

# SIMRAC

## Final Project Report

Title: THE SAFE USE OF MINE WINDING ROPES

Volume 1: Executive Summary

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Research  
Agency: Mine Hoisting Technology  
CSIR

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## OVERVIEW

The final report on the SIMRAC funded project consists of seven volumes. Volume 1 (this document) presents an overview of the entire project. The other volumes are collections of relevant research reports. The following table lists all the volumes of the final report:

| VOLUME | TITLE AND REFERENCE  |
|--------|--|
| 1      | EXECUTIVE SUMMARY  |
| 2      | <p>RECOMMENDATIONS FOR CHANGES IN ROPE SAFETY FACTORS</p> <ul style="list-style-type: none"> <li>• Hecker, G.F.K. <i>Motivation for Proposed Changes to Chapter 16 of the Minerals Act: Rope Safety Regulations for Drum Winders</i> CSIR Contract Report MST(93)MC1674, June 1993</li> <li>• SABS Working Group 2 <i>Draft Code of Practice for the Performance, Operation, Testing and Maintenance of Drum Winders relating to Rope Safety</i> Document submitted to the South African Bureau of Standards</li> </ul>  |
| 3      | <p>ROPE TERMINATIONS</p> <ul style="list-style-type: none"> <li>• Borello, M. <i>Laboratory Evaluation of White Metal and Resin Cappings for use as Winder Rope Terminations</i> CSIR Contract Report MST(93)MC1838, November 1993</li> <li>• Borello, M. <i>Splicing Techniques for Mine Winder Ropes</i> CSIR Contract Report MST(94)MC2260, October 1994</li> <li>• Borello, M. <i>Performance of Resin filled Sockets prepared by the Mining Industry</i> CSIR Contract Report MST(94)MC2166 No.940155, November 1994</li> <li>• Borello, M. <i>Performance Evaluation of Resin Filled Sockets used at Premier Diamond Mine</i> CSIR Contract Report MST(94)MC2264 No.940226, December 1994</li> <li>• Van Zyl, M.N. <i>An Investigation onto the Behaviour and Deterioration of Winding Rope Tangent Points on Conveyance Mounted Compensating Sheaves</i> CSIR Contract Report MST(95)MC2491 No.950132, May 1995</li> <li>• Wainwright, E.J. and Borello, M. <i>Rope Terminations for Mine Hoisting Applications</i> CSIR Contract Report MST(94)MC2260 No.940236, March 1995</li> </ul> |

| VOLUME | TITLE AND REFERENCE   |
|--------|---|
| 4      | <p data-bbox="388 338 1271 371">CODE OF PRACTICE FOR ROPE CONDITION ASSESSMENT</p> <ul style="list-style-type: none"> <li data-bbox="420 383 1392 495">• Borello, M. <i>Results of Tests on Sections of Discarded Ropes</i> CSIR Contract Report MST(94)MC2122 No.940126, June 1994</li> <li data-bbox="420 506 1361 618">• Borello, M. and Kuun, T.C. <i>The effect of Cut Wires on the Strength of Winding Ropes</i> CSIR Contract Report MST(94)MC2333 No.940286, December 1994</li> <li data-bbox="420 629 1439 775">• Wainwright, E.J. <i>Discussion of Results of Tests on Discarded Ropes in terms of the Draft Code of Practice for Rope Condition Assessment</i> CSIR Contract Report MST(95)MC2470 No.950125, May 1995</li> <li data-bbox="420 786 1423 931">• James, A. <i>A Literature Review of the use of Magnetic Testing of Steel Wire Ropes, with particular regard to Rope Discard Criteria</i> CSIR Contract Report MST(95)MC2487 No.950131, May 1995</li> <li data-bbox="420 943 1428 1088">• Wainwright, E.J. <i>Discussion of Results of Second Series of Tests on Discarded Ropes in terms of the Draft Code of Practice for Rope Condition Assessment</i> CSIR Contract Report MST(96)MC2887 No.960167, May 1995</li> <li data-bbox="420 1099 1392 1200">• Hecker, G.F.K. and Kuun, T.C. <i>Further Tests to Study the Effect of Cut Wires on the Strength of Winding Ropes</i> CSIR Contract Report MST(96)MC2333 No.960171, April 1996</li> </ul> |
| 5      | <p data-bbox="388 1227 1287 1261">TRAINING MANUALS FOR INCUMBENT ROPE INSPECTORS</p> <ul style="list-style-type: none"> <li data-bbox="420 1272 1326 1350">• Wainwright, E.J. <i>Module 1: Study Guide for Wire Rope Inspectors</i> CSIR Report MST(96)MC2886 No.960166</li> <li data-bbox="420 1361 1412 1440">• Wainwright, E.J. <i>Module 2: An Introduction to Mine Winders</i> RCA Training Manual, September 1995</li> <li data-bbox="420 1451 1373 1529">• Wainwright, E.J. <i>Module 3: Technology of Wire Ropes for Mine Winding in South Africa</i> RCA Training Manual, 1994</li> <li data-bbox="420 1541 1365 1619">• Kuun, T.C. <i>Module 4: Magnetic Rope Testing Instruments</i> RCA Training Manual, November 1995</li> <li data-bbox="420 1630 1389 1709">• Kuun, T.C. <i>Module 5: Practical Aspects of Rope Inspection</i> RCA Training Manual, November 1995</li> <li data-bbox="420 1720 1436 1798">• Borello, M. <i>Module 6: Destructive testing of Wire Ropes</i> CSIR Internal Report MST(92)MC1212, July 1992</li> <li data-bbox="420 1809 1412 1888">• Borello, M. and Hecker, G.F.K. <i>Module 7: Rope Deterioration Reference Book</i> RCA Training Module, December 1994</li> </ul>   |

| VOLUME | TITLE AND REFERENCE   |
|--------|---|
| 6      | <p>CODE OF PRACTICE FOR THE PERFORMANCE, OPERATION, TESTING AND MAINTENANCE OF DRUM WINDERS RELATING TO ROPE SAFETY</p> <ul style="list-style-type: none"> <li>• Kroonstuiwer, J. <i>Investigation into Rope Forces Generated during Emergency Braking Events</i> CSIR Contract Report MST(94)MC2208 No.940189, September 1994</li> <li>• Hecker, G.F.K. <i>Rope Force Measurements during Emergency Braking</i> CSIR Contract Report MST(94)MC2208 No.940190, September 1994</li> <li>• Kroonstuiwer, J. <i>Investigation of Forces in a 4000 m Mine Winding Rope resulting from a Motor Fault Torque</i> CSIR Contract Report MST(94)MC2208 No.940192, September 1994</li> <li>• Hecker, G.F.K. <i>Rope Deterioration: Field Study Requirements and Recommendations</i> CSIR Contract Report MST(95)MC2450 No.950107, March 1995</li> <li>• Kroonstuiwer, J. <i>Load Ranges during a normal Winding Cycle</i> CSIR Contract Report MST(95)MC2573 No.950189</li> </ul> |
| 7      | <p>FORCES ACTING IN SINKING WINDER ROPES</p> <ul style="list-style-type: none"> <li>• Van Zyl, M.N. <i>Rope Force Measurements during Shaft Sinking Operations at Vaal Reefs 11 Shaft</i> CSIR Contract Report MST(95)MC2736 No.950373, December 1995</li> <li>• Van Zyl, M.N. <i>Rope Force Measurements during Shaft Sinking Operations at West Driefontein 10 Shaft</i> CSIR Contract Report MST(96)MC2736 No.950374, January 1996</li> <li>• Van Zyl, M.N. <i>Rope Force Measurements during Shaft Sinking Operations at West Driefontein 9 Shaft</i> CSIR Contract Report MST(96)MC2736 No.950375, February 1996</li> </ul>  |

If a copy of any of the above reports is required, it may be ordered directly from:

The Secretary  
SIMRAC  
P O Box 61809  
Marshalltown  
2107

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## 1. INTRODUCTION

The original proposal for this contract covered a three-year SIMRAC-funded project entitled *Develop a Code of Practice for Performance and Maintenance of Rope Winding Plant*. The main motivation was the need for codes of practice intended to accompany the newly proposed winder rope safety regulations. The following main sub-projects were identified in the original proposal:

- evaluation of the strength and deterioration of rope terminations,
- verification of the discard criteria contained in the code of practice for rope condition assessment,
- projects required to enable the drafting of a code of practice for the performance, operation, maintenance and testing of drum winders, and
- finalisation of the recommendations towards changing the rope safety regulations

Several bodies were formed during the period under review: At the request of the Government Mining Engineer, the SABS formed a technical committee with the title *Mine winding ropes and plant*. This committee held its inaugural meeting on 9 June 1993 during which it appointed two working groups. These working groups were to deal with a code of practice for rope condition assessment and discard criteria for mine winding ropes (including the specification of NDT equipment and training and certification of testing personnel) and a code of practice detailing the performance, operation, maintenance and testing criteria for mine winding plant (pertaining to rope safety and deterioration) respectively.

The SIMGAP Engineering Advisory Group (EAG) held its inaugural meeting on 16 September 1993. During this meeting it was decided to change the title of the project from *Develop a Code of Practice for Performance, Operation, Maintenance and Testing of Rope Winding Systems* to *The Safe Use of Mine Winding Ropes*. During further meetings, the EAG requested several additions to the original set of deliverables.

This report is a summary of all the projects and provides an overview of the deliverables and a short list of the research results.

## 2. CHANGES IN ROPE FACTORS OF SAFETY

### 2.1 RECOMMENDATIONS FOR PHASE 1 CHANGES IN ROPE FACTORS OF SAFETY

The current South African regulations for sizing of mine winder ropes were introduced during 1956, based mainly on circumstantial evidence. A more rational approach was required to meet the demands for improved guarantees of safety and for more economical winding operations. Investigations in this regard were undertaken by the CSIR on behalf of the Chamber of Mines. These studies were guided by the Steering Committee on Factor of Safety of Winder Ropes and were completed just before SIMRAC system commenced. The initial phase of the SIMRAC project was therefore the finalisation of this research and took the form of making final recommendations.

The Steering Committee on Factors of Safety of Winder Ropes appointed a working group to draw up a set of proposals for changing the regulations governing the required rope strength in the Minerals Act. Certain research projects have been conducted to substantiate the recommendations. The results of these projects have shown that a new set of regulations could be recommended for drum winder ropes, although detailed knowledge on rope deterioration was still lacking. Statutory regulations should effectively limit the dynamic load range and the peak dynamic forces. It was requested that static factors be specified in the regulations, however, and to make provision for dynamic winder behaviour in a code of practice. The working group's recommendations and individual discussions can be summarised as follows:

- To align the regulations with commonly accepted engineering practice, it was proposed that they should specify the rope strength at installation and not at discard.
- All winding ropes shall be inspected and discarded according to an approved code of practice for rope condition assessment. It was accepted that the contents of this code will be based on current practice and formalised by proven quantified discard criteria.
- Where no code of practice relating to winder performance is applied, the rope shall have a capacity factor of at least 8 and a static factor of at least 4,5.
- For vertical shafts, where a code of practice for winder performance, operation, maintenance and testing is applied, in as far as it affects rope safety and deterioration, the static factor shall be not less than  $25000/(4000 + L)$ , where  $L$  is the length of the suspended rope in metres, and the dynamic factor shall not be less than 2,5.
- The initial breaking force of incline winder ropes should not be lower than the current values.

These recommendations were reported in the final document issued by the working group. The codes of practice referred to in the recommendations still required development and refinement and these formed the core of the research requirements for the SIMRAC project.

## **2.2 CODE OF PRACTICE FOR THE PERFORMANCE, OPERATION, TESTING AND MAINTENANCE OF DRUM WINDERS RELATING TO ROPE SAFETY**

The South African Bureau of Standards (SABS) established the technical committee TC 801.19 *Wire Ropes*. The scope of this committee is *"Standardisation in the field of design, operation and maintenance of mine winding systems to promote the safe use of winding ropes. Including the standardisation of the examinations and discarding criteria of wire rope."*

During a meeting of the technical committee on 9 June 1993, two working groups were formed. Working group 2 was given the following scope of work:

- avoidance of abnormal damage,
- prevention of overloads and
- prevention of damage to ropes and of excessive stresses.

The CSIR's technical and administrative contributions towards the code of practice are funded under the contract with the Safety In Mines Research Advisory Committee

(SIMRAC). The SIMRAC Engineering Advisory Group monitors the progress of the work and considers requests for required research funding.

Working group 2 identified its scope of work on the basis that safe winding was mainly dependent on the effective condition assessment of the rope. A code of practice was nevertheless required which was aimed at preventing abnormal and accidental rope deterioration.

Having studied the motivation for the proposed regulation in the Minerals Act, which refers to an *approved safety standard pertaining to winder performance, operation, maintenance and testing*, the working group proceeded to draft a code of practice that would fulfil the following requirements:

- The rate of rope deterioration should be limited so that excessive deterioration could not occur from one rope inspection to the next.
- The peak dynamic forces acting in the rope should not cause permanent damage to the rope.
- No foreseeable condition should lead to the failure of the rope.
- Regular inspections and maintenance of the winding system should ensure that the above requirements are always met.

The working group appointed task groups to draft the specifications that would fulfil these requirements. Task group members were selected based on their expertise and experience in each relevant field.



The working group and task group members are listed in the allocation shown below:

| Member          | Affiliation | WG | TG1 | TG2 | TG3 | TG4 | TG5 | TG6 |
|-----------------|-------------|----|-----|-----|-----|-----|-----|-----|
| Atkinson L T J  | W. Controls | ○  |     | ○   | ○   |     | ○   |     |
| Borello M       | CSIR        |    |     |     |     | ○   |     |     |
| Buitenweg A W   | SABS        | ○  |     |     |     |     |     |     |
| Burger S        | DMEA        | ○  |     |     |     |     |     |     |
| Constancon C    | Wits        | ○  |     |     | ○   |     |     |     |
| Dohm M A R      | AAC         | ○  |     | ○   | ●   |     |     | ○   |
| Du Plessis G    | Gencor      |    |     | ○   | ○   |     |     |     |
| Field D E       | Gencor      |    |     |     |     |     | ○   |     |
| Grobler S       | AAC         |    |     |     |     |     | ○   |     |
| Gundersen R E   | GFSA        | ○  | ○   | ○   |     |     | ●   | ○   |
| Hecker G F K    | CSIR        | ○  |     | ●   |     |     | ○   | ○   |
| Hilmer W        | Siemens     | ○  | ○   |     |     |     | ○   |     |
| Laubscher P S   | Consultant  | ●  |     | ○   |     | ●   | ○   |     |
| Lock M J        | Cegelec     | ○  | ○   |     |     |     |     |     |
| McDonald D      | Haggie      | ○  |     |     | ○   | ○   |     |     |
| McKenzie A J    | DMEA        | ○  |     |     |     |     |     |     |
| Mills G         | Leeudoorn   |    |     |     |     |     | ○   | ○   |
| Morley-Jepson W | JCI         | ○  |     |     |     |     |     | ○   |
| O'Conner R      | East Drie   |    |     |     |     | ○   |     | ○   |
| Raymond T G     | JCI         | ○  |     |     |     |     |     |     |
| Sparg E         | Dorbyl      | ○  |     | ○   | ○   |     |     |     |
| Stewart A T     | Gencor      | ○  | ●   |     |     |     |     | ●   |
| Van Zyl M N     | CSIR        | ○  | ○   | ○   | ○   | ○   |     |     |
| Vermaak P L     | West Drie   | ○  |     |     |     |     |     |     |
| Wainwright E J  | Consultant  |    |     |     |     | ○   |     |     |

● ≡ Chairman/Convenor ○ ≡ Member

The main working group discussed the requirements of the safety standard and produced a preamble outlining these. The task groups were appointed and given the following portfolios:

#### Task Group 1

- Electrical drive control
- Monitoring equipment and interlocks
- Electrical control system - operation and maintenance

#### Task Group 2

This task group was formed to draft the requirements for winder brakes. These requirements do **not** address the primary purpose of the brakes, namely to retard the winder, but strive to ensure that the application of the brakes does not lead to excessive rope forces.

**Task Group 3**

- Winder layout geometry, which has to include winder drum and sheave orientation, fleet angles, and catenary geometry.
- Winder drums, coiling, and drum stiffness.
- Headgear sheaves.

**Task Group 4**

- Ropes
- Terminations
- Rope force equalisation systems

**Task Group 5**

Requirements covering aspects of the shaft, specifically:

- Guides.
- Conveyances.
- Conveyance loading and unloading.

**Task Group 6**

This task group dealt with the drafting of requirements and procedures to be followed when an irregular event occurs, and special procedures required for hoisting heavy loads.

The contributions of the various task groups were grouped into the following sections:

**ROPE SELECTION**

This section contains allowed rope constructions, rope quality requirements, mechanical properties and tolerances. Task group 4 has compiled most of the contents of this section.

**DESIGN CONSIDERATIONS**

This is by far the largest section in the document. All fixed parameters of the winding plant are included in this section, for example: Winding plant layout,  $D/d$  ratios, fleet angles, emergency brake capacity, terminations, conveyances, etc. With the information under this section and the Rope Selection section, the basic winder can be designed. The section also contains some design analyses that need to be made to ensure that excessive rope forces are avoided. Reference is also made to appendices that contain recommendations or more detailed information.

**FEEDBACK AND CONTROL SYSTEMS**

This section contains the measurement and feedback requirements for the control of the winder. It does not contain specifications on how these systems are to perform. Such specifications are covered in the following sections.

## **PERFORMANCE**

This section covers the performance specifications for the winding installation, for example, load range and peak rope load limits, alarm and fault detection systems. It includes required automatic winder operations and conditions under which the winder speed is to be reduced to creep speed or those under which the winder should lock out.

## **OPERATION**

This section contains the requirements for the continued safe operation of a winder. Certain operations need to be done at installation or when a malfunction of a winding system component is detected. These do not include any operations covered by the automatic winder control.

## **INSPECTION, TESTING AND MAINTENANCE**

The contents of this section can be grouped into the intervals as follows:

### **At installation or when alterations are made**

- Determination of critical brake settings and dynamic factor
- Fleet angle measurement

### **Daily:**

- Rope inspection
- Inspection of front end and back end terminations

### **Weekly:**

- Verification of critical brake settings
- Static brake holding power test
- Sheave and drum inspection

### **Monthly:**

- Detailed rope inspection
- Functional brake test (includes trip outs with empty conveyances)

### **Three-Monthly**

- Sheave groove profile measurement

### **Annually:**

- Dynamic brake tests to determine the dynamic factor
- Guide gauge measurements

### 3. GUIDELINES FOR DESIGN AND MAINTENANCE OF ROPE TERMINATIONS

There are many types of rope termination for particular applications. The proper selection and preparation of a winder rope termination greatly influence the safety of the winding system. Mine winders operate almost continuously in difficult conditions, comprising such factors as vibration, corrosion and high loads including dynamic loading.

A comprehensive study was done on various types of terminations with the goal to provide guidelines for the selection and maintenance of rope terminations.

#### 3.1 RESIN-FILLED SOCKETS

Ten resin socketed terminations were originally tensile tested in a program done on behalf of the Steering Committee on Factor of Safety of Winder Ropes. All the specimens tested failed clear of the resin socket, which showed that this type of termination has an efficiency of 100%. It was therefore concluded that the resin cappings would be suitable for a series of field trials to further prove their suitability.

##### 3.1.1 Performance of Resin Filled Sockets prepared by the Mining Industry

The efficiencies of resin capped sockets on triangular strand ropes prepared by mine personnel on site were investigated. This presented the opportunity to investigate whether the available literature and specifically the National Coal Board video on the procedures for resin capped socket preparation, is adequate training material for successful future socket preparations.

Six mines were approached to participate in this investigation. Relevant literature and the socket preparation video were issued in advance to the relevant personnel. Personnel from each mine prepared two resin sockets. CSIR personnel were present during most of the actual socket preparations as observers. The prepared sockets were subsequently inspected and tensile tested to destruction at the CSIR laboratories.

Despite the problems with the training material the results of the tests yielded socket strengths of 100% for eleven of the twelve samples. The breaking strength of one sample that fractured at the neck of the socket was 99,7% of the breaking strength of the new rope.

The following was concluded:

- There are serious inadequacies with the current prescribed procedures (i.e. the video and the literature) for socket preparation. These procedures are confusing and too complex. A simple yet comprehensive document, describing the resin capping procedure **for a mine rope**, needs to be produced in the form of a standard or code of practice.
- A new ropeman cannot become an expert in capping merely by reading a book on the subject; he must learn and practice under someone who is already skilled in the work.

### 3.1.2 Field Trial of Resin Filled Sockets

Having concluded that resin cappings were suitable replacements for splices as rope terminations on drum winders, the last part of the investigation was to conduct a field trial. Such an experiment would show how successful resin filled sockets could be prepared and used on a mine, even if it is only based on a single case study. The aim of the field trial was to determine whether there were any deterioration mechanisms (other than those simulated in the laboratory tests) that would influence the strength of the termination.

For the purposes of the field trial it was considered essential that a winder be chosen with high front end loads (i.e. limited by the capacity factor) and short winding cycles (to accumulate as many cycles as possible in the six-month period between front end cuts).

A set of sockets was prepared and operated in the shaft for six months. Besides the routine inspections done by mine personnel, CSIR staff also inspected the sockets every month.

After casting the capping, there was a 1 mm settling ascribed to shrinkage of the resin and a further 3 mm when the termination took the weight of the conveyance. The monthly inspections revealed that the capping settled into the socket by a further 2 mm. This settling was ascribed to the first application of the payload. No other changes (relative movement between the wires and the resin or broken wires) were observed during the monthly inspections.

After six months, the sockets were removed from service and returned to the CSIR for inspection and tensile testing. Mine personnel attempted to remove the capping from one socket. This resulted in damage to both the capping and the socket. The tensile tests showed that both terminations had a breaking strength larger than that of the new rope. The termination that was not damaged failed clear of the socket.

#### Conclusion:

- Resin-filled sockets are suitable replacements (for splices) as winder rope terminations operating in vertical shafts.

#### Recommendation:

- When resin sockets are used on mines where high summer temperatures are experienced, the resin casting process should not be done in direct sunlight or should be done early in the morning. Conversely it should be remembered either to use a booster pack or to heat the socket if the ambient temperature is low.

## 3.2 WHITE METAL SOCKETS

The first part of the project involved determining the efficiency of the socketed rope termination using white metal as filler (capping) material. Ten white metal socketed terminations were tensile tested, two immediately after the white metal had cooled respectively and the other eight after having been fatigue tested at different load ranges for various numbers of cycles. All the specimens tested failed clear of the sockets,

which showed that this type of termination is stronger than the rope (i.e. has an efficiency of 100%).

Members of the mining industry expressed their concern about the effects of poor preparation on the efficiency of these terminations. To address these concerns, eight socketed rope terminations were intentionally prepared badly and tested. This involved tensile and fatigue testing four white metal sockets where the wires on the brush were only wiped before casting. The tests were then repeated on four additional samples, but now the wires on the rope brush were not cleaned at all. In all the tests the rope pulled out of the socket, while the termination efficiency varied between 72,5% and 92,5%.

The effect of not heating the socket to the temperature specified by the National Coal Board (UK) was also investigated. White metal cappings were cast into sockets at five different temperatures ranging from room temperature up to 150°C above room temperature. Although the terminations cast at the two lower temperatures failed at the socket, they also failed at a load that was larger than the new rope breaking strength. The other three terminations failed clear of the socket.

The last part of this investigation involved studying the effect of casting white metal cappings at high temperatures (500° C) on the efficiency of the termination using ropes of different tensile grades. The molten white metal cast at these high temperatures did not affect the efficiency of the termination since in all three tests the rope failed clear of the socket.

#### **Conclusions:**

- White metal cappings are suitable replacements for splices as rope terminations on drum winders, provided the recommended preparation procedures are followed.
- Resin is a more suitable capping material than white metal because of its insensitivity to the cleanliness of the brush and its ease of preparation.
- White metal cappings are very sensitive to the cleanliness of the brush and to a lesser extent to the casting temperature of the socket.
- The efficiency of white metal cappings seems unaffected by the high pouring temperature of the white metal for rope tensile grades up to 2100 MPa.

### **3.3 COMPENSATING SHEAVES**

A rope failed on a BMR winder. This led to a series of investigations into the behaviour of the rope sections at compensating sheaves mounted at the conveyance. The initial investigation concentrated on establishing the strength of tangent point samples at the end of their service periods. The results of the tensile tests showed that tangent points deteriorated quite rapidly on some winders, while other installations operated without any problems. Strength losses of about 50% were not uncommon. The fact that tangent points are at the front ends of winder ropes, where the rope loads are the smallest, averted a greater occurrence of accidents in the past. This should, however, not make the situation less alarming.

The differences in rates of deterioration (from one winder to the next) led to the next part of the investigation, namely a general study into the behaviour of the

compensating sheave and the ropes near the tangent points on three rock winders with different rates of tangent point deterioration. The intention of the field measurements was to provide general information so that any further investigations could be planned appropriately. The field measurements consisted of measuring the rotation of the compensating sheave, the lateral vibration of the rope above the compensating sheave, stresses on the outer rope wires, and the dynamic behaviour of the winder drum during normal rock hoisting.

Tensile tests were done on the tangent point rope samples of the three winders on which the field measurements were done. The results suggested that the tangent point deterioration should be different. However, nothing in the mechanical performance of the three winders was found to support this.

During this investigation no evidence could be found to show that lateral rope movement in the shaft, the amount of compensating sheave rotation during a winding cycle or the tensile grade of the rope influence tangent point deterioration significantly.

#### **Conclusions:**

- Unpredictable, inconsistent and unacceptable rates of tangent point deterioration are most probably caused by corrosion of the rope tangent points rather than by any mechanical means.
- The longer a tangent point is left in service on a winder, the greater the chance becomes for a tangent point to deteriorate to an unacceptable degree.

#### **Recommendations:**

- Regular inspection of the condition of the tangent points is the only proper action that will ensure safety.
- Acceptable degrees of deterioration should be established for rope tangent points on BMR compensating sheaves, and appropriate discard criteria should be defined.

## **4. CODE OF PRACTICE FOR ROPE CONDITION ASSESSMENT**

### **4.1 REFINEMENT OF ROPE DISCARD CRITERIA**

#### **4.1.1 Tests on Sections of Discarded Ropes**

Rope inspectors and mine engineers were requested to submit sections of discarded ropes to the CSIR for destructive tests. The sections to be submitted were to be those that met the discard criteria. The results of the rope inspection were compared to the discard criteria. This comparison, together with the results of the destructive tests, was to be used to validate or, alternatively, to refine the discard criteria.

The test results showed that the discard criteria may be applied for triangular strand and round strand ropes but not to non-spin ropes. Suggestions were made to refine the discard criteria. Due to the limited number of samples tested, not all discard criteria could be evaluated.

The results also showed that not all ropes were assessed and discarded according to the draft Code of Practice for Rope Condition Assessment. About half of the ropes were overdue for discard.

#### Recommendations:

- Non-spin ropes were generally discarded when their strength had reduced by more than 10%. The discard criteria were not properly applied during the inspection - they were only assigned when the laboratory tests were done. Further work is therefore required in interpreting electro-magnetic test traces of these ropes and combining them with revised requirements for non-spin ropes. Requirements for Koepe ropes should be different to those for non-spin ropes operating on drum winders.
- The revised discard factors, based on tests on samples with induced defects, should be incorporated in a revised draft code of practice.
- Considerably more discarded rope samples should be submitted for evaluation. If possible, all ropes discarded in the next years should be assessed.
- Further work is required in clarifying how corrosion is assessed. Maybe only more explicit instructions to rope inspectors are required. On the other hand, adequate arrangements must be made for the various types of electro-magnetic test instruments.
- The importance of correct measurements and observations has been emphasised. The coordination of the work of the rope inspectors and the responsible engineer needs to be clarified and all responsible engineers should be made conversant with the code and the requirements for correct measurement.

#### 4.1.2 Tests on Rope Specimens with Induced Defects

Due to the paucity of good samples obtained from discarded ropes, it was decided to prepare test specimens from new ropes with induced defects. The only defects induced were broken wires (simulated by cutting outer wires) in triangular strand and round strand ropes.

Such tests had previously done by Harvey and Kruger and the discard criteria in the draft code of practice were largely based on the results of these tests. The test results were, however, considered questionable because the loss in breaking strength of the rope was often less than the loss in rope area due to the broken wires and this made no engineering sense.

The results of six-monthly statutory tests on front end rope samples initially show an increase in a rope's breaking strength. This is ascribed to the settling of a rope until there is a more even stress distribution between the different strands and wires. This effect needed to be taken care of in the simulated broken wire tests. The samples were therefore subjected to a fluctuating tensile load before the wires were cut and the rope was tested to destruction.

The results of these tests were different from those obtained by Harvey and Kruger. Least squares fitting was done to find the values of  $B$  and  $Q$  in the equation  $\delta BF = \delta a + B\delta a^Q$  (with  $\delta BF$  the loss in breaking strength and  $\delta a$  the loss in rope area).



The range of samples available from ropes with various constructions that was available for these tests was not sufficient for a comprehensive study. Nevertheless, the analyses of each set results produced consistent results: Where all the broken wires are in a single strand (and this covers about 95% of all cases), the probability that a rope's strength has reduced by more than 10% is acceptably small if the rope is discarded when the broken wire area does not exceed 4% of the rope area.

#### **Recommendations:**

- In none of the 46 cut wire tests was the loss in strength less than the loss in area. This differs from the results reported by Harvey and Kruger. The results of Harvey and Kruger symmetric cuts (less than  $\frac{2}{3}$  of the broken wires in 3 or more adjacent strands) were therefore not considered in the analysis.
- There is overlap between the asymmetric and symmetric sub sets for the results of the 46 tests. A clearer separation between these two sub sets was achieved by redefining asymmetry as: more than 50% of the broken wires in two adjacent strands.
- The new definition of asymmetry means that the cut pattern NON000 (where N = 3, 4, 5, 6) is now defined as symmetric and not asymmetric.
- New winding ropes of 48 mm diameter and 6 × 32 construction should be discarded when the loss in steel area due to broken wires over one rope lay length is equal to or greater than
 

|    |   |  |
|----|---|--|
| 4% | - | when all the broken wires are in one strand or when more than 50% of the failures are in two adjacent strands, |
| 7% | - | when 50% or fewer failures are in two adjacent strands.  |

## **4.2 TRAINING MODULES FOR ROPE INSPECTORS**

The training of rope inspectors is critical to the correct application of the code of practice for rope condition assessment. Members of the working group appointed to draft this code of practice formed a committee, chaired by Mr M A R Dohm of Anglo American, to stipulate the training requirements for incumbent rope inspectors. It was decided that self-study forms an integral part of the training syllabus. A set of training manuals was required for this purpose.

The following table lists the training and reference manuals:

| MODULE | TITLE - AUTHOR  |
|--------|---|
| 1      | Study Guide for Wire Rope Inspectors E J Wainwright                       |
| 2      | An Introduction to Mine Winders E J Wainwright                            |
| 3      | Technology of Wire Ropes for Mine Winding in South Africa* E J Wainwright |
| 4      | Magnetic Rope Testing Instruments T C Kuun                                |
| 5      | Destructive testing of Wire Ropes* M Borello                              |
| 6      | Practical Aspects of Rope Inspection T C Kuun                             |
| 7      | Rope Deterioration Field Guide M Borello, G F K Hecker                    |

\* These training manuals were funded by the Chamber of Mines before the SIMRAC contract commenced.

An additional training module covering legal aspects of rope inspections had originally been drafted, but this training material was later included in the study guide (module 1).

## 5. CODE OF PRACTICE FOR THE PERFORMANCE, OPERATION, TESTING AND MAINTENANCE OF DRUM WINDERS: BACKGROUND INVESTIGATIONS

### 5.1 DYNAMIC ROPE FORCES DURING EMERGENCY BRAKING

The Working Group drafting the Safety Standard for the Performance, Operation, Maintenance and Testing of Mine Winders (SABS TC 801.19 - WG2) had requested an analysis of rope forces that occur during a trip out. The aim of this analysis was to decide whether it is necessary to measure rope forces at the headgear sheave or at the conveyance when the dynamic factor of safety of the rope is being established.

These analyses were an extension of previous work (done under the auspices of the Chamber of Mines) on dynamic rope forces that occurred during brake tests. Drum speed traces obtained during brake tests of several winders were used to calculate the dynamic rope forces. Based on these measurements, a simple method was devised with which the dynamic factor could be established.

After the study, the following conclusions were drawn:

- The peak back end rope forces that occur during emergency braking can be estimated from front end rope force measurements or from conveyance acceleration measurements. It is therefore possible to measure the rope forces either at the front end or at the back end to obtain the peak dynamic rope force.
- The accuracy of the estimated back end forces (from measured front end forces) is within a few percent when the peak accelerations are low.

- With higher accelerations the estimate becomes less accurate. The result, however, is conservative because the actual dynamic forces are lower than the estimated ones.

## **5.2 DYNAMIC ROPE FORCES THAT MAY OCCUR DURING A BRAKE FAILURE.**

When the requirements for the code of practice were compiled, it was decided that under no controlled circumstances should the forces acting on the rope exceed 40% of its strength. It was also realised, however, that the mechanical brake system can fail. This could lead to uncontrolled braking and very high rope forces could result. Concern was expressed that ropes with low static safety factors could then also have dangerously low dynamic safety factors.

A numerical model was compiled to model a rope-conveyance dynamic system. A few cases of brake failure were analysed. Winding systems designed to operate at shaft depths of up to 4000 m according to the newly proposed regulations were modelled. The models were based on conventional designs where there are two brake systems and, in the case of a brake failure, one brake would come on fully.

### **Conclusions:**

- Even in the worst case, the rope forces would not exceed 60% of the rope strength. Although a rope will deform plastically under such high forces, it will not fail.
- If a winder is designed with more than two brakes, clearly the full application of a single brake will have an even smaller effect.

### **Recommendations:**

- No design philosophy was prescribed in the code of practice, but a requirement for calculations was included to show that excessive rope forces do not occur when there is uncontrolled braking. This would ensure that the brakes are not over-designed and rope failure would not occur as a result of brake failure.

## **5.3 DYNAMIC ROPE FORCES RESULTING FROM MOTOR FAULTS**

Similar to the concern about a brake failure leading to excessive rope forces, the concern was expressed that a motor fault could lead to high rope forces. Initial data was supplied by winder motor manufacturers on the motor torque pulse (magnitude and duration) resulting from a short circuit. Analyses of these data suggested that motor faults will lead to rope stresses that may be dangerous. It was therefore decided that more thorough investigations were required.

A proposal for such work was obtained from Anglo American Corporation for work to be done in collaboration with Messrs Cegelec. This work would entail more detailed mathematical modelling to take account of the interaction between motor mechanicals and electricals as well as the entire dynamic system up to and including the conveyance.

**Conclusions:**

- The results of the mathematical modelling showed that the torsional pulses exerted by winder motors during electrical faults are not as severe as initially feared.
- If a motor is rated for the duty it has to perform, the rope forces resulting from fault torques will not lead to the failure of the rope.

**5.4 MEASURING LOAD RANGES ACTING IN WINDING ROPES**

The load range acting in a drum winder is the difference between the maximum and minimum tension that any part of the rope experiences during a winding cycle. The proposed regulation that prescribes a safety factor of  $25\,000 / (4\,000 + L)$  will ensure that the load range on most winders will not exceed 15% of the rope strength. Higher load ranges can occur, however, if ropes with high tensile grades and very light conveyances (allowing larger payloads) are used. It is then possible to reduce the load range again by controlling the winder motor to ensure gentle accelerations and decelerations.

In the code of practice, limitations have been placed on the load range allowed in a winding rope during normal winding. The load range at any point in the rope is not to exceed the 15% of the rope breaking strength more than once in ten cycles.

The purpose of the investigation into load range measurement was to decide how the load range in a winding rope can be measured or calculated for any winder during any winding cycle. Methods of calculating and measuring load ranges were devised for inclusion in the code of practice. In brief, the following four methods were proposed:

- i On line monitoring of winder accelerations and payloads.  
This is essentially the base on the philosophy behind the proposed safety factor.
- ii Load range calculations from measured back end rope forces.  
This method requires a loadcell at the headsheave. The weight of the suspended rope is continuously subtracted from the force read by the loadcell and the load range is the difference between the highest and the lowest value obtained after the subtraction.
- iii Load range calculations from measured front end rope forces.  
This method requires a loadcell at the conveyance. The payload and the rigid body accelerations of the rope are calculated from the loadcell measurements and used to calculate the load range.
- iv Load range calculations from measured front end rope forces.  
This method also requires a loadcell at the conveyance. The payload, the rigid body accelerations of the rope and the first mode of dynamic rope oscillations are calculated from the loadcell measurements. When calculating the load range, sophisticated filtering of the signal obtained from the loadcell is required to separate the rigid body mode from the higher order modes of the dynamic force components.

The methods of calculating the load range in a winding rope were verified by calculating the load from data measured from rock and man winder cycles. Actual recorded data from a South African rock winder was used while hypothetical data created with a numerical simulation was used for a man winder.

Since some methods were considered too complicated to be included in the code of practice, however, only the more elementary ones (i and ii) were included in the code of practice. It was shown, however, that it is possible to calculate load ranges acting in the winding rope from measurements obtained from a conveyance-mounted load cell. The code of practice makes provision for *any proven method* of obtaining the load range. The document that describes this section of work may well be used in future if complex winder controllers are being designed.

## 5.5 REQUIREMENTS FOR A FIELD STUDY ON ROPE DETERIORATION

Most of the requirements in the draft code of practice have been based on the collective experience of members of the working group and task groups that drafted the code. There are still many unknowns, however, regarding rope deterioration. It is therefore necessary to study how different winder parameters and operating conditions influence the degradation of winder ropes. Such a study was outside the scope of the contract, but the requirements for such a study and a programme of work were drawn up.

The equation  $SF = 25000/(4000 + L)$  for the required static factor was motivated on the basis that the load range acting in the rope is the only parameter that requires a limit. A statistical analysis on rope lives obtained on 99 winders has, however, shown that there are many more parameters that influence rope life. Unfortunately the results of this study were very much affected by a lack of proper rope discard criteria. This problem has been addressed when drafting the code of practice for rope condition assessment and a rigorous set of discard criteria was introduced. Nonetheless there is still a lack of understanding of how various operating conditions affect rope deterioration. Consequently, the need for a test facility was expressed to study simulated in-service rope deterioration. A feasibility study has shown that there is not sufficient information available to compile adequate design specifications for such a test facility. It was concluded that further information on rope behaviour on winders was required before it could be assessed whether a test facility could be realised. Even if a test facility could be properly specified, such a facility would most likely be constructed around a full scale mine winder - not necessarily operating on a shaft. The view was expressed that such a facility would be unaffordable.

A different proposed strategy was to study rope deterioration on selected winders and to correlate the results of this study with the operating conditions of the rope. The main advantages of this approach are that no large capital expenditure is necessary and that several tests can be conducted concurrently. The major disadvantage is, of course, that the range of operating conditions will be limited to those set by current installations and that extrapolations must be done with circumspection.

After carefully studying the rope lives obtained on various winders, the reasons for discarding the ropes on these winders and site visits to establish the feasibility of doing field work, the following winders were proposed as study objects:

| Winder   | Study object          |
|--|-----------------------|
| St. Helena No. 4 shaft                                       | Longest rope life     |
| Vaal Reefs No. 1 sub <i>or</i> Hartebeestfontein No. 4 shaft | Wear                  |
| East Driefontein No. 2 shaft                                 | Broken wires          |
| Vaal Reefs No. 4 shaft                                       | Wear and broken wires |
| Counterweight winder (to be selected)                        | Low load ranges       |

A study programme was also proposed that entails the following steps:

- Verification of winder parameters to ensure that any changes to the operating conditions since previous investigations will be considered.
- Corroboration of rope maintenance practice to establish rope hygiene practices.
- Winder behaviour measurement to record winder dynamics so that rope forces can be established.
- Rope inspections to note the onset and progression of rope deterioration.
- Evaluation of discarded ropes to allow detailed rope inspections and destructive tests.
- Laboratory work to measure internal rope stresses and contact stresses and to study rope fatigue behaviour and torsional behaviour. Whenever possible, this work should be augmented by mathematical modelling so that universal solutions can be found.

These recommendations formed the basis for the work being done under a new SIMRAC project GAP 324.

## 6. THE SAFETY OF STAGE AND KIBBLE WINDER ROPES

The proposed new statutory regulations for drum winder ropes will conceivably allow single lift shafts of as deep as 4 000 m. If such deep shafts have to be sunk in the conventional way, stages and kibbles will be used.

The regulations governing the strength of ropes for stage and kibble winders were being investigated under the auspices of a SIMGAP Engineering Advisory Group. The aim of the stage and kibble winder ropes investigation was to obtain guidelines for drafting a code of practice for sinking winders that operate with lower factors than those required by the current regulations.

The measurement of the rope forces on the stage winder and kibble winder at three shafts was the first part of the investigation. The stage rope forces were measured during all types of sinking and stage operations, i.e. during blasting, lashing, stage raising and lowering, kibble crosshead interactions, and water hoisting.

The kibble winder rope forces were measured during all types of normal sinking operations, which are hoisting of loaded kibbles and tipping, hoisting water, transporting personnel and material, transporting jumbo drill rigs, running the winder with only the crosshead attached at the rope end, and emergency braking with loaded kibbles, both ascending and descending, near the bottom of the shaft.

The dynamic rope components measured during lifting of loaded kibbles and jumbo drill rigs were insignificant because of the slow winder speeds employed during these operations. Tipping and hoisting water also did not generate rope dynamics of any significance. The only event, apart from emergency braking (trip-outs), which produced any significant rope dynamics was acceleration of the winder.

The dynamic rope forces generated by kibble winders are less severe than those of permanent drum winders because of the absence of skip loading dynamics. For the rest of the operation of kibble winders, the dynamics are the same as that of permanent drum winders.

The peak-to-peak magnitudes of the dynamic components of the stage rope forces measured during any stage operation were never greater than 2% of the breaking strength of the ropes. The rope forces can therefore be regarded as static. The rope dynamics measured during stage movements, expressed as percentages of the rope breaking strengths, were less for the deeper shafts compared to those at the shallower shaft.

Considering these results, design parameters for sinking winders for deep shafts were investigated.

**Conclusion:**

- It is possible to sink shafts with stage and kibbles winders in the conventional way to depths of 4 000 m, provided that appropriate rope regulations for such operations are drafted. Such regulations would probably need to include references to codes of practices for sinking winders and special considerations for rope condition assessment.