

Safety Considerations

For

Mine Hoisting Systems

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1 Introduction

It is difficult to overstate the importance of having in any underground mine serviced by a vertical shaft, a hoisting system that is both safe and productive. Fortunately, experience indicates that safety and productivity are synonymous; you cannot have one without the other and therefore by corollary, if the hoisting system is designed to be very safe, and operated and maintained that way, then it will almost certainly be highly productive as well.

In recent years, the drive towards improved efficiency and productivity has led to many technical changes in the design, operation and maintenance of mine hoisting systems.

In particular, in Australia, new hoisting systems are highly automated and, with the exception of some maintenance and testing procedures, operate totally unattended, that is: without a driver, operator, platman or onsetter. Supervision of the hoisting system is normally conducted from a remote, central mine-monitoring facility.

The earliest unattended, automatic hoisting systems were installed in Australia over twenty years ago and were quite maintenance intensive. However, provided maintenance was of the highest standard, all the evidence suggests that these hoisting systems can provide a very high degree of operational safety as well as improved performance.

The maintenance of hoisting systems has also changed dramatically. Routine maintenance is reduced to a minimum but condition monitoring and preventative maintenance is embraced. Testing, particularly statutory testing, is increasingly time consuming; hence the current emphasis on automated testing procedures and recording. The implementation of these facilities requires careful consideration during the system design phase.

Ever increasing levels of technical complexity in the electrical and hydraulic sub-systems of the winder require new approaches to maintenance, including in-built expert systems for fault diagnostics and repair, direct modem connection to the technical support of the original system designers, interconnect ability to the mine-wide maintenance support systems and an increased emphasis on staff training, system documentation, operational and maintenance procedures and appropriate quality assurance during implementation and any subsequent modification.

The discussion that follows, focuses on what are considered to be some of the more important technical issues that directly relate to the safety of current hoisting systems.

2 Mechanical Systems

2.1 Drums/Pulleys

2.1.1 Design Requirements

There are no current Australian design standards for drums or friction pulleys although the German TAS and Swedish mines regulations provide good guidance. The practice of using the design guidelines from the Crane Code for all but the smallest winch drums, is to be discouraged. Most competent manufactures employ FEA techniques in their designs, and fracture mechanics analysis is also recommended particularly for complex drum shaft design.

2.1.2 Grooving

The stability or repeatability of the rope coiling on any multi-layer drum winder is very important and the provision of well designed grooving, crossovers and risers on the drum is the best means to ensure good coiling behaviour. Unfortunately, excessive rope vibrations adversely affect many drum winders and poorly designed grooving is often the major contributor to the problem. Rope handbooks contain much useful advice on the appropriate grooving arrangement and geometry to use.

2.1.3 Treads

The maintenance of sufficient friction between the drive pulley and the headropes of a friction winder under all operating conditions, is clearly a fundamental safety issue. The most onerous operating conditions normally occur when emergency braking is applied with a descending load. In these circumstances and particularly for skip winders, it is good practice to calculate the safety margin before rope slip occurs and in doing this, a conservative value for the coefficient of friction between

rope and tread, should be used. The use of high density plastic insert materials, with tested coefficients under wet conditions of around $\mu = 0.4$, provides a good solution, given that the coefficient value used in the calculation is typically $\mu = 0.25$ for stranded ropes and $\mu = 0.20$ for locked coil ropes (UK practice).

2.1.4 Clutches

Clutches enhance the operational flexibility of drum winders, particularly for adjusting rope length, but for safety, each clutch mechanism must be interlocked with the mechanical brake on the clutched drum to ensure the brake is fully applied whenever the drum is unclutched from the shaft. Also each clutched drum should be provided with its own independent supervision system (automatic contrivance).

2.2 Brakes

The issues which so dominated the debate about mechanical brakes in the early 1980's, such as component redundancy and elimination of single line components, higher factors of safety for threaded members in tension and so on, are now generally accepted as normal practice in brake design. The publication in 1973 of the Markham Report [1] did much in Australia to raise the level of awareness of both designers and users to the importance of these issues (even though design standards in Europe and South Africa had embodied many of the same safety concepts for many years). The Regulatory Authorities in Australia and elsewhere quickly incorporated the key elements of this Report's findings into local State Mining Regulations.

In subsequent years, the use of multi-caliper disc braking systems has gained universal acceptance as the best technical solution for the provision of mechanical brakes on all new winders. The design of the brake caliper units themselves has been extensively refined over the years and there are now available from several manufacturers, a range of well proven and reliable units.

The design of the brake discs themselves, has been the subject of considerable research with much emphasis on obtaining a better understanding of the thermal characteristics of the discs under emergency braking conditions [2].

However in specifying braking systems for mine winders there remain important concerns to be addressed.

2.2.1 Retardation Control

Constant force braking systems have been popular because of their simplicity and it is true that in any safety related design, simplicity is a virtue. Such braking systems are also cheaper to produce. However there are serious limitations associated with the use of constant force systems, because of their inherent inability to adjust for changes in the inertia of the combined conveyance and rope masses or for changes in operating conditions, most notably changes in the coefficient of friction between the brake disc and the friction pads of the brake calipers.

Changes in coefficient of friction seem to occur most frequently because of contamination of the brake path; however, another major cause is overheating. This latter effect is often referred to as brake fade [3], and there is considerable anecdotal evidence to suggest that the elimination of asbestos from brake pads, although most welcome from an occupational hygiene point of view, has increased the potential for such fading to occur under arduous braking conditions.

Many of these potential problems can be eliminated or at least their impact reduced, if closed-loop, constant retardation brake control schemes are used. These schemes provide for actual value measurement of the retardation rate during emergency mechanical braking and regulate the hydraulic pressure and thereby the braking force, to control the retardation rate to a predefined value. Several alternative schemes are available [4], [5], and the technology involved is relatively straightforward and well proven. In these circumstances, it is considered prudent that brake control systems employing constant retardation rate control should be used as a matter of preference, on all new mine winders

2.2.2 Thermal Protection

The problem of brake fade was referred to in 2.1 above. In recent times some suppliers of hoisting systems have chosen to place severe limits on the operational use of the mechanical brakes, without, it seems, sufficient consideration being paid to the provision of adequate protection against inadvertent use.

A typical qualification is by way of a covenant in the contract for supply of a new winder that the design of the mechanical braking system will be such that not more than two high speed retardation's may be undertaken in rapid succession. Such attempts to achieve operational safety by contract inhibition are clearly unacceptable and could be argued to constitute an abrogation of the designer's responsibility to provide a fail-safe braking system. A preferable approach would ensure that provision is made in the braking system design for backup protection to automatically detect malfunction and in the event of brake fade, inhibit further use.

Such protection would, as a minimum, require thermal modelling of the braking system, in a manner similar to the way in which solid-state motor protection relays provide protection for electric motors against thermal overstressing, due to excessive starting.

2.2.3 Overbraking Protection

Statutory requirements generally mandate that the minimum design brake force be calculated as some defined multiple of the maximum static out-of-balance force measured at the winder during normal operation. Typically, for a friction winder or single drum winder, this multiple is 2.5 times but can be up to 3 times for a double clutched, double drum winder.

While this approach ensures that the braking system will be able to generate ample holding and/or retarding force even in the face of conveyance overload, it also has the undesirable effect of providing the potential for too much dynamic braking in some situations. This situation can be particularly critical for single drum winders under emergency braking with the conveyance travelling in the upwards direction, and also for friction winders with low safety factors against rope slip.

This situation is greatly improved under emergency braking conditions by the use of constant retardation control as discussed in 2.2.1 above, but the potential always remains for a brake malfunction to cause the application of excessive braking.

The design problem is especially demanding where dynamic braking of single drum winders is concerned. With the conveyance travelling in the up direction, it is often the case that to maintain retardation rates below a reasonable limit of say, 5 metres per second per second, it is necessary to inhibit all mechanical braking and rely on the rotational inertia of the mechanical system to overcome the desire of gravity to retard the conveyance at 9.8 metres per second per second. Under these circumstances, any malfunction of the braking system, has by virtue of its fail-safe design, the potential to cause excessive braking and this in turn, may lead to a slack rope situation and/or miscoiling at the drum.

2.2.4 Testing

Regular brake testing was, in years gone by, always the primary responsibility of a winder driver. Normally at the start of every shift, the new driver would carry out a static brake holding test before doing anything else. Dynamic brake tests were usually part of the weekly test routine.

Hand in hand with the advent of automatic, unattended mine hoisting systems has come the introduction of automated testing of the winder protection system, including the brakes.

Now, with our modern winders there are two, and often three levels of overwind and overspeed protection. Setting a false bank in midshaft to test the overspeed protection normally requires a series of overspeed tests and if these are not carefully arranged, the testing regime itself can invoke an unnecessarily harsh sequence of emergency brake applications.

During the design, careful thought should be given to providing an appropriate level of testing without overstressing the system, especially the brakes. However, it must be expected that a winder, during its operating life, will experience many more emergency brake stops as a result of routine testing, than should ever result from real emergencies, and the design of brake components must reflect this reality.

2.2.5 Fault-finding and Diagnostics

Too often in the past, the only real thought given by the designers of the brake system to the personnel charged with the responsibility of maintenance of the braking system, was to provide a maintenance and operating instruction manual. This usually consisted of an equipment list, a brief

description of operation and hydraulic circuit, and often little else.

Unfortunately, it seems some things never change, and it is apparent that even for some of the most modern winders, that the braking system, particularly the brake hydraulic system and its associated electrical interface to the overall winder control system, remains the most poorly provided for when it comes to automated fault-finding, self-diagnostics and preventative maintenance tools. To be effective, these important maintenance features must be considered and addressed during the design and documentation phase.

Many electronic subsystems on the winder are now routinely provided with a high degree of self-diagnostics and instrumentation to aid in fault-finding. For the electrical drive, Aexpert systems are available from some manufacturers to guide and enhance the efforts of maintenance support personnel. Connection via modem, to the distant technical support of the suppliers' engineers is also available for many parts of the electrical system. Why are not comparable diagnostic and technical support systems available for the braking system? Perhaps because those of us responsible for specifying user requirements have not been insistent enough?

2.3 Ropes and Attachments

2.3.1 Design Standards

Relevant Australian Standards include:

- AS 3569 Steel Wire Ropes
- AS 3637 Underground Mining – Winding Suspension Equipment

Rope and Attachment Manufacturers' Handbook:

The handbooks provide essential technical information concerning the use, installation, maintenance and operation of this equipment.

2.3.2 Factors of safety

- Throughout Australia and indeed, the world, there is little consistency in the statutory requirements for Factors of Safety applying to the use of ropes and rope attachments, which probably reflects the lack of any real science underlying the selection of any particular set of numbers for these FOS. Currently there is much discussion and research in South Africa to provide a basis for significant reductions in FOS to possibly as low as 3.5.
- This process is driven by the current need in South Africa to mine at extreme depths and while there is generally no real technical problem complying with the various FOS currently specified, no doubt the South African experience will be watched closely and judged over time. In the interim in Australia, it would seem likely that FOS for ropes will converge about the average of the empirically derived figures presently in use, in particular, 5.5 for rock and 6.5 for personnel with further reduction by up to another 0.5 for deeper shafts, say greater than 500m deep.

2.4 Conveyances

This generic term includes skips, cages and counterweights and combinations of skip/cage.

2.4.1 Design Standards

- Australian Standard AS3785.4 Underground Mining-Shaft Equipment: Conveyances for Vertical Shafts

2.4.2 Safety Issues

- All conveyances must have appropriate facilities for shaft inspection, which is normally best done from the roof of the conveyance. Suitable platforms and (removable) handrails for use by at least 2 persons should be provided. The conveyance should be able to be controlled by persons travelling on the top platform. Typically, a pendant type plug-in control station with controls for emergency stop, up/down, inch up/down, normal stop as well as voice communications is required.
- Continuous overload protection should be provided on all cages, and preferably on all skips.
- For rope-guided conveyances, the minimum clearance between conveyances and fixed objects should be not less than 350mm and between conveyances, 550mm.

- Conveyances should be designed to withstand all loads arising from overwinds, including arrestor and overwind safety catch reactions.
- Skips should have sufficient capacity to minimise spillage, typically providing a minimum of 500mm of freeboard at design load for design density ore. In this respect, it is imperative to design for a conservative volumetric broken density and include an allowance for moisture content (assume 5% unless verified data available).

2.5 In-shaft Safety Devices

This category of equipment includes detaching hooks and detaching plates, jack catches, overwind arrestors.

2.5.1 Design Standard

- Australian Standard AS3785.1 Underground Mining-Shaft Equipment: Drum Winder Overwind Safety catch Systems.
- Australian Standard AS3785.2 Underground Mining-Shaft Equipment: Friction Winding Arresting Systems and Overwind Safety Catch Systems.
- Australian Standard AS3637.2 Detaching Hooks.

2.5.2 Safety Issues

- Detaching devices and jackcatches should be of a proven design which has been type tested in accordance with the Standard. There are many 'home-made' versions around, but should be avoided. 'King' type hooks are recommended
- Detaching devices and jackcatches should be resiliently mounted to absorb the fall-back forces and these mounting systems must also be tested properly. There is little point in having jack catches if they cannot withstand the impact forces of a fully loaded conveyance falling back the full catch tooth pitch distance.
- While there are many types of arrestors that have been used over the years, the best linear force system currently available is the 'SELDA' type. Unfortunately, current suppliers are limited and the installed cost of these systems is high.

2.6 Emergency Egress Equipment

2.6.1 Emergency Situations

Abnormal or emergency conditions can arise in many ways and require varying responses to return the hoisting system to a safe state. Typical hazardous conditions include:

- Loss of power supply or failure of the electric drive system while personnel are in the cage or on top of the skip for maintenance or shaft inspection.
- Mechanical failure of the drum, bearings, shaft etc which prohibit the drum from being rotated.
- Obstruction in the shaft, or hang-up of the conveyance possibly resulting in slack rope.
- Overload, overspeed or overwind of the conveyance as discussed in 2.4 above.

There are a range emergency egress options that should be considered as part of the design of every hoisting system.

2.6.2 Gravity Winding

This is the simplest approach and uses an artificially created out-of-balance eg, large water bag, in one conveyance to force it to descend while the other ascends. Normally the mechanical brakes are utilised to control the descent. This system is most useful for friction winders where the out-of-balance remains relatively constant. Drum winders often have a considerable zone around mid-shaft where the out-of-balance is insufficient to overcome the system friction. Even for a friction winder, this approach still requires that the drum is free to rotate and the conveyances loaded to enable them to be brought to the surface by some other means.

2.6.3 Pony Drives

These consist of an auxiliary drive, capable of being powered from a standby power source, which is moved into position to directly drive the drum. Some simple means of controlling the mechanical brakes is required. Although relatively inexpensive to install, this system is of little use if the drum cannot be rotated or the conveyance is stuck.

2.6.4 Independent Winch Systems

These systems have the advantage of providing access to or from the mine as well as egress for personnel trapped on the conveyance, totally independent of the hoisting system. With the addition of a standby diesel generator, the system can also be independent of the main power supply. With some prior planning, rope-changing winches used for maintenance can double as the egress winch. The system needs to be capable of reasonably rapid deployment.

3 Electrical Systems

3.1 Control and Protection

In this age of digital electronics, microcomputers and advanced communication networks, modern hoisting systems should logically, be expected to exploit these technologies to improve safety and productivity.

The significant advantages which these technologies provide, have been discussed in a number of recent papers [7], [8]. In summary, the major advantages include:

- All types of control including drive systems, brake interface, speed-distance protection, sequential control and operator interface, are provided in a single technology;
- Digital systems provide a drift-free environment;
- Mechanical interconnections are simplified and minimised;
- Diagnostics are greatly enhanced;
- Communications interface is simplified;
- Changes are generally made in software thus simplifying the process.

Within the Australian context, digital control systems were in use on mine winders in the late 1960's albeit in a discrete hardware form. The first partial digital drive controls did not arrive until the early 1980's and finally in 1996 the first fully digital mine winder was commissioned. This winder incorporated an approved digital automatic contrivance (speed-distance protection system) and was the first to do so in Australia. While the technical advantages of these technologies are undeniable and in the long term, irresistible, the challenge for designers is to ensure that their incorporation into safety related applications such as the speed and distance protection mine hoisting systems is accomplished in a way that enhances safety and reliability. In this respect, there are a number of key issues to be addressed, namely:

3.1.1 Design Principles

There are no specific Australian design standards for the design of winder control systems, although there is guidance provided in the German TAS and Swedish Regulations and in the Markham Report [1]. There is such a wide range of available technologies, ranging from simple electro-hydraulic to advanced computer networked systems, that no single design standard could ever hope to adequately cover the ground.

However, irrespective of the technology used, the control system is conceptually viewed as comprising at least 3 independent subsystems, namely:

- A closed-loop regulating system which controls the position and speed of the conveyances.
- A protection system which independently monitors the operation of the winder and intervenes in a predefined way in the event of a detected malfunction of the regulating system.
- A supervision system which monitors independently, the protection system and ensures its integrity.

The general principle upon which design of the control system should be based, is that the failure of any single component should not jeopardise the safe operation of the system, including if necessary, safe shutdown of the system. Hence, the control system must be designed to be fail-safe, and where this is not technically feasible, be designed with sufficient redundancy to reduce the probability of simultaneous system failure to acceptable levels. In all cases, the design must be submitted to rigorous risk analysis to ensure these principles have been adhered to.

Most modern winders now use 'digital' or computer-based supervisory devices in place of the traditional electromechanical automatic contrivance (Lilley etc)

3.1.2 Conveyance Protection

In its simplest interpretation, a mine winder's single purpose is to control the motion of the conveyances in a shaft. The central issue then, for safe operation of the hoisting system, is to ensure the safe movement of these conveyances.

Whilst accurate control of the winder drum is an essential element in the correct operation of the conveyances, it is not enough. It is also necessary to directly monitor, to the fullest extent technically possible, the performance of both the conveyances themselves and the rope system which connects them to the winder drum.

Safety issues relating to the rope system are discussed in Section 4 below. Considerations for the safety and protection of the conveyances, particularly in the context of unattended operation i.e. no cage attendant or travelling onsetters, are:

(a) Overload Protection

All conveyances should be provided with overload protection. There are a range of technical solutions available to achieve reliable conveyance overload protection but the preferred means must surely be to measure the actual payload in the conveyance at the point of attachment of the rope(s) to the conveyance.

Monitoring of motor current can be used as a backup protection to direct conveyance weighing systems but is inferior as a means of primary protection. (A possible exception is the case of skip hoisting by use of a friction winder where the argument for direct conveyance weighing is less convincing). However, for all cages and all skips hoisted by drum winders, direct conveyance weighing is the preferred solution.

(b) Emergency Stop Facility

All conveyances, on which personnel are required to travel in the shaft, should be provided with an emergency stop facility installed on the conveyance. Irrespective of the means of transmission of the stop signal, it should have a reaction time of less than 100 milliseconds.

(c) Other Cage Interlocks

Apart from the above, cages require additional safety features, including:

- Interlocks for shaft gates closed
- Interlocks for cage doors closed
- Voice communications to surface
- Interlocks for chairing beams or fold-out platforms
- Interlocks for minimum rope tension setting during inching and chairing operations.

(d) Other Skip Interlocks

Apart from those outlined above, skips require the following specific safety interlocks including:

- Skip door closed/latched; this is especially important for scroll operated, bottom dump skips
- Skip empty at tip; this could be provided by:
 - ⇒ A rope tension measuring system (preferred option)
 - ⇒ A motor current detection system (which should only be used as a backup to actual rope tension measurement, because it can only operate after the brakes have lifted at commencement of wind).
 - ⇒ Skip Alook-through[≡] systems which use light or other propagated signals to look through the skip at the completion of dumping to determine if all the material has emptied. This system is really only practical with bottom dump skips.

There are currently a number of proprietary systems available to measure the tension in the hoisting rope(s) at the conveyance [6]. These all involve the transmission of these signals, from the conveyance to the winder control systems.

3.1.3 Rope System Protection

For drum winding systems, the rope(s) still constitutes a *Single-line* component. Multirope friction winders are much better off in this respect and therefore should be inherently safer to operate in an automatic, unattended mode where the performance of the ropes is not monitored by a driver.

Key design issues relate to the provision of the following:

(a) Slack Rope Protection

There are a variety of ways in which slack rope between the winder drum and the conveyance may be detected including:

- Measurement of motor current
- Rise in tail rope loop on friction winders
- Trip wires across the rope openings for a drum winder

More exotic approaches include the use of:

- Rope striping
- Load cells under head sheaves or friction winder drums

There are also *After-the-event* or *Parachute* systems which are designed to operate after the slack rope occurrence has escalated to the point of conveyance free-fall and these include:

- Safety grippers which are only feasible on old timber guided shafts
- Conveyance catchers which operate after rope break to latch on to steel or rope guides.

The exotic approaches although much debated in the past, have it seems, now passed into extinction, while prevention is always much better than any parachute. The first mentioned detection methods are all still useful as backup protection, but none provide the efficacy of a system which directly measures the tension in the hoisting rope(s), and if this drops below a preset threshold value, initiates an emergency stop. Such systems should be used for primary slack rope protection on all winders particularly drum winders, and can be integrated with overload protection discussed in Section 3.1 above. The argument in favour of such systems for friction winders is less compelling, given that slack rope at the conveyance will always cause the tail rope loop to rise, and/or rope slip to occur. However, detection at the conveyance will always be quicker and ensure that the entire hoisting system is brought to rest in the minimum time, which is essential in the case of slack rope events.

(b) Rope Slip Protection

Rope slip on a friction winder is a very serious malfunction. It represents a complete loss of control of the conveyance and if allowed to persist will render useless every other protection system, save for the fortunate circumstance, where the onset of rope slip is such that the conveyance overspeed does not exceed the ability of end of shaft arrestors to decelerate it safely to rest.

Consequently most designers adopt a very conservative approach to ensuring that rope slip will not occur, even under the most arduous operating conditions. Typically this involves:

- Use of conservative values of coefficient of friction between ropes and treads. Although manufacturers' published test data indicates a minimum of $\Phi = 0.4$ under wet conditions for modern high-density plastic tread insert material, current practice is to use $\Phi = 0.25$ for standard ropes, and $\Phi = 0.2$ for lock coil ropes. In addition, the dynamic braking rates and conveyance masses should be chosen to provide a static $T1/T2$ ratio of not more than 1.5.
- Use of constant retardation rate control as discussed in Section 2.2.1.
- Redundant monitoring systems to quickly detect if any significant difference exists between the rope speed at the drum and the rotational speed of the friction drum.

- Use of soft electrical braking wherever possible, following detection of rope slip. The exceptions are when the conveyance is at, or near the end of, wind or there has been a malfunction in the electrical system, which has caused the rope slip.

(c) Rope Miscoiling Protection

This remains the area of concern for automatic, unattended operation of drum winders. It is inherently difficult to detect miscoiling at the drum and a really comprehensive solution to this problem remains as a challenge for the future. Systems currently in use involving mechanical trip bars across the face of the drum(s) or proximity switches are not greatly effective unless gross miscoiling occurs.

Fortunately, the consequences of miscoiling for a drum winder are usually nowhere near as serious as rope slip on a friction winder and the lack of good, sensitive protection against miscoiling should not be a significant inhibition to safe operation of unattended drum winders. Provision of video surveillance of the winder drum would be of some assistance in this matter.

3.1.4 Software Design

For modern digital control systems, hardware just seems to get better and better while software development, particularly for those subsystems that provide the safety net for the hoisting system, continues to be an area of significant concern.

Generally, hoisting systems exploit the use of two types of software:

- Imbedded or system software which is normally not application related and is well defined, tested and implemented. Examples of this type of software are to be found in drive controls, standard computer operating systems, communications protocols etc; and
- Applications software which is developed specifically for this type of application, ie: a hoisting system.

The dividing line between the two is somewhat blurred. Some manufacturers have developed standardised software (and associated hardware configurations) for important safety related subsystems such as distance-speed protection, brake interface and safety interlocking which have been extensively tested and approved by relevant statutory authorities, as well as proven on many hoisting systems. Such software provides a high degree of comfort to the user and great restraint is necessary when invoking any change, either by technical specification during implementation or subsequent modification after installation.

In contrast, there arises all too often, the situation where the applications software for a new hoisting system is unique or a major variant of older software upgraded to this particular application. Often this happens for the best of reasons, typically to exploit more advanced software capabilities or to meet a specific demand of the user to promote compatibility or uniformity of computer systems and software throughout the entire mine. Because of the practical difficulties associated with any user or third party auditor attempting to establish the real status of any applications software system, it is well advised to treat all such software as entirely new and project specific, and in consequence, to invoke a formal process of software verification and risk assessment to ensure that the software provided to monitor, control and protect the hoisting system is fit for purpose. This involves at least:

- a process of software verification in which the ability of the software (and associated hardware) to satisfy the functional requirements specified for the hoisting system, can be appropriately reviewed, tested and assured; in short a quality assurance system.
- a process of risk analysis to ensure that the safety related, functional requirements of the hoisting system have been anticipated and understood by the software (and hardware) designer. This process addresses the fundamental questions:
 - ⇒ what can go wrong?
 - ⇒ how likely is it to happen?
 - ⇒ what are the consequences?

There are a number of excellent standards [9], [10] and [12] which provide guidance for the process of software development and verification. Risk analysis of technological systems is the subject of IEC

Standard 300-3-9 [11]. The best current guidelines to assessing the safety integrity of programmable electronic systems in safety related applications, is the HSE document [12].

3.2 Communications

Discussion of communications once meant knocker signals, but for modern practice these are virtually irrelevant (apart from those continuing practices like shaft sinking where manually driven winders are the norm). Safety is very much dependant on reliable communications and this now typically requires consideration of:

Voice communications between personnel in the cage or on top of the skip/cage and others on the surface.

Data communications between the conveyance control and protection systems and the main winder control system.

Data communications between the winder control system and the remote mine SCADA system.

Voice communications in an emergency situation between personnel in/on the conveyance and mine rescue personnel.

3.3 Operator Interface

Almost overwhelmingly, today's hoisting systems operate autonomously, with little more than remote operator supervision. Maintenance still needs the hands-on involvement of an operator, now typically the maintenance electrician. With this change from people with their hands on the levers to mostly computers with their software/firmware/hardware paradigm, it is important to understand the options available and their implications in terms of the processes needed to ensure that the hoisting system will be maximally SAFE.

This paper is unable to canvass the detail of this complex human/machine (cybernetic interface) interaction but the basic options include:

Manual control - where an operator has complete control over the normal operation of the system, including selection of acceleration, deceleration, mechanical braking rates, speed and position of the conveyance.

Automatic control - where the machine control systems determine the normal operating parameters without the direct intervention of a human operator. All emergency conditions are dealt with by the machine control system. Maintenance requires human intervention. There are several versions of this mode:

- ⇒ **Remote** control - where the machine operates automatically but the remote operator has the facility to intervene (ie emergency stop facility).
- ⇒ **Unattended** control - where the machine operates automatically and the remote attendant has the facility to monitor (see) but not intervene (control).

The safety implications of embracing any particular mode of operation can only be determined on the merits of each individual mine's operating and maintenance practices and its technical support capability.

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