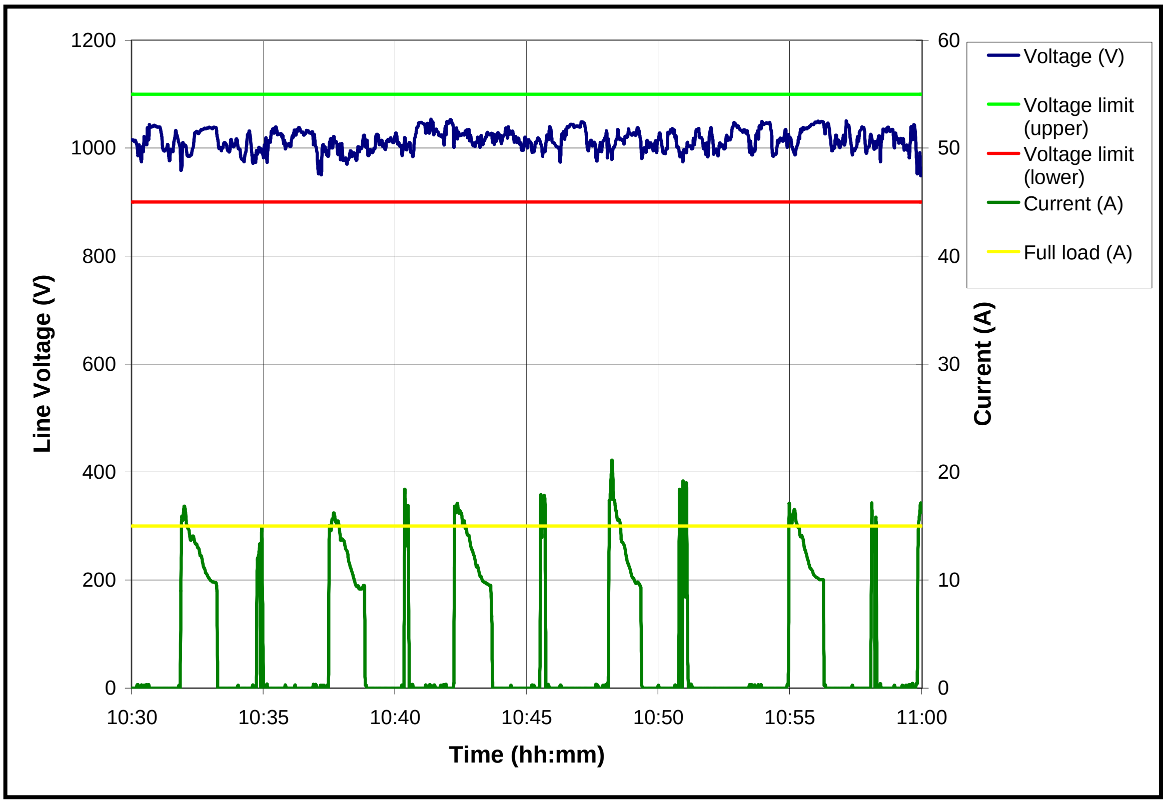


Figure 5.3-1: Load current and voltage for the conveyor motor – Afternoon shift 21 June 2005 (30 minute period).

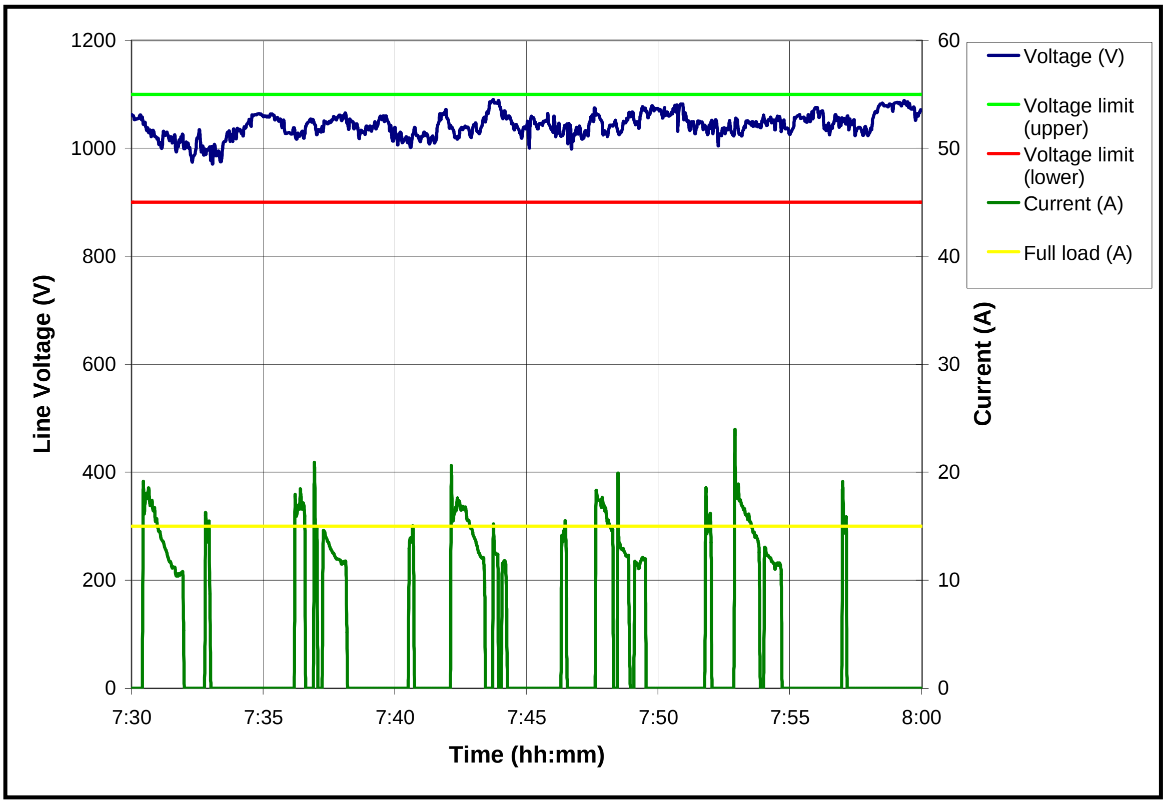


Figure 5.3-2: Load current and voltage for the conveyor motor – Afternoon shift 4 July 2005 (30 minute period).

The amplitude of the peaks and the average consumption over a cycle and the duration of a cycle also differ. It was found that the duty cycle of the conveyor motor on the afternoon shift of 21 June 2005 was much more consistent than on the afternoon shift of 4 July 2005, which is again a result of the operator of the car in question.

Table 5-19 shows the percentage of time that the conveyor motor was utilised during a shift, as well as the percentage of time that the motor was overloaded and underloaded while being utilised. It can be seen that the conveyor motor was overloaded for only about 18% of the time.

Table 5-19: Data for the total current consumption of the conveyor motor.

	Morning	Afternoon	Afternoon	Afternoon
	21-Jun-05	20-Jun-05	21-Jun-05	04-Jul-05
Tonnes/CM/Shift	2030	1890	2320	2124
% Time of shift producing	17.09%	14.61%	17.59%	18.09%
% of Production time underloaded	82.91%	82.04%	78.82%	63.28%
% of Production time overloaded	17.09%	17.96%	21.18%	36.72%

Figure 5.3-3 and Figure 5.3-4 show histograms of the current and power consumed by the conveyor motor. The average current consumption of the conveyor motor was between 10 A and 11 A, with the shuttle car in section 50 (afternoon shift on 4 July 2005) consuming higher currents on average. The motors were, however, constantly consuming currents between 10 A and 16 A. The average power consumption was between 14 kW and 16 kW, with the car of section 50 consuming between 17 kW and 18 kW on average.

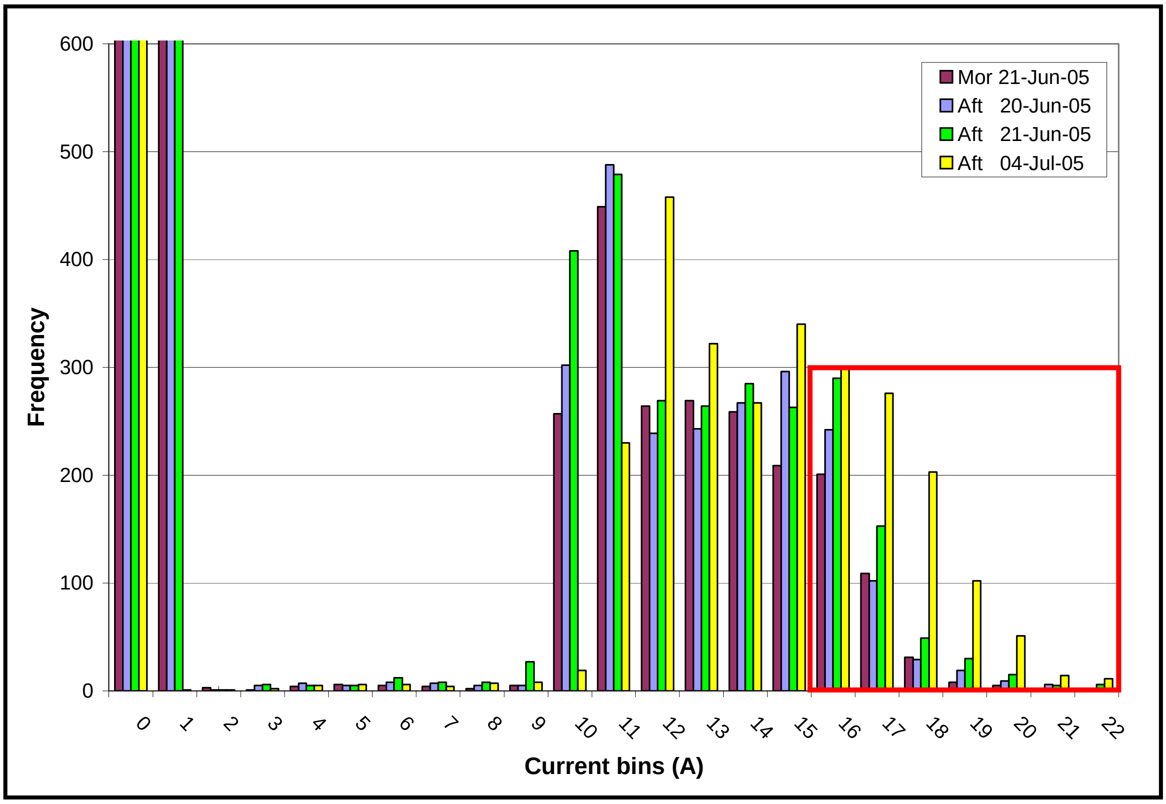


Figure 5.3-3: Histogram for current consumed by the conveyor motors.

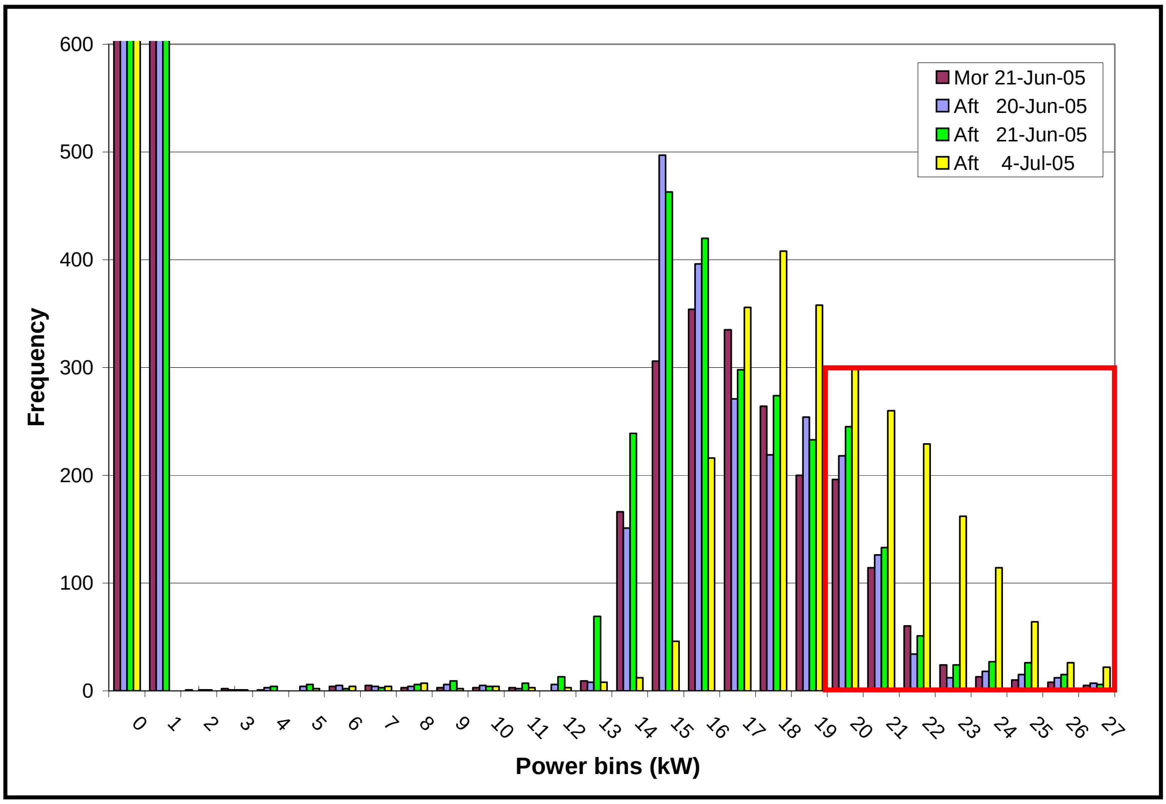


Figure 5.3-4: Histogram for power consumed by the conveyor motors.

The thermal time constant for the conveyor motor is 30 minutes and it should stabilise at 155℃ if operated at full-load for a period long enough to reach thermal equilibrium. The ambient temperature was 24℃. Figure 5.3-5 shows the load current and motor winding temperature for a conveyor motor over a shift. It was clear from the motor winding temperature and the average consumption of the motor that the motor was not overloaded.

This motor would not be a limitation if the production were increased, because the load on the car is fixed and only the duty cycle can be increased. There will also always be a period at rest (when the shuttle car is travelling between the Feeder breaker and the continuous miner) when the motor will have time to cool.

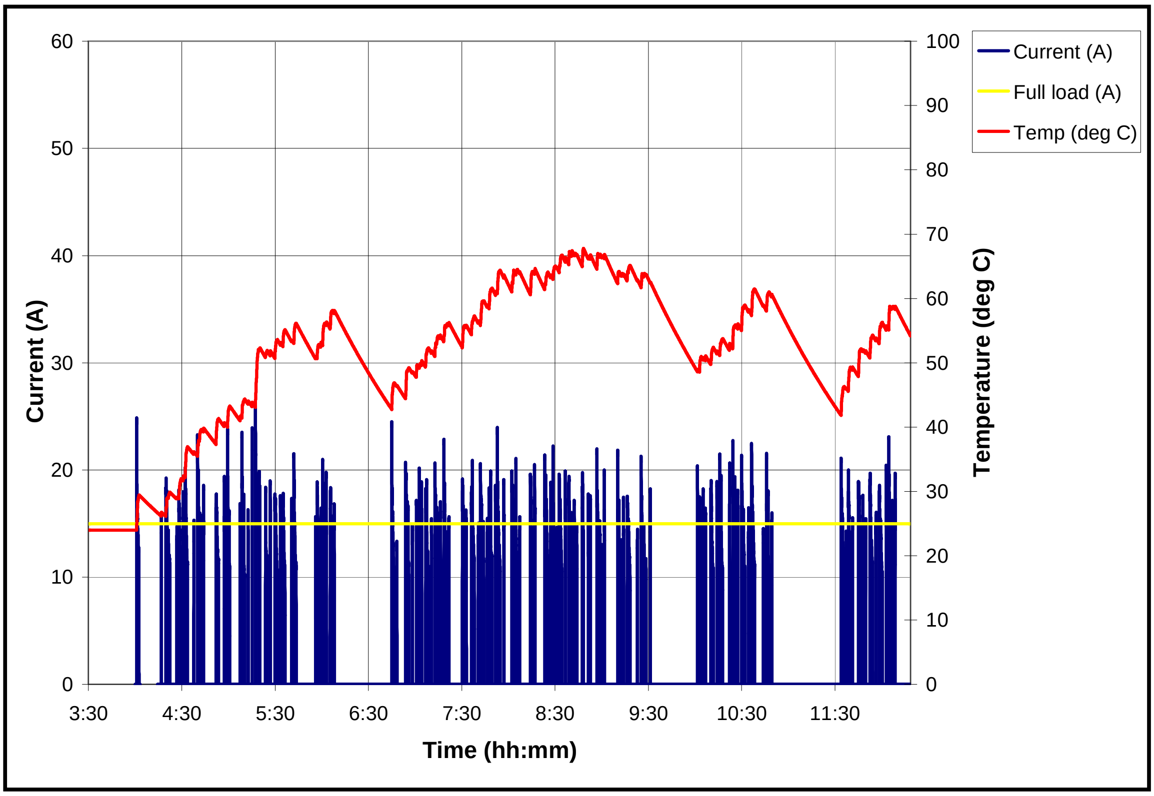


Figure 5.3-5: Load current and motor temperature for the conveyor motor – Afternoon shift 4 July 2005.

5.3.2 Pump motor

The pump motor is used to drive the hydraulics on the shuttle car (see Chapter 2). This motor runs continuously as long as the shuttle car is being utilised. The pump motors measured in both sections were 15 kW induction motors with a full-load current rating of 11.8 A (see Table 5-20 for details).

Table 5-20: Nameplate data of the pump motor on a shuttle car.

Shuttle car Pump Motor					
Power	15	kW	Voltage	950	V
Duty	S1		Current	11.8	A
Ins class	F		RPM	1460	
			pf	0.86	

Table 5-21: Production figures for shifts when the pump motor was monitored.

Date	Sect 51		Sect 50	
	Morning	Afternoon	Morning	Afternoon
4-Jul-2005	-	**-**	1800	**2124**

Table 5-21 shows the production in section 50 when the consumption of the pump motor was measured. Figure 5.3-6 and Figure 5.3-7 show the voltage and load current consumed by the pump motor for two shifts over a 30-minute period. There was a small fluctuation in the consumption of the pump motor, but generally the consumption was quite constant. This motor has recently been upgraded from a S6 10 kW motor to a S1 15 kW motor.

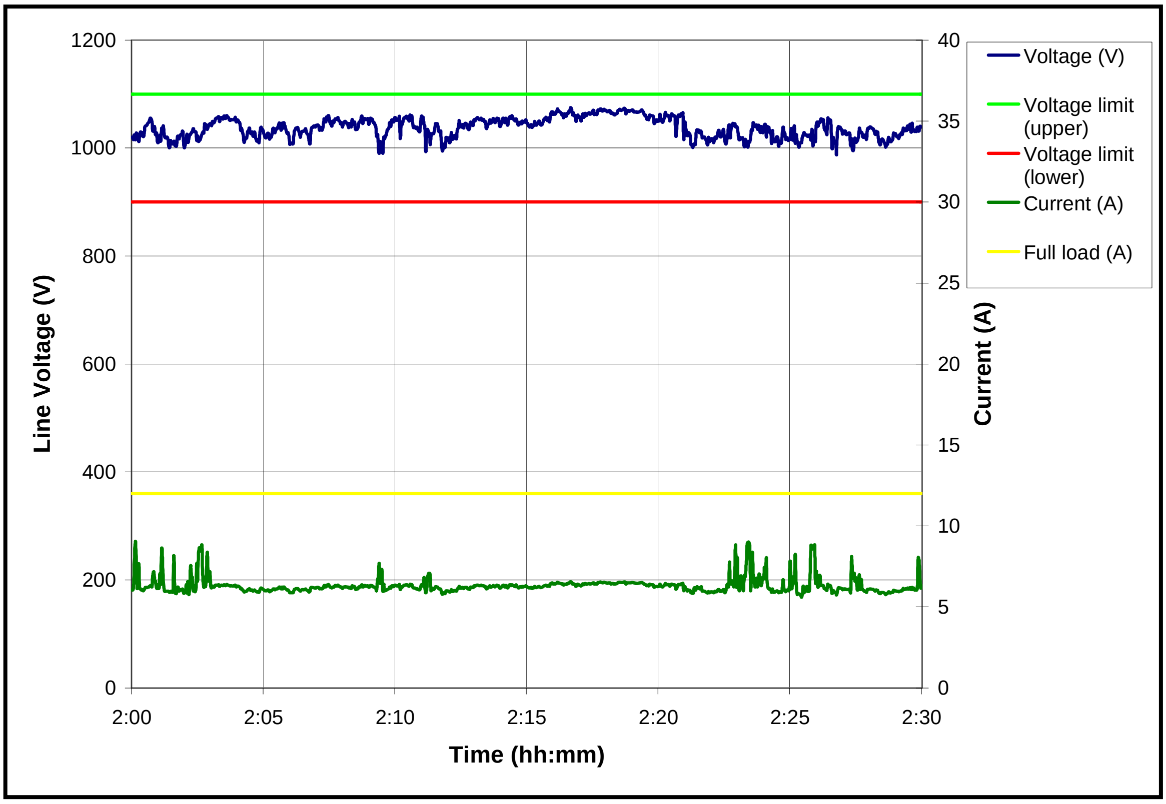


Figure 5.3-6: Load current and voltage for the pump motor – Morning shift 4 July 2005 (30 minute period).

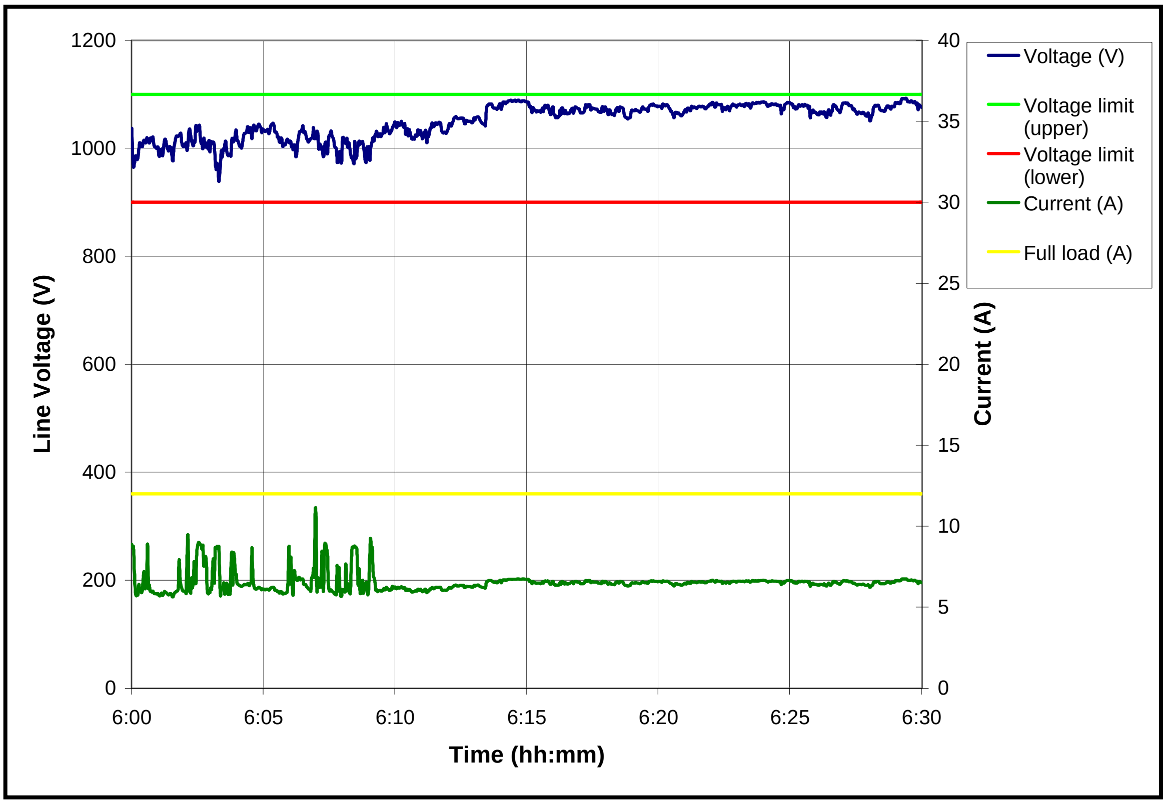


Figure 5.3-7: Load current and voltage for the pump motor – Afternoon shift 4 July 2005 (30 minute period).

Table 5-22 shows the percentage of time that the pump motor was utilised during a shift, as well as the percentage of time that the motor was overloaded and underloaded while being utilised. The motor runs continuously for the whole shift.

Table 5-22: Data for the total current consumption of the pump motor.

	Morning	Afternoon
	04-Jul-05	04-Jul-05
Tonnes/CM/Shift	1800	2124
% Time of shift producing	87.69%	89.64%
% of Production time underloaded	99.97%	100.00%
% of Production time overloaded	0.03%	0.00%

Figure 5.3-8 and Figure 5.3-9 show the current and power consumed by the pump motor. The average current consumption of the pump motor was between 6 A and 7 A. The average power consumption was between 8 kW and 9 kW.

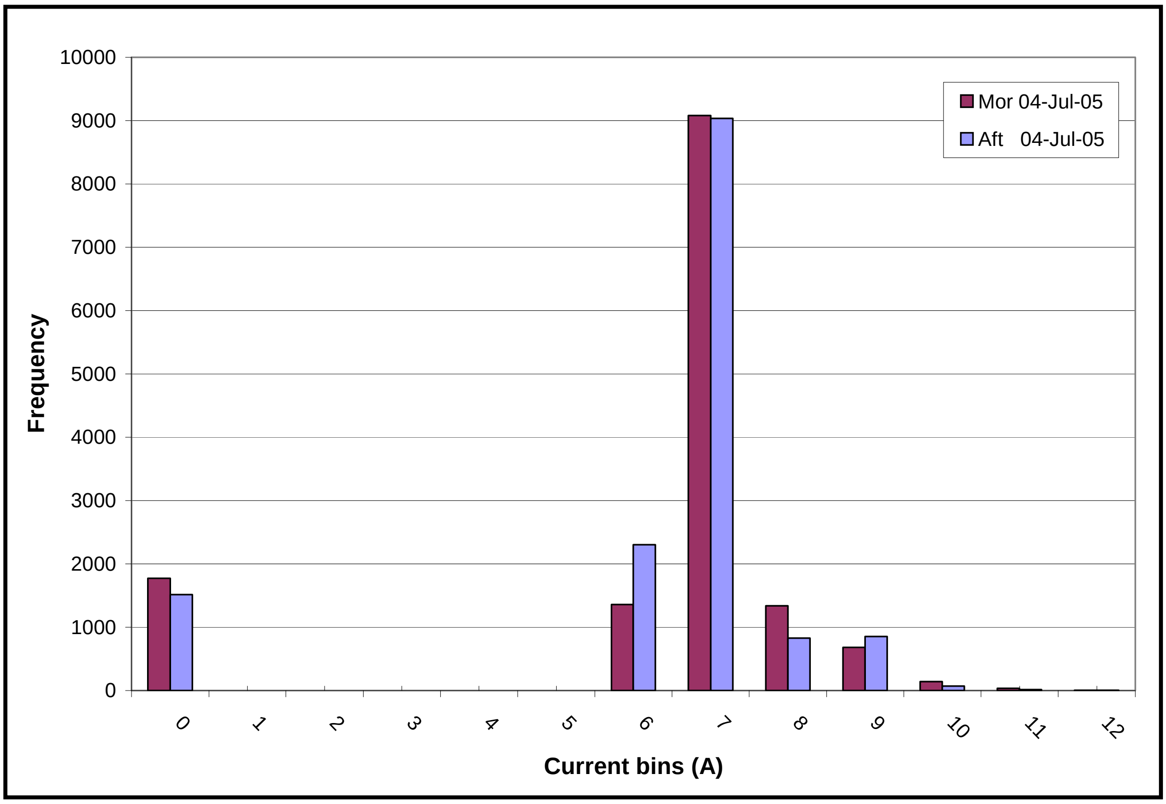


Figure 5.3-8: Histogram for current consumed by the pump motors.

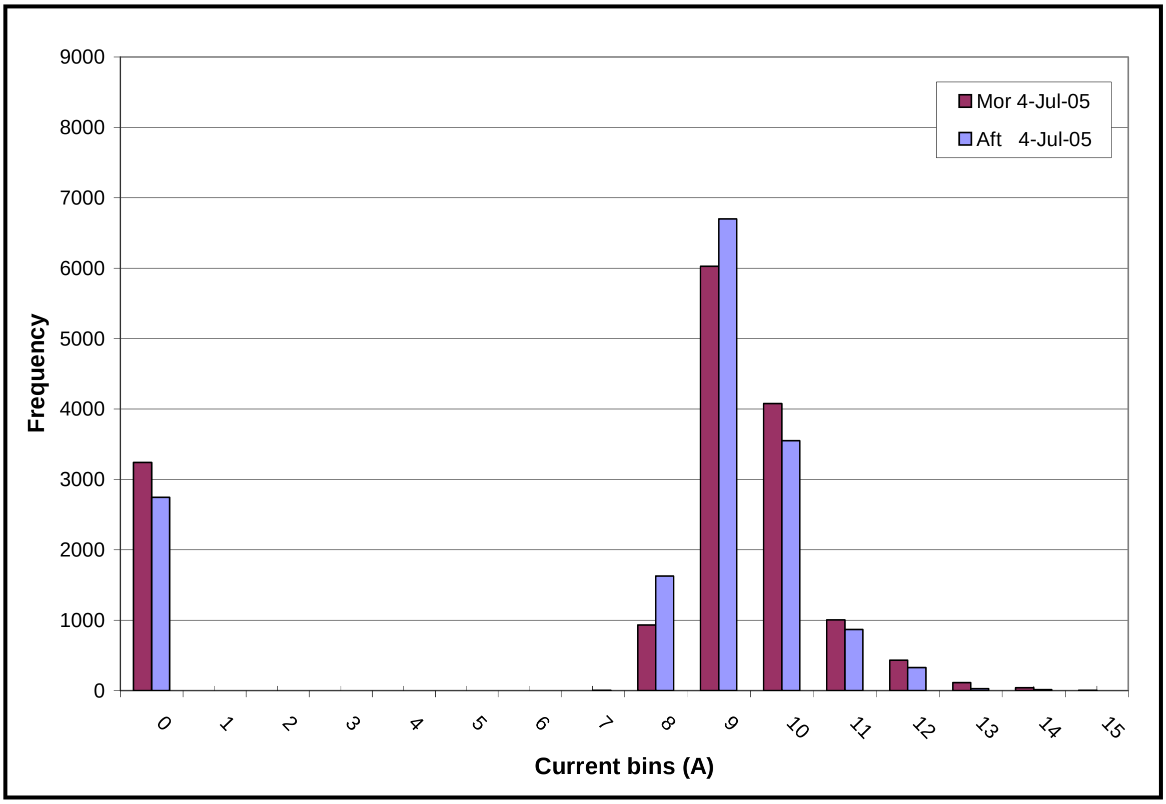


Figure 5.3-9: Histogram for power consumed by the pump motors.

The thermal time constant for the pump motor is 30 minutes, and it has class F insulation. Therefore it should stabilise at 130℃ if operated at full-load for a period long enough to reach thermal equilibrium, and the temperature may not exceed 155℃. The ambient temperature was 24℃. Figure 5.3-10 shows the load current and motor winding temperature for a pump motor over a shift. The 15 kW motor is too large for this application. It was therefore not necessary to upgrade the motor to 15 kW, but to use a 10 kW class H S1 motor instead.

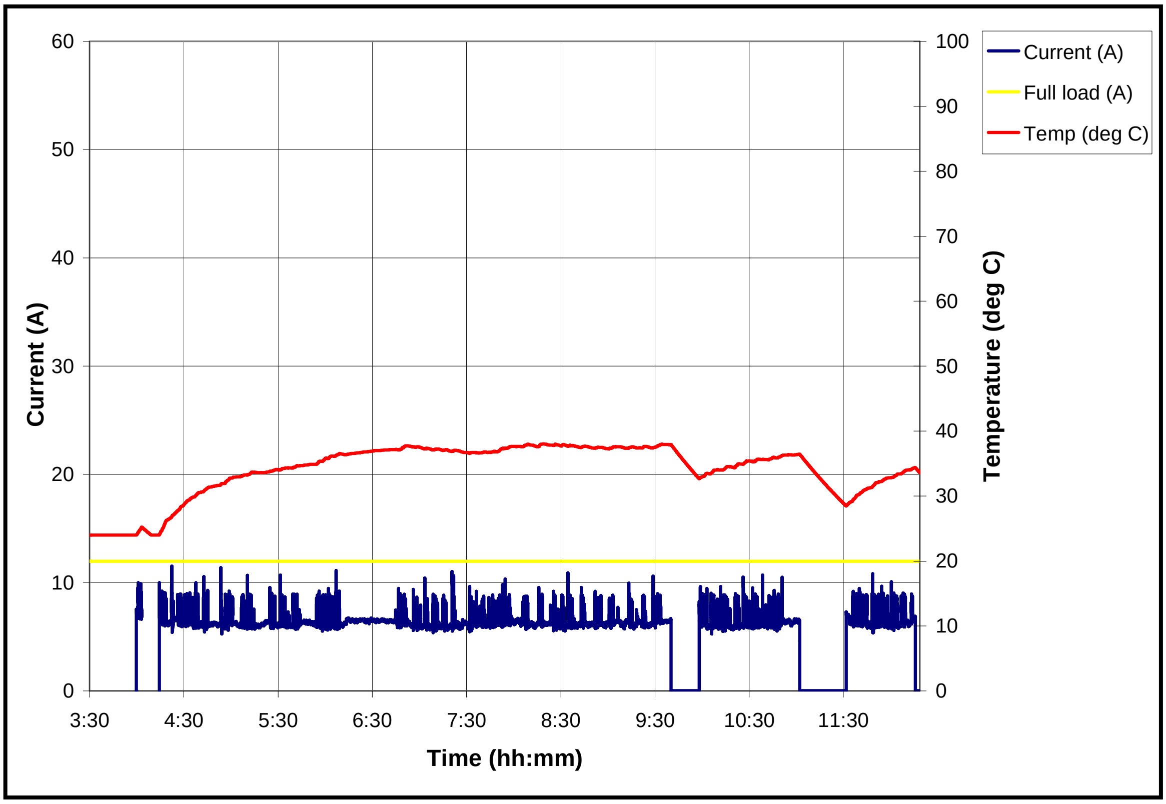


Figure 5.3-10: Load current and motor temperature for the pump motor – Afternoon shift 4 July 2005.

5.3.3 Traction motors

The traction motors of a shuttle car are used to transport the shuttle car and its load from the continuous miner to the feeder breaker or to return from the feeder breaker to the continuous miner with no-load (see Chapter 2). This is the main function of a shuttle car. The traction motors measured in both sections were 250 V, 22 kW DC motors with a full-load current rating of 102 A (see Table 5-23 for details).

Table 5-23: Nameplate data of the traction motors on a shuttle car.

Shuttle car Traction Motors					
Power	22	kW	Voltage	250	V
Duty	S2 - 60		Current	102	A
Ins class	H		RPM	1600	

Table 5-24: Production figures for shifts when the traction motors were monitored.

Date	Sect 51		Sect 50	
	Morning	Afternoon	Morning	Afternoon
20-Jun-2005	1200	1890	-	-
21-Jun-2005	**2030**	**2320**	-	-
4-Jul-2005	-	**-**	1800	**2124**

Table 5-24 shows the production in the respective sections when the consumption of the traction motor was measured. Figure 5.3-11 and Figure 5.3-12 show the power consumed by the RH traction motor for two shifts over a 30-minute period. The power consumed by the traction motors fluctuates considerably.

It should be remembered that the shuttle cars are being driven on uneven ground, over rocks and sometimes through mud, with 16 tonnes of coal loaded on the car. The major part of the consumption is under the rated power of the motors. The duty cycle of the motors differ because of different operators, different conditions and changing distances and routes between the continuous miner and the feeder breaker.

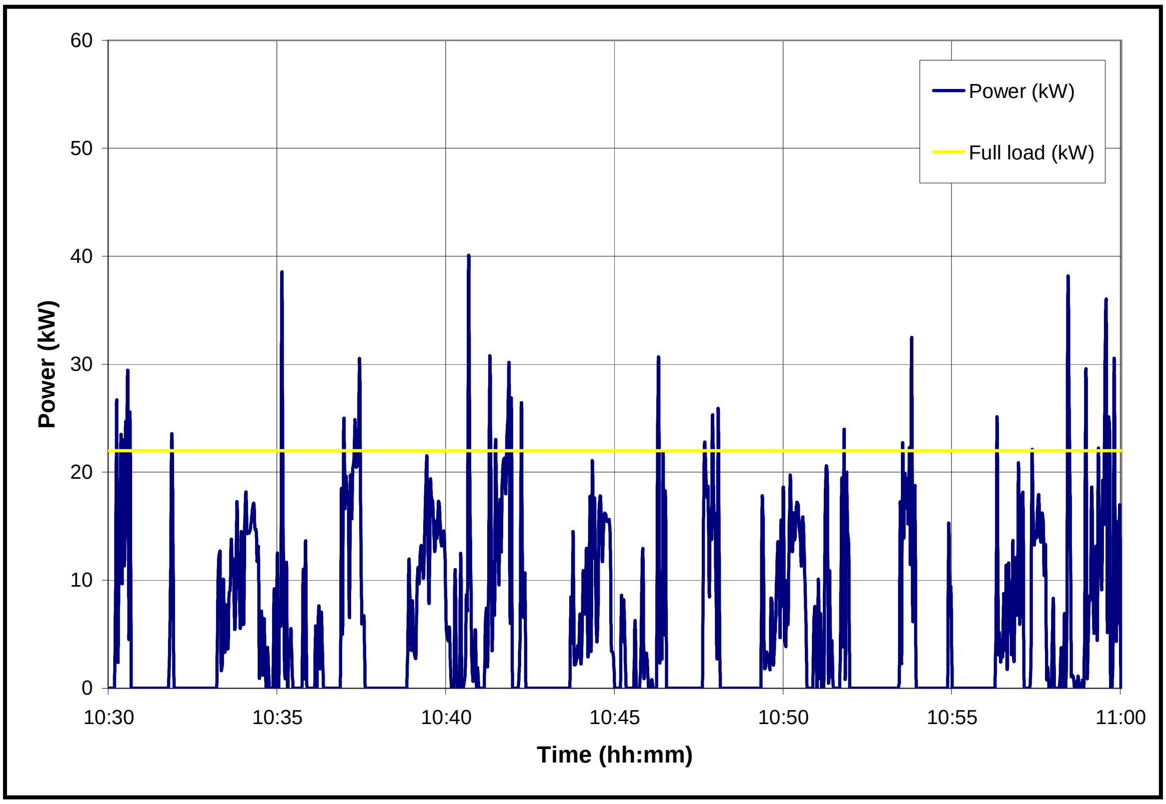


Figure 5.3-11: Power consumed by the RH traction motor – Afternoon shift 21 June 2005 (30 minute period).

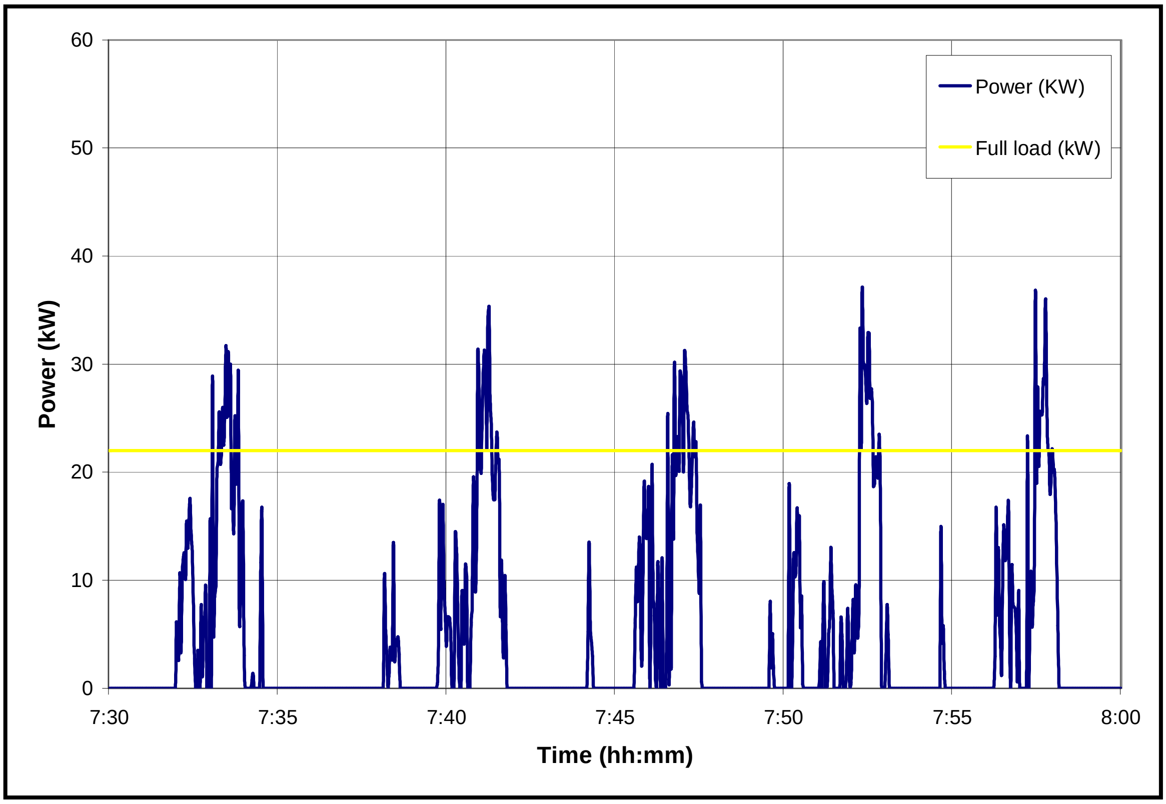


Figure 5.3-12: Power consumed by the RH traction motor – Afternoon shift 4 July 2005 (30 minute period).

Table 5-25 shows the percentage of time that the RH traction motor was utilised during a shift, as well as the percentage of time that the motor was overloaded and underloaded while being utilised. The motors are only used for about 25 % of the time on a shift, which means that a lot of time was spent waiting to be loaded with coal, and waiting to finish unloading the coal at the feeder breaker. The motor was underloaded for approximately 80% of the time, depending again on the operator.

Table 5-25: Data for the total current consumption of the RH traction motor.

	Morning	Afternoon	Morning	Afternoon
	21-Jun-05	21-Jun-05	4-Jul-05	4-Jul-05
Tonnes/CM/Shift	2030	2320	1800	2124
% Time of shift producing	28.77%	30.83%	25.44%	21.96%
% of Production time underloaded	80.29%	83.82%	75.90%	66.95%
% of Production time overloaded	19.71%	16.18%	25.10%	33.05%

Figure 5.3-13 and Figure 5.3-14 show histograms of the current and power consumed by the RH traction motor. The average current consumed ranged between 40 A and 100 A. The average power consumed ranged between 12 kW and 16 kW in section 51 (21 June) and between 2 kW and 8 kW in section 50 (4 July).

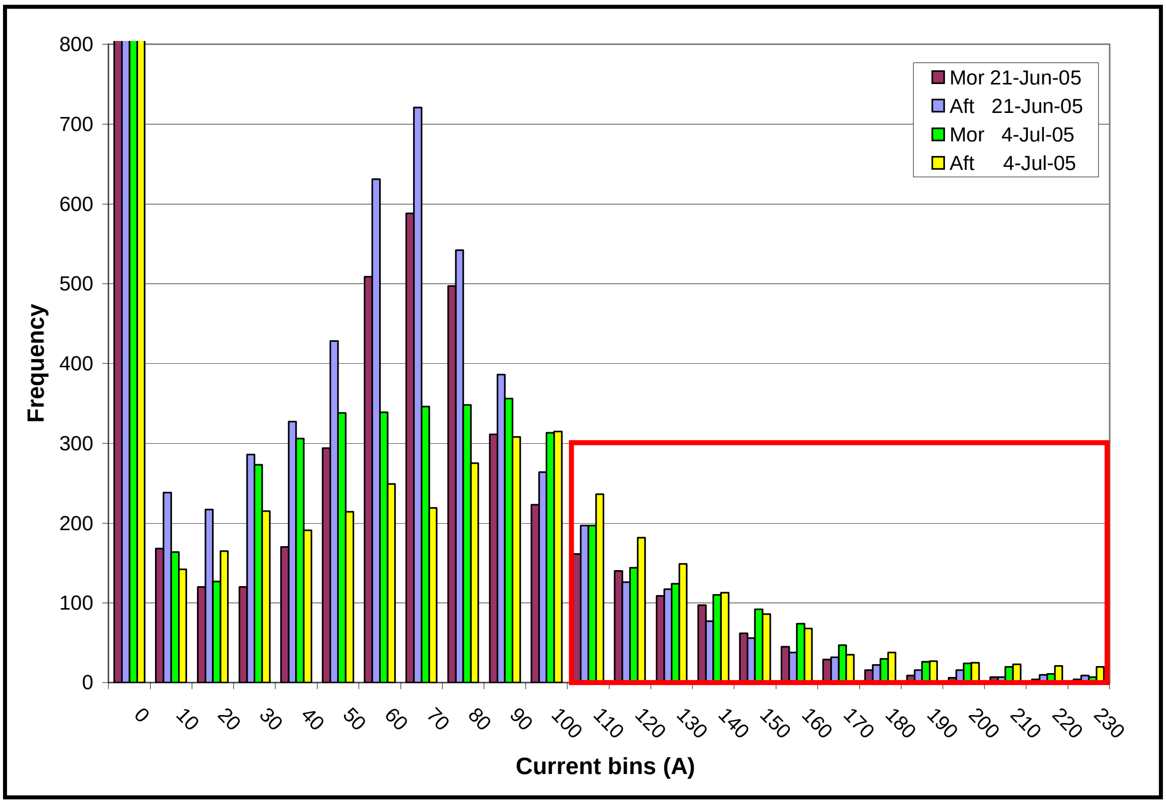


Figure 5.3-13: Histogram for current consumed by the RH traction motors.

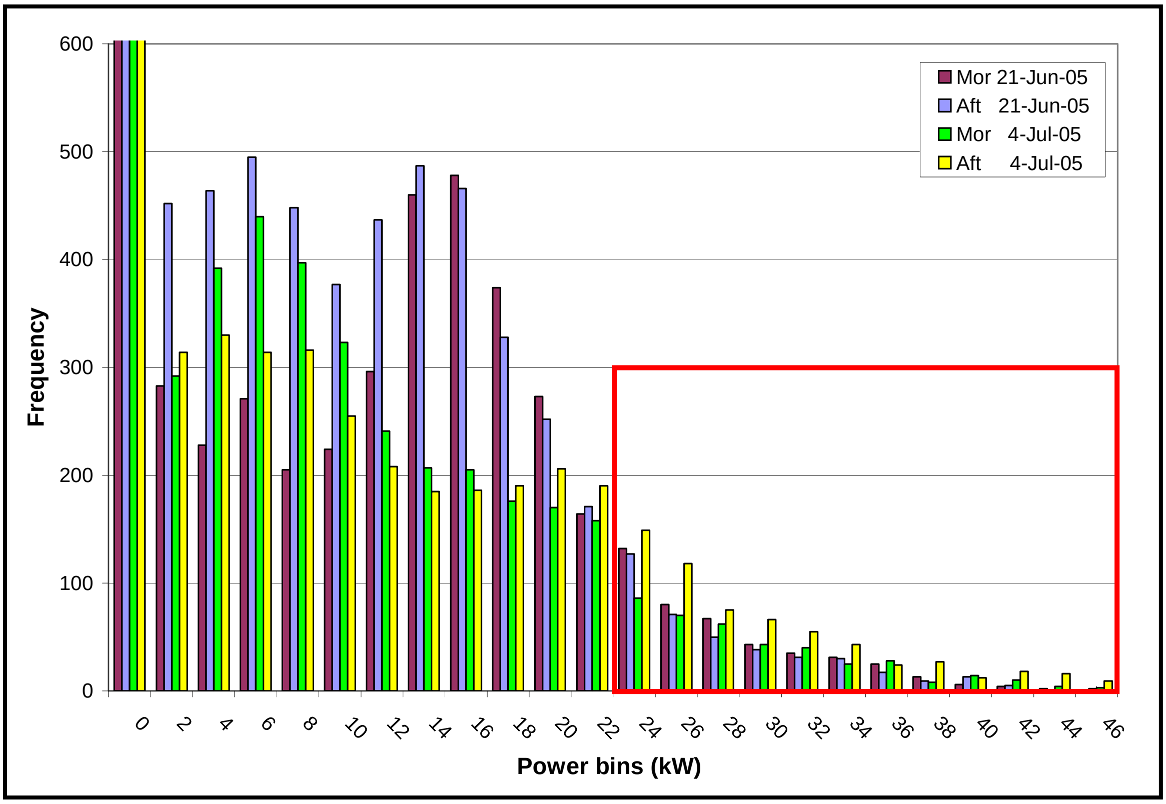


Figure 5.3-14: Histogram for power consumed by the RH traction motors.

The thermal time constant for the traction motor is 30 minutes and its temperature should stabilise at 155℃ if operated at full-load. The ambient temperature was 24℃. Figure 5.3-15 shows the load current and motor winding temperature for the RH traction motor over a shift. The temperature of the windings were fluctuating considerably, but were relatively low because there was ample time for the motor to cool down between cycles.

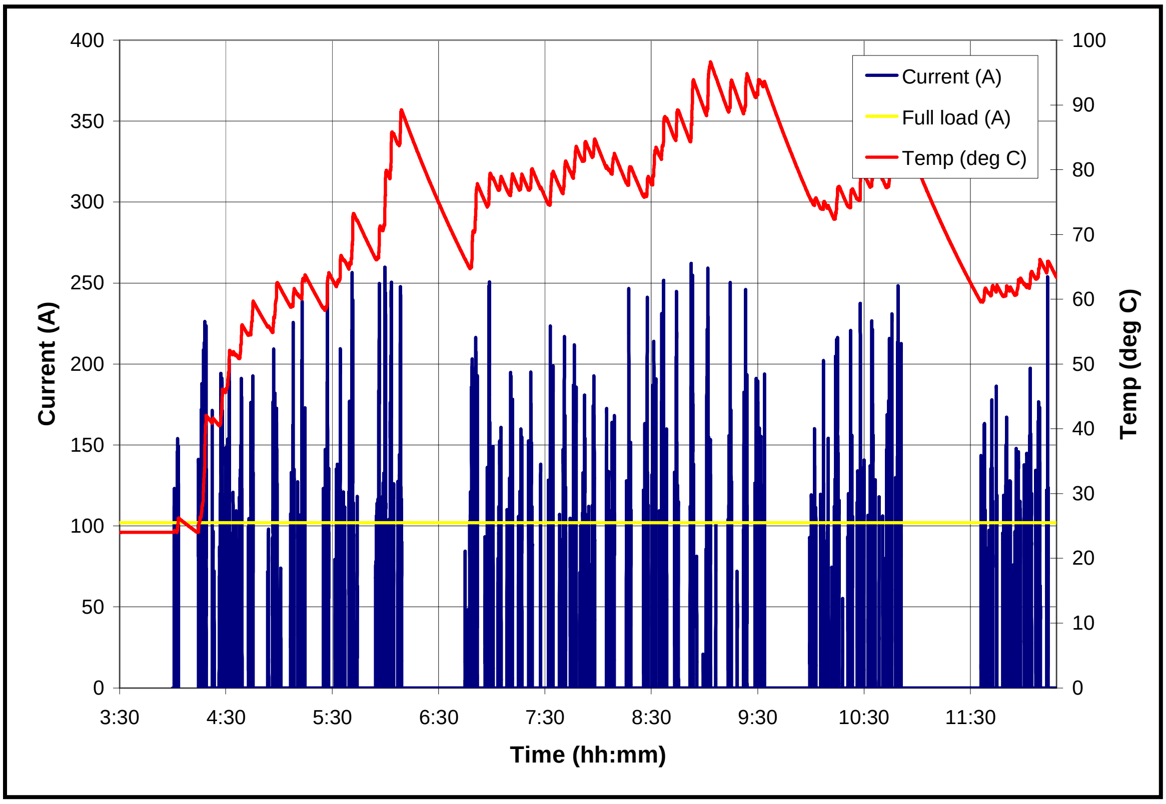


Figure 5.3-15: Load current and motor temperature for the RH traction motor – Afternoon shift 4 July 2005.

The traction motors on the shuttle car are not a limitation at present and it will also not become a limitation when production is increased. The reason is that there will always be periods between cycles when the motor will have time to cool. Also, the motors are lightly loaded when travelling back unloaded from the feeder breaker to the continuous miner.

5.4 FEEDER BREAKER

There are variations on the size and number of motors used on a feeder breaker. Twistdraai Central Colliery normally use a feeder breaker with one 55 kW motor on the feeder and two 55 kW motors on the crusher of feeder breaker. These motors are normally running on no-load, because the shuttle cars are not continuously dumping coal on the feeder breaker.

5.4.1 Conveyor motor

The conveyor motor is located on the feeder part of the feeder breaker (see Chapter 2). It is used to drive the belt that conveys the coal, dumped by the shuttle car, to the crusher part on the feeder breaker. The motor normally runs continuously, albeit on no load for most of the time, as it is only loaded for a short while after a shuttle car has dumped coal on the feeder breaker.

The conveyor motor measured in both sections was a 55 kW induction motor with a full-load current rating of 39 A (see Table 5-26 for details).

Table 5-26: Nameplate data of the conveyor motor on a feeder breaker.

Feeder breaker Conveyor Motor					
Power	55	kW	Voltage	1000	V
Duty	S1		Current	39	A
Ins class	H		RPM	1475	
			pf	0.87	

Table 5-27 shows the production in the respective sections when the consumption of the conveyor motor was measured. Figure 5.4-1 and Figure 5.4-2 show the voltage and load current consumed by the conveyor motor for two shifts over a 30-minute period. It may be noticed that there was a small fluctuation in consumption when the motor was loaded and when it was running with no load. If everything were measured at the same time, it would have been possible to see exactly when the shuttle car dumped its load and when the feeder breaker finished conveying the coal to the crusher.

Table 5-27: Production figures for shifts when the conveyor motor was monitored.

Date	Sect 21		Sect 51	
	Morning	Afternoon	Morning	Afternoon
31-May-2005	1782	1716	-	-
1-Jun-2005	1254	**1980**	-	-
2-Jun-2005	1320	**2145**	-	-
28-Jun-2005	-	-	**2204**	1740

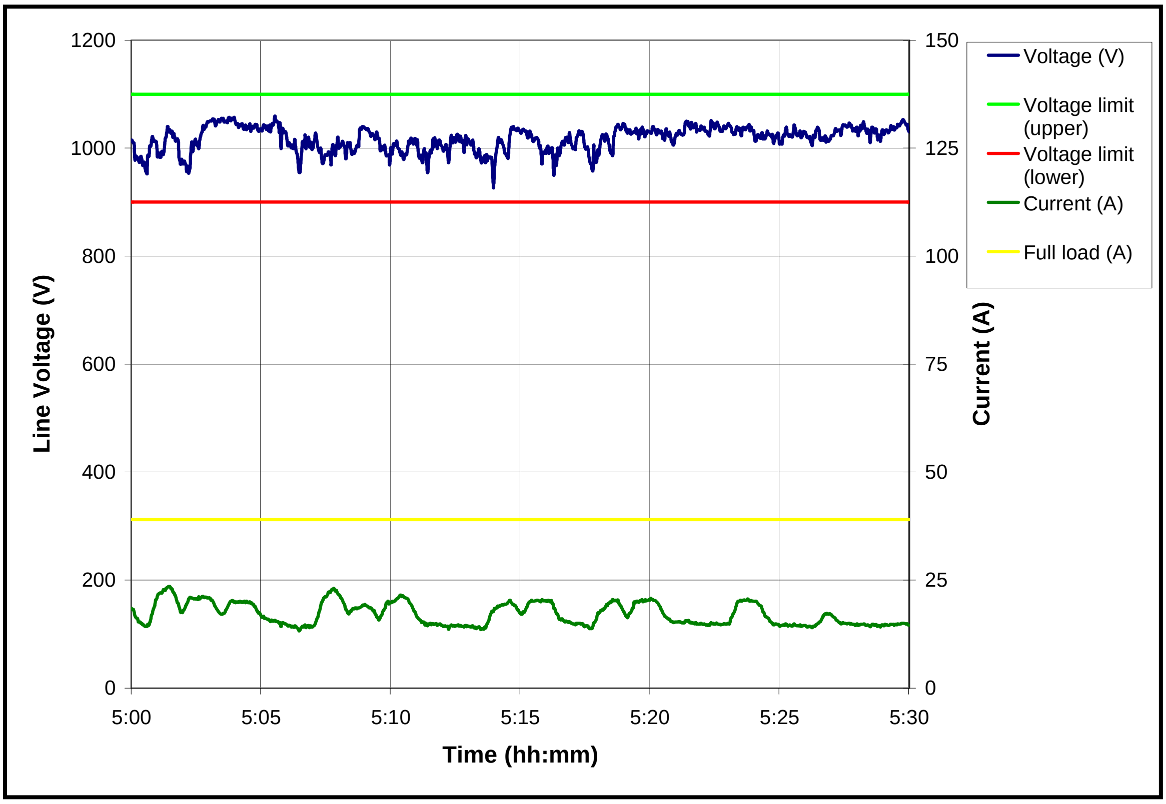


Figure 5.4-1: Load current and voltage for the conveyor motor – Afternoon shift 2 June 2005 (30 minute period).

The peaks experienced by the conveyor motor of the feeder breaker were far smaller than, for example, those experienced by the cutter motors of the continuous miner. The motors on the feeder breaker, especially the conveyor motor, consumed load much more consistently than the other motors used in a production section. From the measurements it was clear that motor is overrated. The feeder breaker is the only piece of equipment that is not controlled by an operator.

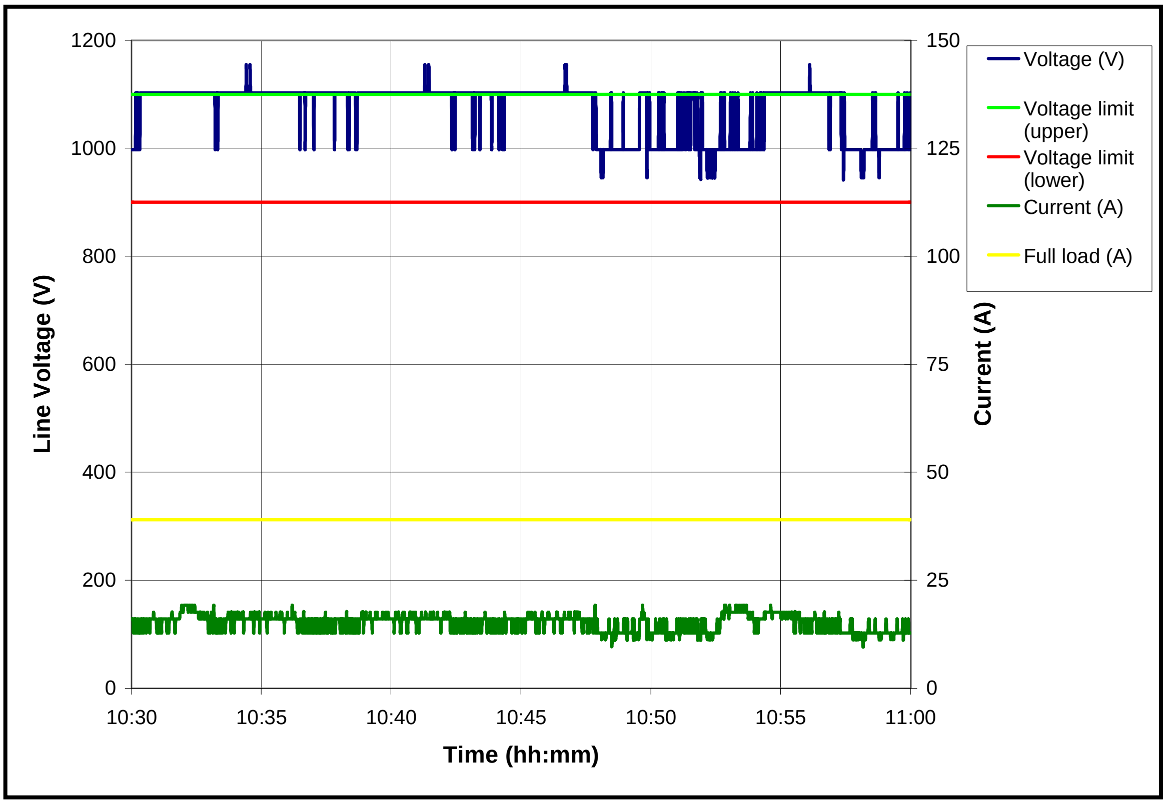


Figure 5.4-2: Load current and voltage for the conveyor motor – Morning shift 28 June 2005 (30 minute period).

Table 5-29 shows the percentage of time that the conveyor motor was utilised during a shift, as well as the percentage of time that the motor was overloaded and underloaded while being utilised.

Table 5-28: Data for the total current consumption of the conveyor motor.

	Afternoon	Afternoon	Afternoon	Morning
	31-May-05	01-Jun-05	02-Jun-05	28-Jun-05
Tonnes/CM/Shift	1716	1980	2145	2204
% Time of shift producing	72.91%	84.52%	63.90%	98.32%
% of Production time underloaded	100.00%	100.00%	100.00%	100.00%
% of Production time overloaded	0.00%	0.00%	0.00%	0.00%

Figure 5.4-3 and Figure 5.4-4 show histograms of the current and power consumed by the conveyor motor. The average current consumption of the conveyor motor was between 14 A and 16 A when loaded. There was a smaller peak for some shifts between 20 A and 21 A, which must have been when the motor was loaded. The measurement on the morning shift of 28 June 2005 was made with the MA 100 protection relay.

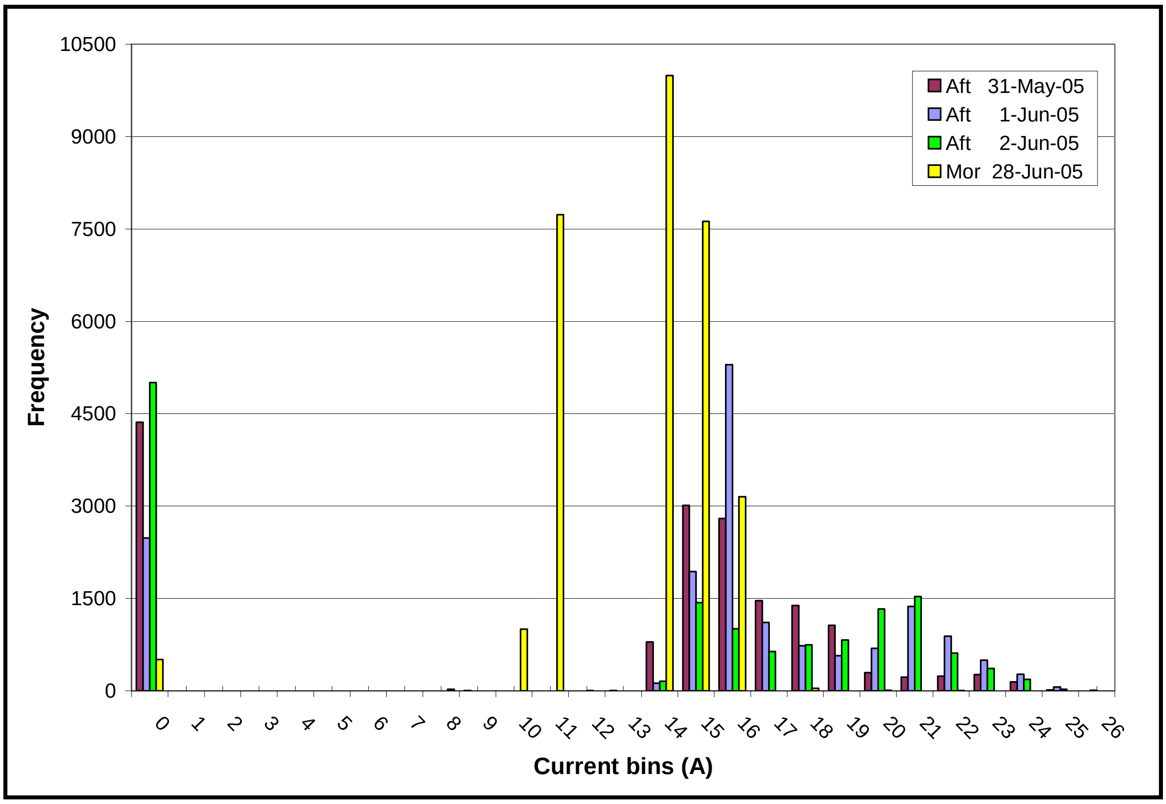


Figure 5.4-3: Histogram for current consumed by the conveyor motors.

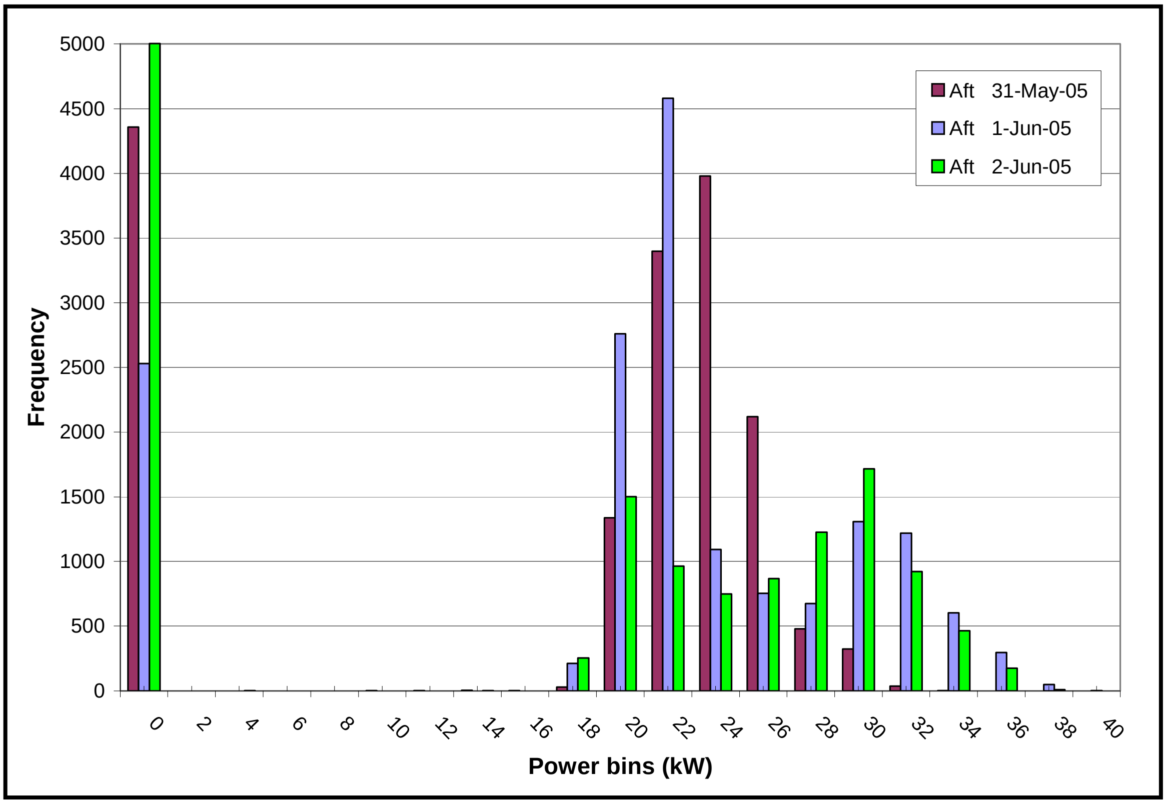


Figure 5.4-4: Histogram for power consumed by the conveyor motors.

The consumption of the conveyor motor in section 51 (morning shift on 28 June 2005) differed significantly from that measured in section 21. Average current consumed was between 13 A and 15 A, with a smaller peak between 10 A and 11 A, which must have been when the motor was not loaded. This difference in consumption could be ascribed to different speed settings used for the conveyors. The consumption of the motors would thus be different as they were on different points on the speed torque curves of the motors. The average power consumption was between 18 kW and 24 kW, with a smaller peak between 28 kW and 30 kW when the motor was loaded.

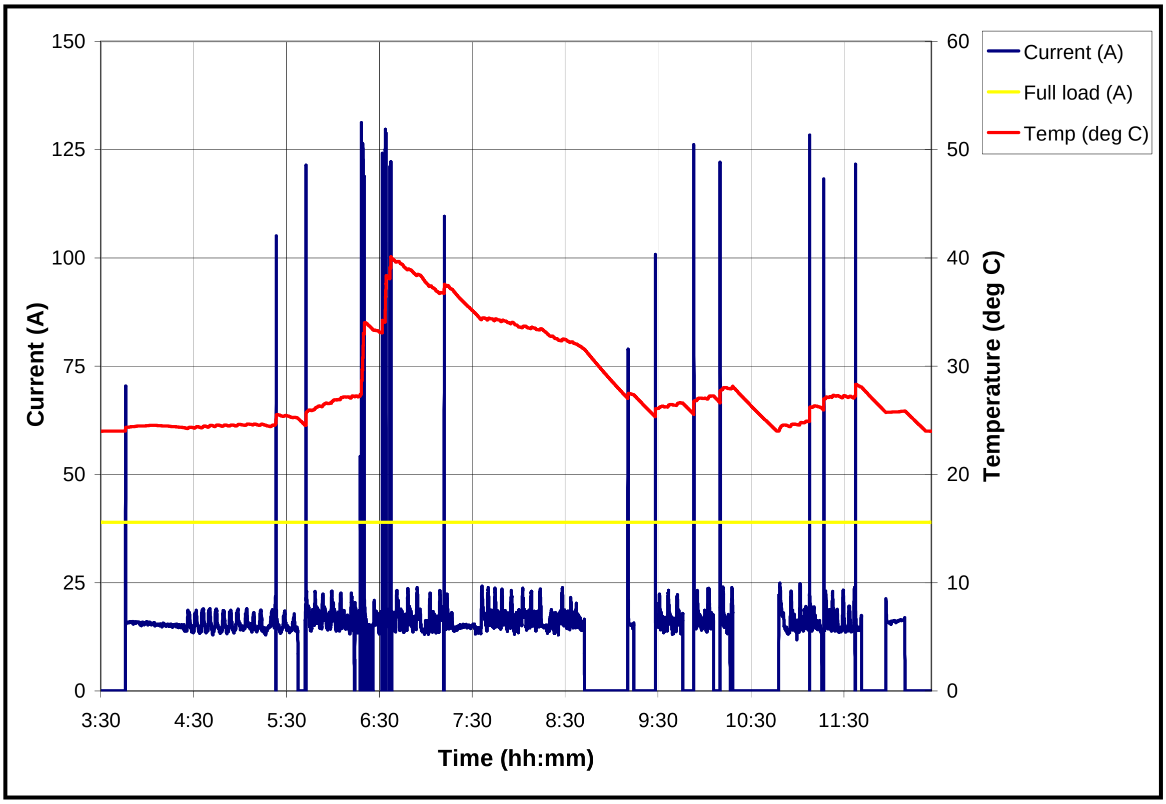


Figure 5.4-5: Load current and motor temperature for the conveyor motor – Afternoon shift 31 May 2005.

The thermal time constant for the conveyor motor is 45 minutes and it should stabilise at 155℃ if operated at full-load for a period long. The ambient temperature was 24℃. Figure 5.4-5 shows the load current and motor winding temperature for a conveyor motor over a shift. It is clear that the motor was oversized for this application. A 30 kW motor can perhaps be used for this application if the motor satisfies the torque requirements to start the conveyor.

The mechanical capacity of the feeder breaker limits the load on the conveyor motor. It is physically impossible to put more coal on the feeder part of the feeder breaker, as it can only take a certain load at a time. It is clear that the motor is not a limitation and will only become a problem when mechanical changes are made to the feeder breaker so that it is able to process more coal.

5.4.2 Crusher motors

The crusher motors are located on the breaker part of the feeder breaker (see Chapter 2). They are used to crush the coal into smaller particles before it is dumped onto the section conveyor belts. This motor is also normally running continuously and mostly at no load.

Typical nameplate data for the crusher motors of a feeder breaker can be seen in Table 5-29. The crusher motors measured in both sections were 55 kW induction motors with a full-load current ratings of 39 A (see Table 5-26 for details).

Table 5-29: Nameplate data of the crusher motor on a feeder breaker.

Feeder breaker Crusher Motor					
Power	55	kW	Voltage	1000	V
Duty	S1		Current	39	A
Ins class	H		RPM	1475	
			pf	0.87	

Table 5-30 shows the production in the respective sections when the consumption of the crusher motor was measured. Figure 5.4-6 and Figure 5.4-7 show the voltage and load current consumed by the RH crusher motor for two shifts over a 30-minute period. There was a smaller fluctuation in consumption of the crusher motors with time. These motors were also not influenced by operators and consumed power consistently.

Table 5-30: Production figures for shifts when crusher motors were monitored.

Date	Sect 21		Sect 51	
	Morning	Afternoon	Morning	Afternoon
31-May-2005	1782	1716	-	-
1-Jun-2005	1254	**1980**	-	-
2-Jun-2005	1320	**2145**	-	-

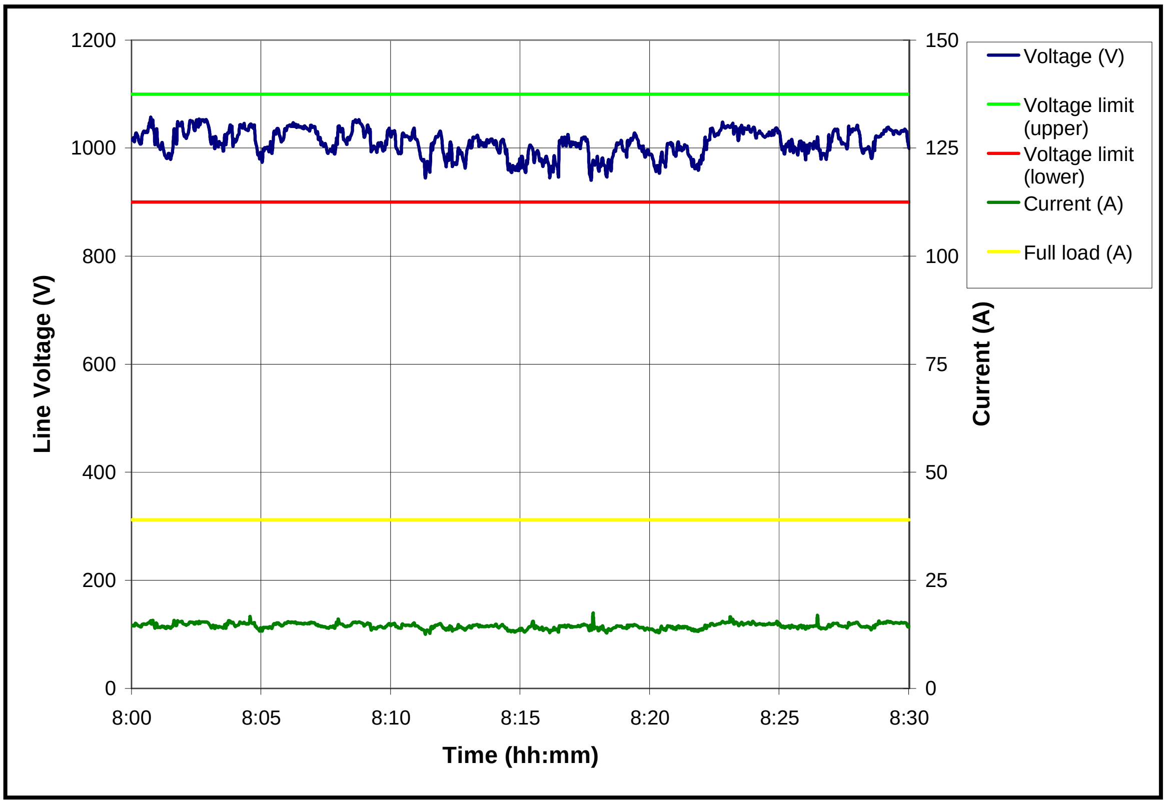


Figure 5.4-6: Load current and voltage for the RH crusher motor – Afternoon shift 1 June 2005 (30 minute period).

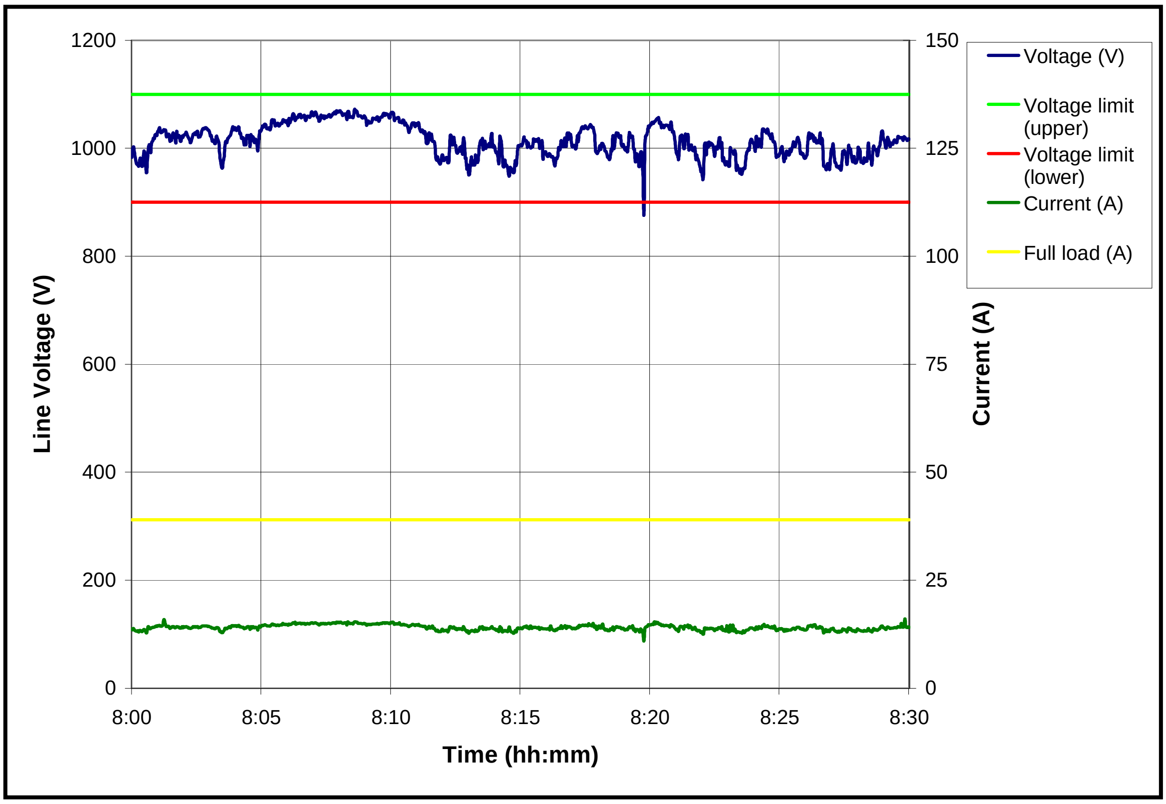


Figure 5.4-7: Load current and voltage for the RH crusher motor – Afternoon shift 2 June 2005 (30 minute period).

Table 5-31 shows the percentage of time that the RH crusher motor was utilised during a shift, as well as the percentage of time that the motor was overloaded and underloaded while being utilised. It is clear from the table that the motor's capacity was never fully used.

Table 5-31: Data for the total current consumption of the RH crusher motor.

	Morning	Afternoon	Afternoon	Afternoon
	31-May-05	31-May-05	01-Jun-05	02-Jun-05
Tonnes/CM/Shift	1782	1716	1980	2145
% Time of shift producing	74.50%	74.43%	84.89%	64.34%
% of Production time underloaded	100.00%	100.00%	100.00%	100.00%
% of Production time overloaded	0.00%	0.00%	0.00%	0.00%

Figure 5.4-8 and Figure 5.4-9 show histograms of the current and power consumed by the RH crusher motor. The average current consumption of the crusher motor was between 14 A and 16 A. The average power consumption was between 16 kW and 24 kW. The consumption of the motors was fairly constant.

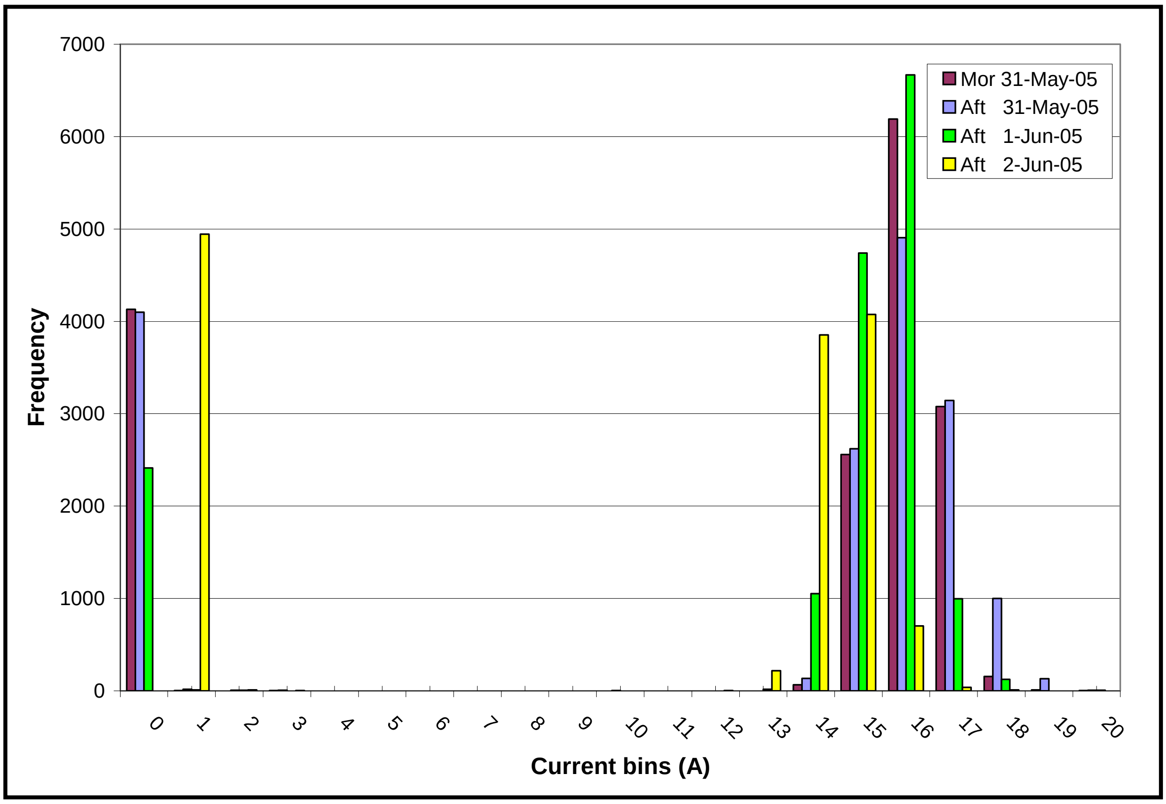


Figure 5.4-8: Histogram for current consumed by the RH crusher motors.

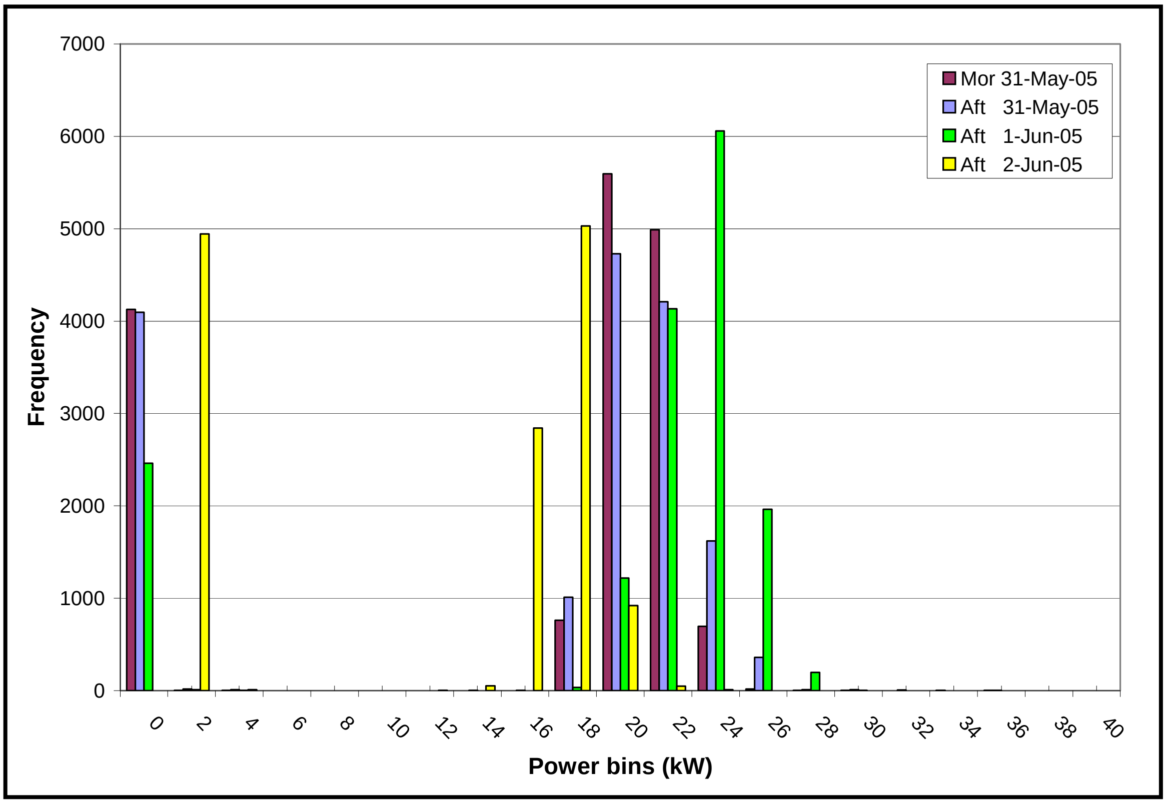


Figure 5.4-9: Histogram for power consumed by the RH crusher motors.

The thermal time constant for the crusher motor is 45 minutes and it should stabilise at 155℃ if operated at full load for a long enough period. The ambient temperature was 24℃. Figure 5.4-10 shows the load current and motor winding temperature for the RH crusher motor over a shift. This motor is also not working near its capacity.

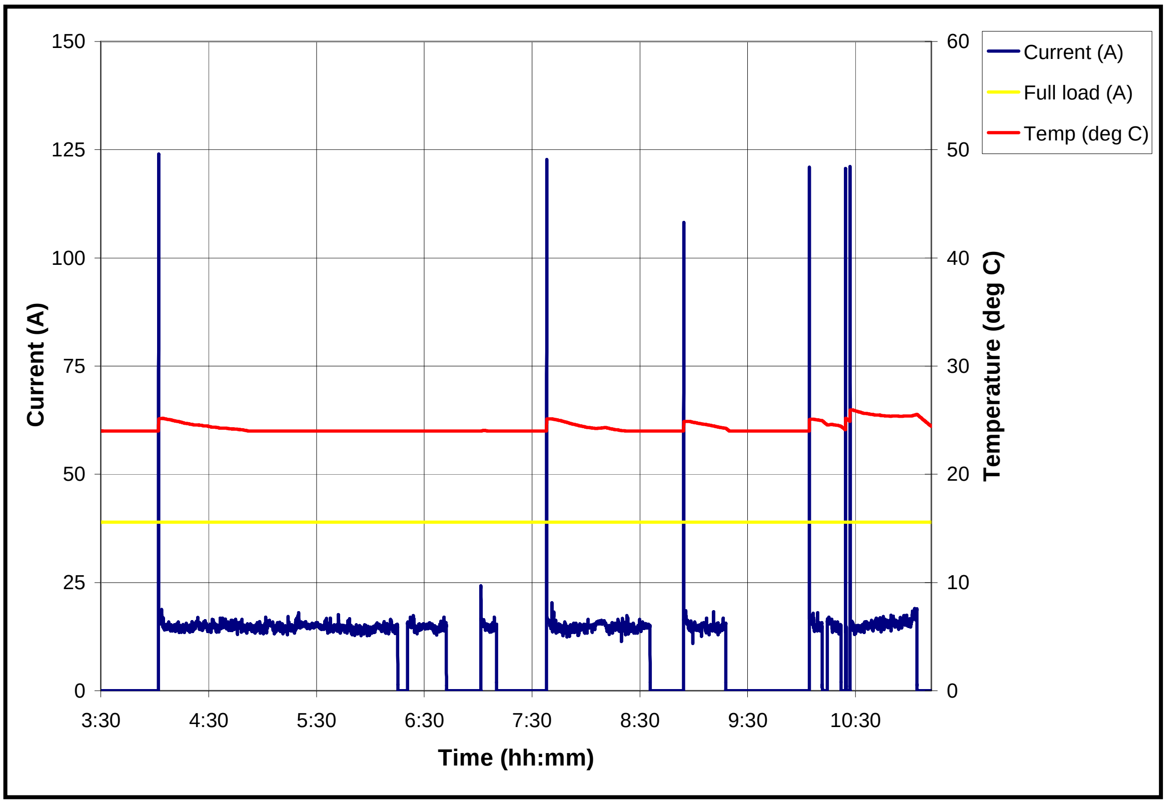


Figure 5.4-10: Load current and motor temperature for the RH crusher motor – Afternoon shift 2 June 2005.

It is clear that the motor is not a limitation and will only become a problem when mechanical changes are made to the Feeder breaker so that it is able to process more coal. A good option will be to install smaller motors on the feeder breaker which will be running more efficiently than is the case at the moment. A 30 kW motor would be ideal for this application if the motor satisfies the torque requirements for the application.

5.5 ROOFBOLTER

The pump motor of the roofbolter could not be measured directly, because the flameproof enclosure of the roofbolter was too small to fit the measuring instrument (ION 7700) inside. The measurements were made on the supply to the Roofbolter when the in-section electrical distribution network was measured.

This meant that the actual voltage and current consumed included those of control circuit of the roofbolter and the lights. Voltage drop in the cable should also be taken into account. It was, however, assumed that the contribution from the lights and control circuit was minimal, and data could be used as an accurate representation of the total consumption of the roofbolter motor.

5.5.1 Pump motor

The pump motor is used to drive all the operations of the roofbolter, for example tramming, drilling and supporting (see Chapter 2). This motor runs continuously as long as the roofbolter is being utilised. The pump motors measured in both sections were 30 kW induction motors with a full-load current rating of 20 A (see Table 5-26 for details).

Table 5-32: Nameplate data of the pump motor on a roofbolter.

Roofbolter Pump Motor					
Power	30	kW	Voltage	1000	V
Duty	S1		Current	20	A
Ins class	F		RPM	1460	
			pf	0.94	

Table 5-33 shows the production rates in the respective sections when the consumption of the pump motors was measured.

Table 5-33: Production figures for shifts when the pump motor was monitored.

Date	Sect 21		Sect 61	
	Morning	Afternoon	Morning	Afternoon
17-May-2005	858	**2145**	-	-
18-May-2005	1320	**2112**	-	-
19-May-2005	**1716**	**2013**	-	-
23-May-2005	-	-	**1740**	**2030**
24-May-2005	-	-	1450	**2320**
25-May-2005	-	-	**2320**	1160

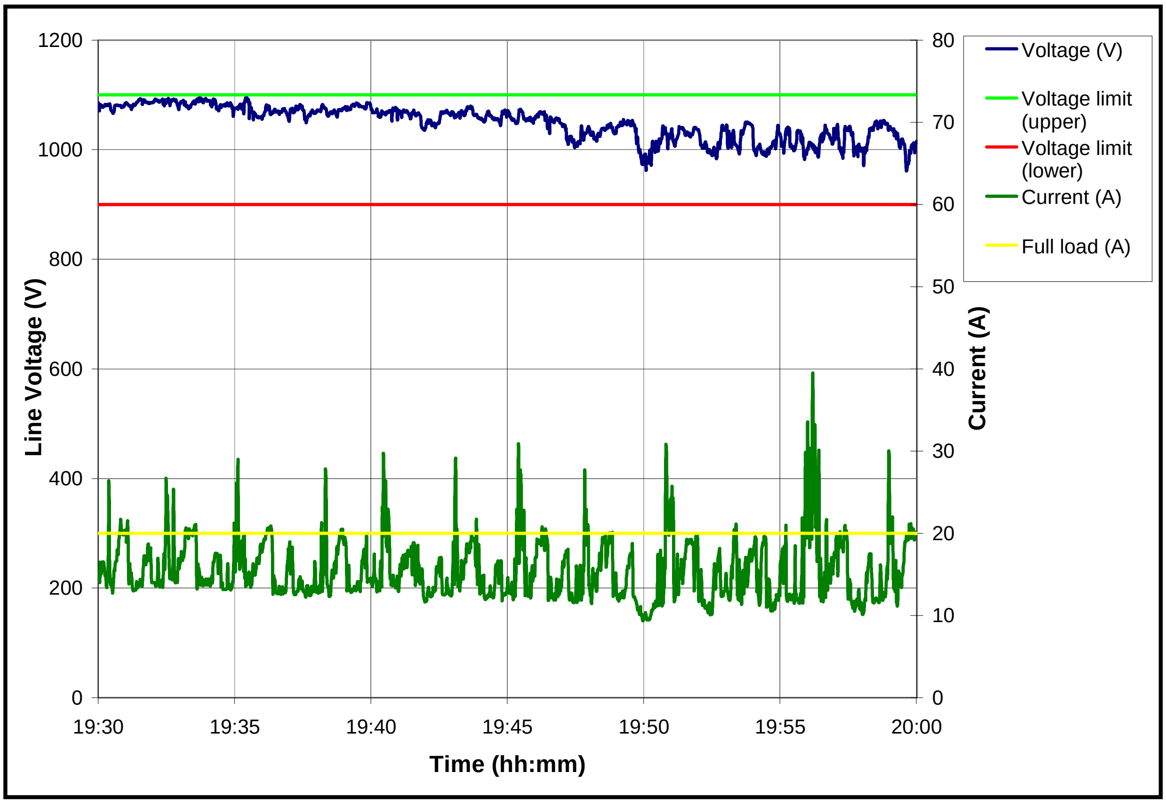


Figure 5.5-1: Load current and voltage for the pump motor – Afternoon shift 19 May 2005 (30 minute period).

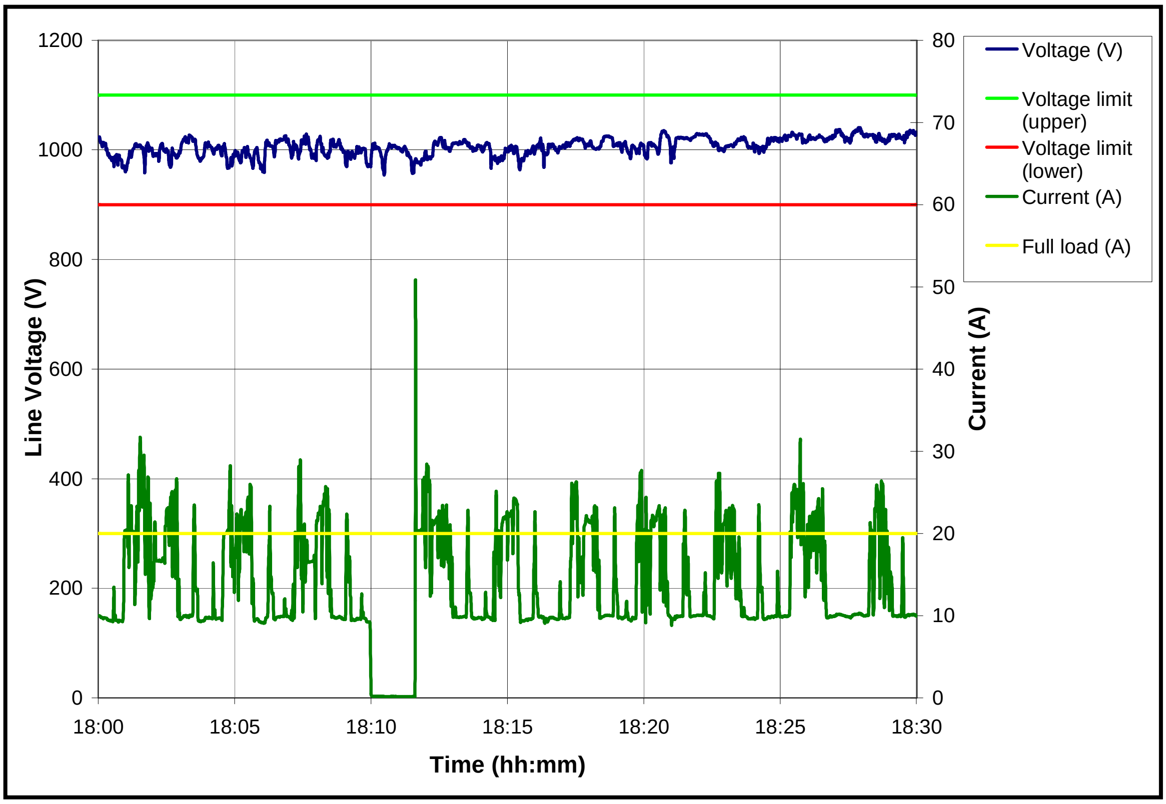


Figure 5.5-2: Load current and voltage for the pump motor – Afternoon shift 24 May 2005 (30 minute period).

Figure 5.5-1 and Figure 5.5-2 show the voltage and load current consumed by the pump motor for two shifts over a 30-minute period. The load consumed by the pump motor fluctuates considerably, but the average consumption was still below the full-load current.

Table 5-34 shows the percentage of time that the pump motor was utilised during a shift, as well as the percentage of time that the motor was overloaded and underloaded while being utilised. The pump motor was continuously running while the roofbolter was used. From the table it is clear that the motor was underloaded for more than 90% of the time.

Table 5-34: Data for the total current consumption of the pump motor.

	Morning	Afternoon	Morning	Afternoon
	19-May-05	19-May-05	25-May-05	24-May-05
Tonnes/CM/Shift	1716	2013	2320	2320
% Time of shift producing	53.73%	80.38%	71.58%	30.11%
% of Production time underloaded	89.80%	91.81%	95.05%	72.38%
% of Production time overloaded	10.20%	8.19%	4.95%	27.62%

The reason for the significant difference in loading at section 61 was that two different roofbolters were measured on 24 May 2005 and 25 May 2005, on each occasion used by different operators. Roofbolter 121 was measured on 24 May and roofbolter 112 on 25 May. Figure 5.5-3 shows a histogram of the current consumed by the pump motor. The average current consumption of the pump motor was between 9 A and 13 A. Current varied between 9 A and 20 A.

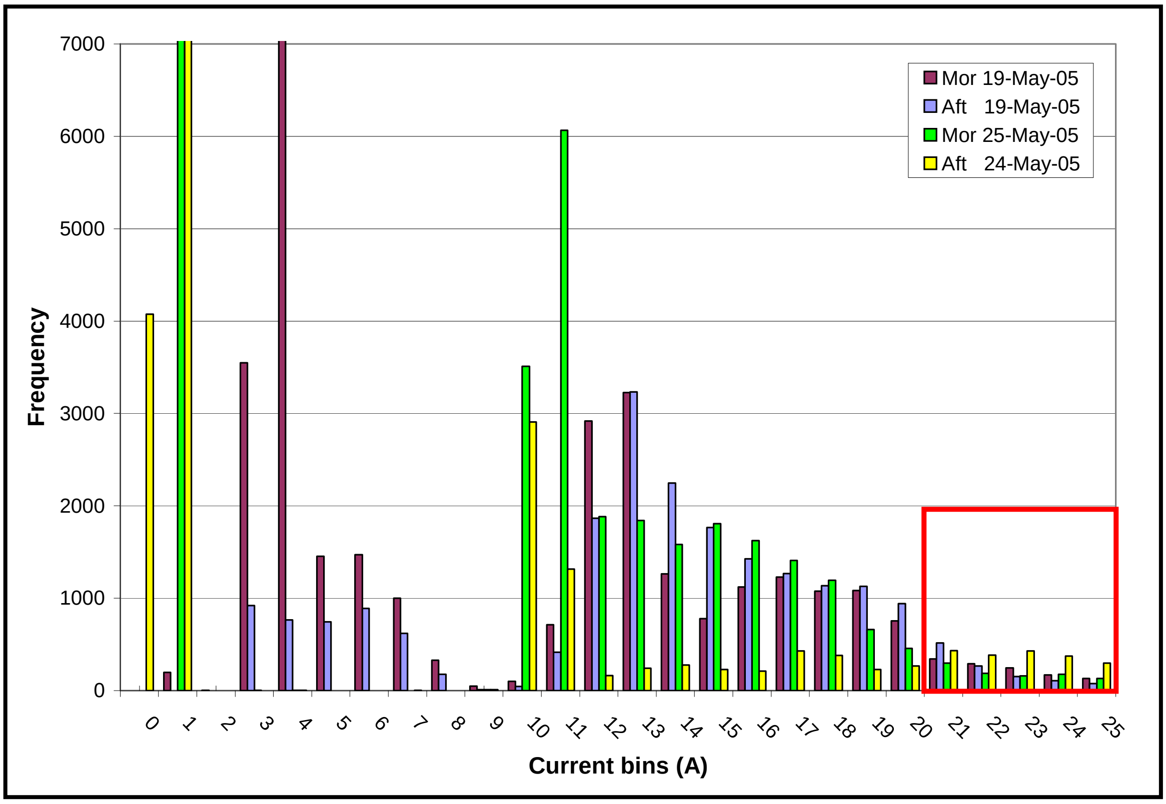


Figure 5.5-3: Histogram for current consumed by the pump motors.

The thermal time constant for the pump motor is 40 minutes and it has class F insulation (operated at class B). The temperature should stabilise at 130℃. The ambient temperature was 24℃. Figure 5.5-4 shows the load current and motor winding temperature for a pump motor over a shift. The pump motor was running at less than 130℃. A peak in temperature was experienced at the end of the cycle, possibly as a result of drilling into rock or tramming through mud. This motor should not become a limitation if production is increased. Only the duty cycle of the motor will change, which should not present a problem.

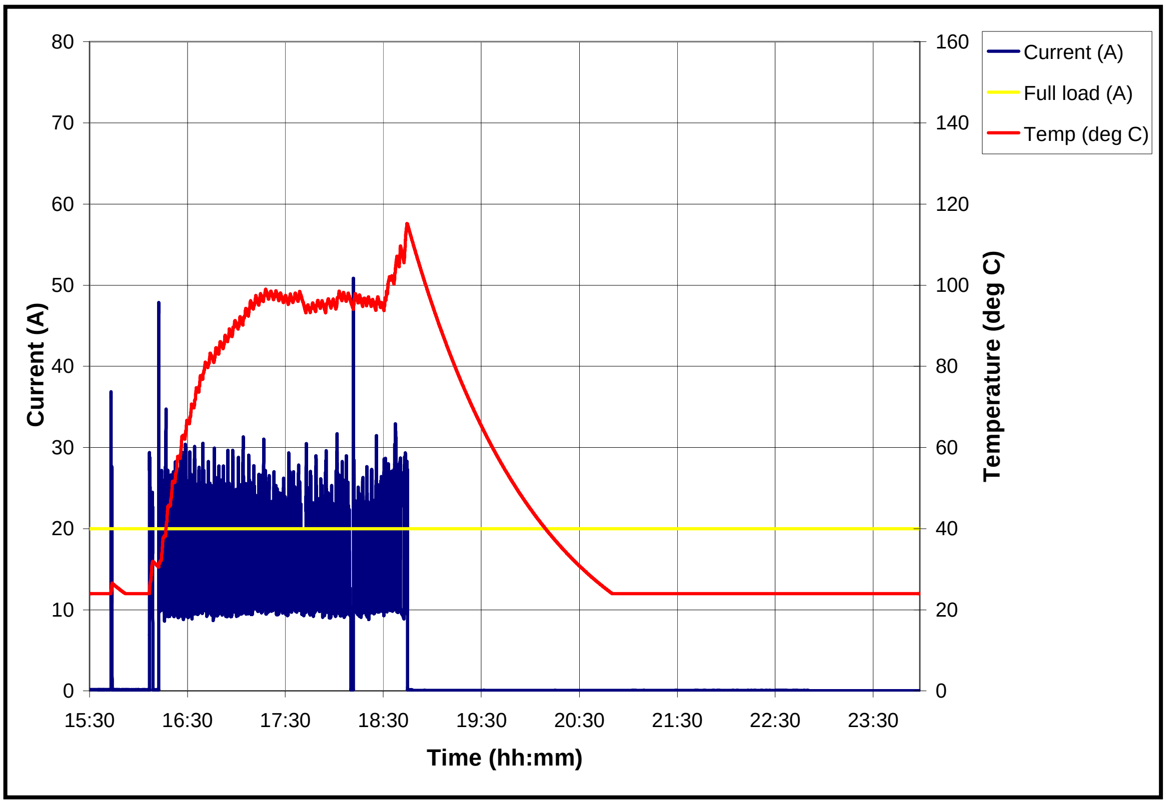


Figure 5.5-4: Load current and motor temperature for the pump motor – Afternoon shift 24 May 2005 (30 minute period).

5.6 CONCLUSION

There are many variables that have an influence on coal production. The coal seam height, hardness of the coal and other environmental conditions has an influence on production. Breakdowns of the mining equipment, although it can be reduced up to a point through proper maintenance, can have a crippling effect on production. The equipment can sometimes run for weeks without any serious breakdown, and then it can have major breakdowns on each shift for a number of days.

The most significant variable in the sections, however, are the people working in the sections. Motivation is undoubtedly the most striking influence on production. This can clearly be seen in the daily production results of the different sections. The effect of the operators could be seen clearly in the consumption of the gathering head motors in section 21 on 9, 10 and 13 June (see CD attached to back cover of the report).

Operators change shifts each week, morning shift of this week works the afternoon shift of the following week and vice versa. The consumption of the morning shifts on

9 and 10 June differed from that of the afternoon shifts on the same days. This might be attributed to the operating styles of the different operators. The consumption profiles of the morning shift of 9 and 10 June 2005 were similar to the consumption profiles of the afternoon shift of 13 June 2005. This meant only one thing: The consumption of the motors is more dependent on the operator of the continuous miner than it is on the production output. It is also clear from the data that if, for example, one continuous miner is forced a lot harder than another continuous miner, and it does not necessarily take out more coal.

Overloading a motor within bounds does not mean that the motor will stop working immediately. However, it has an effect on the life expectancy of the motor, because the windings of a motor overheat more if overloaded than during normal full-load conditions. If the temperature of the motor exceeds the maximum temperature of insulation material, the life of the motor is reduced. Motors are designed for 25 years of operation without being rewound. Although the conditions in which the motors are operated are not ideal, the motors should not fail after only 8 to 18 months.

The motors on the continuous miners are generally overloaded, except for the gathering head motors and 50 kW DC traction motors. The gathering head motors will be able to sustain further increases in production and they should not become a problem. The 50 kW traction motors are not a limitation, but should be monitored if production is further increased. An increase in production will increase the duty cycle of the motors, which will result in the motor having less time to cool down between cycles, resulting in the motor exceeding its thermal limits.

The 37 kW DC traction motors have already been replaced with 50 kW DC traction motors on some of the continuous miners. This was the correct option, as the 37 kW motors are already a limitation and they regularly exceed the thermal limits of the insulation. The DC motors used on the on the continuous miners are all operated as S1 duty type motors, but they are rated for a S2 duty (60 min). Changing the duty type of the traction motors will help the traction motors to sustain higher production rates. Another problem at the traction motors of the continuous miner were that the voltages supplied to the traction motors exceeded the 250 V rating of the motors on a regular basis. More than 400 V were applied to the motors for periods.

The cutter motors were overloaded on some shifts. Further increases in production rates will cause the cutter motors to become a limitation. The conveyor motor and the pump motor of the continuous miners are already a limitation, especially the pump motor.

The motors on the feeder breakers were underutilised. They will not become a limitation, even if they are continuously conveying and crushing coal. The reason is that the mechanical capacity of the feeder breaker limits the load on the conveyor and the crusher motors. It is physical impossible to put more coal on the feeder part of the feeder breaker, as it can only take a certain load at a time. Even if the presently used 55 kW motors are replaced with smaller motors (30 kW), the feeder breakers will not become a limitation are fitted

The motors on the shuttle cars were not a limitation and they will remain so, unless the loading capacities of the shuttle cars are changed. The motors will also be able to sustain production increases, because only the duty cycle of the motors will change. The motors will always have time to cool down, because the traction motors are not running when the shuttle car is loading or unloading. The conveyor motor has time to cool when the shuttle car trams from the continuous miner to the feeder breaker, for example. The pump motor of the shuttle car is constantly loaded within the rating of the motor.

The pump motor of the roofbolter was not a limitation, as it is not fully utilised. The motor will also be able to sustain further production increases until it is working a full shift, as long as the size of the instantaneous load on the motor does not change.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

It is difficult to determine at what point any given motor or cable will become overloaded for sustained higher production rates. Far too many variables influence the production rates, of which the operators of the equipment certainly have the largest contribution.

One continuous miner, for example, will consume much more power than the same continuous miner with a different operator on the next shift. The continuous miner consuming more power will not necessarily mine more coal or remove more coal in direct relationship with the amount of additional power consumed. The investigation could, however, determine if any of the motors or cables are generally overloaded or whether they still have spare capacity.

6.1 DISCUSSION OF RESULTS

A number of obstacles had to be overcome or be dealt with to complete the investigation, especially when measuring the mining equipment. Measurements were hampered by dependency on limited transport, the availability of artisans, space limitations in flameproof equipment, the availability of measuring equipment and wiring schemes that differed from panel tot panel. An ION7700 was used for most of the measurements.

Measurements on the shuttle cars were limited, and roofbolters could not be measured directly as a result of the size of the flameproof enclosures. Sometimes there was no space to fit a measuring instrument into the panel, e.g. many shuttle cars are not fitted with large flameproof panels.

The results included in the previous two chapters are only summaries of the data, with some general tendencies outlined and some worst case experiences discussed. The compact disk attached to the back cover of this report has more detail and information on the data obtained from each shift. This section will only give a short overview on the results obtained in the previous two chapters.

6.1.1 In-section electrical distribution network

The trailing cables of the roofbolter and the feeder breaker still have huge spare capacity. The 16 mm^2 cable of the roofbolter could be replaced with a 4 mm^2 cable and it will still have spare capacity. The instantaneous load on the feeder breaker can almost be doubled without exceeding the cable's capacity. The average current drawn between the three motors on the feeder breaker is slightly above the full load current of a single motor.

The trailing cable of the shuttle car is becoming a limitation. The actual current rating of the cable is not the cause of the limitation, but it has to be derated according to the number of cable layers coiled on the cable drum. There will, on average, be more layers on the drum when the distance between the coal face and the feeder breaker is shorter, which means that the cable will be operated continually in a derated state. The coiled cable on the drum may thus become hot while the rolled-out length of the cable remains cool. Further investigations should be done on the temperature of the coiled cable on the drum and the effect of this induced "overloading" on the life expectancy of the cable.

The trailing cable of the continuous miner is already a limitation and it was confirmed when the cable outside temperature was measured, as the cable is fairly hot already (55℃). Further increases in production will only emphasise the inadequacy of the cable, because the cutter, gathering head and conveyor motors will run under full load for longer periods. Increasing the size of any of the motors on the continuous miner will also increase the limitation. The overloading of the cable has a considerable effect on the life expectancy of the trailing cable.

Neither the gate end boxes, MSU, flameproof transformer nor the cables supplying them with power were found to pose limitations. The flameproof transformer, however, experiences excessive peak current consumptions, mainly as a result of the consumption of the cutter motors on the continuous miner. This is, however, not a problem, as transformers can handle larger overloads for longer periods than for example motors.

6.1.2 Production equipment

The pump motor of the roofbolter is not a limitation at present and should not become one even if production is increased to the point where the pump motor is utilised for the full duration of a shift. The average current consumed is below the full load rating of the pump motor, and as long as this is the case, the duty cycle of the motor can be increased.

The motors on the feeder breaker have the largest spare capacity of all the motors used on the mining equipment in a section. The duty cycle can thus be increased to 100% as the motors are consuming far less current than they are rated for. The load on these three motors did not vary much between no load and full load conditions. Smaller 30 kW motors could be used with ease instead of the 55 kW motors.

The motors on the shuttle car are not a limitation and should not become a limitation as long as the coal-carrying capacity of the shuttle cars is not increased. Only the duty cycle of the motors will change if production rates were to be increased and not the size of the instantaneous load on the motors. The load on the pump motor of the shuttle car is normally constant and it does come close to the full load rating of the motor. This motor is already running for the largest part of a shift. The traction motors and conveyor motor on the shuttle car have fixed cooling periods that will only show minor changes when production is increased. This is because the conveyor motor only works when the car was loading or unloading, not when tramming between the continuous miner and the feeder breaker.

Most of the motors on a continuous miner were already a limitation or would become a limitation if production were to be increased. The 37 kW traction motors, the conveyor motor and the pump motor of the continuous miner is already a limitation, as these motors continuously exceed their full load ratings and their maximum thermal levels. This applies especially to the pump motor. The cutter motors were not a limitation, but are at a critical point, as further increases in production will cause the motor to become a limitation.

The gathering head motors of the continuous miner not a limitation and should not easily become a limitation if production is increased, as the average load on the motor will not increase, only the duty cycle. The 50 kW traction motors are not a limitation at present, but a close eye should be kept on them when the production is increased, because that could lead to the motor becoming a limitation. The voltages applied to the traction motors however exceed the ratings of the motors regularly.

6.2 CONCLUSION

The maximum production capacity that could be sustained with the present in-section equipment could not be determined due to a number of variables that could not be controlled. Due to these variables it cannot be specified that a certain motor was 10% overloaded at a specific production rate. This would require measurements over an extended period to determine if a component is being operated close to its maximum sustainable capacity.

Equipment operators have the greatest influence on the results. The load on the equipment differed, because the operators use the equipment differently as can be seen by the consumption of the continuous miner traction motors on 10 and 13 June. The operator on the morning shift on 10 June was also the operator on the afternoon shift on 13 June, and the operator on the afternoon shift of 10 June was also the operator on the morning shift of 13 June. The operator on the morning shift on 10 June clearly worked the motors harder than the other operator.

Some motors worked harder than others, although the total production output for these motors was lower than that of the motors that were not working as hard. Another factor that had to be taken into account was that motors from different suppliers, for example TECO, JOY and a rewound motor, would differ despite having similar ratings. Due to the design and manufacturing or repairs motors can have different torque vs speed curves. This means that one motor would be able to handle a certain load while another motor’s life was reduced under the same load. Other variables influencing the load on the components, but to a lesser extent, were the hardness of the coal and the seam height.

The seam heights and hardness in the sections studied differed; section 21 has a higher seam of around 4 m, while sections 50, 51 and 61 have seams 3 m thick. The seam in section 51 contains a lot of rock, to the extent that the continuous miner sometimes had to mine a higher part of the seam or leave a part of the roof to avoid cutting too much rock. The result is that some motors worked harder to produce the same amount of coal. This is another reason why the load on the motor could not be directly related to a certain production level.

The present sustainable production capacity of the equipment could be determined to a degree. This sustainable production capacity holds true only for that component measured under the conditions while it was being measured. The measurements provide information on whether a specific component is exceeding its capacity already and if it will exceed its design capacity if production is further increased.

The effect of overload conditions, either voltages or currents, on the expected life of the motors and cables was not determined. It is, however, certain that the overload conditions will reduce the expected life of the equipment considerably. It was also not determined how the overload conditions and mechanical factors contribute to cable and motor failures.

The motors used in the sections are generally rated for a S1 type duty, which means that the motors are rated to run continuously at the rated load. Only the motors on the feeder breaker are normally running continuously. All the other motors are started and stopped continuously, an application for which they were not designed. Additional heat is generated when a motor starts, in the motor itself as well as in the supply cables. This decreases the thermal capacity of the motors and cables. The presence and effect of voltage unbalances, and negative sequence currents and voltages were not investigated. These could easily cause motors to overheat.

The duty cycles of the AC motors were normally in order. However, the instantaneous load on the motors was generally exceeding the full load rating of the motors. This resulted in the temperature of the motor increasing when the duty cycle of the motor is increased, because the motor no longer has enough time to cool.

Most of the equipment forming part of the in-section electrical distribution network still has sufficient spare capacity, except for the cable supplying the continuous miner with power. This cable is already a limitation. The motors on the mining equipment, except for the motors on the continuous miner, will also be able to sustain further production improvements.

The most striking limitation in a standard section is the trailing cable and the motors of the continuous miner. The solution to this problem is, however, not so obvious. The size of the motors on the continuous miner cannot readily be increased, because the supply cable of the continuous miner is already a limitation. The cable size can also not be increased, because it is already too large to be handled. The cable is thus limiting the possible solution for the underpowered motors. One possibility is to increase the voltage levels from 1000 V to 3.3 kV, but this will be a costly exercise. Another possibility is to accept the premature failure of motors as a result of constant overloading and to determine what production rate is the most cost effective.

However, further increasing motor or cable sizes may at some point no longer be cost effective, or it may become physical impossible. Different solutions will have to be found before production can be increased. Solutions may include: a different mining method, more shuttle cars in a standard section or using battery haulers instead of shuttle cars for example.

6.3 SUGGESTIONS FOR FURTHER INVESTIGATION

There are several things that Sasol Mining can do to react more proactively to future bottlenecks in the production sections. The following suggestions are made:

- Continuous measurements should be taken on all the equipment and motors used in a production section, in effect meaning that this investigation is repeated each day. This can be achieved by using protection equipment with measuring and recording functions from which data can be easily downloaded to the surface, either automatically via the radio network or by removing a memory stick at the end of each shift.

  A computer program should automatically evaluate the measurements and generate a report on the maximum and average current consumed by the motor, the time it used by the shift, the time it was overloaded (if at all), the voltage levels in the section, if the motors' phases were balanced and if two motors working together are dividing the load equally etc. All the data can then be stored in a database to determine general tendencies and limitations. The measured data can also be used as performance measures for the sections and the operators of the different pieces of equipment.

According to changeable settings in the program, it should give an alarm if a motor or cable was overloaded constantly or if a fault is detected. The engineer and foreman should have access to the report after each shift, which will inform them of problems or possible limitations with any motor or cable. If all the data is downloaded in real time it can be done throughout each shift.

- Form a team consisting of specialists in production and production equipment. The team should consist of mining, electrical, mechanical and industrial engineers, experienced artisans and operators of the respective equipment. The team must make suggestions and recommendations on all the aspects involving production, shift changes, number of people in a section, types and number of equipment used in a section and the bonus schemes.

  The team should also be experts in all aspects of the production equipment used in the sections, including the design of the equipment, protection relays used and the standards and components used on the electrical and mechanical aspects of equipment. They should be able to determine why some sections are not producing and should help these section and shifts put systems and procedures in place so that production can be increased. Their aim should be to get all the sections to be top producing sections by decreasing the gap between the best and the worst sections. Best practices of operators must be determined, and this can be used to train other operators.

  The team should evaluate all the data recorded on the equipment in the sections to determine possible future limitations and general tendencies. Informed decisions can be made based on the measurements, for example whether a section might perform better with 3 or even 4 shuttle cars or whether a Long Airdox continuous hauler would be a better option. The team should be empowered to decide on the equipment that should form part of the "standard" section.

The team can also make recommendations on how to design equipment to make it easier to operate and be more user and maintenance friendly. They should also investigate new products from suppliers and must keep suppliers informed of Sasol Mining's needs.

- Create an accurate database with information on all the electric motors and trailing cables used in the sections. The information should include the purchase date of a motor, when installed, how long it was utilised, the reason for failure and the refurbishment data. The database can be used to determine the average life of a motor and the most common reason for failures. Such reasons for failure must be eliminated through thorough root cause analysis and by acting on the outcome of the investigations.

- The production rate at which the equipment is most cost effective must be determined. The expected life of motors and cables and the repair and maintenance costs should be weighed against increased production rates. As an example, is it more efficient to constantly produce at 2400 tonnes/CM/shift for 8 months before replacing the cutter motors on the continuous miner, or would it be more profitable to produce at 2000 tonnes/CM/shift and to replace the cutter motors after 3 years of service? Quantity is not always quality, in other words, more is not always better.

- An investigation should be done into converting voltage levels in a section from 1000 V to 3.3 kV if further increases in production are to be made. The trailing cable of the continuous miner and a number of the motors used on the continuous miner are at present already being overloaded. Further increases in production will require more of these motors to be replaced with larger motors, which will increase the load on the trailing cable even more. The size of the cable cannot be increased, as it is already difficult to handle.

All these shortcomings will be solved if the supply voltage is changed to 3.3 kV. Cables will be smaller and easier to handle, voltage drops should not occur and it would be general beneficial for the motors.

- Electric motors from different suppliers must be thoroughly tested. Tests should be done to determine the efficiency of the motors, the power generated, torque curves and the efficiency of the cooling method used. All this data should be compared with the price of the new motor and the maintenance cost of the motor. Some motors are cheaper, but may only run for 6 months, where a more expensive motor from a different supplier may run trouble-free for 24 months or longer. The cost as a result of downtime on the cheaper motor may make the more expensive motor a more cost efficient option.

- Use AC traction instead of DC traction on continuous miner and shuttle cars [27]. JOY is already manufacturing shuttle cars and continuous miners that use AC traction with variable frequency drives. AC variable frequency drives provides significant increases in power and speed and reduces maintenance cost. Motor inventory is also reduced. The increase in speed translates into more trips between the continuous miner and the feeder breaker over a given period, which in itself translates into an increase in production.

  The operators of the equipment have better control over the speed of the equipment, as the shuttle car accelerates gradually much like in an automobile, and not by selecting a specific speed as it is presently done. This reduces the instantaneous load on the gearboxes, as load is applied more gradually, resulting in a longer expected life for the mechanical components of a traction system.

- The motors on the continuous miner must be given time to cool down before the machine is switched off completely, similar to the requirements of most turbo diesel engines. After the operator of the continuous miner switches off the continuous miner, the pump motor must run on for 30 minutes, which will enable the cooling system to work. This will allow motors to be cooled effectively for an additional 30 minutes after they have stopped working before the cooling system stops and motors have to rely on radiation for cooling. At present the cooling system is stopped immediately when the machine is switched off. This arrangement must be automatic, not depending on the intervention of an operator.

- A motor is designed for a duty period of 20 years before it needs to be rewound and overhauled. A motor that is overloaded will not just stop working, but failures will become more common. This is because the expected life of a motor is reduced each time the motor exceeds its thermal limits as a result of continuous overload conditions. Most of the motors on the mining equipment are replaced long before 20 years of service.

  The cost to reduced motor life and production losses because of a breakdown should be compared to the profit of increased production. Again a question of whether it is more cost effective to produce continuously at 2000 tonne/CM/shift than at 2400 tonne/CM/shift but with unacceptable costly stoppages.

REFERENCES

[1] Ressources GSC. Available: http://spans.gscc.nrcan.gc.ca/~ren/coal/drag.html [Date of access: August 2005].

[2] Lecture sets on coal mining methods, School of Mining Engineering, University of the Witwatersrand

[3] JOY Mining Machinery, 1995. ***12HM31 Continuous Miner - Model A/B/C Illustrated Spare Parts Manual***. Johannesburg. Manual. Unpublished.

[4] JOY Mining Machinery , ***10SC22S 16 tonne Shuttle Car Illustrated Spare Parts Manual***. Johannesburg. Manual. Unpublished.

[5] McCarthy Mine Machinery , 1990. ***M800 Feeder Sizer Illustrated Spare Parts Manual***. Witbank. Manual. Unpublished.

[6] JOY Mining Machinery,1996. ***12HM21 Continuous Miner Illustrated Spare Parts Manual***. Johannesburg. Manual. Unpublished.

[7] JOY Mining Machinery, 1999. ***12HM31 Contnuous Miner - Model AA Illustrated Spare Parts Manual***. Johannesburg. Manual. Unpublished.

[8] McCarthy Mine Machinery , 1990. ***Buffalo Feeder Breaker M500SDW/Non-driven unit Illustrated Spare Parts Manual***. Witbank. Manual. Unpublished.

[9] McCarthy Mine machinery, 1990. ***Buffalo Feeder Breaker - M500/Driven unit Illustrated Spare Parts Manual***. Witbank. Manual. Unpublished.

[10] SASCoal, 1998. ***Roofbolter - Forklift type Illustrated Spare Parts Manual***. Secunda. Manual. Unpublished.

[11] SASCoal, 1998. ***Roofbolter - Scissor type Illustrated Spare Part Manual***. Secunda. Manual. Unpublished.

[12] JOY Mining Machinery , ***Continuous Miners***. [Brochure] Available: http://www.joy.com [Date of access: April 2004]

[13] JOY Mining Machinery , ***Haulage Systems***. [Brochure] Available: http://www.joy.com [Date of access: April 2004].

[14] FFE minerals, ***Buffalo.*** [Brochure] Available: http://www.ffemineralsbuffalo.co.za/ [Date of access: December 2005].

[15] JOY Mining Machinery , ***JOY bolting solutions.*** [Brochure] Available: http://www.joy.com [Date of access: April 2004]

[16] JOY Mining Machinery , ***JOY product line.*** [Brochure] Available: http://www.joy.com [Date of access: April 2004]

[17] LEESON. Available: http://www.leeson.com/products/techref/metric.htm [Date of access: June 2004].

[18] SANS 60034-5, Ferdinand Postma Library, Potcefstroom campus of the North-West University

[19] Web Marlin. Available: http://www.iprocessmart.com/leesom/ leeson_conversions_reference.htm [Date of access: June 2004].

[20] SANS 60034-6, Ferdinand Postma Library, Potcefstroom campus of the North-West University.

[21] SABS IEC 60034-1, Ferdinand Postma Library, Potcefstroom campus of the North-West University

[22] WEG Electric motor manual, ***Guide for selecting and maintenance of electric motors***, Available: Zest motors Trichardt.

[23] Aberdare Power cables, ***Cable facts and figures,*** Available:Aberdare.

[24] Zocholl, S. E., ***Comparing motor thermal models.*** Document 6164, Schweitzer Engineering Laboratories, Inc., Pullman, WA.

[25] Mining weekly, ***New face at the coal face***, vol 8 no 19, May 24 – 30 2002.

[26] Mining weekly, ***Synfuels plus***, vol 10 no 19, May 21- 27 2002.

[27] Coalage Magazine, ***Joy announces AC Variable Frequency Drive Shuttle car***, October 2003.

[28] Goldratt, E.M., Cox, J. ***The Goal, A process of ongoing Improvement***, Creda Communications.

[29] Leiria, A. , Nunes, P. , Morched, A. et al., ***Induction Motor Response to Voltage Dips.*** International Conference on Power Systems Transients, New Orleans, 2003.

[30] Ibtiouene, R. , Laporte, B. , 1999. ***Steady-State Torque Analysis of a Brushless Direct Current Motor with Inset Permanent Magnets.*** Electric Machines & Power Systems [online], Vol. 27 (Issue 1). Available from: EBSCO Host [Accessed 12 March 2004].

[31] Bellettre, J. , Sartre, V. , Biais, F. et al., ***Transient state study of Electric Motor.*** Applied Thermal Engineering [online], Vol. 17 (Issue 1). Available from: Sciencedirect].

[32] Emanuel, P. , 1985. ***Motors, Generators, Transformers and Energy***. London: Prentice-Hall inc.

[33] Tripathy, S.C. , Lakervi, E. , 2000***. Evaluation of Transformer Loading A bove Nameplate Rating.*** Electric Machines & Power Systems [online], Vol. 28 (Issue 7). Available from: EBSCO Host [Accessed 12 March 2004].

APPENDIX A ELECTRIC MOTOR DUTY TYPES

There are 10 categories of duty cycles [21].

A.1 DUTY TYPE S1 – "CONTINUOUS DUTY"

Motor is operated with a constant load for a sufficient time to allow the machine to reach thermal equilibrium. The appropriate abbreviation for a continuous duty cycle is ***S1***.

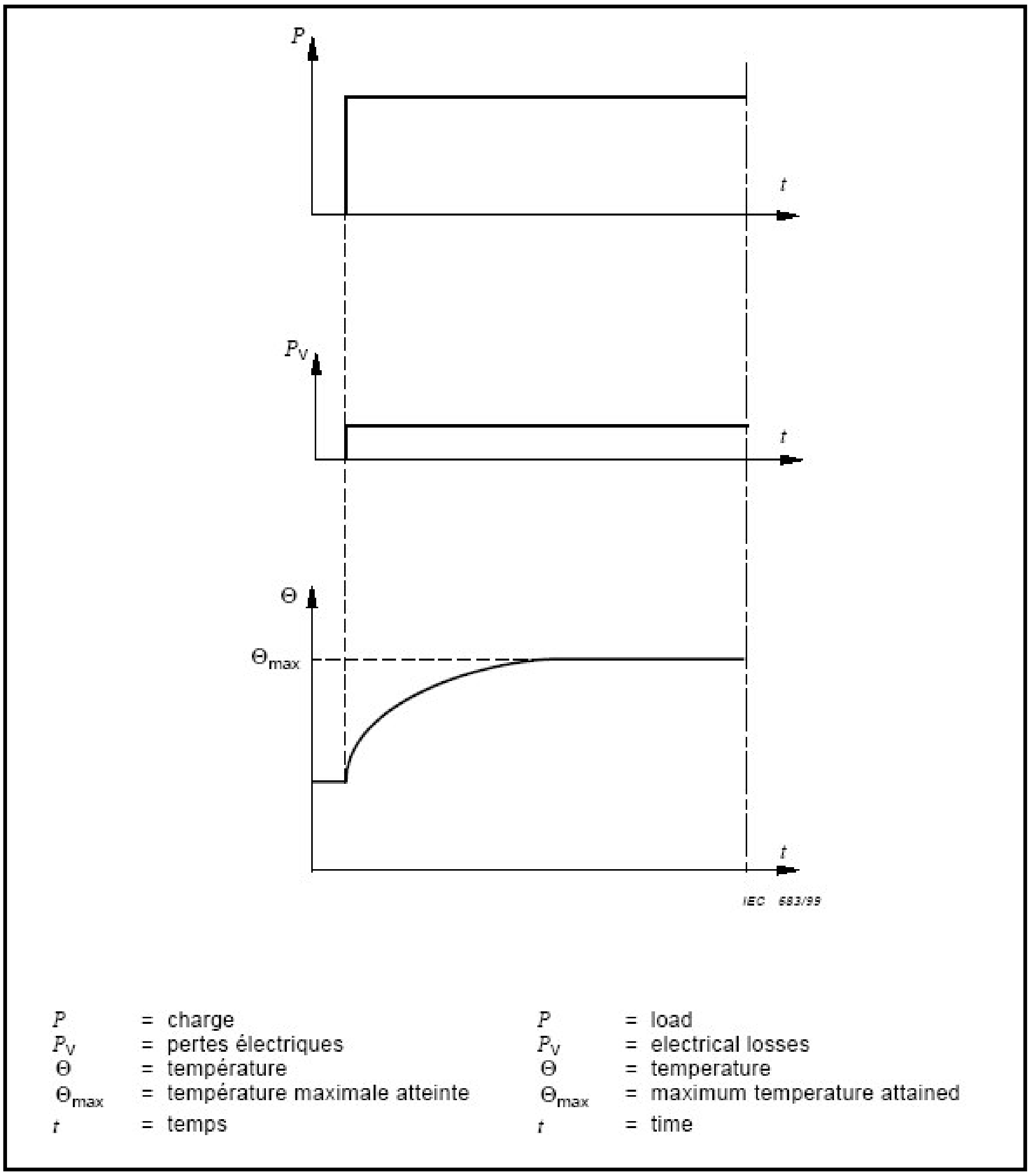


Figure A-1: Electric motor duty type S1 [21].

A.2 DUTY TYPE S2 – "SHORT TIME DUTY"

Motor is operated with a constant load for a time, which is less than required to reach thermal equilibrium. The motor is then allowed to rest and de-energise for a period that should be of sufficient duration to re-establish machine temperature within 2K of the coolant's temperature. The appropriate abbreviation for a short time duty cycle is S2 with an indication of the duration of the duty for example: S2 60 min.

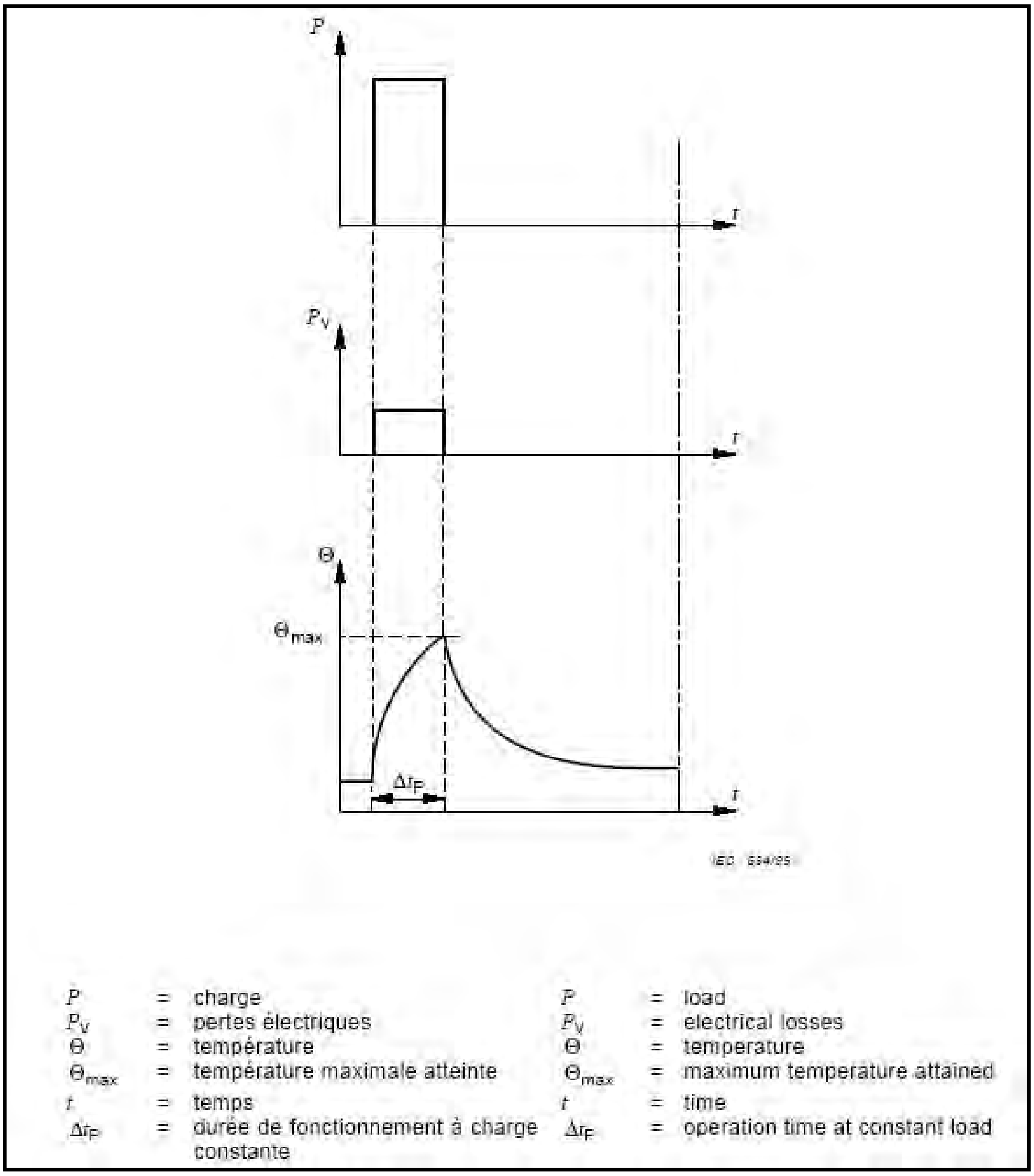


Figure A-2: Electric motor duty type S2 [21].

A.3 DUTY TYPE S3 – "INTERMITTENT PERIODIC DUTY"

Periodic duty implies that the time on load is less than required to reach thermal equilibrium. An S3 type motor is subject to a sequence of identical duty cycles. The duty cycle includes a period at constant load and then a rest and de-energised period. The starting current of each cycle does not significantly affect the temperature rise. The appropriate abbreviation is S3, followed by the cyclic duration factor. The cyclic duration factor is the operational time at full load as a percentage of the time of one cycle. For example: S3 25%.

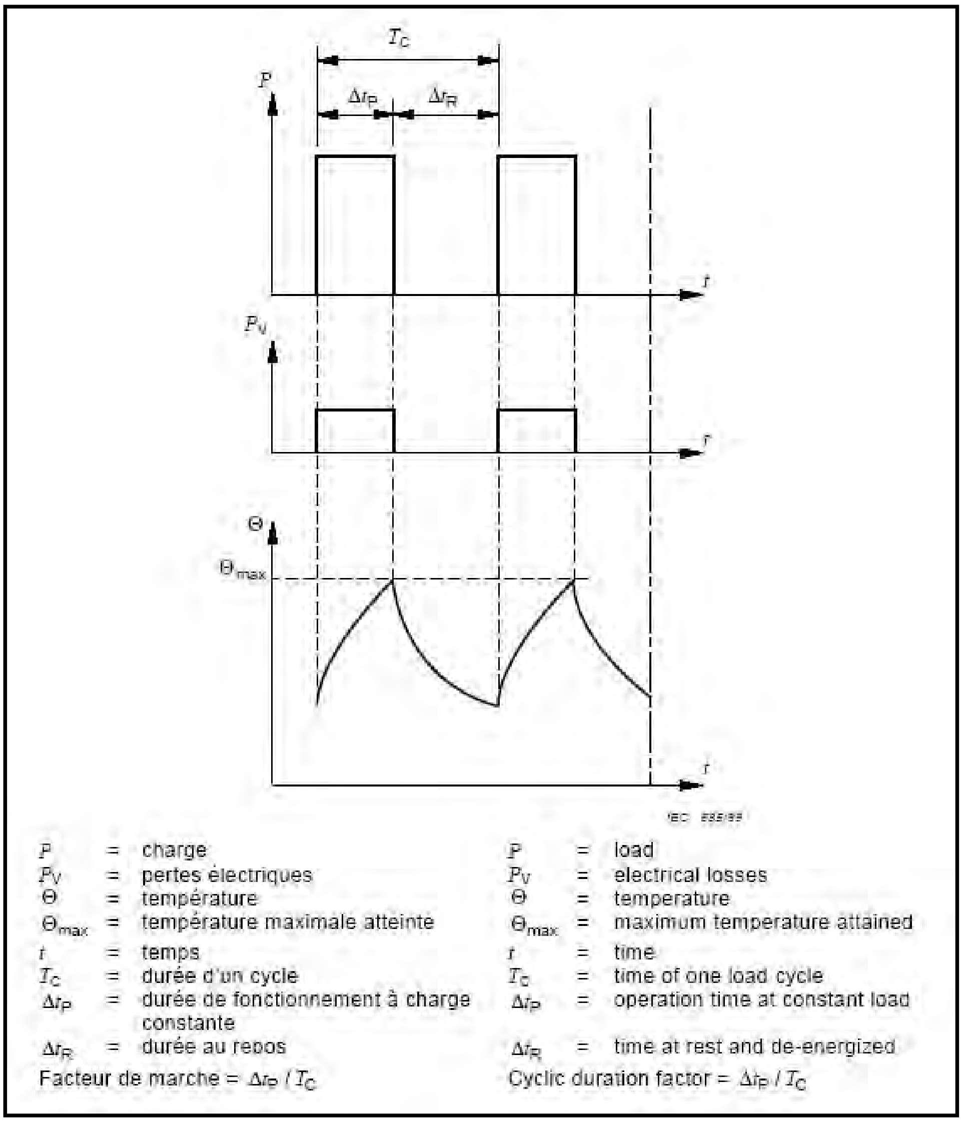


Figure A-3: Electric motor duty type S3 [21].

A.4 DUTY TYPE S4 – “INTERMITTENT PERIODIC DUTY WITH STARTING”

A sequence of identical duty cycles, but each duty cycle includes a significant starting time, a time of operation at constant load and then a rest and de-energised period. The appropriate abbreviation is S4, followed by the cyclic duration factor and the moment of inertia(J_m) of the motor and the moment of inertia of the load (J_{ext}), both referring to the motor shaft. For example:

$$S4\ 25\%\ J_m = 0{,}15\ kg \cdot m^2\ J_{ext} = 0{,}7\ kg \cdot m^2$$

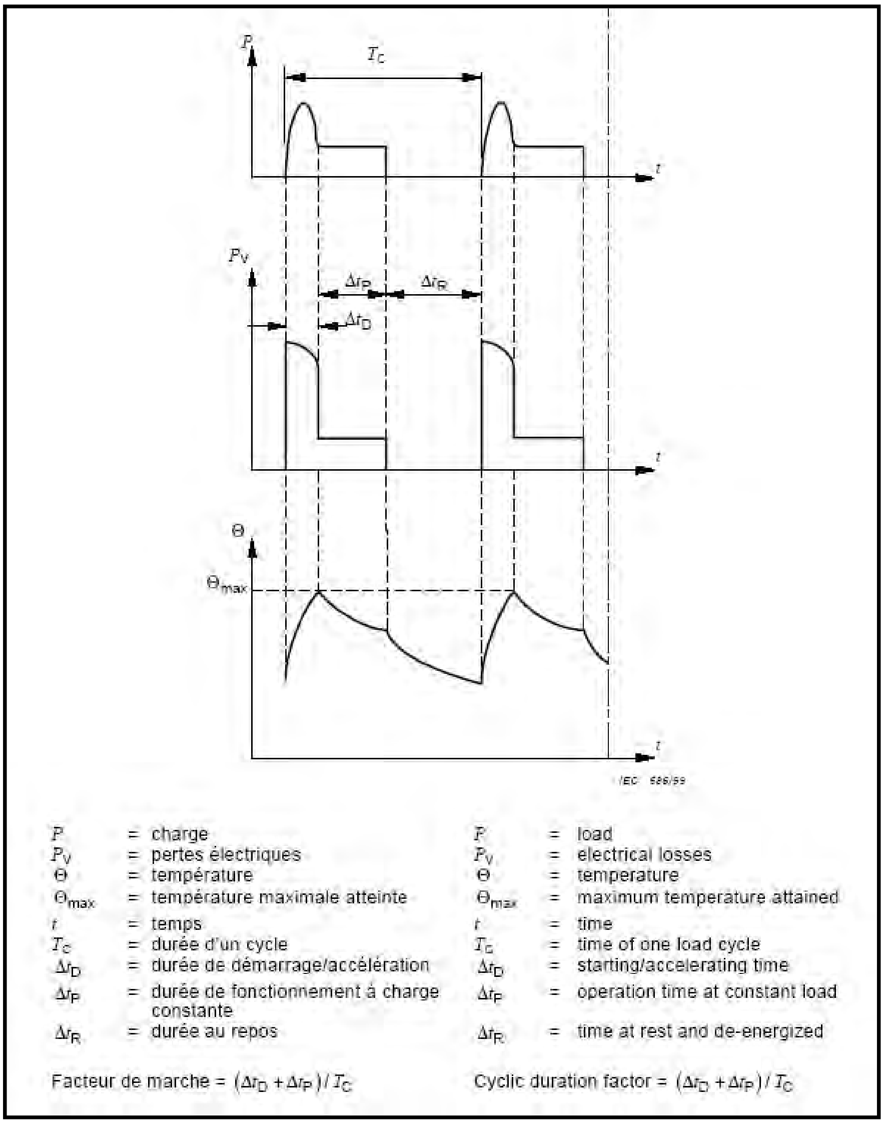


Figure A-4: Electric motor duty type S4 [21].

A.5 DUTY TYPE S5 – "INTERMITTENT PERIODIC DUTY WITH ELECTRIC BRAKING"

A sequence of identical duty cycles, but each duty cycle consists of a starting time, a time of operation at constant load, a time of electric braking and then a rest and de-energised period. The appropriate abbreviation is S5, followed by the cyclic duration factor and the moment of inertia of the motor (J_m) and the moment of inertia of the load (J_{ext}), both referring to the motor shaft. For example:

S5 25% Jm = 0,15 kg·m^2 Jext = 0,7 kg·m^2

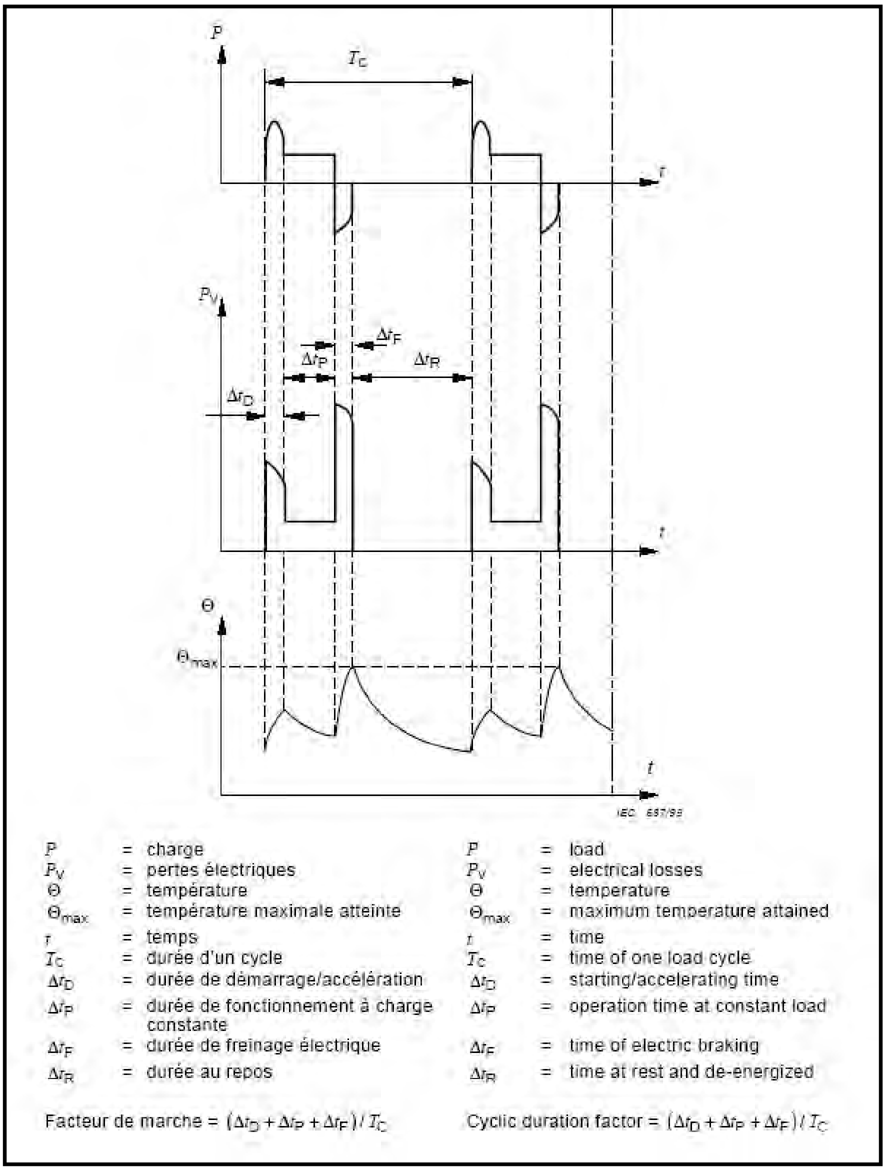
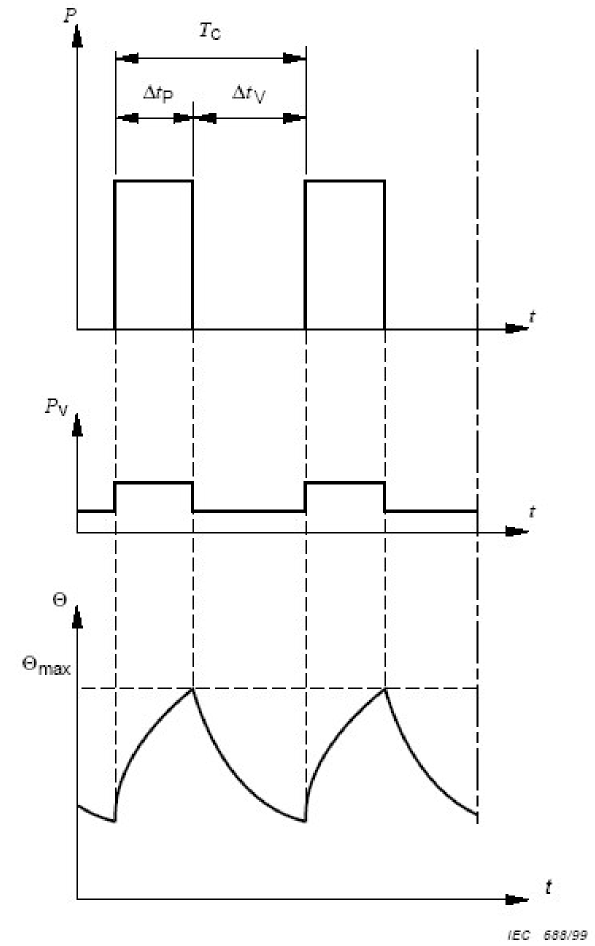


Figure A-5: Electric motor duty type S5 [21].

A.6 DUTY TYPE S6 – "CONTINUOUS OPERATION PERIODIC DUTY"

A S6 type motor is subject to a sequence of identical duty cycles. Each cycle includes a period of operation at constant load and a period of operation at no-load. There is no time at rest and de-energised. The appropriate abbreviation is S6, followed by the cyclic duration factor. The cyclic duration factor is the operation time at full load as a percentage of the time of one cycle. For example: S6 40%



P	=	charge	P	=	load
P_V	=	pertes électriques	P_V	=	electrical losses
Θ	=	température	Θ	=	temperature
Θ_{max}	=	température maximale atteinte	Θ_{max}	=	maximum temperature attained
t	=	temps	t	=	time
T_C	=	durée d'un cycle	T_C	=	time of one load cycle
Δt_P	=	durée de fonctionnement à charge constante	Δt_P	=	operation time at constant load
Δt_V	=	durée de fonctionnement à vide	Δt_V	=	operation time at no-load

Facteur de marche = $\Delta t_P / T_C$

Cyclic duration factor = $\Delta t_P / T_C$

Figure A-6: Electric motor duty type S6 [21].

A.7 DUTY TYPE S7 – “CONTINUOUS OPERATION PERIODIC DUTY WITH ELECTRIC BRAKING”

A sequence of identical duty cycles, but each cycle consists of a starting time, a time of operation at constant load and a time of electric braking. There is no time at rest and de-energised. The appropriate abbreviation is S7, followed by the moment of inertia of the motor (J_m) and the moment of inertia of the load (J_{ext}), both referring to the motor shaft. For example:

$$S7\ J_m = 0{,}4\ kg{\cdot}m^2\ J_{ext} = 7{,}5\ kg{\cdot}m^2$$

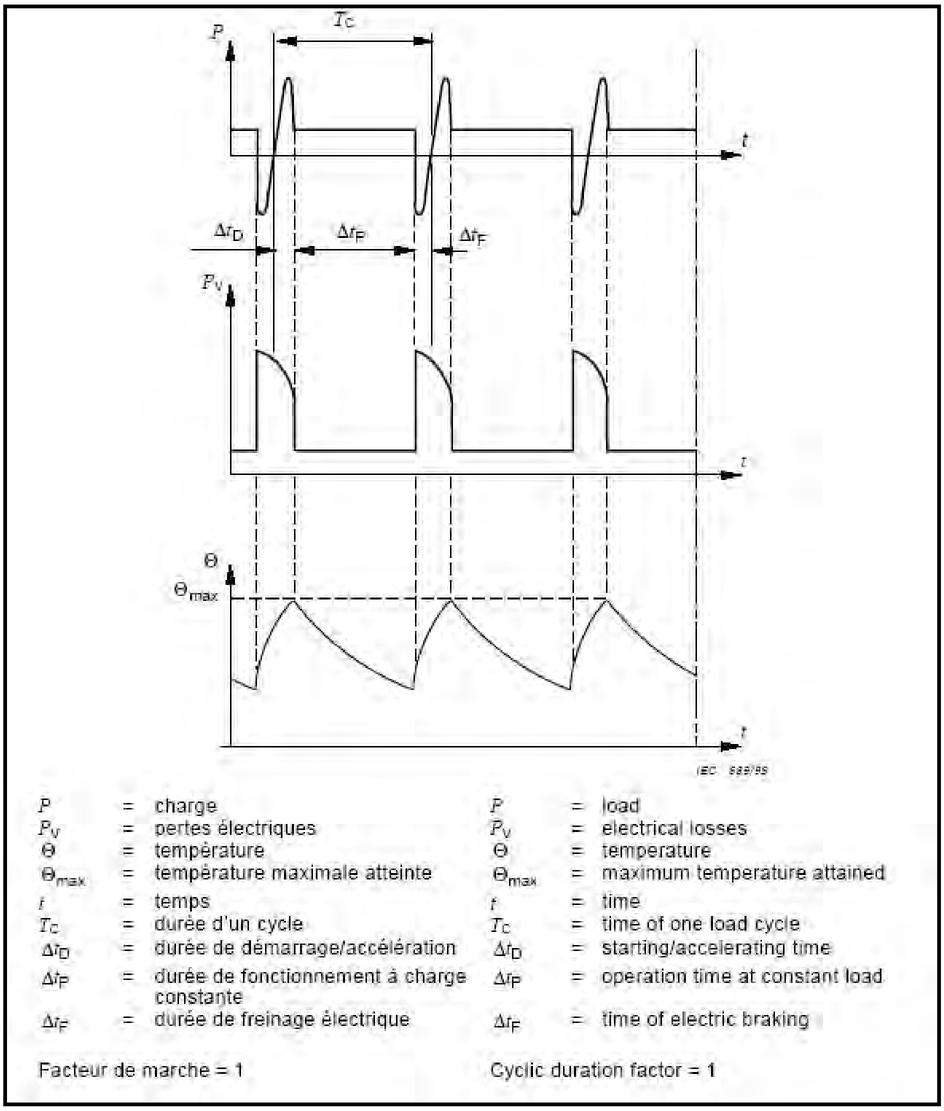
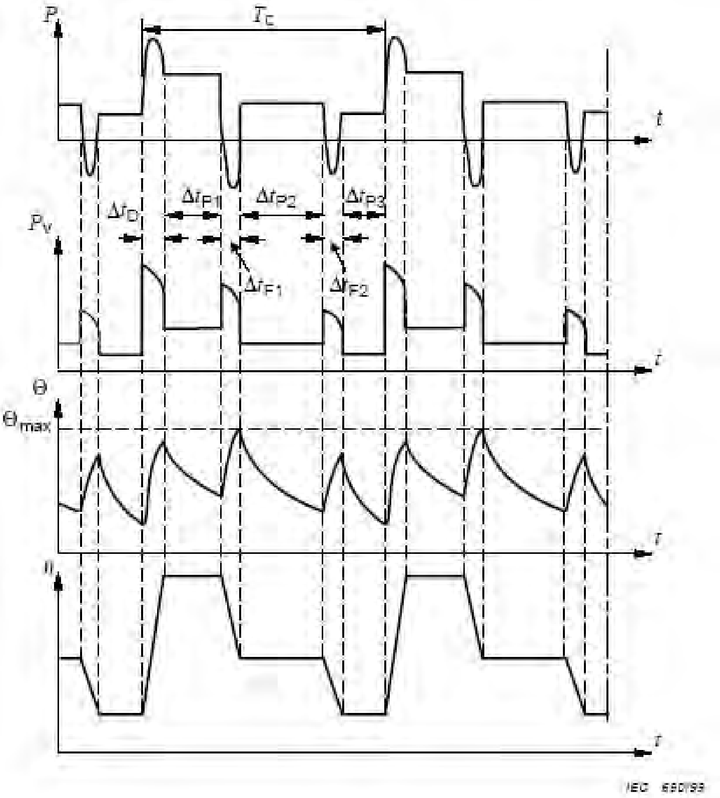


Figure A-7: Electric motor duty type S7 [21].

A.8 DUTY TYPE S8 – "CONTINUOUS OPERATION PERIODIC DUTY WITH RELATED LOAD/SPEED CHANGES"

A sequence of identical duty cycles, but each cycle consists of a time of operation at constant load corresponding to a predetermined speed of rotation. This is followed by one or more times of operation at other constant loads corresponding to different speeds of rotation. There is no time at rest and de-energised. The appropriate abbreviation is S8, followed by the moment of inertia of the motor (J_m) and the moment of inertia of the load (J_{ext}), both referring to the motor shaft. The load speed and cyclic duration factor for each speed condition is also given for example:

S8 $J_m = 0,4\ kg \cdot m^2$ $J_{ext} = 7,5\ kg \cdot m^2$	16 kW	740 min^{-1}	30%
	40 kW	1460 min^{-1}	30%
	25 kW	980 min^{-1}	40%



P	=	charge	P	=	load
P_V	=	pertes électriques	P_V	=	electrical losses
Θ	=	température	Θ	=	temperature
Θ_{max}	=	température maximale atteinte	Θ_{max}	=	maximum temperature attained
n	=	vitesse	n	=	speed
t	=	temps	t	=	time
T_C	=	durée d'un cycle	T_C	=	time of one load cycle
Δt_D	=	durée de démarrage/accélération	Δt_D	=	starting/accelerating time
Δt_P	=	durée de fonctionnement à charge constante (P1, P2, P3)	Δt_P	=	operation time at constant load (P1, P2, P3)
Δt_F	=	durée de freinage électrique (F1, F2)	Δt_F	=	time of electric braking (F1, F2)

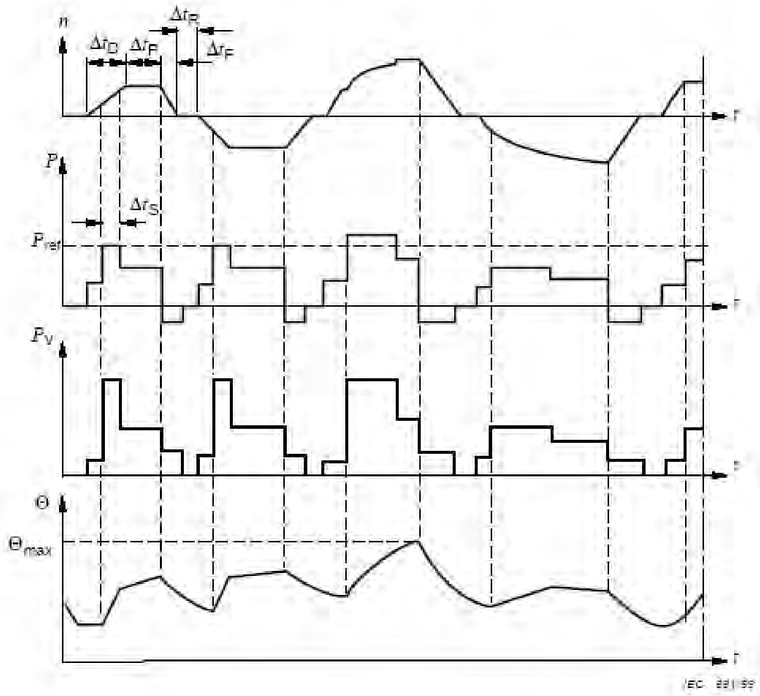
Facteur de marche = $(\Delta t_D + \Delta t_{P1}) / T_C$; $(\Delta t_{F1} + \Delta t_{P2}) / T_C$; $(\Delta t_{F2} + \Delta t_{P3}) / T_C$

Cyclic duration factor = $(\Delta t_D + \Delta t_{P1}) / T_C$; $(\Delta t_{F1} + \Delta t_{P2}) / T_C$; $(\Delta t_{F2} + \Delta t_{P3}) / T_C$

Figure A-8: Electric motor duty type S8 [21].

A.9 DUTY TYPE S9 – "DUTY WITH NON-PERIODIC LOAD AND SPEED VARIATIONS"

Load and speed vary non-periodically within the permissible operating range. The duty type includes frequently applied overloads that may greatly exceed the reference load. A constant load appropriately selected and based on duty type S1 is taken as reference value "P_{ref}" for the overload condition. The abbreviation for this duty type is S9.



P	= charge	P	= load
P_{ref}	= charge de référence	P_{ref}	= reference load
P_V	= pertes électriques	P_V	= electrical losses
Θ	= température	Θ	= temperature
Θ_{max}	= température maximale atteinte	Θ_{max}	= maximum temperature attained
n	= vitesse	n	= speed
t	= temps	t	= time
Δt_D	= durée de démarrage/accélération	Δt_D	= starting/accelerating time
Δt_P	= durée de fonctionnement à charge constante	Δt_P	= operation time at constant load
Δt_F	= durée de freinage électrique	Δt_F	= time of electric braking
Δt_R	= durée au repos	Δt_R	= time at rest and de-energized
Δt_S	= durée de fonctionnement en surcharge	Δt_S	= time under overload

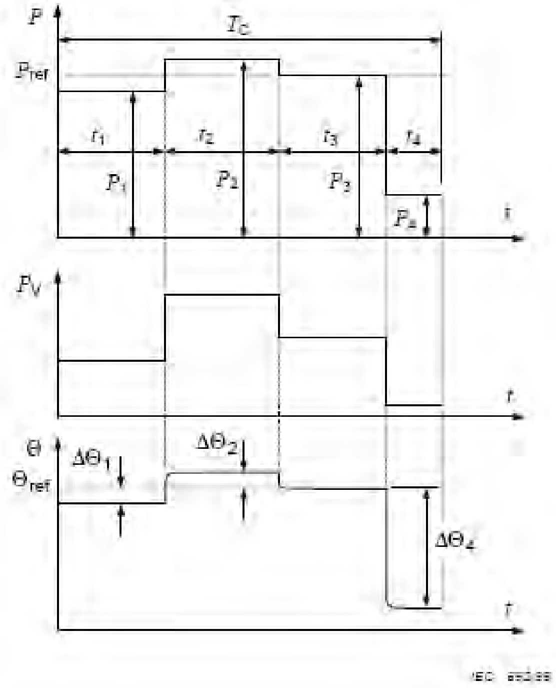
Figure A-9: Electric motor duty type S9 [21].

A.10 DUTY TYPE S10 – "DUTY WITH DISCRETE CONSTANT LOADS"

This duty type consists of four or less discrete values of load. Each load value must be maintained for sufficient time to allow the machine to reach thermal equilibrium. The minimum load within a duty cycle may be classified as the no-load, rest or de-energised period. The abbreviation for this duty type is S10. This is followed by the p.u. quantities $p/\Delta t$ for the respective load and its duration and the TL quantity for the relative thermal life expectancy of the insulation system. The reference value for the thermal life expectancy is the rating at continuous running duty with permissible limits of temperature rise based on the S1 duty type. The letter r indicates the period at which the load is at rest and de-energised. For example:

S10 $p/\Delta t$ = 1,1/0,4; 1/0,3; 0,9/0,2; r/0,1 TL = 0,6

A constant load appropriately selected and based on duty type S1 is taken as reference value "P_{ref}" for the discrete load condition.



P	=	charge
P_i	=	charge constante pendant un cycle
P_{ref}	=	charge de référence basée sur le service type S1
P_V	=	pertes électriques
Θ	=	température
Θ_{ref}	=	température à la charge de référence basée sur le service type S1
t	=	temps
t_i	=	durée d'une charge constante pendant un cycle
T_C	=	durée d'un cycle
$\Delta\Theta_i$	=	différence entre l'échauffement de l'enroulement au cours de chacune des charges pendant un cycle et l'échauffement basé sur le service type S1 à la charge référence

P	=	load
P_i	=	constant load within a load cycle
P_{ref}	=	reference load based on duty type S1
P_V	=	electrical losses
Θ	=	temperature
Θ_{ref}	=	temperature at reference load based on duty type S1
t	=	time
t_i	=	time of a constant load within a cycle
T_C	=	time of one load cycle
$\Delta\Theta_i$	=	difference between the temperature rise of the winding at each of the various loads within one cycle and the temperature rise based on duty cycle S1 with reference load

Figure A-10: Electric motor duty type S10 [21].

APPENDIX B MSU

See Compact Disk attached to back cover for Appendix B.

APPENDIX C FLAMEPROOF TRANSFORMER

See Compact Disk attached to back cover for Appendix C.

APPENDIX D GATE END BOXES

See Compact Disk attached to back cover for Appendix D.

APPENDIX E CM TRAILING CABLES

See Compact Disk attached to back cover for Appendix E.

APPENDIX F SC TRAILING CABLES

See Compact Disk attached to back cover for Appendix F.

APPENDIX G FB TRAILING CABLES

See Compact Disk attached to back cover for Appendix G.

APPENDIX H RB TRAILING CABLES

See Compact Disk attached to back cover for Appendix H.

APPENDIX I CM CONVEYOR MOTOR

See Compact Disk attached to back cover for Appendix I.

APPENDIX J CM PUMP MOTOR

See Compact Disk attached to back cover for Appendix J.

APPENDIX K CM GATHERING HEAD MOTORS

See Compact Disk attached to back cover for Appendix K.

APPENDIX L CM CUTTER MOTORS

See Compact Disk attached to back cover for Appendix L.

APPENDIX M CM TRACTION MOTORS

See Compact Disk attached to back cover for Appendix M.

APPENDIX N SC CONVEYOR MOTOR

See Compact Disk attached to back cover for Appendix N.

APPENDIX O SC PUMP MOTOR

See Compact Disk attached to back cover for Appendix O.

APPENDIX P SC TRACTION MOTORS

See Compact Disk attached to back cover for Appendix P.

APPENDIX Q FB CONVEYOR MOTOR

See Compact Disk attached to back cover for Appendix Q.

APPENDIX R FB CRUSHER MOTORS

See Compact Disk attached to back cover for Appendix R.

APPENDIX S RB PUMP MOTOR

See Compact Disk attached to back cover for Appendix S