ROPES :
AN EXPERT SYSTEM FOR CONDITION ANALYSIS OF WINDER ROPES

by

LANCE K. WILLIAMSON
B.Sc (ENG) Mech, University of Cape Town, 1987

THESIS

Submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering in the Department of Mechanical Engineering, University of Cape Town, January, 1990.

DECLARATION

This is to certify that the results, calculations and any other work presented in this thesis are essentially my own work, and that no part of it has been submitted for a degree at any other university.

....

L K Williamson

January, 1990

DEDICATION

I would like to dedicate this thesis to my parents for all their support and encouragement.

ACKNOWLEDGEMENTS

I acknowledge, with my sincere appreciation, the help of the following people:

Professor R K Penny, for his interest and wide ranging assistance as supervisor of this thesis,

Mr J P Prinsloo, for his time and effort in providing expert input to the program as head of the Anglo American Rope Testing Division, (Fochville),

Mr P J Badenhorst, for his expert contributions as rigger foreman on Western Deep Levels Gold Mine,

Western Deep Levels Gold Mine personnel, for their support and assistance, and

Anglo American Corporation of South Africa and Western Deep Levels Gold Mine, for their financial assistance.

SYNOPSIS

This project was commissioned in order to provide engineers with the necessary knowledge of steel wire winder ropes so that they may make accurate decisions as to when a rope is near the end of its useful life. For this purpose, a knowledge base was compiled from the experience of experts in the field in order to create an expert system to aid the engineer in his task.

The EXSYS expert system shell was used to construct a rule-based program which would be run on a personal computer. The program derived in this thesis is named ROPES, and provides information as to the forms of damage that may be present in a rope and the effect of any defects on rope strength and rope life. Advice is given as to the procedures that should be followed when damage is detected as well as the conditions which would necessitate rope discard and the urgency with which the replacement should take place.

The expert system program will provide engineers with the necessary expertise and experience to assess, more accurately than at present, the condition of a winder rope. This should lead to longer rope life and improved safety with the associated cost savings. Rope assessment will also be more uniform with changes to policy being able to be implemented quickly and on an ongoing basis as technology and experience improves.

The program ROPES, although compiled from expert knowledge, still requires the further input of personal opinions and inferences to some extent. For this reason, the program cannot be assumed infallible and must be used as an aid only.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF FIGURES — PAGE

LIST OF TABLES — PAGE

1. INTRODUCTION

Winder ropes provide the life support system for deep-level mining operations. It is these steel wire ropes that transport workers to and from the work place, while also performing the important task of removing the gold-bearing reef from the depths of the earth. Should these ropes become inoperable, the entire mining operation would come to a halt. As there are no suitable alternative methods available for bringing the ore to the surface, the financial livelihood of the mine would be severely affected.

An unscheduled winder rope replacement operation due to failure to predict the end of a rope's serviceable life could prove to be a costly error. The catastrophic failure of a winder rope, although not common, is the most severe form of rope failure. Such a failure could result in injury to persons and probable loss of life, especially if the rope was from a man winder. The possible shaft damage as a result of such a failure could cause major delays to shaft operations and a resultant loss of revenue.

It is the duty of certificated engineers, together with appointed competent persons to examine the winder ropes periodically. They are required to ascertain the amount of deterioration of the ropes and to make a decision as to when a rope has reached the end of its serviceable life. The expertise required to make an accurate assessment of the condition of a winder rope is usually acquired from experience. This experience will take a person many years of examining of ropes to accumulate in order to obtain the level of proficiency required.

In the past, the certificated engineers in the mining industry had generally worked their way up through the ranks to reach the level of section engineer. With this relatively long training period, it was possible for the prospective engineer to have the time and opportunity to acquire the experience necessary for the analysis of the condition of winder ropes. In recent times, this has however changed. The modern day engineer is generally in possession of a degree or diploma in engineering and has 2 to 3 years experience before obtaining his Government

Certificate of Competency. The examination of winder ropes forms only a small part of the knowledge such an engineer is meant to have acquired in just 2 to 3 years. The engineer is therefore reliant on the experience of his riggers and other competent rope specialists, or he is forced to make conservative estimations on the rope-life with little knowledge on which to base his decision.

A conservative decision is not necessarily a bad one when it comes to rope-life estimation, but how conservative the decision is can be pure conjecture. If the decision was based on experience and knowledge of rope deterioration then it is possible to quantify the degree of conservativeness and substantiate any decision. However, if the decision to remove a rope has little basis in experience and knowledge, it is not a decision made in the interests of good business acumen. Such decisions are in many instances inconsistent and have indiscernible accuracy. The inexperienced engineer is forced into conservative decisions out of the need for self-preservation. It is his career which is on the line, should a major accident occur as a result of rope failure.

The information available at present on the condition analysis of winder ropes is very scant and limited to a large degree to the minds of experienced rope personnel. A basic outline of what faults can occur in ropes and what to check for is available in various papers on the subject. How to actually check for these faults, where and when they are likely to occur, and what effect they will have on the life of a rope is however not forthcoming from publications. It is for these inferences and experience-based rules of thumb that an expert in the field is required.

Experts, like most personnel, are prone to retirement, leaving the service of the company and even death. With their unavailability to the company goes their immense wealth of knowledge and experience. It is therefore in the interests of any company to try to retain this information in some form for permanent availability. It is for this task that expert systems have found acceptance.

At present on Western Deep Levels Gold Mine, the recognised rope expert is close to retirement. Without an apparent successor being available, it is imperative that something be done to prevent the loss of this valuable resource. The mine has purchased an expert system package or shell known as EXSYS. It was envisaged to use this rule-based expert system shell to construct a knowledge base on the evaluation of the condition of winder ropes and the effect of prevailing deteriorative conditions on the serviceable life of a rope.

An accurate assessment of rope condition would enable maximum rope life to be obtained with the associated cost saving benefits through the early detection of rope damage, the cause of the damage could be ascertained and illuminated before the rope becomes unserviceable. Although conservative rope discard decisions promote safety, it is envisaged that more accurate rope assessment will provide the same levels of safety with increased rope life. There will therefore not be a trade-off of safety against rope life, but rather an increase in rope life through improved rope condition analysis.

PROBLEM STATEMENT

This thesis was commissioned by Western Deep Levels Gold Mine in order to provide the practicing engineer with a knowledge-base of information regarding the condition analysis of a winder rope. The knowledge-base was to be incorporated into an expert system program making use of the EXSYS expert system package, which had been previously purchased by the mine.

The expert system program was required to use the information forthcoming from the visual and electro-magnetic rope inspections to make inferences as to the condition of the rope. The program needed to take into account the legal regulations pertaining to winder ropes as well as the mine policy as regards criteria for rope discard. The program was to inform the engineer as to the extent of any damage present in the rope and the procedure to be followed to rectify the situation, should the damage be of such a nature that it warrants rope discard, then the urgency of discard must be specified, i.e. immediate, as soon as possible, or in the near future.

It was necessary to ensure that the expert system could be updated or altered by the engineer with relative ease. This would allow for a dynamic system in order that improvements in technology could be taken into account by the system at a later date.

In order to accomplish the above goals, this thesis first examines the subject of expert systems by means of a review. This is followed by a general outline of the constructions and uses of winder ropes and culminates with the compilation of the expert system program named ROPES. This program is intended as an aid to the engineer when analysing the condition of winder rope and applying necessary remedial actions.

2. REVIEW OF EXPERT SYSTEMS

2.1 THE DEVELOPMENT OF ARTIFICIAL INTELLIGENCE TO THE CONCEPT OF EXPERT SYSTEMS

Expert systems were the result of the development of artificial intelligence to the point where it was realised that expert heuristic knowledge was needed to produce accurate solutions to particular problems. One of the early areas of attention of artificial intelligence was in game-playing and puzzle-solving problems in 1974 (1). This idea was called 'state space search' and had the following three ingredients:-

(a) A starting state
e.g. the initial state of a chess board

(b) A test for detecting final states or solutions to the problem
e.g. the simple rule for detecting checkmate in chess

(c) A set of operations that can be applied to change the current state of the problem
e.g. the legal moves of chess

A simple form of state space search called 'generate and test' was used in the program to do the following:-

(a) Generate a possible solution in the form of a state in the search space
e.g. a new board position as the result of a move

(b) Test to see if this state actually is a solution by seeing if it satisfies the conditions for chess
e.g. checkmate

(c) If the current state is a solution, then stop, else go back to step (a)

From this it could be seen that more information would be required for the program to produce winning moves. The experience, imagination and analytical skills of an expert in the field would have to be incorporated in the program in order to obtain a heuristic method of searching for solutions.

In the 1950's artificial intelligence was used for theorem proving (1). Knowledge relevant to the problem solution was represented by a set of axioms which were used to prove solutions to be theorems as they followed from theory.

From the mid-1960's to the mid-1970's the artificial intelligence scientist sought to provide the computers with a knowledge base in order for them to have the ability to understand and reason. This area of research was largely unsuccessful as in order to make computers perceive analogies and learn from experience, one is required to have some theory of how humans achieve and exercise cognitive skills.

Over the last decade, developments reached the point where it was decided that in order to give a computer program the problem solving attributes of a human, it has to be provided with vast amounts of high quality knowledge about a specific problem area (2). As the knowledge had to come from experts in the specific fields, the problem solving programs were called expert systems.

From this point the subsequent evolution of expert systems can best be described in terms of a thesis, an antithesis and a synthesis (3).

THESIS: states that a general method of expert problem solving can be found and can be applied to many different problems. One main problem with this is that there is no place to put specialised procedural knowledge.

ANTITHESIS: states that we should build specific systems for specific tasks, essentially we should be willing to write a new program for each new task, however this method would appear to be intellectually labour intensive.

SYNTHESIS: takes the middle ground. The idea is that many tasks have requirements in common, and these requirements can be met by an expert system "shell".

This project followed the synthesis approach of designing an expert system for condition analysis of winder ropes using the EXSYS expert system shell.

2.2 FEATURES OF EXPERT SYSTEMS

2.2.1 BASIC CHARACTERISTICS OF AN EXPERT SYSTEM

An expert system was defined by the expert systems group of the British Computer Society to be the following:

> "An expert system is regarded as the embodiment within a computer of a knowledge - based component from an expert skill in such a manner that the system can offer intelligent advice or take an intelligent decision about a processing function. A desirable additional characteristic is that it justify its line of reasoning in a manner intelligible to the enquirer. The style adopted to obtain these characteristics is rule-based programming".

In general, a system can be said to be an expert system if it adheres to the following guidelines (4):

(a) The system performs at or near the level of human experts

(b) The system is applied to the difficult and important problems that we associate with calling in human experts as consultants

(c) The system operates in a manner similar to that of a human expert by giving a justification of the reasoning that lead to the expert conclusion

An expert system is defined by Donald A Waterman (2) as a computer program that has the properties shown in Figure 1.

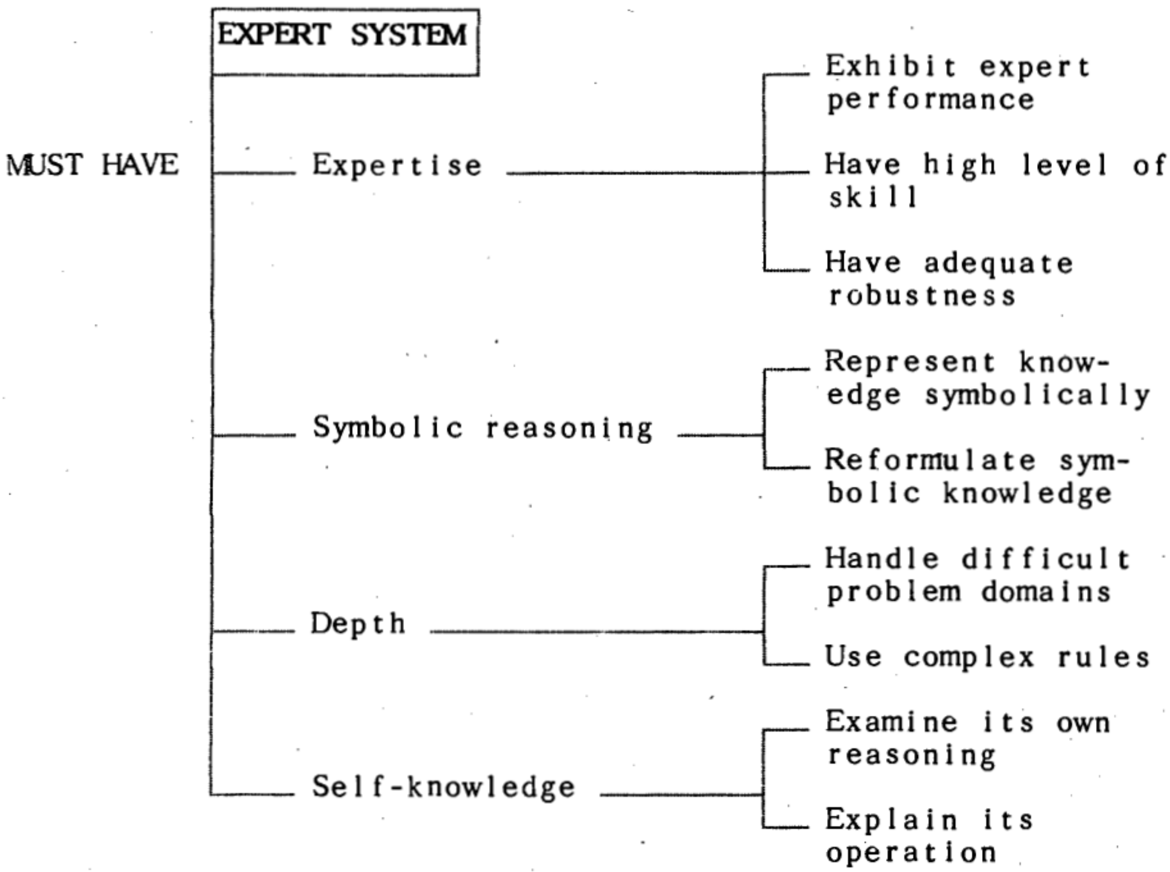

Figure 1: Characteristics of an Expert System (2)

These characteristics are considered in more detail below.

EXPERTISE

An expert system must achieve the same levels of performance in the domain of interest that human experts can achieve. Producing good solutions is however not enough. Real experts not only produce good solutions, but often will find them far more quickly than most novices. An expert system must therefore be skillful by applying its knowledge to produce solutions both efficiently and effectively, using shortcuts or heuristics that human experts use to eliminate wasteful or unnecessary calculations. An expert system must also be robust and have breadth as well as depth in order to mimic an expert.

SYMBOLIC REASONING

Experts tend to choose symbols to represent the problem concept and then apply various strategies and heuristics to manipulate these concepts rather than performing laborious mathematical calculations. The expert system needs to represent knowledge in the form of symbols, interpret the symbols and convert the problem to a form that lends itself to a fast or efficient solution.

Examples of symbols are shown below.

rope

fatigue

0.1

DEPTH

An expert system has depth; that is, it operates effectively in a narrow domain containing difficult, challenging problems. Thus the rules in an expert system are necessarily complicated, either through their individual complexity or their sheer number.

SELF KNOWLEDGE

A rule-based expert system is capable of working back through its rules in order to justify the conclusions reached. This explanation of results will give the user more confidence in the results as well as in the system. It is also easier to prodict and test the effect of a change on the operation of such a system. This can also aid the system development and make it easier to debug.

2.2.2 DIFFERENCES BETWEEN EXPERT SYSTEMS AND CONVENTIONAL COMPUTER PROGRAMS

Expert systems differ from conventional programs mainly in that they manipulate knowledge rather than data. The main differences between expert systems and conventional programs have been set out in Table 1.

EXPERT SYSTEMS	CONVENTIONAL PROGRAMS
manipulation of knowledge	manipulation of data
heuristic	algorithmic
inferential process	repetitive process

Table 1: Comparison of Expert Systems with Conventional Computer Programs

2.2.3 BASIC STRUCTURE OF AN EXPERT SYSTEM

An expert system consists of four main components which are briefly described below. A schematic diagram (Figure 2) shows the layout of these components in the expert system (5).

(a) USER INTERFACE

The user interface is the mechanism which allows the user to communicate with the system and to create and use a data base for the specific case at hand. This is normally accomplished by means of a PC or main frame computer with the necessary program to interact with the interface engine.

(b) INTERFACE ENGINE

The interface engine incorporates reasoning methods, which in turn act upon input data and knowledge from the knowledge base, to solve the stated problems and provide an explanation of how it arrived at the solution.

(c) RULE BASE

The rule base is a storage facility for facts, rules, heuristics and situation patterns pertaining to the problem area.

(d) INFORMATION BASE

The information base enables the user to update the data without changing the rules of the system. The Transfer of information to the base from external sources (e.g. data base programs, charts, tables etc.) can be accomplished using this facility.

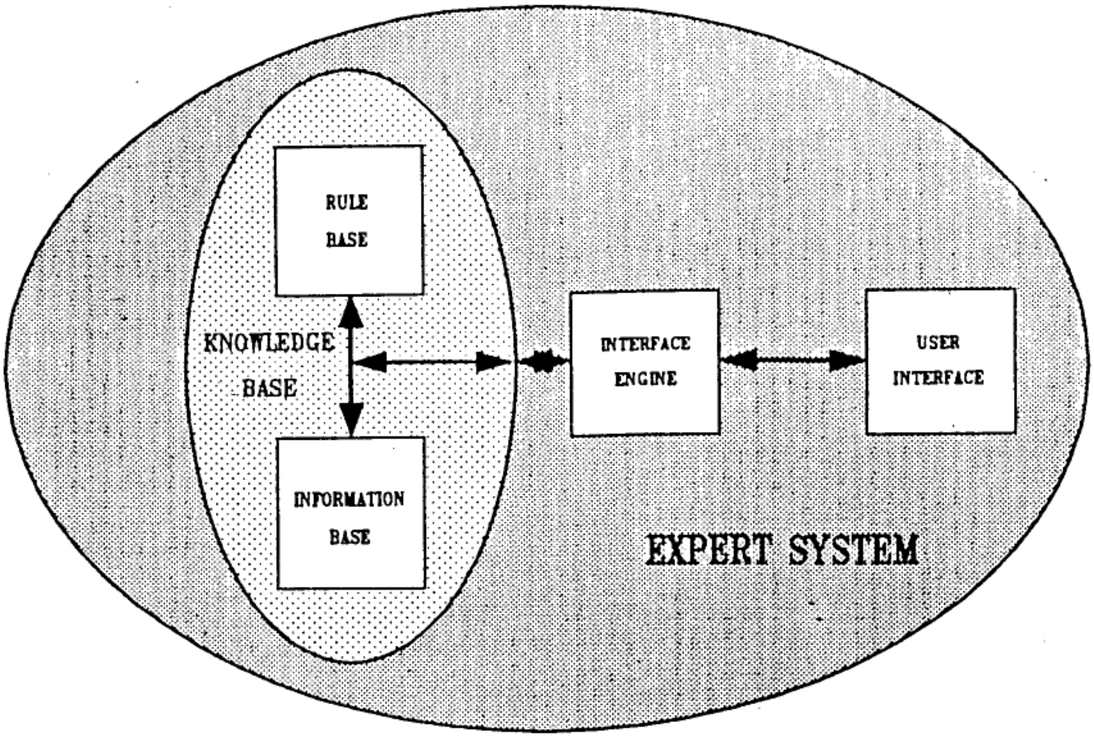

Figure 2: Schematic Layout of an Expert System

2.3 ATTRIBUTES OF A GOOD EXPERT FOR EXPERT SYSTEM DEVELOPMENT

A description of what constitutes an "expert" is given below by Paul E. Johnson (6).

> "An expert is a person who, because of training and experience, is able to do things the rest of us cannot; experts are not only proficient, but also smooth and efficient in the actions they take. Experts also know a great many things and have tricks for applying what they know to problems and tasks, they are also good at plowing through irrelevant information in order to get at basic issues, and they are also good at recognising problems they face as instances of types with which they are familiar."

The domain expert plays a vital role in the successful development of an expert system. Some attributes of a good domain expert are set out below (7).

(a) The expert should be thoroughly familiar with the domain, including:
- Task expertise built up over a long period of task performance
- Knowledge of the organisations that will be developing and that will be using the expert system
- Knowledge of the user community
- Knowledge of technical and technological alternatives

(b) The expert's knowledge and reputation must be such that if the expert system is able to capture a portion of the experts expertise, the systems output will have credibility and authority.

(c) The expert should commit a substantial amount of time to the development of the system, including temporary relocation to the development site, if needed.

(d) The expert must be capable of communicating his knowledge, judgement and experience.

(e) The expert should be cooperative, easy to work with and eager to work on the project.

(f) The expert should have an interest in computer systems, even if not a computer specialist.

2.4 EXPERT SYSTEMS IN INDUSTRY

2.4.1 APPLICATION AREAS AND USES FOR EXPERT SYSTEMS

Expert systems have been successfully implemented in a number of areas of industry (2), some of which are listed in Table 2.

Agriculture	Manufacturing
Chemistry	Mathematics
Computer Systems	Medicine
Electronics	Meteorology
Engineering	Military Science
Geology	Physics
Information Management	Process Control
Law	Space Technology

Table 2: Application Areas for Expert Systems

The expert systems were developed in these areas for the following uses:

Diagnosis of conditions
Monitoring of systems
Instruction of personnel
Troubleshooting
Design
Interpretation of data
Scheduling

2.4.2 APPLICATION SUCCESSES OF EXPERT SYSTEMS

In the April 1989 issue of "Mechanical Engineering" it was stated in an article edited by David Horn (9) that the number of expert systems installed in industry was probably not more than 2,000. Of these, many are prototypes, but there are some notable successes. Among them are the system that is emulating a machinery maintenance expert at Campbell Soup Co., the tax expert system known at ExperTax at Coopers and Lybrand, the American Express's Authoriser's Assistant. Technology Applications of Jacksonville, Fla., is currently building a knowledge-based system to increase the safety of nuclear power plants (9).

One of the more notable successes is XCON (9), co-developed by Digital Equipment Corp. and Carnegie - Melon University. XCON is used by Digital Equipment to configure computer orders, including items such as cables, memory boxes and components. Before XCON, Digital Equipment experienced delays in computer orders, due to a shortage of qualified configuration experts.

A real-time expert system that has found applications across a number of industries is G2 from Gensym Corp. (Cambridge, Mass.) (9). It is designed for large applications where hundreds or thousands of variables are monitored concurrently. It is tailored for such complex real-time applications as process control, computer-integrated manufacturing, financial trading, network monitoring, and automatic testing.

System 90, developed by Septor Electronics (El Paso, Tex.) is in use in major car manufacturers in U.S., England, Italy and Germany (9). The system controls the transfer-machines and has reportedly increased their average uptime from 48 to 90 percent.

At the Kennedy Space Centre in Florida, Lockheed Corp. has developed the world's largest knowledge-based system to trace signals through hundreds of thousands of electrical connections of the space shuttle orbiters (9). The Space Centre also has several projects under way to use a system known as KATE (knowledge-based autonomous test engineer) for both launch-vehicle operations and cargo processing (9).

General Electric has developed an expert system named CATS (8) which performs troubleshooting for diesel-electric locomotive engines. The system was initially designed with 50 rules and now has in excess of 500 rules. Another troubleshooting knowledge-based system is IN-ATE (8). This system is for the electronics field and produces automatically a binary pass/fail decision tree of test points to be checked.

ACE is a system in regular use for preventative maintenance of telephone cable (8), by selecting equipment for the said maintenance. The knowledge base is a database containing repair activity records.

It can be seen from the aformentioned applications that significant benefits have been obtained from the use of expert systems. The benefits include the increased availability of "experts", improved productivity, monitoring of complex systems and direct financial benefit from preventative maintenance. There are a substantial number of systems under development at present which would serve to indicate that the number of expert systems in use in industry should increase dramatically in the future.

At present the emphasis has turned to the design of expert systems by means of packages or shells. These shells provide the framework around which different expert systems can be constructed. As a number of expert systems can be designed for different applications and at relatively low cost with a shell, the use of expert systems has become a viable proposition for smaller industries.

Due to the fact that all expert systems have the same basic layout and requirements, the race is now on to see who can develop the ultimate expert system shell. This shell would have to be suitable for any application in any field of any discipline. As the development of an expert system from scratch is a costly exercise, it would appear that future system development will be accomplished using universally conformable expert system shells.

A list of some of the manufacturing and engineering applications of expert systems in use in industry (8) has been set out in Appendix A.

A list of engineering applications of expert systems designed at the University of Cape Town but not necessarily in use in industry is given in Appendix B.

2.5 ADVANTAGES AND DISADVANTAGES OF EXPERT SYSTEMS

The following can be seen to be advantages of expert systems:-

ADVANTAGES

Expert systems provide for the retaining of expert knowledge within a company after the expert has left its service.

Expert systems provide readily obtainable and consistent solutions to difficult or complex problems.

Changes can be made to expert systems to incorporate new information without necessitating major changes to the original system.

Expert systems allow for the distribution of information through the company for simultaneous use at a number of places at any time, even after business hours.

Expert systems can be used as teaching aids for inexperienced personnel as well as being a backup reminder system for personnel with experience in the relevant field.

The following can be seen to be disadvantages of expert systems:-

DISADVANTAGES

Expert systems require a vast amount of resource time to develop.

Expert systems are unable to reason from first principles.

Expert systems can not exhibit commonsense knowledge.

An expert system solution to a specific problem must be verified by a human as being correct due to the fact that legal action, over an incorrect solution, can not be instituted against a computer program.

3. TYPES OF WINDERS AND WINDER ROPES IN USE

3.1 THE CONSTRUCTION OF STEEL WIRE ROPES

A steel rope is comprised of a number of strands (usually six) which are twisted around a central core. This core could be made up of fibre or a single strand (Wire Main Core - WMC) or it could be a complete steel wire rope (Independent Wire Rope Core - IWRC). The rope strands are made up of a number of wires laid up symmetrically in a helical formation. Figure 3 shows the components of a rope.

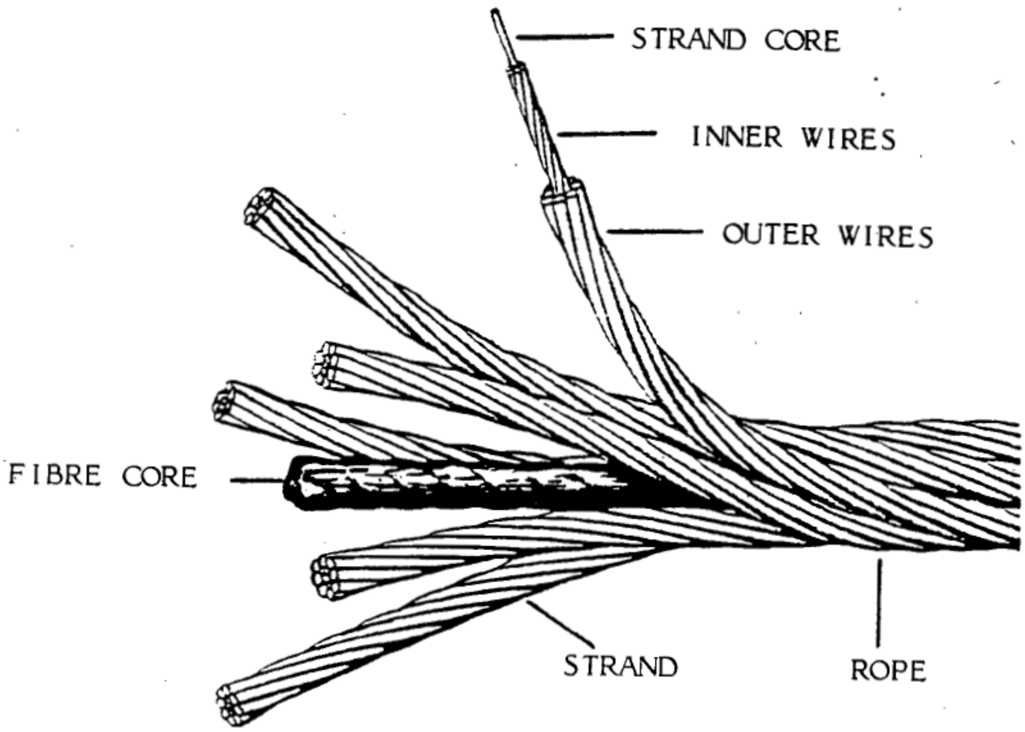

Figure 3: Components of a Rope

Steel wire ropes are used essentially for transmitting tensile forces. The main characteristics which make them so well suited to this function are flexibility and their strength in terms of both mass and diameter. The tensile strength of rope steel can be up to four times higher than that of structural mild steel of the same cross-sectional area. By varying the rope construction, it is also possible to create ropes with resistance to abrasion, repeated bending, shock loading and pressure.

Starting with the way in which the strands in a rope are laid up, it is possible to design a rope for different environments. There are two general methods of laying strands in a rope, namely, Ordinary Lay and Lang's Lay (10). In an Ordinary Lay rope, the wires of the strands are laid in one direction and the strands are laid into the rope in the opposite direction. In a Lang's Lay rope, both the wires in the strands and the strands in the rope are laid in the same direction. This allows for a spread of wear over a greater length of wire in the strand, due to the larger contact area offered. An improvement in fatigue properties is also evident. Lang's Lay is used where resistance to abrasion is required. By having a rope construction with large outer wires and a Lang's Lay, it is possible to obtain optimum resistance to abrasion.

Unlike an Ordinary Lay rope, the Lang's Lay rope cannot be used for lifting loads which are free to rotate. In winding the Lang's lay rope is favoured as guide rails are employed in the shaft for the cages and skips. Lang's Lay ropes do however tend to form loops when slack which result in kinks when the rope is tautened. Figure 4 shows the difference between Ordinary and Lang's Lay.

ORDINARY LAY

LANGS LAY

Figure 4: Comparison of Ordinary Lay with Lang's Lay

Whether a rope is Ordinary or Lang's lay, it can be either right-hand or left-hand lay. Generally, all ropes are right-hand lay, i.e.

looking down the length of the rope, the strands will spiral in a clockwise direction. The left-hand lay ropes are used in conjunction with right-hand lay ropes on Blair multi rope winders to counteract spin while also being used for drilling purposes to prevent unscrewing of right-hand threads.

In an effort to overcome the spinning which occurs in a rope, it is necessary to construct the rope with two layers of strands laid up in opposite directions. The opposing torques generated by each layer will tend to balance or neutralise each other. The inner rope will be laid up left-hand while the outer covering layer of strands will be laid up in a right-hand direction. When the rope is put under load, the inner and outer layers will tend to unlay in opposite directions and so balance each other. Hence the concept of non-spin ropes. The lay length of a strand or rope is the pitch of the wire helix in a strand or the strand helix in the rope. i.e. the distance between the points where a wire or a strand reappears along the same plane in a strand or a rope. (Figure 5).

Figure 5: The Lay Length of a Wire in a Strand

The lay of wires in a strand or the strands in a rope can be unequal or equal. In an unequal lay strand, the wires in the strand vary from layer to layer so that the wires of an outer layer do not lie in the grooves formed by the underlying layer, thus resulting in a tendency toward nicking of the wires between layers, as well as extra bending when the rope is in operation. In equal lay ropes, the wires in the inner and outer layers have the same lay lengths and hence the wires in an outer layer would be in the grooves formed by the wires of the underlying layer. There is therefore no interlayer nicking of the wires during operation of the rope and internal wear is less than that present in unequal lay ropes. In unequal lay ropes, secondary bending occurs as a result of the wires having to bend in one direction when a rope passes over a sheave while also bending in another direction over underlying wires. As a result, equal lay ropes have a higher failure life than unequal lay ropes. Equal lay ropes also have more resistance to crushing and are generally preferred to unequal lay ropes in winding operations.

The number of wires in a rope has a significant influence on the properties of a rope, as well as its life. The greater the number of wires in a rope, the greater is its flexibility and resistance to bending fatigue, over the same bending radius. This flexibility as a function of the number of wires in a rope is however not transferable between all the different construction methods.

Triangular strand ropes are by nature of their construction the most rigid ropes irrespective of the number of wires in the rope. The size of the outer wires will however give an indication as the the abrasive resistance of the rope in all constructions. Smaller wires wear faster than larger ones.

The core of a rope is an important constituent of a rope in that primarily it supports the strands and allows the rope to bend without distortion. Secondary functions of a core are possibly more important in that a fibre core provides necessary lubricant for internal wires while a wire rope core provides vital support to prevent the rope from becoming flattened and distorted when subjected to high drum or sheave pressures or crushing.

A recent development in the manufacture of ropes is the drawing of a strand through a die after it has been formed (10). This process produces a strand in which the exterior wires are considerably flattened and the inner wires deformed so as to produce a plane surface contact instead of a line contact between them. The process serves to increase the strength and fatigue life of ropes. There are however limitations to this process as regards size and tensile strength of the wire used.

As different winding applications and winders demand varying rope constructions and characteristics, the ropes used on the different types of winders will be outlined when the individual winders are discussed.

3.2 SINGLE-DRUM WINDERS

A single-drum winder is used where space restrictions in a shaft make it impossible to accommodate a second conveyance. These winders are normally service winders and are used mainly for conveying personnel between levels. On Western Deep Levels, (WDL) the single-drum winders are used for incline shafts and not in vertical shafts.

As the name suggests, a single-drum winder consists of one drum driven by a D.C. motor. (Figure 6). A single-drum winder always has an overlay rope by law. Disadvantages of these winders are the fact that they always operate in an out-of-balance condition which requires more power and a larger motor than if the load was balanced. The winder does however have few moving parts and requires less maintenance than more complex systems.

In inclined shaft applications, simple triangular strand winding ropes are used. Due to the high abrasion factor, a Lang's Lay is preferred. The rope core is usually fibre as there is very little crushing force on the rope. An inclined shaft rope is usually discarded due to mechanical damage such as kink at the front end while deflection sheaves and rollers can cause extensive wear damage to the rope if they are not correctly maintained. A seized roller will result in rapid abrasive wear of a rope which will increase hyperbolically as a groove is worn in the roller by the rope. An inclined shaft rope will seldom have to be replaced due to broken wires or fatigue.

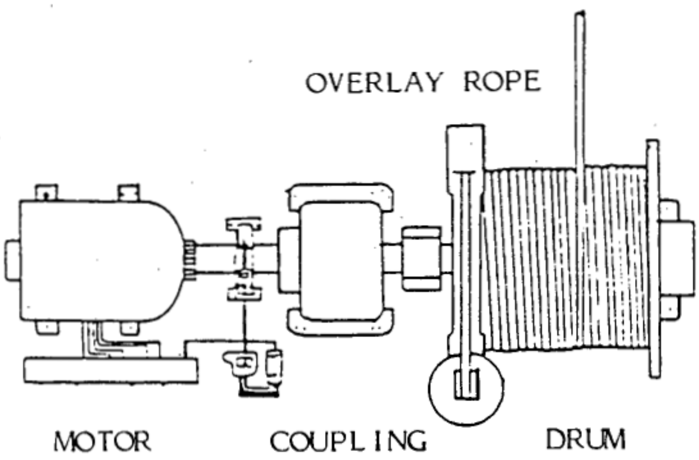

Figure 6: Layout of a Single-Drum Winder

3.3 DOUBLE-DRUM WINDERS

A double-drum winder consists of two single drums linked by means of a shaft. Under normal running conditions, the drums run in unison with each having its own set of brakes which are activated simultaneously. By means of clutching, it is however possible to operate the drums individually. Normally a conveyance is connected to each drum, but where space in the shaft is limited, a counter-weight can be used to balance the load. On Western Deep Levels the double-drum winders are used mainly for the transport of man and machinery and for service winders. Limited rock winding is undertaken using these winders.

An advantage of double-drum winding is that simultaneous raising or lowering of men or material to a level can be done. Under emergency conditions, the winder can be used as a single drum. One disadvantage of the double-drum winder is that in cutting rope for a test or pulling back ends, the possibility of a long and a short rope could arise. The conveyances could then not be used between two specific levels without clutching each trip. The maintenance cost of these winders is also higher than for the single-drum winders.

As far as the ropes of a double-drum winder are concerned, the law stipulates that the right-hand drum will have an overlay rope, while the left hand drum has an underlay rope. The principle of underlay and overlay ropes is illustrated in Figure 8. The ropes used on double drum winders vary according to the duty of the winder, i.e. the depth of wind and payload.

The majority of ropes on double-drum winders are triangular strand, Lang's lay ropes with fibre cores. These ropes are used for depths of wind less than 2,000m. Where the depth of wind is over 2,000m, a non-spin triangular strand rope with a wire main core is preferred.

At greater depths, rope spin and crushing due to the weight of the rope become critical factors. In some instances, a compound triangular strand rope is used for increased rope strength. A Lang's Lay rope is essential to reduce rope wear.

3.4 KOEPE WINDERS

Koepe winders are friction winders used for rock winding on Western Deep Levels. In this system the rope is driven by friction between the rope and the driving sheave with the typical wrap of rope around the sheave wheel being greater than pi radians. The main advantage of friction winding is that such a system can be very economical in terms of power consumption. The Koepe system does however need more attention than drum-winding systems with rope life decreasing due to non-ideal friction winding systems being used.

The ideal Koepe application (11) is for depths up to about 1,000m with a large drum (100 to 200 times rope diameter), no deflection sheaves (which are very detrimental to ropes), and no tail-rope sheaves at all, - just free loops with adequate clearance and a small load range. Figure 7 (a) shows an ideal Koepe layout.

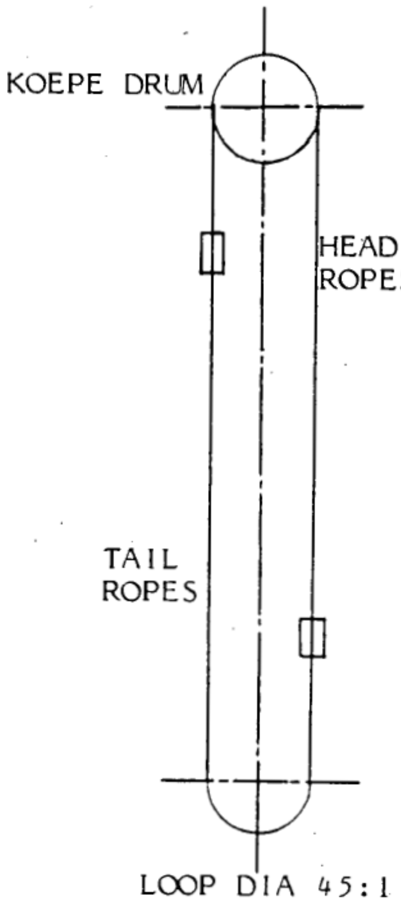

Figure 7(a): An ideal Koepe Layout With No **Deflections**

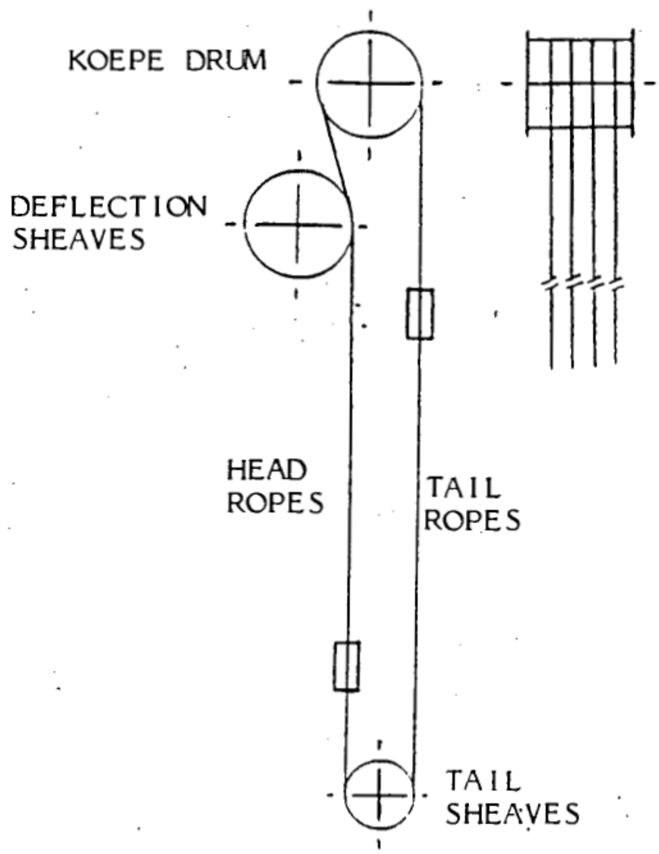

Figure 7(b): Koepe Layout at WDL With Deflection and Tail Sheaves

On Western Deep Levels, the size of the main shafts is such that free-looping tail ropes cannot be accommodated and deflection and tail sheaves need to be used. This is extremely detrimental to rope life as the rope is subjected to continual reverse bending by the deflection sheaves. The lining used in the tail sheaves tends to restrict the movement of the rope wires as well as contributing to abrasive wear of the rope. Both the aforementioned conditions lead to premature failure of the rope.

The Koepe layout in use on the main shafts is shown in Figure 7(b). There are four head and four tail ropes employed in the system. The sub-shaft Koepe winders do however have free-looping tail ropes, but deflection sheaves are still required. The sub-shaft winders have four head ropes and only two tail ropes.

The head ropes in use are 15 strand, non-spin ropes of Lang's Lay with a wire main core. The main shaft tail ropes are mainly 17 strand non-spin ropes of Lang's Lay and wire main core, while the sub shaft tail ropes are of compound strand construction with wire main cores. Due to the mechanism of friction winding, the Koepe head ropes cannot be protected from wear and corrosion by lubrication to the same extent as drum winder ropes. Lubrication of head ropes is limited to internal wires only with galvanising being used to oppose the onset of corrosion in lower tensile grades of steel wire ropes.

In Koepe head ropes, it is usually the number of broken wires, due mainly to fatigue, that determines the life of the rope. The ropes usually fail in the region which passes through the sheave when there is maximum load being accelerated (i.e. when the skip is at shaft bottom). External wear on the head ropes is minimal, but internal wear is severe due to the wrap over the head pulley. The lack of external greasing on the head ropes makes them susceptible to corrosion.

The ropes which pass through tail sheaves are affected by external wear which can progress rapidly if the sheave groove is not maintained at the correct size. Corrosion is also a major destroyer of tail ropes as any water in the shaft tends to collect on the undersides of the tail ropes and the tail sheaves. Water on the tail sheaves will be transmitted to the ropes as they pass through the sheaves.

Tail ropes being largely non-spin ropes are susceptible to bird-caging or the loosening of outer strands. If the tail rope sheaves are too tight, the outer strands of a rope will be subjected to pressures along the direction of the lay and will tend to unlay. The resulting loose outer strands will be able to move over one another to a certain extent and an increase in fatigue will result.

3.5 BLAIR MULTI-ROPE WIRES

The Blair winder is currently a popular winder due to the fact that it provides a relatively cheap and effective method of increasing skip winding capacity. The winder is comprised of two drums with two ropes on each drum being connected to the conveyances. it is the extra rope which enables heavier loads to be pulled from greater depths. The winder is driven by twin D.C. motors or twin A.C. motors, while the drums are either mechanically or electrically coupled. On Western Deep levels, drums are mechanically coupled with D.C. drives.

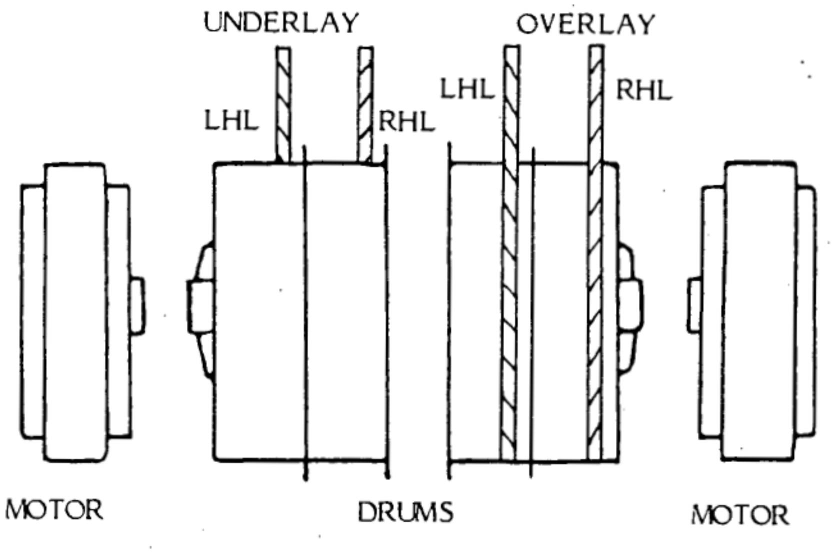

Figure 8: Layout of a Blair Multi-Rope Winder

Figure 8 shows a mechanically coupled Blair winder, showing the positions of the motors and drums. Each drum is divided in two to accommodate the two ropes. On the right hand drum, both ropes are overlay, while on the left hand drum, the ropes are underlay.

On the individual drums, the right hand rope has a right hand lay (RHL) while the left hand rope on the same drum has a left hand lay (LHL). This is arranged so as to minimise the torsion on the skips and their guides as a result of the build up of spin in the ropes.

The ropes used on the multi-rope winders are compound triangular strand ropes with fibre cores. The rope steel has a relatively high tensile strength of 1,900 MPa, while the depth of wind is over 2,350m. Due to the high duty of these winders, the ropes are usually discarded as a result of excessive broken wires. Wear is not as critical a factor due to the good coiling on the drums.

4. THE INSPECTION OF WINDER ROPES

4.1 THE LEGAL REQUIREMENTS PERTAINING TO WINDER ROPE INSPECTION

The inspection of winder ropes is carried out daily by the rigger and monthly by the section engineer. The legal requirements associated with these inspections appear in the Mines and Works Act and Regulations of the Republic of South Africa (12). The regulations pertaining to these inspections are set out below.

COMPETENT PERSON/RIGGER

It is the duty of the appointed competent person to examine the winding equipment (regulation 16.74.1) as follows:-

"at least once in each day the winding ropes, the balance ropes or tail ropes, the connection of the winding ropes to the drums, the connections referred to in regulation 16.18, the conveyances and the main members by which they are suspended and any safety catches attached thereto, the pulley wheels and sheaves, the brakes, the depth indicators, the safety devices and all external parts of the winding equipment upon the proper working of which the safety of persons depends: Provided that these examinations will not be necessary on any day mentioned in section 9 (1) of the Act, if the winding plant makes less than 50 trips during any such day."

ENGINEER

It is the duty of the engineer to perform a rope examination (regulation 16.75.3) as follows:-

"at least once in each calendar month at intervals not exceeding 45 days, the structure of the winding rope and the balance or tail rope, with a view to ascertaining the amount of deterioration thereof.

For the purpose of this examination, the rope shall be cleaned at places selected by the person making the examination who shall note any reduction in the circumference of the rope, any variation in the length of lay of rope, the superficial condition of the wires as to wear, corrosion, fractures and brittleness, and all other data necessary for ascertaining the amount, extent, and distribution of the deterioration of the rope. If the examination discloses features such as undue or rapid wear or fractures of the wires,which, although not constituting sufficient reason for condemning the rope, call for more than usual attention, the examination required under this paragraph shall be made more frequently."

The engineer is also required to examine all portions of the winding equipment on which the safety of persons depends after every accident or occurrence referred to in regulation 25.6(a). This examination must take place before winding operations are resumed.

Should a defect be discovered during any rope examination, regulation 16.77 stipulates that the procedure followed should be the following:-

"If on any examination required in terms of regulation 16.73, 16.74, 16.75 and 16.76 there is discovered any weakness or defect which may endanger the safety of persons, and such weakness or defect cannot be remedied immediately, the person making the discovery shall report such weakness or defect to the manager without delay. Until such weakness or defect is remedied the winding plant shall not be used except in so far as may be necessary to remedy such weakness or defect."

4.2 PRESENT INSPECTION PROCEDURES

4.2.1 VISUAL INSPECTIONS

A definite method or procedure for the daily and monthly inspection of winder ropes is not specified by law. As a result, the inspection procedures followed on the mine will differ from person to person. A generally accepted procedure has however been set out for daily and monthly visual inspections.

DAILY - RIGGER

The rigger will examine that attachments connecting the rope to the cage to ensure that there is no structural damage to the attachments and that the splice in the rope at this point is secure. The rope will then be run past the rigger at slow speed in order for him to check for kinks, external broken wires, ineffective grease dressing and any other signs of mechanical damage. If the rigger detects any form of damage, he will stop the winder and check the extent of the problem. Should the damage warrant the attention of the engineer, but not be too critical, the rigger will mark the spot on the rope in order that the engineer may inspect that area at a convenient time. In the case of severe damage, the engineer must be summoned immediately.

The rigger will also examine the rope on the drum to check for wear caused by coiling on the drum.

MONTHLY - ENGINEER

The engineer will examine the attachments connecting the rope to the cage to ensure that no structural damage has occurred. The humble hook will be inspected before it is cleaned in order to see from the grease whether or not the hook has been struck by falling objects in the shaft. The humble hook is then cleaned and inspected for cracks and other forms of damage. The rope splice and cage guides are also inspected whereafter any necessary regreasing is carried out.

The rope itself is then inspected for wear, corrosion and broken wires at a number of points along the length of the rope. The rope diameter and lay length is also measured at these points. The initial point to be examined is at the front end of the rope about 1m above the splice. The first layer cross-over is also examined while the rest of the rope is examined at different points over its length. These points of examination are changed for each inspection. The distance between two points of examination in a length of rope is recommended to be equivalent to 20 turns of rope around the drum.

The point where the rope emerges from the hawse hole on the drum is also examined to check for goosenecking of the rope at that point. The presence of a gooseneck will lead to rapid wear in that area. The dead layers of rope on the drum are checked to see that they are correctly seated and that there is no excessive crushing occurring due to insufficient tension in the rope at that point. The dead layers are also checked for broken wires and wear. Lastly, the engineer will check the sheave profile and groove size using profile gauges or by making a plaster cast of the sheave groove.

4.2.2 ELECTRO MAGNETIC TESTING

The electro-magnetic (EM) testing of a rope is carried out by the AAC Mechanical Engineering Department - Rope Testing Division. This department will assess the condition of the rope and submit their findings to the relevant engineer. From their recommendations and the eningeer's personal inspections, the engineer will decide when a rope has reached the end of its useful life.

EM testing instruments are continually being upgraded and at present, the technology used involves the passing of an electrical current through the rope. The electrical properties of this current are used to detect and measure the extent of defects or damage to the rope. Both alternating and direct currents are passed through the rope to detect different forms of damage. This damage is then depicted on a trace of the currents.

The alternating current machine has the rope set up to form the core of a transformer through which an alternating current is passed at 80 Hz. The machine provides a trace of the induced electro-motive force (emf) in the secondary coil of the transformer which is calibrated to give a zero reading with a new rope in position. Any loss of steel in the rope would result in a reduction of the induced electro-motive force in the secondary coil. The loss of steel would indicate internal corrosion or core failure with large separation of the core. The percentage loss of steel can be calculated from the area under the trace datum as seen in Figure 9.

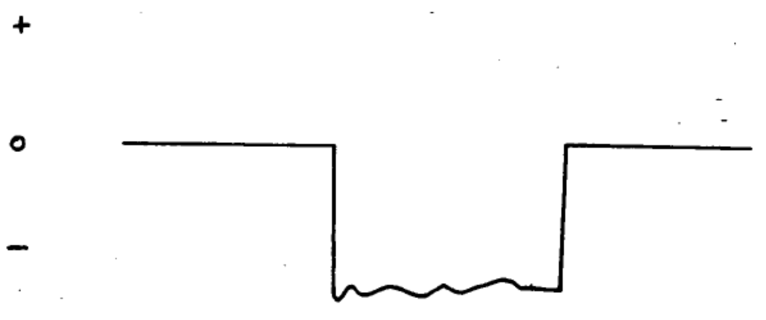

Figure 9: AC Trace Showing Loss of Rope Steel

A second trace on the AC machine shows the permeability of the rope and will indicate a change in contact area between the individual wires in the rope. An increase in contact would indicate a tightening of the wires as would occur when a kink has formed in the rope. A decrease in contact would indicate the presence of corrosion between the wires.

The direct current machine is used for broken wire detection and makes use of magnetisation with the rope closing the circuit. A broken wire in the rope will create two magnets which will induce an electro-magnetic force as a magnetic field passes through the coil. This electro-magnetic force is then magnified to produce a spike in the DC trace as in Figure 10.

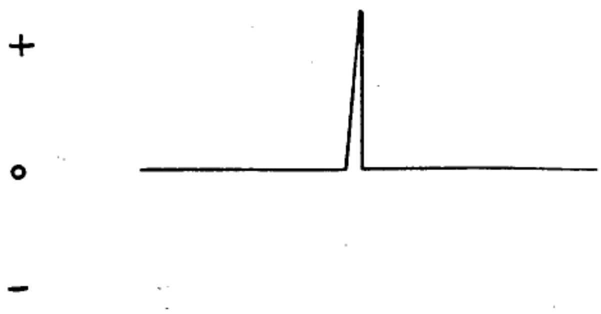

Figure 10. DC Trace Showing the Presence of a Broken Wire

When corrosion is present in the rope, the DC trace spikes will be close together, shorter than the broken wire spikes and tend to integrate to form a trace similar to the loss of steel area trace. Where there is a concentration of broken wires at a point in the rope, the trace will also tend to integrate making counting of the broken wires difficult.

5. THE IDENTIFICATION AND INTERPRETATION OF DAMAGE TO WINDER ROPES

Damage to winder ropes can occur in a number of forms. The most common reasons for the discard of ropes are however the following: excess corrosion, wear and broken wires. The aforementioned factors will be discussed in this chapter, together with other forms of damage which may occur.

5.1 CORROSION

Corrosion is the most dangerous form of damage which can occur in winding ropes due to the difficulties associated in detecting and assessing the extent of the corrosion. The amount of corrosion present in a steel wire winding rope is largely dependent on shaft conditions. The conditions effecting corrosion are the degree of alkalinity of the water vapour in the shaft, the degree of wetness of the shaft, the direction of movement of air in the shaft (i.e. upcast or downcast) and the periods of time during which the rope remains stationary.

In wet shafts, the corrosion initially develops on the outside of the rope and takes the form of mild rust or scale, which is largely removed by abrasive action within the sheave groove.

The degree of acidity of the water can accelerate this corrosion, but it is seldom more serious than in appears; unless winding shocks have contributed to the deterioration by corrosion fatigue. In downcast shafts, the corrosion is generally not as severe as with upcast shafts due to the fact that the air is dry and at an ambient temperature in a downcast shaft. With an upcast shaft, the air is generally humid and contains impurities which dry out the lubricant and cause it to crack up and flake off.

Those shafts which have refrigeration plants necessitating the blowing of cold air over the ropes will also find the lubricant solidifying due to the cold air and flaking off. When the lubricant is removed in this way, corrosion cells or pits are formed, which advance rapidly and provide a means for the development of internal corrosion. When external corrosion is observed, the presence of internal corrosion is likely and may, in some instances, be in an advanced stage.

Internal corrosion occurs as a result of moisture seeping through the external or crown wires of the rope and reaching the inner strands and core of the rope. Here the corrosion takes place without being visible on the exterior surface of the rope. The fibre core in some ropes will act as a wick to spread the water and hence the corrosion through the length of the rope.

Electro-magnetic tests will however pick up the loss of metal due to the corrosive action in order that shaft conditions can be checked to ascertain the source of the moisture. The corrosion will continue until the moisture in the rope has evaporated. Thereafter, active corrosion will cease. Further water seepage into the rope will however re-activate the internal corrosion.

Early visual detection of internal corrosion is possible by monitoring the rope diameter, lay length and appearance of any broken wires. A reduction in rope diameter and change in lay length (usually a reduction) together with traces of external corrosion would indicate the presence of internal corrosion. There is definite internal corrosion when the undersides of outer wires show traces of corrosion. Determining the extent of internal corrosion can however only be satisfactorily accomplished by means of an electro-magnetic test. This test will indicate the amount of metal lost due to the action of the corrosion.

When active internal corrosion is detected, it is recommended that an EM test be carried out weekly to monitor the rate of advance of the corrosion. If the corrosive action is arrested and providing the percentage loss of metal has not exceeded the critical limit, the EM test should then be carried out approximately six-weekly.

Taking into account the affect of other factors which could reduce the tensile strength of a rope, it can be accepted that a 4-5% drop in metal content of the rope due to corrosion would be considered reason to contemplate changing the rope. When corrosion is active, the accuracy of the EM testing apparatus may be questionable. The product of corrosion, viz. metal oxide, is magnetic and may affect the reading given by the instrument. For this reason, a 2-3% drop in metal content where active corrosion is present may be considered serious.

The use of galvanised ropes has greatly retarded the onset of corrosion. In a highly corrosive atmosphere however, the zinc eventually becomes lost and corrosion subsequently proceeds at a rapid rate due to the deterioration of the lubricant by zinc compounds.

With the need for shafts to go deeper and for longer ropes, there has been a need to produce ropes of high tensile strength. High tensile ropes are however by their nature more susceptible to corrosion than low tensile ropes.

An assessment of the degree of corrosion present in a rope and its effective decrease in the breaking force of the rope was carried out by the Mine Equipment Research Unit of the C.S.I.R. (13) The result of this research is given in Table 3.

DEGREE OF CORROSION	PERCENTAGE LOSS IN BREAKING FORCE
traces	0 - .5
very slight	.5 - 1
slight	1 - 2
slight to more than slight	2 - 4
more than slight	4 - 7
more than slight to considerable	7 - 12
considerable	12 - 18
considerable to excessive	18 - 30
excessive	30+

Table 3: The Effect of Corrosion on the Breaking Force of a Rope

It must be noted however that the percentages given in Table 3 will increase considerably when corrosion is accompanied by plastic flow, abrasive type wear, fatigue, nicking or local corrosion pitting.

5.2 WEAR

Internal and external wear will occur to some extent in all ropes. Excessive wear is however and indication of an avoidable factor contributing to the wear. Any such abnormality in the winding system must be corrected immediately as wear aids the advance of corrosion by removing the corrosion scale and presenting a fresh surface for further corrosion.

External Wear

Two types of external wear can occur, namely, abrasive and plastic.

In abrasive wear, the metal is removed from the worn crowns due to rubbing of the rope against an abrasive surface. When the outer wires are reduced to less than half their original depth, spaces will develop between the wires. The wires will then become loose and be able to override each other. The wires will then break rapidly with sharp fractures, or tension fractures at less worn parts. Pure abrasive wear is uncommon in winder ropes. The loss of strength of the wires is however proportional to the loss in their cross-sectional area.

Therefore, in pure abrasive wear, a decrease of 10% in rope strength would be obtained when the diameter of the rope has decreased by approximately 5%. An indication of excessive wear is the formation of Y-splits in the crown wires. This would also suggest the onset of fatigue in the rope and that the rope is nearing the end of its life. These splits normally occur at interlay cross-over points. Wear in a rope can however be minimised by frequent pulling in of the back ends to change the interlay cross-over points on the rope.

Plastic wear occurs as a result of the rope bearing too heavily on some hard surface. As there is too little contact area between the rope and the hard surface to give proper support, the wires in the crown are subjected to excessive pressures at their points of contact with the hard surface. These high pressures cause the wire material to be stressed to a value beyond its yield point but below its ultimate strength. Plastic deformation then occurs in the outer wires with a feature of this wear being the presence of a small bulge running along each side of the deformed crowns. Since these bulges are formed by a cold work process, they are brittle and are liable to crack. The cracks formed may act as stress raisers and develope into fatigue cracks which may lead to the fracture of the wire. The loss in tensile strength through flattening is however seldom as serious as it appears.

Internal Wear

Due to the laying up of wires across one another in the rope and the varying tension in the rope, the wires cut into one another. Wires layed up in the same direction of lay will produce long grooves on one another, while those of opposite direction of lay will produce nicks on one another. Excessive pressure on the rope will then result in grooves becoming deep. Together with corrosion, this can lead to the rapid advance of internal wear.

5.3 BROKEN WIRES

The occurrence of a broken wire in a rope should provide an exact indication as to the percentage loss of strength of the rope. The nature of the construction of the rope however allows for most of the weight carried by a broken wire to be taken up by other wires over a few lay lengths and the overall breaking force of the rope is not unduly affected. For this reason, the loss of breaking force of a rope due to broken wires is dependent on the number of broken wires, and more importantly, the relative positions of the breaks.

An electro-magnetic test is the most effective method of determining the presence of broken wires in a rope. The procedure followed is to look for clusters of broken wires and to monitor the percentage increase in the number of broken wires between tests. When a rope is nearing the end of its useful life, the number of broken wires will increase as fatigue sets in. Fatigue breaks are characterised by square ended fractures with no reduction in cross-sectional area of the wire. Should fractures with these characteristics occur when the rope is still fairly new, it would indicate that the rope is being work-hardened, due to alien forces acting on the rope surface. This is usually a result of incorrect sheave groove profiles which should be rectified as soon as possible. When the broken wires over the length of rope form clusters of 6 to 8 broken wires per meter, rope should be replaced due to the onset of fatigue.

If there is a concentration of broken wires at a point in the rope, it. is necessary to examine the area more closely. If the electro-magnetic test shows a loss of metal at this point, it would indicate that the core has separated. In such an instance, the rope should be changed immediately, while in the case of Koepe tail ropes, the change could be scheduled for the weekened. An hour-glass necking at a point where the test shows broken wires and loss of metal would indicate the failure of the core and inner strands. Such a rope must be discarded immediately.

If there is no associated loss of metal in an area with a high concentration of broken wires, the following guidelines are recommended:-

(a) Discard the rope if in any length of ten times the diameter of the rope, the number of visible broken wires exceeds 5 percent of the total number of wires in the rope (14).

(b) Discard the rope if there are four broken wires in one lay length in one strand. If the rope has a Lang's lay, it can be changed at a convenient time, provided it is inspected daily until such time that it is changed and the condition does not deteriorated. If the rope is of non-spin fishback construction, it must be changed immediately as a lost strand from such a construction could cause severe shaft damage, due to the lively nature of the rope.

Should a broken wire be noted at regular intervals along a length of rope, the lay length of the rope should be checked as the broken wires may just be breaks of the same wire. When a wire breaks, it will loosen and could start to creep. With this creeping, the wire is liable to break where it appears at the outer surface of the rope. (i.e. once in every lay length).

If a metal object should be dropped down the shaft accidentally, an electro-magnetic test must be carried out immediately before winding operations are resumed. A visual inspection of the rope may not reveal any broke wires due to the lubricant making them difficult to spot. An electro-magnetic test however will reveal any mechanical damage.

5.4 MECHANICAL DAMAGE

The most common form of mechanical damage suffered by ropes is kinking. A kink is formed when a rope goes slack, forms itself into a closed loop to relieve the twist in the rope, and is then pulled tight. The resulting kink is more a twisted spiral which will shorten the lay length of the rope and cause rapid deterioration due to fatigue at the kink.

The electro-magnetic test will detect a kink due to the change in permeability of the rope at the kink. The tightening of the wires will increase the contact area in the rope and a loss of area will be reflected on the AC trace. The DC trace will also show a deflection due to the increased contact area between the wires.

Any kink discovered in a rope warrants immediate rope discard unless it is possible to cut out the length of rope affected.

6. ROPES: EXPERT SYSTEM DEVELOPED TO AID WINDER ROPE CONDITION ANALYSIS

6.1 THE EXSYS EXPERT SYSTEM DEVELOPMENT PACKAGE

EXSYS is a generalised expert system development package or shell. Expert systems developed with EXSYS will ask the user questions relevant to a subject while the user is required to answer by selecting one or more answers from a list or by entering data. The computer will continue asking questions until it has reached a conclusion. The conclusion will be displayed as the selection of a single solution or a list of possible solutions arranged in order of likelihood.

The EXSYS expert system development package makes use of rule-based programming. The rules used by the program are IF-THEN-ELSE type rules. A rule being made up from a list of IF conditions (normal English sentences or algebraic expressions) and lists of THEN and ELSE conditions (more sentences) or statements about the probability of a particular choice being the appropriate solution to the problem.

If all the IF conditions in a rule are true, the rules THEN conditions are added to what is known to be true. If any of the IF conditions are false, the ELSE conditions are added to what is known. The computer determines what information it needs and will get this from other rules rather than asking the user. After all the rules in the knowledge base have been addressed, the program will list the solutions from the rules satisfied by the information presented.

Features of EXSYS include its ability to explain how it arrived at its conclusion, why it arrived at the conclusion, and its ability to interface with external programs for data transfer. With the use of the EXSYS Developer's Toolkit, the user can incorporate graphical representations and images in the expert system program. The major restriction to developing expert systems with EXSYS is the fact that all information must be represented in IF-THEN-ELSE or rule form. While allowing for probability to be incorporated in solutions, the package is not able to update probabilities automatically as a result of the input of additional relevant information.

The EXSYS development package consists of five main programs:

EXSYS.EXE: The runtime program for running existing expert system knowledge bases.

EDITXS.EXE: The program for developing, editing and testing expert system knowledge bases.

SHRINK.EXE: A utility program to compress the size of an edited knowledge base, rearrange the data in a file for rapid access and remove unused variables and formulas.

FASTER.EXE: A utility program to rearrange the order of rules for maximum speed in backward chaining.

MERGE.EXE: A utility program to combine two knowledge bases into a single knowledge base.

6.2 CONSTRUCTION OF THE KNOWLEDGE BASE

In order to gather information on the subject, an extensive literature survey was undertaken. Not much had been written on condition analysis of winder ropes, while most of the information available is outdated. The company which manufactures the ropes used, was also unwilling to contribute in any way to this project. As a result, most of the information used to compile the knowledge-base was obtained directly from "experts" in the field.

The knowledge base for the expert system (named ROPES) was compiled from the combined expertise of Messrs. JP Prinsloo (AAC Rope Testing Division) and PJ Badenhorst (Western Deep Levels Gold Mine - Rigger Foreman). The program is designed to be used by an engineer to ascertain rope condition after both visual and electro-magnetic tests have been carried out on the rope. It is however possible to operate the program after only one of the aforementioned examinations has been carried out.

Initially the program will ask for information obtained from the visual examination and make inferences as to the rope condition from these observations. The majority of data is then required from the results of the electro-magnetic test. The program will run through all the rules and give a list of all conditions that may be present in the rope as a result of rules being true. From these conditions and their respective probabilities, the engineer can formulate a plan of action as regards the relevant rope.

Due to the vast number of combinations of different forms and degrees of damage that can exist in a rope, it is impossible to accurately quantify the loss of strength in a rope due to every combination of conditions. For this reason the definite discard conditions and generally accepted procedures for certain conditions have been included in the program. Some of the 'grey areas' have been addressed, but not every conceivable condition can be included. It is however possible for the engineer to update the program relatively easily by adding rules to the rule base. This is essential if the knowledge base it to remain acceptable to the user.

A listing of the program - ROPES is given in Appendix C. The knowledge-base consists of thirty-four rules while there are thirty-two possible rope conditions available. The first three rules in the knowledge-base have been included as experience has indicated that Koepe ropes will deteriorate rapidly after a certain number of trips and mine policy dictates their maximum life.

The subsequent rules require information from the usual inspection of the rope as undertaken by the engineer. The information required includes the following: the extent of any external abrasive wear or plastic flow; the physical measurements of rope diameter and lay length; the presence of external corrosion; the occurrence of goosenecking at the hawse hole; broken wires with signs of crushing on the dead layers of rope on the drum. If any of the aforementioned conditions exist, the program will then ask for more information if needed, to make a decision on the condition of the rope.

The following set of rules in the knowledge-base use the information discernable from the traces obtained from the electro-magnetic testing machine. The number and position of any broken wires, metal loss or change in contact between wires in the rope are conditions which, if detected, are examined in more detail by the program.

The percentage metal loss indicated by the electro-magnetic tester is used extensively in rope discard decisions, although the exact relationship between metal loss and strength loss of the rope is not 100% certain. This matter is however being addressed by Anglo American at present. Should any changes to the program be necessary as a result of their findings, they can be made by means of the EDITOR facility available in the EXSYS package. This also applies to policy changes or new developments that could affect rules in the program. The rules in the program are however generally accepted as being applicable to condition analysis of winder ropes in use at this time with the present testing equipment available.

Extensive verification of the program has been conducted under the auspices of the visual inspection personnel and the electro-magnetic rope testing personnel in particular. The program can be used as a training manual for both sets of personnel as well as a reminder and aid to a practicing engineer.

A copy of the program - ROPES is included on a floppy disk inside the front cover of the report. This program can however only be run if the user has access to the EXSYS expert system package. Due to copywrite restrictions, this package cannot be included in the report.

6.3 RUNNING THE EXPERT SYSTEM PROGRAM

The minimum system requirements for running the expert system program are as follows:

IBM PC, XT, AT or compatible
320k RAM
One floppy disk drive
DOS 2.0 or higher
EXSYS Expert System Package

The following steps are necessary in order to run ROPES:

1. Boot up the computer with DOS 2.0 or higher.
2. Insert the EXSYS runtime disk into the floppy disc drive and type EXSYS
3. When prompted for an expert system file name, remove the runtime disk and replace it with the disk containing the ROPES program
4. Type ROPES and then input the operating formats and information required when prompted
5. When asked to choose from a number of options and you need to input more than one option, list the options wanted on a single line interspaced with commas and then enter the row, e.g. 1, 3, 7. (enter)
6. After the program has supplied the final rope conditions present, exit the program by entering Q (quit) when prompted
7. Information can be stored for later use if necessary

7. CONCLUSIONS

From the compiling of the expert system, the following conclusions could be drawn:

1. The visual inspection of winder ropes is by itself a totally inadequate method of assessing the true conditions of a winder rope. These inspections can only reveal external or mechanical damage to a rope with associated limited human accuracy and consistency.

2. Although not able to quantify adequately the relationship between rope damage and loss of rope strength, the electro-magnetic test reveals the presence of damage both internally and externally in a rope.

3. The engineers rely largely on the experience of the person conducting the electro-magnetic tests and his interpretation of the outputs from his testing machine in order to come to a conclusion as to the condition of a rope.

4. The decision to discard a rope is seldom ratified by examining and destructively testing the piece concerned.

5. The expert system - ROPES, will provide engineers with the necessary expertise and experience to assess more accurately than at present, the condition of a winder rope. This will ensure longer rope life and improved safety with the associated cost savings.

6. Any changes in rope policy can be made uniformly and without requiring the redevelopment of the expert system program.

8. RECOMMENDATIONS

1. In order for the engineer to make accurate decisions on rope life, he should become better acquainted with the electronic instruments used for rope testing.

2. The expert system - ROPES, should be used by the engineer as an aid for making consistent and accurate rope assessments based on experience and research while also being used as a training module for junior engineers.

3. Every decision to discard a rope should be ratified by destructive testing as a matter of course.

4. The tasks of electro-magnetic testing of ropes and that of deciding when a rope has reached the end of its useful life should be entrusted to one person or organisation.

5. The building up of the knowledge-base must continue as an ongoing process to take into account new technology and experience gained.

9. REFERENCES

1. Jackson P (1986) INTRODUCTION TO EXPERT SYSTEMS, Addison - Wesley Publishers Limited, pp 1-12

2. Waterman DA (1986) GUIDE TO EXPERT SYSTEMS, Addison - Wesley, Reading, Massachusetts, Chapters 1-4, pp 1-31

3. Hersov MA (1988) PUMP FAILURE ANALYSIS USING EXPERT SYSTEMS, Design Project No. 47, University of Cape Town

4. MacGregor KJ (1988) EXPERT SYSTEMS, course notes, University of Cape Town

5. Butcher GC (1988) INVESTIGATE AND DESIGN AN EXPERT SYSTEM FOR USE IN QUALITY MANAGEMENT, Design Project No. 9, University of Cape Town

6. Johnson PE (1983) WHAT KIND OF EXPERT SHOULD A SYSTEM BE? Journal of Medicine and Philosophy, vol. 8, pp 77-97

7. Goyal SK, Prepau DS, Lennon AV, Gunderson AS, Reineke RE (1985) COMPASS: AN EXPERT SYSTEM FOR TELEPHONE SWITCH MAINTENANCE, Expert Systems Journal, July 1985, vol. 2, No. 3

8. Buchanan BG (1986) EXPERT SYSTEMS: WORKING SYSTEMS AND THE RESEARCH LITERATURE, Expert Systems Journal, January 1986, vol. 3, No. 1

9. Horn D. (1989) EXPERT SYSTEMS EMERGE FROM THEIR SHELLS, Mechanical Engineering Journal (CIME), April, 1989.

10. Haggie Rand Limited (1987) STEEL WIRE ROPES FOR MINE HOISTING.

11. Pinder BF (1981) WINDING ROPES: THEIR SELECTION, MAINTENANCE, AND FUTURE TRENDS, The Certificated Engineer, May 1981

12. THE MINES AND WORKS ACT and REGULATIONS, Republic of South Africa, (1977), Kerlaw Publishers (Pty) Ltd.

13. Archer LG (1971) THE INTERPRETATION OF DATA GIVEN ON THE CERTIFICATE OF TEST CONDUCTED ON A WINDING ROPE. The Certificated Engineer, December, 1971, pp 263-273.

14. Finlayson RM (1987). ENGINEERING MANAGER'S INSTRUCTIONS - WINDERS.

APPENDICES

APPENDIX A: MAINTENANCE AND ENGINEERING APPLICATIONS OF EXPERT SYSTEMS IN USE IN INDUSTRY.

SITE	EXPERT SYSTEM AND DESCRIPTION	SOURCE
British Steel Corp. Scunthorpe rod mill	ICLX Aid technicians diagnose in rod milling process	
Campbell Soups	Troubleshoot problems in soup cookers, anticipate failures	John Alden TI (Dallas)
Delco Products	Engine Cooling Advisor. Diagnose cause of noise in automobile engine cooling system	Steve Dourson Delco
Delco Products	Motor Brush Designer. Construct design of brushes and springs for small elec motors	Steve Dourson Delco
DEC	ISA Schedule orders for manufacturing and delivery	Neil Pundit DEC (Hudson)
DEC	Dispatcher. Schedule dispatching of parts for robots	J McDermott Carnegie Gp.
GE	Cats. Diagnose problems in diesel-elec. locomotive	P Bonissone GE
Hitachi	Control railroad train braking for accuracy and comfort	E Feigenbaum Stanford
Kawasaki Steel	Detect cracks in billets and direct grinding	A Miyajima Kawasaki
Kawasaki Steel	Stowage Planner. Develop cargo storage plans for warehouse	A Miyajima Kawasaki
Westinghouse	VT Configure orders for new elevator systems	J McDermott S Marcus, CMU
Westinghouse	Nuclear fuel enhancement	D Michie Turing Inst. (Glasgow)
Westinghouse	Isis. Schedule manufacture steps in job shop	M Fox, CMU
Xerox, Reprographics	Pride. Create and analyse new designs for copiers	S Mittal Xerox, (PARC)

APPENDIX B: ENGINEERING APPLICATIONS OF EXPERT SYSTEMS DEVELOPED AT THE UNIVERSITY OF CAPE TOWN, BUT NOT NECESSARILY IN USE IN INDUSTRY

SITE	EXPERT SYSTEM AND DESCRIPTION	SOURCE
UCT	COMPSEL Selection of flat plate solar collectors (EXSYS)	JJ May (1986)
UCT	GEAR Gear design (EXSYS)	CV Gamede (1986)
UCT	FAILURE Diagnosis of metal component failures (EXSYS)	HS Thomo (1987)
UCT	FRIG Troubleshooting guide for a refrigeration plant (EXSYS)	LK Williamson (1987)
UCT	PUMP Pump failure analysis (VP-Expert)	MA Hersov (1988)
UCT	UPSETS Knowledge - base on upset forging (EXSYS)	BJ Kivido (1987)
UCT	V BELT Design of a power transmission using V-belts (EXSYS)	A O Parker (1987)
UCT	XRAY.KBS Quality control analysis of weld x-rays	GC Butcher (1988)

APPENDIC C: Listing of the expert system - ROPES

```
Subject:
    CONDITION ANALYSIS OF WINDER ROPES


Author:
  L.K. WILLIAMSON  (WDL)


Starting text:
  ROPES is a program designed to aid the engineer in determining the
  condition of winder ropes.  Information obtained from visual
  inspections and electro-magnetic tests carried out on the rope is
  required by the program in order that an assessment of rope life can
  be made.


Ending text:
  From the information supplied the following conditions have been found
  to exist.


Uses all applicable rules in data derivations.
```

RULES:

RULE NUMBER: 1

IF:

The rope being examined is a surface koepe head rope
and [NO OF TRIPS] >= 70000

THEN:

The rope must be discarded in accordance with WDL mine policy as regards life limits for koepe ropes - Probability=9/10

RULE NUMBER: 2

IF:

The rope being examined is a sub-shaft koepe head rope
and [NO OF TRIPS] >= 110000

THEN:

The rope must be discarded in accordance with WDL mine policy as regards life limits for koepe ropes - Probability=9/10

RULE NUMBER: 3

IF:

The rope being examined is a koepe tail rope
and [NO OF TRIPS] >= 175000

THEN:

The rope must be discarded in accordance with WDL mine policy as regards life limits for koepe ropes - Probability=9/10

RULE NUMBER: 4

IF:

The visual inspection reveals goose-necking at the hawse hole

THEN:

The wedge profile at the hawse hole must be checked as it appears to be too sharp - Probability=9/10

RULE NUMBER: 5

IF:

The visual inspection reveals broken wires with signs of crushing on the dead layers of rope on the drum

THEN:

The rope was wound onto the drum with insufficient tension when installed - provided the no. of broken wires in the rope has not resulted in the rope losing 10% of its strength the condition can be corrected by doubling down with the correct mass, else the rope must be discarded - Probability=9/10

RULE NUMBER: 6

IF:

The visual inspection reveals external abrasive wear resulting in flats being formed on crown wires reducing them to less than 2/3 of their original diameter
and [ROPE DIA] <= 0.95*[NROPE DIA]

THEN:

The rope must be discarded immediately as wear has reduced the area of rope metal by 10% which is equivalent to a 10% drop in rope strength - Probability=10/10

REFERENCE:

The Mines and Works Act and Regulations (Regulation 16.33)

RULE NUMBER: 7

IF:

The visual inspection reveals external abrasive wear resulting in flats being formed on crown wires reducing them to less than 2/3 of their original diameter

and The crown wires have Y-splits

THEN:

Abrasive wear is resulting in the onset of fatigue in the rope - the rope is nearing the end of its useful life and should be discarded as soon as possible - Probability=9/10

RULE NUMBER: 8

IF:

The visual inspection reveals external abrasive wear resulting in flats being formed on crown wires reducing them to less than 2/3 of their original diameter

and Wear at a point in the rope is evident at an interlay cross-over

and Crown wire flattening is occuring without associated flaking of steel

THEN:

The back-ends need to be pulled more frequently to prevent excess wear at interlay cross-over points - Probability=8/10

RULE NUMBER: 9

IF:

The visual inspection reveals external abrasive wear resulting in flats being formed on crown wires reducing them to less than 2/3 of their original diameter

and Wear at a point in the rope is evident at an interlay cross-over

and Crown wire flattening is occuring with associated flaking of steel

THEN:

The back-ends need to be pulled more frequently to prevent excess wear at interlay cross-over points - Probability=8/10

and The rope is showing signs of fatigue at the interlay cross-over points and must be monitored as it is nearing the end of its useful life - Probability=8/10

RULE NUMBER: 10

IF:

The visual inspection reveals external abrasive wear resulting in flats being formed on crown wires reducing them to less than 2/3 of their original diameter

and Wear at a point in the rope is evident at a point other than at an interlay cross-over

THEN:

The sheave groove profile should be checked - Probability=9/10

and Bad coiling on the drum is suspected - Probability=8/10

RULE NUMBER: 11

IF:

The visual inspection reveals plastic flow resulting in the rope taking on the appearance of a pipe

and Cracks are visible in the bulges along the deformed crowns

THEN:

Plastic flow is resulting in the onset of fatigue in the rope - preparations should be made for a rope change in the near future - Probability=8/10

and The sheave groove profile should be checked - Probability=10/10

RULE NUMBER: 12

IF:

The visual inspection reveals a decrease in rope diameter or a marked change in lay length

and The visual inspection reveals the presence of external corrosion

THEN:

Internal corrosion in the rope is suspected - Probability=8/10

and Moisture is being deposited on the rope - the source of which must be determined and removed - Probability=10/10

RULE NUMBER: 13

IF:

The visual inspection reveals the presence of external corrosion

THEN:

Check the condition of the rope lubricant (if applicable) - Probability=10/10

RULE NUMBER: 14

IF:

The visual inspection reveals the presence of external corrosion
and Corrosion is present on the undersides of outer wires

THEN:

Internal corrosion in the rope is suspected - Probability=9/10

RULE NUMBER: 15

IF:

The electro-magnetic test reveals metal loss at a point in the rope
and At the point of metal loss there is NOT a cluster of broken wires

THEN:

Internal corrosion in the rope is suspected - Probability=9/10

RULE NUMBER: 16

IF:

The electro-magnetic test reveals metal loss at a point in the rope
and The metal loss is >= 5%

THEN:

The rope must be discarded immediately as corrosion has caused a 10% reduction in rope strength - Probability=10/10

RULE NUMBER: 17

IF:

The electro-magnetic test reveals metal loss at a point in the rope
and The % metal loss has increased since last measured

THEN:

Active internal corrosion is present in the rope - Probability=9/10

RULE NUMBER: 18

IF:

The electro-magnetic test reveals metal loss at a point in the rope
and The % metal loss has stayed constant since last measured

THEN:

Internal corrosion in the rope is inactive - Probability=8/10

RULE NUMBER: 19

IF:

The electro-magnetic test reveals metal loss at a point in the rope
and The metal loss is >= 3% but < 5%
and Active internal corrosion is present in the rope = 9/10

THEN:

A rope change must be scheduled as the rope is reaching 10% strength reduction due to active internal corrosion - Probability=7/10

RULE NUMBER: 20

IF:

The electro-magnetic test reveals metal loss at a point in the rope
and The metal loss is < 5%
and Internal corrosion in the rope is inactive = 7/10

THEN:

The internal corrosion in the rope has been arrested - EM tests should be scheduled approximately 6 weekly as further corrosion could result in the loss of strength of the rope reaching 10% - Probability=7/10

RULE NUMBER: 21

IF:

The electro-magnetic test reveals metal loss at a point in the rope
and The metal loss is < 3%
and Active internal corrosion is present in the rope = 9/10

THEN:

Active internal corrosion is reducing the rope strength and an EM test should be carried out weekly until such time that the corrosion becomes inactive - provided that there is not a 10% reduction in rope strength in the interim - Probability=9/10

RULE NUMBER: 22

IF:

The electro-magnetic test reveals the presence of 2 or more broken wires in the rope
and The broken wires are repeating themselves at fixed intervals over a length of the rope

THEN:

The wire breaks in the rope may be multiple breaks of the same wire - the distance between the breaks must be checked against the lay length of the rope - Probability=7/10

RULE NUMBER: 23

IF:

The rope being examined is a koepe tail rope
and The electro-magnetic test reveals metal loss at a point in the rope
and At the point of metal loss there is a cluster of broken wires
and An hourglass effect is NOT visible at the point of metal loss

THEN:

The rope core has separated and a rope change should be scheduled for the next weekend - Probability=9/10

RULE NUMBER: 24

IF:

The rope being examined is a surface koepe head rope or a sub-shaft koepe head rope
and The electro-magnetic test reveals metal loss at a point in the rope
and At the point of metal loss there is a cluster of broken wires
and An hourglass effect is NOT visible at the point of metal loss

THEN:

The rope core has separated and a rope change must be scheduled immediately - Probability=10/10

RULE NUMBER: 25

IF:

The electro-magnetic test reveals metal loss at a point in the rope
and At the point of metal loss there is a cluster of broken wires
and An hourglass effect is visible at the point of metal loss

THEN:

The rope core and inner strands have failed and the rope should be changed immediately - Probability=10/10

RULE NUMBER: 26

IF:

The electro-magnetic test reveals the presence of 2 or more broken wires in the rope

and The broken wires are highly concentrated over a length of 10 diameters of rope length

and [BW10D] >= .05*[WIRES]

THEN:

Discard the rope immediately as the rope strength has decreased by over 10% due to a concentration of broken wires over a 10 diameter length in the rope - Probability=10/10

RULE NUMBER: 27

IF:

The electro-magnetic test reveals the presence of 2 or more broken wires in the rope

and In one lay length in one strand there are 4 or more broken wires

and The rope construction characteristics are Langs lay

and [BW10D] < .05*[WIRES]

THEN:

A strand in the rope has been lost due to broken wires and a rope change must be scheduled. The rope must be inspected daily till changed to ensure no further damage occurs - Probability=10/10

RULE NUMBER: 28

IF:

The electro-magnetic test reveals the presence of 2 or more broken wires in the rope

and In one lay length in one strand there are 4 or more broken wires

and [BW10D] < .05*[WIRES]

and The rope construction characteristics are non-spin fishback

THEN:

A strand in the rope has been lost and the rope must be changed immediately due to the dangers associated with losing a strand in a non-spin rope - Probability=9/10

RULE NUMBER: 29

IF:

The electro-magnetic test reveals the presence of 2 or more broken wires in the rope

and In one lay length in one strand there are 3 broken wires

and [BW10D] < .05*[WIRES]

THEN:

The point where there are 3 broken wires in one lay length must be inspected daily for further damage - thought must be given to changing the rope - Probability=9/10

RULE NUMBER: 30

IF:

The electro-magnetic test reveals the presence of 2 or more broken wires in the rope

and The broken wires are greater than 2 metres apart

THEN:

The broken wires in the rope are well spaced and not unduly affecting the rope strength - Probability=8/10

RULE NUMBER: 31

IF:

The electro-magnetic test reveals the presence of 2 or more broken wires in the rope

and The broken wires are numbering about 3 per metre of rope length

THEN:

The point where the broken wires are numbering 3 per metre should be marked and visually inspected to ascertain the cause of damage ie. mechanical, fatigue etc. The rope condition at this point is still acceptable, but must be monitored at the following inspection or EM test - Probability=9/10

RULE NUMBER: 32

IF:

The electro-magnetic test reveals the presence of 2 or more broken wires in the rope

and The broken wires are numbering between 6 and 8 per metre of rope length

THEN:

The onset of fatigue in the rope is resulting in the broken wires occuring in high density clusters. This condition is an indication that the rope is reaching the end of its life and should be monitored with a view to a rope change in the near future - Probability=9/10

RULE NUMBER: 33

IF:

The electro-magnetic test reveals metal loss at a point in the rope

and The electro-magnetic test reveals an increase in contact area between the wires on the AC contact trace corresponding to an apparant loss of rope area on the AC area trace at the same point in the rope

THEN:

A kink in the rope is suspected at the point of loss of rope area. This point must be examined and the kink cut out if possible, else the rope may have to be discarded if the kink is severe - Probability=9/10

RULE NUMBER: 34

IF:

The visual inspection reveals no serious visual form of damage

and The electro-magnetic test reveals no metal loss or broken wires in the rope

THEN:

The rope has no noticeable defects and can be assumed to be in good serviceable condition - Probability=9/10

QUALIFIERS:

1 The rope being examined is

a surface koepe head rope
a sub-shaft koepe head rope
a koepe tail rope
none of the above

2 The visual inspection reveals

external abrasive wear resulting in flats being formed on crown wires reducing them to less than 2/3 of their original diameter
plastic flow resulting in the rope taking on the appearance of a pipe
a decrease in rope diameter
a marked change in lay length
the presence of external corrosion
goose-necking at the hawse hole
broken wires with signs of crushing on the dead layers of rope on the drum
no serious visual form of damage

3 The crown wires have

Y-splits
no Y-splits

4 Wear at a point in the rope is

evident at an interlay cross-over
evident at a point other than at an interlay cross-over
not evident

5 Cracks are

visible in the bulges along the deformed crowns
not visible in the bulges along the deformed crowns

6 Corrosion is

present on the undersides of outer wires
not evident on the undersides of outer wires

7 The electro-magnetic test reveals

metal loss at a point in the rope
the presence of 2 or more broken wires in the rope
no metal loss or broken wires in the rope
an increase in contact area between the wires on the AC contact trace corresponding to an apparant loss of rope area on the AC area trace at the same point in the rope

8 At the point of metal loss there is

a cluster of broken wires
NOT a cluster of broken wires

9 The metal loss is

>= 5%
>= 3% but < 5%
< 5%
< 3%

10 The % metal loss has

increased since last measured
stayed constant since last measured

11 The broken wires are

greater than 2 metres apart
numbering about 3 per metre of rope length
numbering between 6 and 8 per metre of rope length
highly concentrated over a length of 10 diameters of rope length

12 An hourglass effect is

visible at the point of metal loss
NOT visible at the point of metal loss

13 In one lay length in one strand there are

4 or more broken wires
3 broken wires
less than 3 broken wires

14 The rope construction characteristics are

Langs lay
ordinary lay
non-spin fishback
none of the above

15 The broken wires are

repeating themselves at fixed intervals over a length of the rope
randomly spread throughout the length of the rope

16 Crown wire flattening is

occuring with associated flaking of steel
occuring without associated flaking of steel

CHOICES:

1 The rope must be discarded in accordance with WDL mine policy as regards life limits for koepe ropes

2 The wedge profile at the hawse hole must be checked as it appears to be too sharp

3 The rope was wound onto the drum with insufficient tension when installed - provided the no. of broken wires in the rope has not resulted in the rope losing 10% of its strength the condition can be corrected by doubling down with the correct mass, else the rope must be discarded

4 The rope must be discarded immediately as wear has reduced the area of rope metal by 10% which is equivalent to a 10% drop in rope strength

5 Abrasive wear is resulting in the onset of fatigue in the rope - the rope is nearing the end of its useful life and should be discarded as soon as possible

6 The back-ends need to be pulled more frequently to prevent excess wear at interlay cross-over points

7 The rope is showing signs of fatigue at the interlay cross-over points and must be monitored as it is nearing the end of its useful life

8 The sheave groove profile should be checked

9 Bad coiling on the drum is suspected

10 Plastic flow is resulting in the onset of fatigue in the rope - preparations should be made for a rope change in the near future

11 Internal corrosion in the rope is suspected

12 Moisture is being deposited on the rope - the source of which must be determined and removed

13 Check the condition of the rope lubricant (if applicable)

14 The rope must be discarded immediately as corrosion has caused a 10% reduction in rope strength

15 Active internal corrosion is present in the rope

16 Internal corrosion in the rope is inactive

17 A rope change must be scheduled as the rope is reaching 10% strength reduction due to active internal corrosion

18 The internal corrosion in the rope has been arrested - EM tests should be scheduled approximately 6 weekly as further corrosion could result in the loss of strength of the rope reaching 10%

19 Active internal corrosion is reducing the rope strength and an EM test should be carried out weekly until such time that the corrosion becomes inactive - provided that there is not a 10% reduction in rope strength in the interim

20 The wire breaks in the rope may be multiple breaks of the same wire - the distance between the breaks must be checked against the lay length of the rope

21 The rope core has separated and a rope change should be scheduled for the next weekend

22 The rope core has separated and a rope change must be scheduled immediately

23 The rope core and inner strands have failed and the rope should be changed immediately

24 Discard the rope immediately as the rope strength has decreased by over 10% due to a concentration of broken wires over a 10 diameter length in the rope

25 A strand in the rope has been lost due to broken wires and a rope change must be scheduled. The rope must be inspected daily till changed to ensure no further damage occurs

26 A strand in the rope has been lost and the rope must be changed immediately due to the dangers associated with losing a strand in a non-spin rope

27 The point where there are 3 broken wires in one lay length must be inspected daily for further damage - thought must be given to changing the rope

28 The broken wires in the rope are well spaced and not unduly affecting the rope strength

29 The point where the broken wires are numbering 3 per metre should be marked and visually inspected to ascertain the cause of damage ie. mechanical, fatigue etc. The rope condition at this point is still acceptable, but must be monitored at the following inspection or EM test

30 The onset of fatigue in the rope is resulting in the broken wires occuring in high density clusters. This condition is an indication that the rope is reaching the end of its life and should be monitored with a view to a rope change in the near future

31 A kink in the rope is suspected at the point of loss of rope area. This point must be examined and the kink cut out if possible, else the rope may have to be discarded if the kink is severe

32 The rope has no noticeable defects and can be assumed to be in good serviceable condition

FORMULAS:

1 [NO OF TRIPS] >= 70000

2 [NO OF TRIPS] >= 70000

3 [NO OF TRIPS] >= 70000

4 [NO OF TRIPS] >=110000

5 [NO OF TRIPS] >= 110000

6 [NO OF TRIPS] >= 175000

7 [NO OF TRIPS] >= 70000

8 [NO OF TRIPS] >= 70000

9 [NO OF TRIPS] >= 70000

10 [ROPE DIA] <= .95[NROPE DIA]

11 [ROPE DIA] <= 0.95*[NROPE DIA]

12 [BW10D] >= .05*[WIRES]

13 [BW10D] < .05*[WIRES]

14 [BW10D] < .05*[WIRES]

VARIABLES:

1 NO OF TRIPS
the number of reversals of the rope over the head pulley
Numeric variable

2 ROPE DIA
the measured diameter of the rope in mm
Numeric variable

3 NROPE DIA
the nominal rope diameter as specified by the manufacturer in mm
Numeric variable

4 BW10D
the number of broken wires in a length of 10 diameters in the vicinity of the high concentration of broken wires.
Numeric variable

5 WIRES
the total number of individual wires in the rope
Numeric variable

APPENDIX D: Courses completed in partial fulfillment of the M.Sc. Degree

	COURSE	YEAR	CREDITS
CIV 525S	Contract Law	1988	3
END 512X	Engineering Economy and Optimisation	1988	5
END 522Z	An Introduction to Finite Elements	1989	3
END 524Z	Engineering Software Design and Development	1989	3
MEC 515Z	Production Systems Design	1988	4
MEC 520Z	Project Management	1988	2
		Total	20

Minimum number of course credits required: 20

COURSE DESCRIPTIONS

CIV 525S Contract Law

The course reviews the Law of Contract to develop a framework for the analysis of standard documentation for both main and sub-contracts. Important aspects of mediation, arbitration and court procedures are stresses as is the need to identify and resolve legal problems through timeous negotiation. Disputes which have gone to law or arbitration will be studies to illustrate principles.

END 512X Engineering Economy and Optimisation

This course is designed to provide skills in the use of quantitative techniques in making and optimising economic decisions. It comprises three parts.

i) **Operations Research**

Mathematical models for decision making. Optimisation techniques, linear programming, queueing theory and simulation. Problem formulation and the interpretation of results. Statistics.

ii) **Engineering Economy**

Techniques and concepts for economic decision making. The use of interest and annuity relationships in selecting between alternatives. Risk and uncertainty in economic decision making.

iii) **Scheduling Models**

Arrow and precedence diagrams for project scheduling. Lead lay relationships, time cost optimisation and resource scheduling.

END 522Z An Introduction to Finite Elements

The use of the finite element method in various engineering disciplines. Finite elements available in 1-D and 2-D applications. Approach to problem solving techniques using finite elements. The use of finite element packages. Topics include stress analysis, heat transfer, seepage flow and fluid flow.

END 524Z Engineering Software Design and Development

Microcomputer hardware components, DOS operating system, software design methodologies, modularity and information hiding, logic and decision tables, data abstraction and file handling. Testing and debugging. Man-machine interface and Computer graphics. Project management and documentation. Software tools and packages. Numerical representation and accuracy.

MEC 515Z Production System Design

Technology forecasting
Logistics systems
Processing models
Work methods and work measurement
Quality control

MEC 520Z Project Management

The need for Project Management; the objectives
Planning and implementing a project
Organising for Project Management
The tools of Project Management
Problems of communication; handling contractors, handling meetings
Projects Costing and Cost Control Techniques