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THE HIGHLIGHTS OF MINE HOISTING '96

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Synopsis : An international mine hoisting conference was held in Gliwice, Poland in October 1996. Subject matter included economic and legal aspects, safety in particular, reliability, drives, control systems, brakes, ropes, conveyances and attachments and headgears. The author had the opportunity to attend the conference sessions which were held over a three day period. This paper contains a summary of the safety and technical highlights of the conference as well as a list of all the published papers. Where applicable, figures from the conference proceedings have been included.

1. INTRODUCTION

The Mine Hoisting '96 international scientific and technical conference was held in Gliwice, Poland from 8 to 10 October 1996. This was the forth conference of its kind. The first being the International Conference on Hoisting of Men, Materials and Minerals held in Johannesburg in 1973. The second, with the same name, took place in Toronto, Canada in 1988 followed by the Mine Hoisting '93 conference in London, June 1993. The next international hoisting conference will be held in the year 2000, in South Africa.

The conference sessions were attended by approximately 210 delegates representing fifteen countries. The sessions were held at the Faculty of Mining and Geology of the Silesian Technical University in Gliwice and the conference was organised by the KOMAG Mining Mechanisation Centre and WUG, the Polish State Mining Authority. KOMAG is a mining equipment research, development, design and project organization. The company is also actively involved in statutory testing of mining equipment and machinery. A total of 1018 people are employed in projects primarily in the field of coal mining and coal preparation.

The organisers of the conference decided that due to the large number of papers (58) it would not be practical to have them all presented by the respective authors in three days. The majority of the papers were discussed and summarised by the various session chairmen and eleven authors were given the opportunity to present their own papers. The languages of presentation were Polish and English with simultaneous translation. **Figure 1** shows the distribution of the published and presented papers amongst the countries represented. In a number of cases the session chairmen discussed their own papers, these have also been indicated in **Figure 1**.

The contents of eighteen papers, considered to be of most interest from a safety and technical point of view, are discussed in the six sections which follow :

2. General hoisting problems
3. Safety and legal aspects
4. Drives and control
5. Hoisting machine mechanicals
6. Hoisting ropes
7. Conveyances and shaft protection

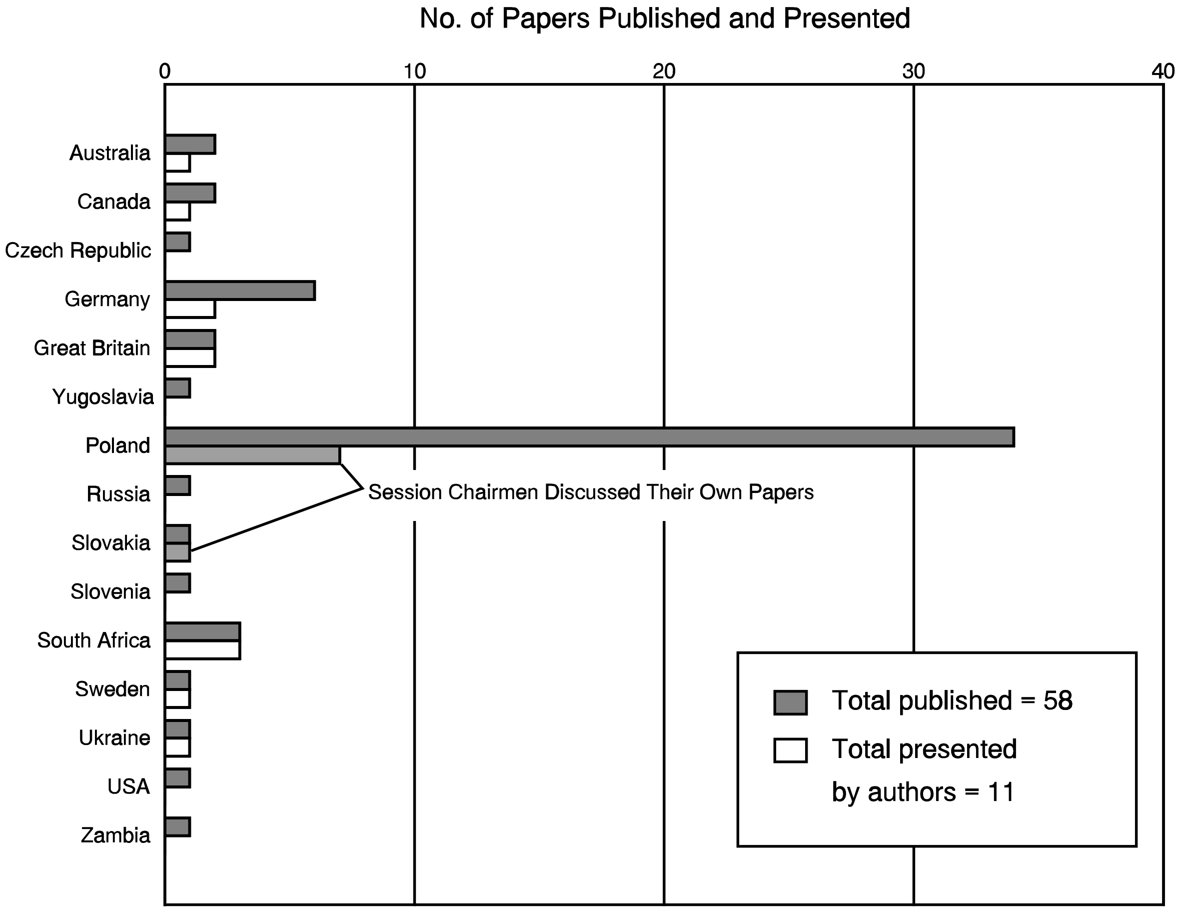


Figure 1 - Country based distribution of papers published and presented.

A full list of the published papers is given in Section 9. Persons interested in reading any of the complete papers are welcome to contact the author through the GENCOR Technical Services Division.

2. GENERAL HOISTING PROBLEMS

2.1 Mobile Emergency Hoists

Goldstien[1] gives the technical specifications which are characteristic of mobile emergency hoists in Poland. The mobile emergency hoist service was established in the early 1970's. Each regional mining association possessed an emergency hoist which was maintained by one of the mines in an area. The hoist would serve the needs of the mines, within an association, in the event of a shaft emergency. The original mobile hoists were installed on low bed trailers, towed by specially designed trucks. Hoist masses varied between 5 to 10,5 tonnes, operating at maximum speeds of 2 m/s, from a depth of up to 1200 m. These hoists were all electrically powered. **Figure 2** shows a typical application. In order to qualify for the emergency hoist service, the mines had to ensure the installation of adequate foundation work at the bank, electrical supply for the hoist drive and an additional sheave in the headgear.

Some mines did not fulfil the necessary requirements and cases arose where the hoists could not be operated in critical emergencies. A decision was subsequently taken to develop a fully mobile, self powered hoist with its own sheave arrangement, cages and shaft communication system. The 'head' sheave of the new system is mounted on a telescopic extension arm with a normal length of 10 m and a further extension capacity of 6 m. This allows a maximum sheave hight above ground level of 14,7 m.

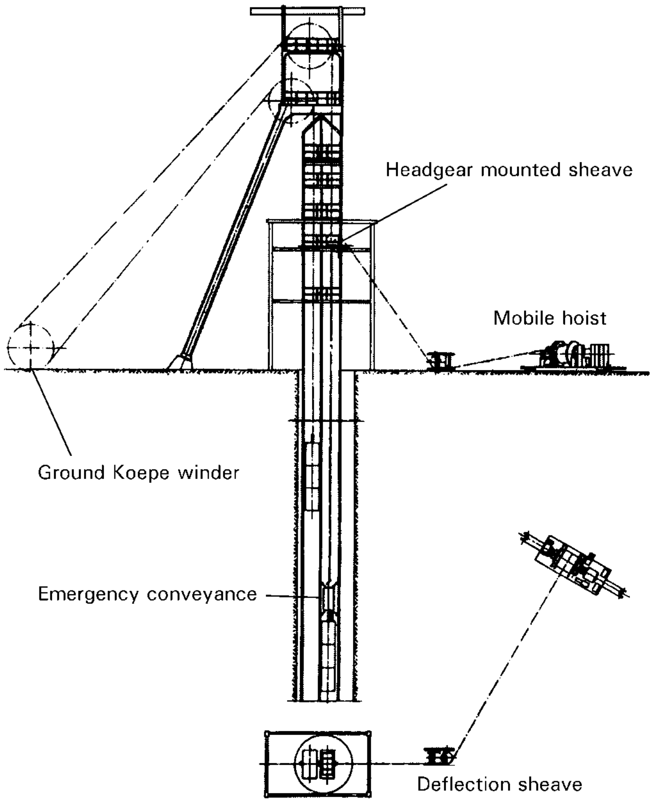


Figure 2 - A mobile emergency hoist installation[1] - original system.

The new hoist specifications are :

Hoisting speed (1st layer)	0,6 m/s
Hoisting speed (16th layer)	1,17 m/s
Drum diameter	650 mm
Rope diameter	22 mm
Hydraulic motor power	43,6 kW
Hoist mass	27 tonnes
Road travelling speed (max)	63 km/h

Operation was first a trial basis whereafter a full licence was granted by the Polish State Mining Authority. Power for the hydraulic hoist drive, braking system and stabilising cylinders is taken from a STEYR truck engine. Two oil pumps of 118 l/min and 57 l/min are utilised in the system.

A major technical problem was overheating of the oil system while lowering at slow speed below a depth of 800 m. This was overcome by the installation of a Swedish made OILTECH cooler with a 500 V, 4 kW electric motor. Accurate depth indication also posed a problem considering the 16 layers of rope on the drum. Electronic counting of the rope sheave rotation replaced the traditional drum shaft counter.

Cage to driver communication was initially achieved by the installation of a four wire telephone cable in the core of the galvanised, 17 strand, non-spin hoist rope. Slip rings and contact bushes were installed at the end of the drum shaft for the communication link. After a three year period, the telephone cable was damaged and a change was made to MOTOROLA 7000A hand held radio units.

The main design purpose of the mobile hoist is the evacuation of personnel trapped in a shaft due to hoist system failure. This is particularly important in shafts serviced by only one winder. The hoists are also used to carry out inspections in shafts without hoisting equipment. It turns out that approximately 80% of the trips to mines are for inspection of shafts that are out of operation. Renovation work in shaft recommissioning projects is also carried out.

The Central Mine Rescue Station hoist has also been utilised in the evacuation of personnel through 1 m diameter wells from a depth of 124 m.

2.2 International Standardisation of Mine Hoisting Safety Standards

Burger[2] addresses the need for international standardisation of factors pertaining to the safe operation of mine winders and ancillary equipment. Details of safety standards that should be of concern to engineers responsible for the design, operation and maintenance of mine winders are also given. The safety standards are discussed in the South African context and originate from the International Labour Organisation's Code of Practice on Safety and Health in Coal Mines. Burger reports that, in South Africa, men and material winding accidents account for 84 % while rock winding accidents occur relatively seldom constituting only 16 % of the total.

The objectives of an international standard would be to bring about agreement on, and rationalisation of specifications for quality of performance. Guidelines would be provided to distinguish between good and bad practices. The compilation of such a standard would mean that accessibility to specialised knowledge would be significantly improved. It is however important to realise that safety cannot be ensured simply by defining factors of safety.

Burger recommended to the conference participants that a decision be made whether to proceed with the establishment of a technical committee under the auspices of the International Standards Organisation (ISO) and International Electrotechnical Commission. A statement of intent has since been issued by the Chairman of the Mine Hoisting '96 organising committee in which Burger's proposal is accepted and permission is given to proceed. The ISO in Geneva has been contacted regarding the proposal and they have indicated that incorporation of safety standards for mine hoisting and ancillary equipment could be accommodated. The ISO have suggested that a South African delegation visit Geneva to lay the ground work for this initiative.

2.3 The Development of Integrated Mine winders

Schubert[3] of MAN GHH gives a detailed design introduction on integrated mine winders and summarises the advantages and disadvantages of the integrated design principle. **Figure 3** schematically illustrates the typical construction of the integrated winder.

The invention of the integrated motor solution dates back to the 1950's. However, limitations relating to the application of DC motors, with ring type commutators, to these hoist designs did not make them practical. Only when cyclo-converter controlled AC motors became proven technology in the early 1980's, did it become feasible to place them symmetrically between the bearings inside a Koepe drum.

The rotor consists of electromagnetic poles in a circular arrangement within the drum. Power for the pole excitation is transmitted via a set of slip rings. The stator, which forms the inner part of the motor, is usually connected to the foundation by means of the main shaft. The electric power supply for the stator is routed trough the hollow bored shaft. A radially bored hole allows the cable to pass from the shaft centre to the stator. Only one radial hole is allowed and it is placed in a area where no bending stresses occur. Recently a new design has been introduced which allows the cabling to pass through stationary ventilation rings which are placed between the shaft and the bearings of the drum. MAN GHH generally use self aligning roller bearings which need to be isolated to avoid being damaged by motor induced currents. Cooling air is introduced in the motor area and a typical air flow pattern is shown in **Figure 3**.

The absence of a rotating shaft requires an alternative design for conveyance position control. Slotted disks, which induce light impulses on detectors when the hoist is moving, are attached to the drum. The digital signals coming from these detectors, combined with tachogenerators running on the disc brake paths, ensure adequate hoist position control.

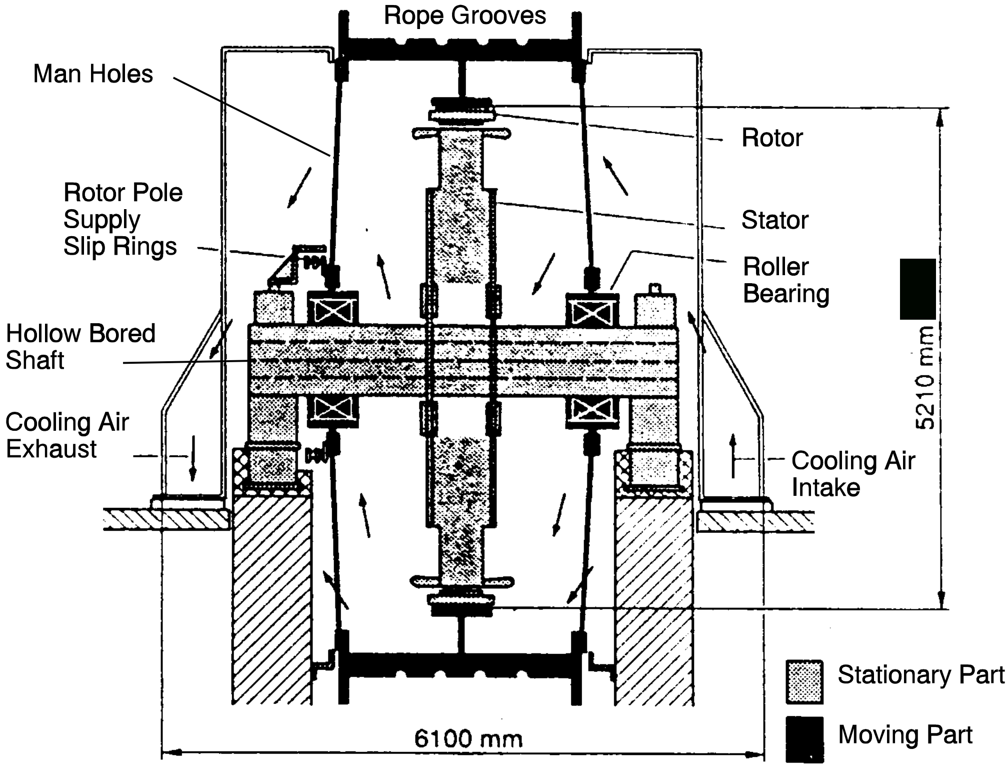


Figure 3 - Example of an integrated Koepe winder[19].

The foundation of the integrated hoist is symmetrical and has only two main load carrying points. The design is such that foundation flexibility and small in-service adjustments cannot result in any damage to the hoist and in particular to the motor.

The main advantages of the integrated hoist are :

- Space saving design. Especially in the case of tower mounted hoists, it not only reduces the tower volume but improves the load distribution.
- Reduces requirements and cost of foundations.
- Reduced time for building construction.
- The design limits excessive motor eccentricities since alignment between the stator and rotor are part of the original design.
- Lower inspection and maintenance needs.

Schubert states that the principle is applicable to hoists of 1000 kW and up and that it is possible to install an integrated motor in a drum with a diameter of 3 m. It is also suited to single drum, hoisting machines. In the case of double drum hoists, the integrated motor may be successful if a second motor becomes economic as opposed to one or two clutches (electrical coupling).

The 19th century was the time of steam engines, the 20th century that of electric drive stands. Schubert proposes that the 21st century should be the time for the integrated machine.

3. SAFETY AND LEGAL ASPECTS

3.1 Safety by Design

Jackson[4] examines a number of key issues relating to mechanical braking, conveyance and rope system protection and electrical control systems which should be considered during the design process of any new hoisting system. Mine hoists are required to be increasingly productive but never at the expense of safety. It is clearly stated that safety and productivity are synonymous and one cannot exist without the other. In Australia the newer hoisting systems are highly automated. Operation is almost entirely unattended, without a driver or onsetter. Supervision of the hoisting system is usually conducted from a remote mine monitoring station.

The maintenance of hoisting systems in Australia has changed considerably. Routine maintenance has been reduced to a minimum but condition monitoring and preventative maintenance has increased significantly. Ever increasing hoist hydraulic and electrical sub-system complexity has resulted in new approaches to maintenance. Built in 'expert' systems for fault diagnostics and repair as well as direct modem connections to the original system designers is becoming more and more common. Emphasis is being placed on staff training, system documentation and appropriate quality assurance during implementation.

Discussing braking systems, Jackson states that the use of multi-calliper disc brakes has gained universal acceptance as the best technical solution for mechanical braking on new winders. The removal of asbestos from brake pads seems to have increased the potential for brake fade to occur under arduous braking conditions. It is therefore recommended that closed loop braking systems be used. These systems provide for actual retardation rate measurement during emergency braking, regulating the hydraulic oil pressure to control the retardation at a predefined value.

The normal over-design of braking systems can result in the undesirable effect of too much braking in certain situations. This is particularly relevant to emergency braking of single drum winders. In many cases, with the conveyance travelling upwards, it is necessary to inhibit mechanical braking and rely on the inertia of the system (gravity) for retardation. Under these circumstances, any malfunction of the braking system (fail to safe) has the potential to cause excessive deceleration which can lead to slack rope and possible miscoiling on the drum (also occupant injury).

Jackson states that, in its simplest interpretation, a mine winder's single purpose is to control the motion of the conveyance in the shaft. The central issue of safe operation is to ensure the safe movement of the conveyance. With this in mind, all conveyances should be provided with overload protection, preferably by means of actual measurement at the point of attachment of the rope to the conveyance. Conveyances on or in which personnel are required to travel should also be provided with an emergency stop facility mounted on the conveyance (ignoring the possibility of sabotage). Interlocks should be provided on all shaft gates and on cage doors. Voice communication from the cages to surface is also desirable. On skips, interlocks should be fitted to check for closed doors, especially on the bottom discharge type. Rope tension measurement on skips is the preferred option for payload control. All slack and tight rope monitoring systems should initiate an emergency stop in the event of the measured loads falling outside of predetermined limits.

Miscoiling on unattended drum winders remains an area of concern. Systems currently using mechanical trip bars across the face of the drums or proximity switches are generally not very effective unless gross miscoiling occurs. Video surveillance of the winder drum is a possible solution to detect miscoiling.

In the age of digital electronics, microcomputers and advanced communication networks, hoisting systems should be expected to exploit these technologies. The main advantages are :

- Drive systems, brake interface, speed-distance protection and operator interface are all provided in a single technology.
- Digital systems are drift free.
- Mechanical interconnections are minimised.
- Fault diagnostics are greatly enhanced.
- Changes are normally made to the software, simplifying the development process.

A more detailed paper on the implementation of advanced digital systems for a Koepe hoist is discussed in Section 4.1.

3.2 Developments in Winder Safety Management at ZCCM

Government mining regulations in Zambia require that incidents which may endanger safety be reported irrespective of whether injury was caused. Nduli[5] describes the use of reportable incident records and audits on equipment and practices, in identifying sort falls in safety systems. Reportable occurrences have been found to be a good indicator of existing hazards.

During the 1987/88 financial year, Zambia Consolidated Copper Mines (ZCCM) produced 24,2 Mt of copper ore from underground and open pit operations. Of the total ore mined, 75,2% was hoisted through shaft systems. Shaft accidents can be very serious in terms of losses to life and injury, equipment damage and production losses. It is therefore appropriate that appointments, operations and maintenance on winding machinery are more strictly regulated than for other engineering equipment.

At ZCCM, reportable incidents increased steadily from 1990 to 1995 with a peak in 1993. Since then the trend has been downward except in the category of operator errors which could be curbed by improving operating procedures. **Table 1** list major accidents that have occurred in the last 12 years.

An accident which occurred on 16/4/95 highlighted the weakness of spliced rope terminations. Calculations, presented by Nduli, show that the force generated by the falling cage, leading to the failure of the splice, was 79,8 % of the manufacturers nominal braking strength. As a result of this accident, a decision has been taken to replace the 61 (43,3%) spliced rope terminations with high efficiency resin sockets. **Figure 4** shows the position of the cage just prior to the accident. It is clear that an effective slack rope monitoring system would have tripped the hoist and that a more efficient termination may have withstood the cage shock load.

Improvements in shaft conditions and shaft station security have been made and it is realised that good shaft conditions are more beneficial than protection systems. Engineering personnel are currently taking over responsibility for shaft maintenance and executive summaries of the generally large winder service contract technical reports enable engineers to quickly pursue corrective action.

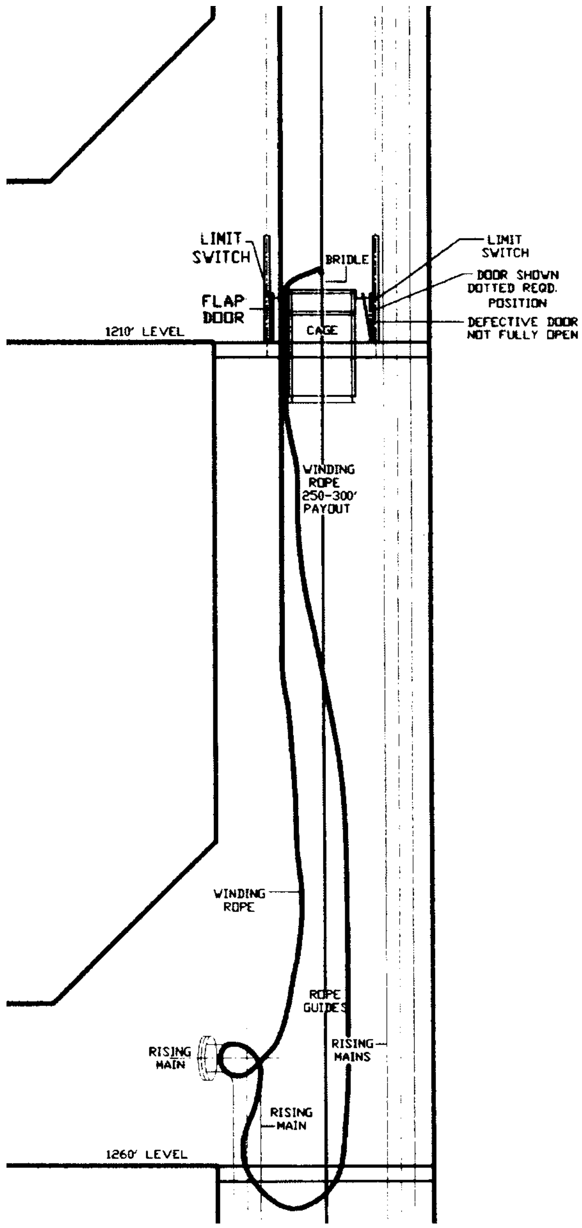


Figure 4 - VS1B cage held at the shaft door[5], slack rope accident. See **Table 1**.

Table 1 - Recent major accidents at ZCCM[5].

DATE	DETAILS	CAUSE
1985	Konkola Division 1 Shaft Man Koepe Winder 10t Locomotive fell in shaft from 2210 foot level and crashed into cage which was at 3400 foot level with 3 men. Three fatalities were recorded.	Lack of security at shaft stations. Disregard of procedures for test running of locomotives.
01/04/87	Nchanga Division C Shaft Man Winder Cage Rope detached during maintenance. No injuries.	Disregard of procedures. Existing procedures inadequate.
16/11/92	Nkana Division CSV Maryanne Hoist Cage rope detached in headframe. Counterweight rope detached from drum. Counterweight crashed at bottom of shaft. No injuries.	Procedures and Regulations overlooked.
04/01/93	Luanshya Division Baluba 1 Shaft Rock Winder tripped when loud bang heard from shaft. Winder pedestals moved 6mm and 3 strands on 6 strand rope broke. Slack rope protection was ineffective.	New skip held on proud bolthead in tipple path. Excess rope paid out into shaft, dislodged skip which fell through approximately 30m.
27/04/94	Konkola Division 3 Shaft Man Koepe Winder. Balance Rope broke.	Poor maintenance. Corrosion not detected.
16/04/95	Konkola Division VS1B Hoist Rope broke at splice when cage fell at approximately 100m after hanging precariously at shaft door. (See Fig.4. VS1B Cage held at Shaft door.) Cage crashed at shaft bottom. No injuries.	Poor maintenance of shaft doors, inadequate procedures, poor enforcement of standards and ineffective slack rope protection.
03/09/95	Nkana Division Central Shaft Rock Winder Emergency trip of safety circuit because a sheave wheel shaft had sheared.	Non-destructive test of sheave wheel shaft not carried out.

3.3 The Safety of Single Rope Hoisting

Jance[6] raised the point that, if a hoist rope in a single rope winding system fails, the occupants of the conveyance would be in serious danger, especially if there is no additional safety system to prevent the cage from falling down the shaft. Ropes in this situation are termed single-line components. A single-line component being one that, upon failing, would cause failure of the entire system.

If the conveyance jams in the guides during a descending journey in the upper section of the shaft and then releases, the rope or another part of the suspension gear will most likely fail catastrophically. Numerous winding installations are equipped with slack rope detection systems to prevent this type of accident. Jance however presents a calculation which shows that a 56 mm triangular strand rope, with an attached mass of 22,6 tonnes, would fail if a slack rope situation occurred in the first 300 m of the shaft. The calculation assumed a winding speed of 12,2 m/s and a slack rope educed emergency retardation rate of 3,2 m/s² yielding 23,3 m of slack prior to dislodgement.

The Vaal Reefs No. 2 shaft accident of 1980, where a cage with 31 workers fell 16 m in the sub-bank area, is given as an example. The cage transom was torn away from the cage resulting in the death of all the occupants. Two similar occurrences occurred in Australia in 1991 and 1993, resulting in rope termination failures with the conveyances falling down the shafts. Fortunately no persons were injured in these accidents.

The Western Australian Mines Inspectorate has recognised that the level of protection given to conveyances travelling in steel and rope guides is inadequate. In view of the potential hazard of the single-line component in drum winding, a research and development program has been established to investigate a suitable device which will reduce the risks.

The proposed solution involves initial friction wedge gripping of the steel guides with subsequent energy dissipation by drawing wire rope slings through restrainer mechanisms fitted on the conveyance. Another alternative is the use of Strain Energy Linear Ductile Arrester (SELDA) strips or the similar Lamar arrester box and strip as shown in **Figure 5.**

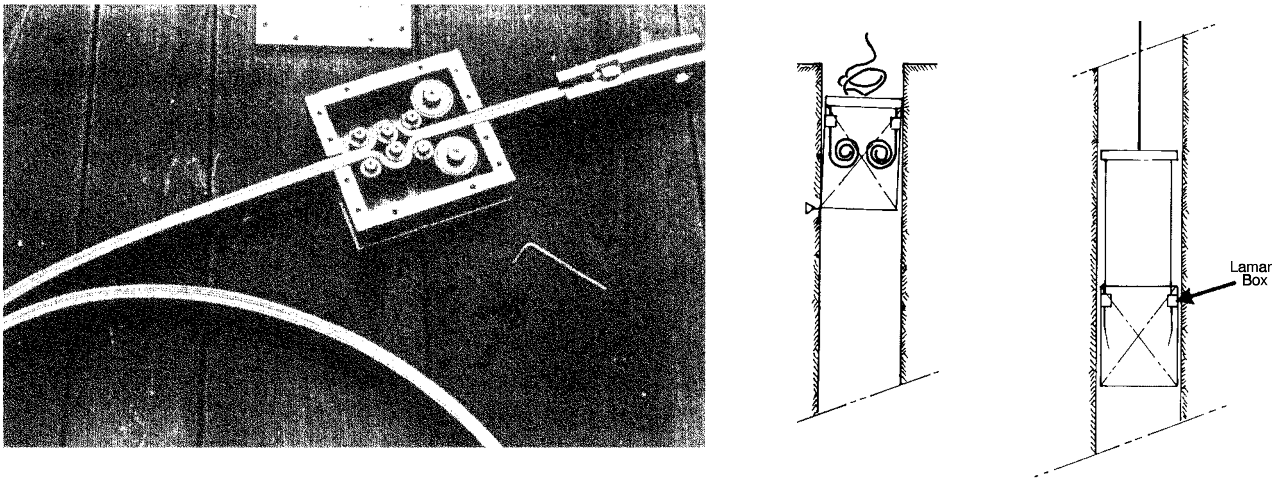


Figure 5 - Lamar cage arrestor and an example of implementation[6] (A similar concept was discussed by Rowe[20] at the Mine Hoisting '93 conference).

3.4 Hoisting Regulations in Poland

Zygmunt and Wojtowicz[7] discuss the legal regulations governing shaft hoists in Poland. Shaft hoists are identified as the main element in mining transport and the system of control and supervision of hoist safety is described. The Polish Mining and Geology Law concentrates primarily on aspects of occupational safety, working conditions, maintenance practices and underground fire hazard protection. Technical specifications for hoist constructions, principles of operation and control and examples of maintenance record keeping documentation are also included in the regulations. Separate sub-sections are devoted to specifying the operating principles for permanent ancillary hoists and mobile hoists which were discussed in Section 2.1.

Routine hoist inspections are carried out by experts nominated by the State Mining Authority. Areas of inspection include conveyances, ropes, suspension gear, winder testing and NDT of safety critical hoist elements. The frequency of hoist inspections is determined according to the hoist duty. The regulations give authority to the experts to put a hoist out of operation if the safety requirements are not adhered to. The polish system of ensuring a high level of occupational safety is complemented by the requirement that equipment, materials and machinery used has to be approved by the appropriate state authority.

The approval permit does not cover aspects such as product endurance or operational suitability if these properties do not have an impact on safety. All equipment (including winders, conveyances, rope sheaves, suspension systems, shaft signalling and communication systems and ancillary equipment technologically connected to vertical transport) must be approved. The main component of the approval process comprises product testing. Technical documentation and operating instructions are carefully reviewed. Laboratory tests are carried out on equipment and the possible impact on safety as well as operational advantages are evaluated. The manufacturer's technical capabilities are placed under scrutiny and it is ensured that the necessary quality control procedures exist. In addition, the manufacturer's references are checked. In certain cases the State Mining Authority may require the applicant to conduct a trail run of the product within the mining environment. This is particularly relevant in the case of complex equipment prototypes. The experiences of Zygmunt and Wojtowicz to date suggest that the structuring of the approval process is appropriate.

Zygmunt and Wojtowicz also report that analysis of accident situations involving equipment showed that, in the majority of cases, improper organisation and technical maintenance were the primary causes, not structural design properties.

4. DRIVES AND CONTROL

4.1 Remote Control of Koepe Hoists

Stewart and Della Ventura[8] examine the extensive modernization of an existing 2.6 MW hoist control system. The conventional driver controls, deceleration system, Lilly controller and automated loading box controls were replaced by a PLC system and PC based man-machine interface (MMI) using Microsoft Windows NT as an operating system. Fibre optic networks were used extensively in the communication between the main control PLC, hoist drive interface, headgear tip, loading box, bank and hoist driver console.

Interesting problems included the replacement of all conventional indication lights, buzzers and analog meters with a 21" computer display screen and the installation of a fail safe replacement for the Lilly controller. Position monitoring of the hoist was achieved by installing an absolute optical encoder driven by the deflection sheaves. This is the preferred solution as the deflection sheaves are less prone to rope slip because of their lower inertia. An additional incremental encoder was fitted to the Koepe drum and a comparison of its signal with that from the deflection sheaves gives an accurate measure of rope slip. The hoist control console consists of a control joystick, a brake joystick, an emergency stop button, an industrial mouse and a personal computer with a screen (Pentium 133 MHz).

A seven element hard wired primary safety circuit is used. All other protective features are incorporated in the PLC system. Fault logging of all alarms and trips is done by the PC system. The replacement for the Lilly controller is in the form of a dual PLC based digital hoist supervisor. In the case of rope slip, automatic resynchronisation is performed using magnetic switches installed in the shaft.The output of the control system is through fully redundant PLC relays which are wired into the primary safety circuits.

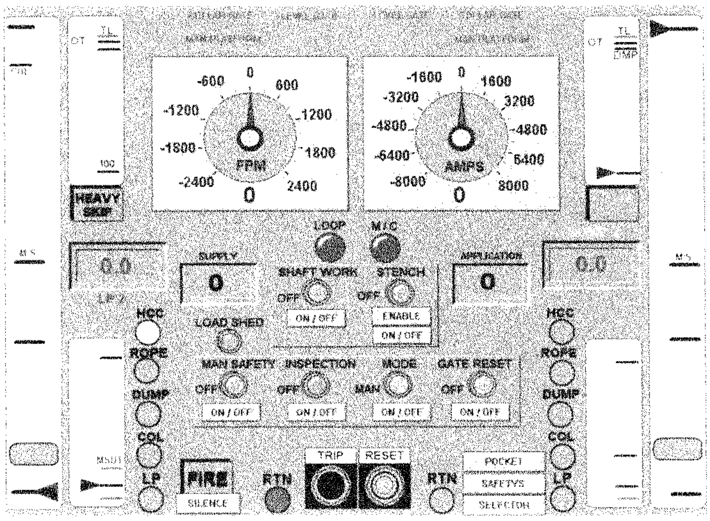
The fully automatic loading box is controlled from the MMI system. Additional information concerning ore levels in the underground and surface bins is obtained from the mine-wide ore handling PLC network.

In order to ensure operator confidence in the system, much effort went into the development of a clearly presented, well defined display. Fast response of the PC system was also of particular importance in satisfying the operator's requirements. The MMI system offers various screens required for sophisticated hoist control. **Figure 6** shows the main operating and brake hydraulic system screens.

Stewart and Della Ventura also give an example of such a system developed to service a semi-automatic man hoist with 40 levels. Apart from the benefits of improved safety, greater levels of automation, flexibility and information, the economic benefits of these systems are :

- Fewer operators or centralised mine control.
- Low cost due to standard hardware and software packages.
- Improved integration of hoist control functions.
- On-line help facilities for hoist diagnostics.

There are also facilities for importing on-screen CAD drawings for fault finding and photographic identification of components. Maintenance instructions can be shown and video camera displays of critical operations are possible in separate windows. It is suggested that remotely located mines would benefit the most from these features.



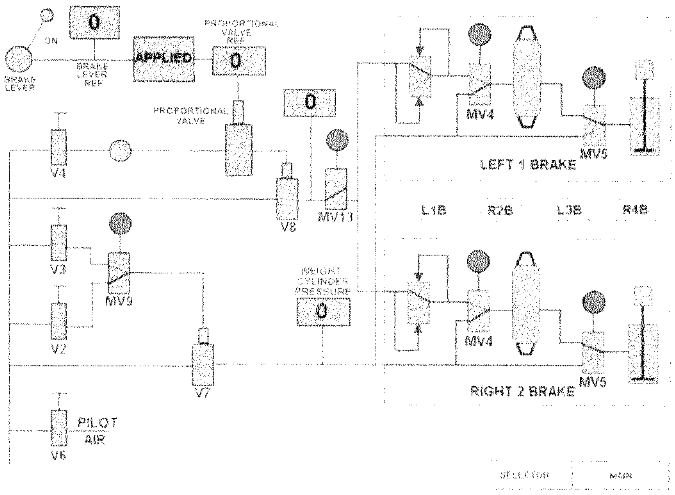


Figure 6 - MMI operator screens of a PC based Koepe hoist control system[8].

5. HOISTING MACHINE MECHANICALS

5.1 Disc Brake Technology

Richardson[9] considers the history and development of disc brake technology for mine winders. The bicycle was one of the early users of this technology. When the pneumatic tire was introduced in the mid 1800's lever brakes onto the outside of the wheel were no longer possible. Designers developed a calliper system similar to the bicycle brakes of today. Even in motor vehicles disc brakes are not a new idea either and were used on racing cars and motor cycles in the early part of this century. Although disc brakes were not used extensively, they were established as an efficient alternative to drum brake systems. Indications are that the first disc brakes on drum winders were used by the Phelps Dodge Corporation of Arizona in the late 1920's. They were manually applied with a dead weight back up.

The major development in disc brakes for mine winders started over 20 years ago when Siemens, ASEA and Twiflex began to investigate the use of spring applied, hydraulically released brake callipers. The companies utilised Belleville disc springs as the means of brake force application.

The failure of a drum braking system led to the death of 18 men and serious injury to a further 11 in the Markham Colliery disaster in the UK in 1973. The incident was entirely due to the failure of a spring nest centre rod which rendered the mechanical brakes totally ineffective. A subsequent move to eliminate single-line components resulted in the adoption of disc brakes. The use of several brake callipers ensures that the braking power is only partially affected even with total failure of one of the units. It is generally recommended to retain at least 50% of the designed braking capacity in the event of failure of any braking system component. Interestingly, with disc brakes, fouling of a brake path with oil or rope dressing could significantly affect the performance of the system since all callipers on that path would be affected. This is also the case with drum brakes, however disc brake systems have the advantage that for each disc there are two braking surfaces.

Since the Markham accident, disc brakes have been used extensively in the UK and the South African, Australian, Canadian and German mining industries are also using disc brake technology in new hoisting applications. Compact calliper designs rely on the use of high integrity disc springs and high performance friction materials. Disc brakes have been applied to Koepe winders, single and double drum as well as Blair multi-rope winders. On larger winders (>3m ∅) brake disks are usually segmented with radial keying to ensure surface alignment. Gaps are also introduced to allow for thermal expansion. Steel plate with a tensile strength of 550 MPa and good ductility is normally used.

Comments have been made that disc brakes are not suitable for application on drum winders because of their inability to cater for drum end float (associated with clutching mechanisms). Richardson suggests that this problem could be overcome by engineering rolling element bearings to accommodate limited float in drums and drum shafts. The use of thrust faces or lipped bearing races is recommended.

A single braking disc is not recommended. However, there are also cases where an excessive number of callipers (32) have been applied on one winder. The problem of such a design is the complication of hydraulic and electrical circuits within the winder system.

Two examples of Twiflex callipers are given :

- VS Calliper = 180 kN force
  1040 cm² pad area
  Min. disc diameter = 1 m
  Minimum disc thickness = 38 mm

- VMS 2 Calliper = 400 kN force
  2200 cm² pad area
  Minimum disc diameter = 1.5 m
  Minimum disc thickness = 38 mm

Both of these callipers contain nested disc springs which apply the braking force in the event of hydraulic pressure loss. The brakes are hydraulically released with back pressure being used to control the braking force during normal stoping duties. NDT is applied to all of the major castings and adjustment of air gaps is achieved with the use of accessible adjusting spindles. **Figure 7** shows the layout of the callipers.

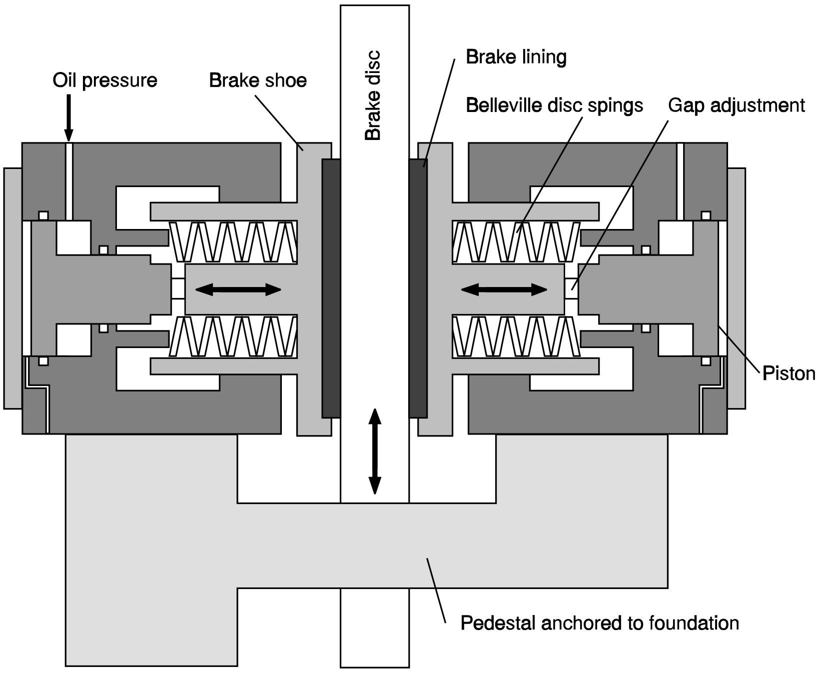


Figure 7 - Basic layout of disc brake calliper units, adapted from Brokenshire[22].

Larger pad areas are preferred as this reduces the likelihood of developing high and damaging brake pad temperatures. Pad temperatures are not usually permitted to exceed 250 °C. Temperatures in excess of this can lead to deterioration of the friction material and brake fade.

VS callipers have been used world wide for many years and the VMS 2 callipers are being applied in large winding installations in South Africa, Canada and Australia. The Vaal Reefs No. 11 Shaft rock winder is one of the latest to be equipped with these callipers. Twiflex strongly recommend the application of fewer larger callipers as this solution results in simpler structures, hydraulic circuits and electrical systems.

6. HOISTING ROPES

6.1 Hoisting Rope NDT Developments in Canada

Pryde[10] states that one of the objectives of mine operators should be to obtain the maximum safe working life from hoisting ropes. Non-destructive testing using dual function instruments can be of great assistance in assessing the state of rope degradation. The dual function instruments measure the loss in cross-sectional metallic area (LMA) caused by corrosion and wear and indicate local faults (LF) caused by broken wires, lay distortion and inter-strand nicking. Pryde refers to the Rotescograph which has two flux gate sensors for measuring LMA and two sensing coils for detecting local faults.

Signals are usually displayed on a two channel strip chart recorder. The LMA trace, combined with the nature of the LF trace can be used to determine if a rope has reached the end of its useful life. There are, however, limitations associated with the use of dual function instruments :

- The instruments usually average the LMA over the length of the test head. If the LMA is localised over a section of rope shorter than the scanning length then the averaging process may not adequately detect the loss.
- The LF trace measures the flux leakage from discontinuities in the rope such as broken wires. The amplitude of the signal depends on the distance of the defect from the coil, the severity of the defect and the gap length.

The second point results in defects of equal severity giving different signals amplitudes depending on their distance from the sensing coils. The LMA trace is not affected by the depth of a defect within the rope. In an attempt to improve the operation, Rotesco is currently working on the *computerisation* of the dual function instrument, the measurement of LMA using *solenoid coils* and LF detection with *multiple segment coils* which will be capable of determining the distribution of defects within the rope.

The benefits of computerisation are :

- Reduced operator errors both in interpretation and setting of calibration parameters.
- Automatic malfunction checks.
- Correction of circuit saturation caused by unexpected excessive defects.
- Comparison of successive tests to determine rate of deterioration.
- Calculation of total magnetic area for comparison to new and previous in-service tests.
- Interpretation of signals from the segmented LF sensing coils by software algorithms will allow determination of defect distribution within the rope.
- Digital filtering and integration techniques will improve condition assessment compared to visual examination of the results.

During the measurement of LMA, the test head magnetically saturates the rope. The proposed solenoid coil measures the LMA by measuring the amount of magnetic flux in the rope. The length over which the magnetic flux influences the coil is approximately equal to the diameter of the coil. The system can therefore be designed to have a scanning length equal to the rope diameter and is then more likely to detect localised losses in cross-sectional area. Another benefit of using solenoid coils to measure LMA is that unlike flux gate sensors, the signals from the coil are not influenced by external magnetic sources or by residual magnetism in the rope.

Present NDT systems use two sensing coils to detect localised faults. The proposed new method would employ four separate coils. The computer will measure the differences in the signals from the coils and should then be able to determine the distribution, location and severity of local faults. With this additional information, it would be possible to correct the amplitude of the LF trace so that like defects would show similar amplitudes irrespective of their position (depth within the cross-section) in the rope.

Accurate condition assessment of hoisting ropes can not be achieved simply by the analysis of NTD traces. Other very important factors also need to be taken into account, namely :

- Results of visual inspections, lay length and diameter measurements.
- Histories of previous ropes operating on the same system.
- The tonnage pulled and cycles completed (work done).
- Estimated tonnages (life) provided by the rope manufacturer.
- The results of destructive tests.

Pryde points out that destructive tests are usually conducted on sections of rope that have never travelled over the sheave wheel and it is therefore necessary to combine the information with results of the other tests in order to make an accurate assessment. Rotesco has started a project with several mines in Ontario which is investigating the usefulness and practicality of using all the above mentioned information together in extending the safe working lives of hoisting ropes.

6.2 Hoisting Rope NDT in the USA

Poffenroth[11] discusses the practical applications and benefits of hoisting rope NDT. The US Department of Labour, Mine Safety and Health Administration (MSHA) has been actively involved in the NDT of personnel hoisting ropes for 20 years.

A basic description of the principle of NDT operation is given :

A magnetic head encircles the rope which, by means of a constant magnetic flux, magnetises a length of rope as it passes through the head. Variations in a constant magnetic field are sensed and electronically processed to produce an output voltage which is proportional to the change in metallic cross-sectional area within the region of influence of the magnetising *circuit. Magnetic flux leakage created by a discontinuity in the rope, such as a broken wire, is also sensed, processed and displayed. Two channels of information are therefore available, the loss is metallic cross-sectional area and the localised faults*. **Figure 8** shows the layout of a typical rope NDT head.

It is vital that ropes be monitored in a reliable manner and a visual inspection alone is not always sufficient. NDT has proven to be a very effective means to enhance safety and complement a good preventative maintenance program. Poffenroth states that there is no substitute for a thorough visual examination of a hoisting rope. However, if NDT is included, both safety and efficiency can be significantly enhanced. It is also important to observe the LF trace and to conduct visual examinations at questionable points along the length of the rope. A NTD trace from a new rope, before it goes into service, is later useful in determining when and where a rope begins to deteriorate. It is also possible that such an initial test could show manufacturing damage in a new rope.

To ensure maximum NDT reliability and accuracy it is important to understand the capabilities and limitations of the instrumentation. The ASTM E1571 "Standard Practice for Electromagnetic Examination of Ferromagnetic Steel Wire Rope" includes a section on the limitations of wire rope NDT. Some of these include :

- Flaws at or near rope terminations or ferromagnetic steel connections cannot be detected.

- Deterioration of a purely metallurgical nature is not easily distinguishable.

- Loss in metallic cross-sectional area measurements show changes relative to the section of rope on which the instrument was calibrated.

- It may be impossible to decern broken wires with relatively small diameters, with small gaps between broken ends or individual broken wires within closely spaced multiple breaks.

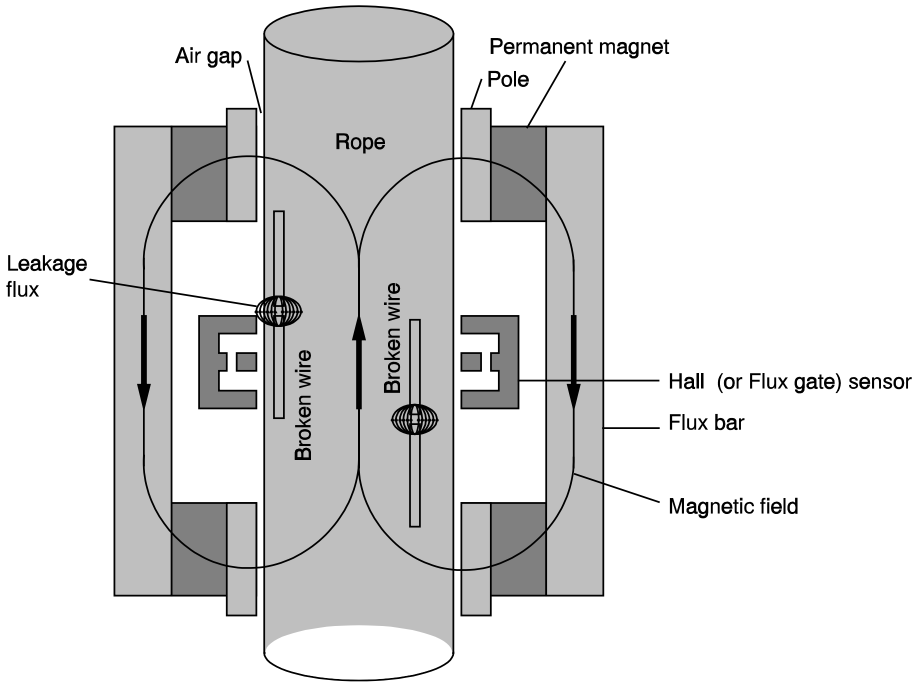


Figure 8 - Main components of a typical hoist rope magnetic non-destructive testing (NDT) head.

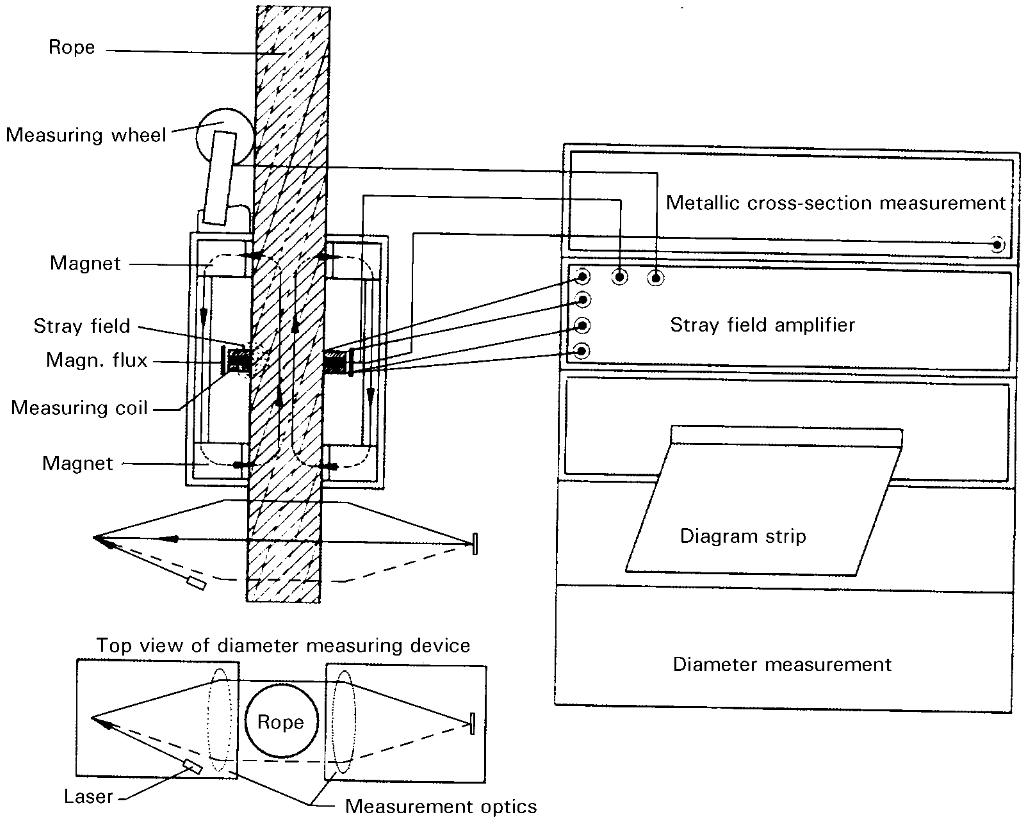


Figure 9 - Rope NDT system with three measurement parameters[12].

Because deterioration of a purely metallurgical nature is difficult to distinguish, more frequent examinations may be necessary after broken wires begin to appear. A rapid increase in the number of broken wires is indicative of fatigue.

6.3 Non-Destructive Hoist Rope Testing in Germany

Langebrake et al.[12], of the DMT Institute of Hoisting and Transport in Germany, report that a NDT system has been developed which, in addition to the LMA and LF traces, simultaneously measures rope diameter. **Figure 9** shows the layout of the system. This method of rope NDT condition assessment takes into account the measured variation in diameter when interpreting the LMA and LF traces.

The principle of operation of the LMA and LF detection systems is similar to those described in sections 6.1 and 6.2. Interestingly the method of measurement shown in **Figure 9** is used primarily on Koepe head ropes where no rope dressings are applied. It is quite likely that the diameter measurement system may not be as effective on well greased drum winder ropes.

6.4 Flat Steel Wire Rubber Balance Ropes

Poturalski and Carbongno[13] present the current technical parameters of flat steel wire rubber balance ropes manufactured by the SAG company in Poland. SAG stands for Steel Anticorrosive Guma which is rubber in Polish. **Figure 10** shows the basic construction of the ropes and **Figure 11** shows the cross-sections of various configurations.

The construction includes an even number of steel ropes each with an opposite direction of lay. The ropes are entirely coated in two layers of rubber. The inner layer has a high level of adhesion to the rope wires and the outer layer is fire and abrasion resistant, with an antielectrostatic nature thus eliminating the discharge of sparks. Both the inner and outer rubber layers are capable of withstanding temperatures down to -30°C without cracking. The rubber and steel ropes are bonded together in a vulcanising press during manufacture. The widths of the SAG ropes vary from 60 to 300 mm with thicknesses between 29 mm and 35 mm. SAG rope masses range from 4 kg/m to 19 kg/m and the tensile grade of the roping wires is between 1370 MPa and 1770 MPa. The ropes are supplied by four manufacturers, three Polish (Drumet, Linodrut and Falind) and one German (Thyssen). During manufacture it is critical for the galvanised wire ropes to be kept absolutely clean to optimise the rubber to steel adhesion.

After more than ten years of experimentation with the concept, a suitable design solution was developed. The SAG factory was subsequently built in 1989 with the first rope being completed in November of that year. By August 1996 the factory had produced 175 ropes, 100 of which are operating in Polish shafts to a maximum depth of 1000 m. The maximum shaft depth at which the ropes have operated at is 1100 m in the Ukraine.

The advantages of the flat steel wire rubber balance ropes are :

- The construction is suited to magnetic inspection techniques using specially designed heads.
- Rope mechanical damage is easily identifiable and can be repaired on-site.
- The design eliminates completely the effects of corrosion.
- The collection of spillage on balance ropes is eliminated.
- The construction is completely torque balanced which results in smooth operation of the tail rope loop.
- The rubber layer protects the rope wires from mechanical damage in the shaft.

If the shaft depth is greater than 1000 m, use is made of wire ropes with extended lay lengths (equalling 8.2 x diameter instead of 6.17 x diameter). It was found that this decreases the individual rope torques by up to 50 %.

Mateja and Swider[14] investigated the operational performance of SAG ropes. A data set of 113 ropes was considered, having a combined operating life of 269 years. Thirty ropes required additional on-site rubber vulcanisation once, ten ropes were repaired twice and only seven required repair between three and eight times. In the majority of cases damage of the rubber was caused by falling objects in the shaft. These objects include nuts, bolts, small steel elements and pieces of the shaft casing. The damaged areas are cleaned and repaired by a portable, electrically powered vulcanisation repair kit. So far, none of the ropes in operation have required removal for safety reasons. It was calculated that, on average, the probability of a SAG rope being damaged is once in every 3,2 years of operation.

Carbogno and Sala[15] presented the latest designs for SAG rope terminations. **Figures 12 and 13** show the self locking wedge capel and the closed capel design. In the case of the closed design it is possible to completely seal off the exposed metallic parts of the rope from aggressive atmospheres.

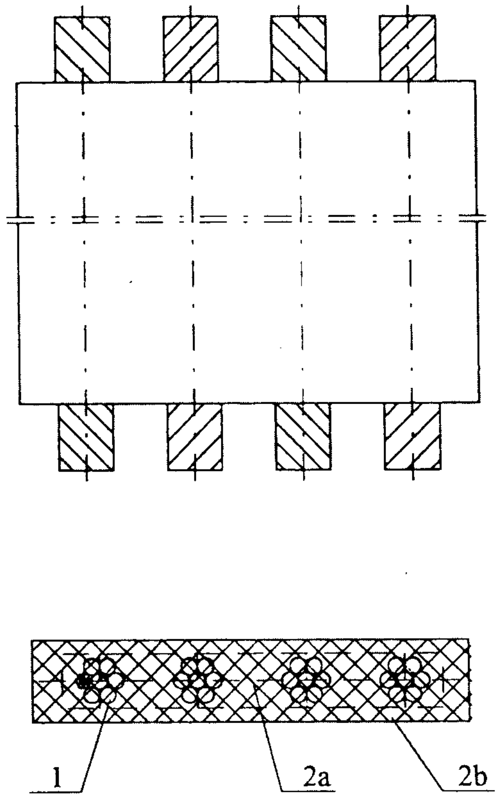


Figure 10 - SAG rope construction[13]
1 - Ordinary lay ropes of W6x25 construction, with opposite directions of lay.
2a, 2b - Inner and outer rubber layers.

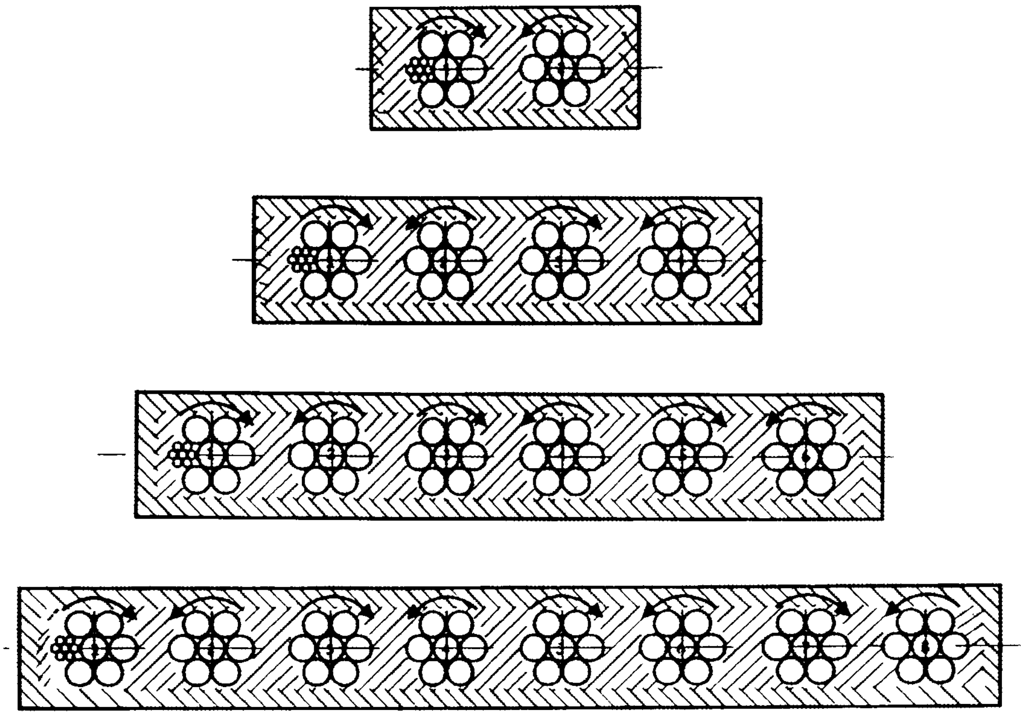


Figure 11 - Cross-section configurations of the SAG flat steel wire rubber balance ropes[13].

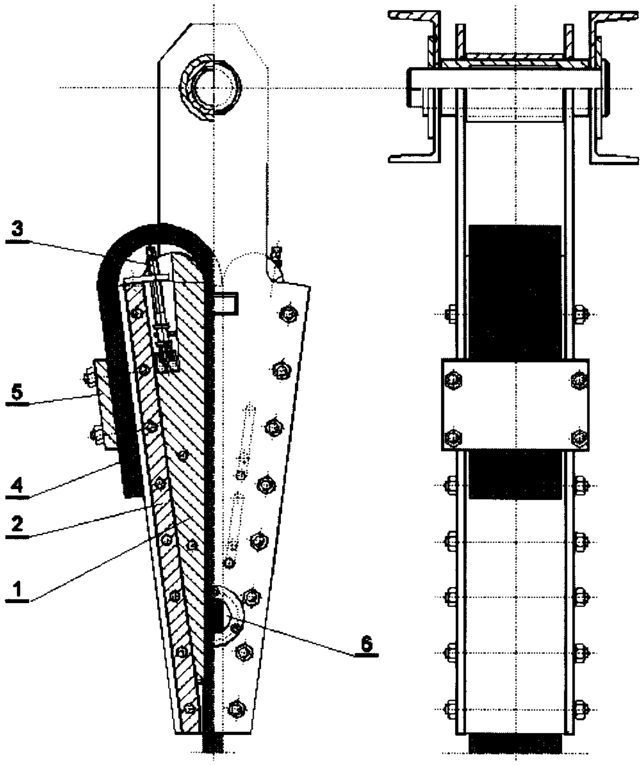


Figure 12 - The self locking wedge capel for SAG ropes[15]
1 - Wedges, 2 - Jaw, 3 - Tightening screw, 4 - SAG Rope, 5 - Flat Clamp, 6 - Inspection opening.

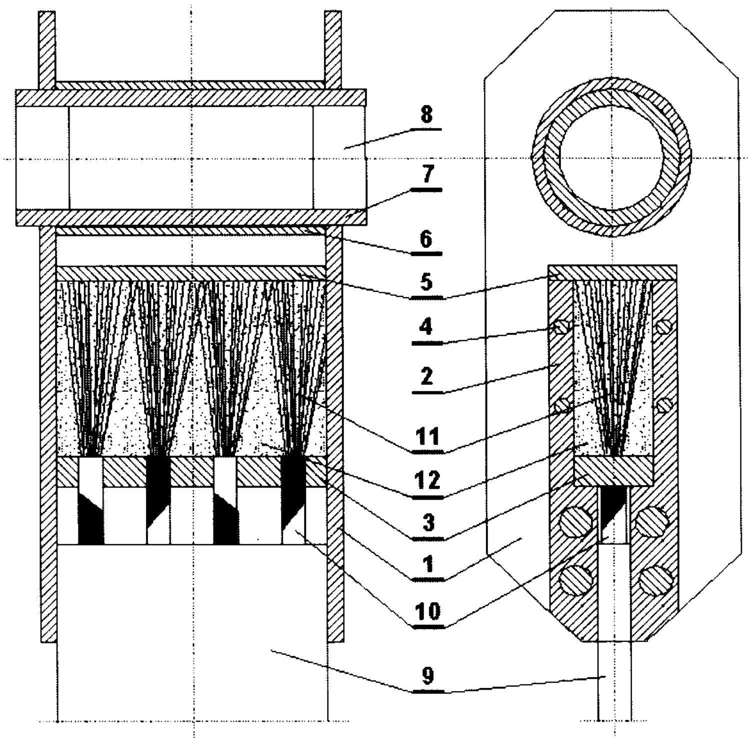


Figure 13 - The closed capel design for SAG ropes[15]
1 - Side plate, 2 - Capel body, 3 - Supporting plate, 4 - Tightening screws, 5 - Cover plate
6,7 - Sleaves, 8 - Pin, 9 - SAG rope, 10 - Steel wire ropes, 11 - Unlaid rope ends,
12 - White metal.

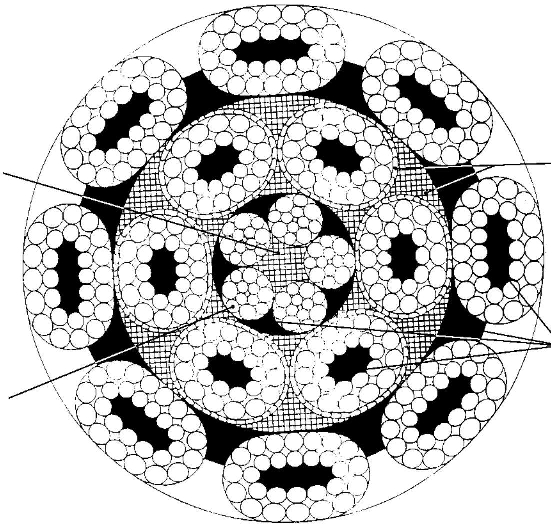


Figure 14 - Patented, three layer flattened strand rope construction[16].

6.5 Flattened Strand Non-Spin Ropes

Heinrich[16] describes a patented, flattened strand rope design for use in deeper level Koepe hoisting installations where non-spin characteristics are required. **Figure 14** shows the cross-section of this rope.

The increasing requirements of hoisting ropes for underground mining forced Schalkeseil GMBH (part of Thyssen) to improve rope construction and performance qualities. The result of the optimisation process was the design shown in **Figure 14**. The direction of lay of the inner two strand layers is opposite to that of the outer strand layer. This ensures balancing of the torque generated by the rope. The strands are all of the Lang's lay type and during closing of the rope polyamide fibres are introduced between the strands to fill the gaps, thereby improving support. Polymer fibres are chosen instead of natural fibres, such as sisal, since they are far less hydroscopic. Natural fibres are also not as pressure and abrasion resistant and consequently do not support the strand layers for an acceptable period of time.

The strand centres of the outer two layers are extruded polyamide profiles which are shaped and sized correctly to enhance the final shape of the strands. The main element of the patented construction is the covering of the second layer of strands with polyamide fibres before they are closed into the rope. The running of the rope over sheaves, as well as vibration cause relative movement between the rope layers. This is particularly severe between the outer layer and the second layer which have opposite lay directions. Inter-wire nicking at the contact points is the main cause of failure of wires in non-spin ropes. By covering the second layer strands with polymer fibre yarns, it is possible to postpone or even avoid this detrimental metallic contact.

Polyamide profiles are added between the outer strands of the rope. They prevent penetration of aggressive media into the inner parts and stop lubricant from being pressed out. The grooves between the round strands of the core are also filled with shaped profiles. The compact core increases transverse stability and minimises rope elongation.

An example of the performance of the new design is given for operation on a six rope Koepe winder hosting a 33 tonne payload from a depth of 1150 m. The winder normally utilised 6x29 round strand ropes with an independent wire rope core (IWRC). The average life for a set of ropes in the corrosive shaft was 16 months. Early 1992 the first set of ropes of the patented design were installed. They gave a service life of 24 months. These were replaced with a second set which lasted 23 months.

The ropes also show very little rotation during winding cycles. An advantage of this is a lower rate of abrasion of the sheave linings. With the previous ropes, linings had to be changed every two to three years. With the flattened strand design there was almost no wear at all after that period of operation.

In the German mining industry, the three layer flattened strand design is now the most common rope used in hoisting installations winding from a depth of 800 m and more. The application of these ropes has led to a substantial improvements in productivity and service life.

7. CONVEYANCES AND SHAFT PROTECTION

7.1 Overwind Energy Absorbtion Systems

Hansel and Wojcik[17] discuss their experiences with over-wind energy absorption systems on Koepe winders. Investigations have shown that over-wind accidents are the most frequent catastrophic accidents in Polish shafts. They constitute approximately 21% of all breakdowns and the average removal time (time to normal operation) is 43 hours. Statistically, the probability of an over-wind occurring is once every 10 years per hoist. The consequences of winding into fixed crash beams are severe and the resulting damage to the conveyance, hoisting and balance ropes is often irreparable. In the case of man winding significant injuries or death can result from such an accident. It is reported that the average cost of removal and repair (excluding losses in output) are in the region of 1 to 2 million Zloty (RM 1.7 to RM 3.4) per accident at 1996 prices.

The frequency of occurrence and consequences prompted various Polish research teams to investigate methods of limiting the effects of overwind accidents. The system, shown in **Figure 15**, was developed by the Rope Transportation Faculty of the Academy of Mining and Metallurgy in Krakow.

During an over-wind the transom (4) and the box section (1) engage and move together. After a short distance, the high tensile steel braking strips change thickness and a braking force is generated by the elastic force of the rubber elements (2) pressing the steel surfaces together. Friction braking systems of this type do not require any maintenance providing that suitable corrosion protection is ensured during manufacture. The authors claim that this design is suitable for arresting conveyances up to a total mass of 50 tonnes travelling at a speed of 20 m/s.

A conveyance catching system is provided in the event that the hoisting ropes were to fail, preventing the conveyance from falling down the shaft. The friction force between the braking surfaces and the braking strips is sufficient to withstand the static load of the conveyance and the balance ropes.

The system has been installed in at least 11 shafts and has undergone extensive laboratory and site testing over a period of more than a ten years. Hansel and Wojcik state that these devices are also suitable for mounting at the shaft bottom for underwind protection. The design allows the possibility of multiple operations with a minimum period required to restore the braking system after an accident.

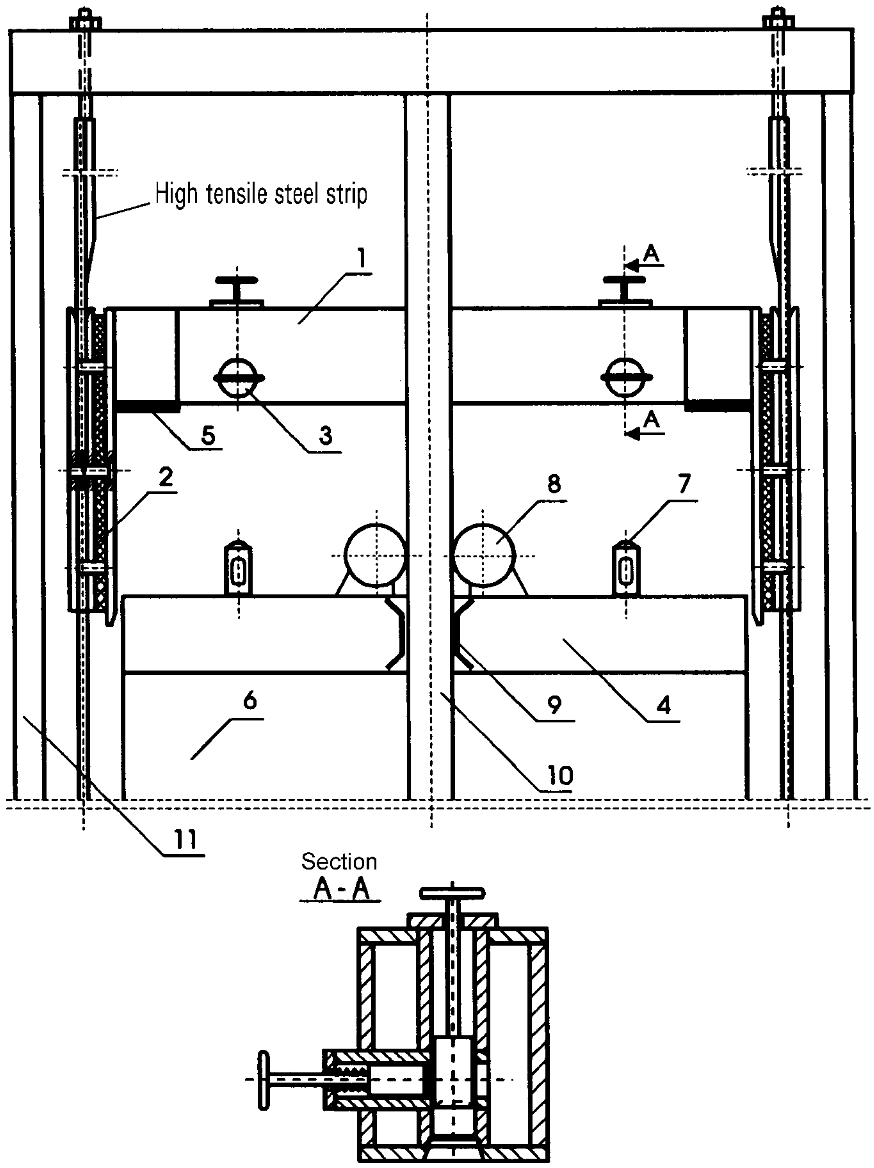


Figure 15 - Elevation of conveyance entering the HS2W-2 friction braking device[21]
1 - Steel box section, 2 - Rubber element, 3 - Sprung conveyance catch, see section AA,
4 - Conveyance transom, 5 - Rubber element, 6 - Conveyance, 7 - Catching pin, 8 - Guide roller,
9 - Slipper plate, 10 - Steel guide, 11 - Headgear member, AA - Sprung conveyance catching mechanism.

7.2 Shaft Station Stoping Devices

Dohm and van Schalkwyk[18] report that the Vaal Reefs No. 2 shaft accident, in May 1995, led to an immediate investigation into the effectiveness of shaft station stoping devices. Initially the investigation focused on physical testing of various devices in operation at the time of the accident, namely "Tank traps" and "T-sprags". These were found to be ineffective in arresting a locomotive travelling at speed. Other devices used on Anglo American gold, coal, diamond and platinum mines were also found to be incapable of performing the task required.

A work group was subsequently established to develop guidelines for shaft station stopping devices. The authors describe the methodology adopted by the work group and the results obtained in their investigations. The guideline was to consist primarily of detailed engineering drawings of devices. These had to be proven, both theoretically and through physical testing, to be capable of stopping moving vehicles with specified energy levels. The guideline was intended to assist engineers in executing their duties and was not to be prescriptive. The engineer would conduct a risk assessment of all the shaft stations under his control, from which the maximum impact energy of vehicles running into the stations could be determined. The engineer could then choose the appropriate stopping devices from the guideline.

Initially all the devices in operation needed to be identified. A survey indicated a total of 130, very few of which were backed by engineering drawings, structural calculations or physical tests. The devices could broadly be categorised into four types namely :

- Farm gate
- RSJ stop block
- Shark fin
- Vula Vala

Next, the variety of vehicles which needed to be stopped had to be identified. They ranged from light hand powered cars to 115 tonne trains travelling at 25 km/h and 40 tonne trackless vehicles travelling at 20 km/h. After the identification of the existing devices and vehicles the work group decided on the following methodology :

- Definition of design requirements.
- Identification of suitable devices for service.
- Detailed structural, energy absorption and foundation analysis.
- Development of test procedures and definition of acceptance criteria.
- Physical testing.
- Review of capabilities based on test results.
- Possible redesign and retesting.
- Incorporation into the guideline, subject to fulfilment of the acceptance criteria.

Rolling stock devices had to be capable of handling kinetic energy values from 50 kJ to a maximum of 300 kJ. In the case of trackless vehicles, units heavier than 30 tonnes would be kept away from station areas and at worst 30 tonne vehicles travelling at 16 km/h under full power would have to be stopped. In addition to strength and energy requirements the devices also needed to be :

- User friendly and have low maintenance requirements.
- Easy to install and safe to operate.
- Clearly visible and easy to inspect.
- Simple to replace after impact damage.

Of the 130 original and additional new generation devices, 26 were subjected to physical testing. Only ten eventually met all the acceptance criteria. Interestingly, the tests showed that in most cases the devices were capable of absorbing approximately 30% more energy that the structural calculations had determined. Considerable portions of the impact energy is in fact absorbed by the test train, with chassis, buffers and links deforming heavily during impact.

The Anglo American *Shaft Station Stopping Device Guideline* also includes suggestions for interlocking the devices with one another and with the winding system. Proposals have been put forward for locking of devices to prevent unauthorised operation as well as designs to operate the stoping devices remotely.

Dohm and van Schalkwyk give a preparation check list for conducting of station stopping device tests and describe the sequence of events to be followed for each test. In cases where a device has two stopping faces (e.g. Vula Vala), both have to be tested. In general, locomotives should lead in all tests to prevent energy dissipation due to a concertina effect. However, if there is any doubt about the capability of the device to stop leading hoppers then an additional test should be conducted with this configuration.

8. ACKNOWLEDGEMENTS

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Influence of the shaft walling's quality on safe operation of its equipment

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