Practical ergonomics in mechanized mining

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Synopsis

The objective of ergonomics is to enhance the effectiveness and efficiency with which human tasks are carried out. Furthermore, the objective is to improve desirable human values. This can be achieved by enhancing safety, reducing fatigue and stress, increasing comfort, increasing job satisfaction, having greater user acceptance and thereby improving the quality of life.

Mechanization has influenced the prevalence of injury, mainly due to the application of human physical effort as the power source. With mechanization, the operator's function is now essentially one of control rather than being an energy source, however, the risk of injury has not diminished. Mechanization in itself has introduced inefficiencies, health risks and physiological stress.

The major objectives of ergonomics are discussed through examples of acceptable and less successful implementation of ergonomics within mechanized mining. The influence of the machine system on the human is addressed and practical solutions to improve and optimize the interaction of the human and the machine are outlined. Furthermore, practical examples of control and display integration, anthropometric and biomechanic influences on design, orientation, posture and stereotypes are used to accentuate the advantages of the application of sound ergonomics principles to the specialized area of mechanized mining.

Introduction

The South African mining industry has undergone significant changes in the past twenty years. Mechanization has increased and there has been a rapid growth in the development of new mining technologies. Unfortunately, unique environmental constraints, especially in underground mines, not only affect the physical capabilities of miners, they also have a profound impact on the design of underground equipment and tools. Challenged with these constraints, the designers of mining equipment have focused on ensuring the optimal operational functioning of new designs, but in this process often neglected ergonomics principles. As a result, miners have to cope with restricted workspaces, less than desirable illumination, obstructed visual access, heat stress, high vibration levels; all major contributory factors in the development of work-related injuries[1]. All these stressors can influence the efficiency and effectiveness with which work can be performed.

Studies[2] conducted by the US Bureau of Mines, showed that engineers almost immediately start to design equipment with little consideration as to how the equipment is to be used by the operator, the sequence of use, or which functions are most important or most frequently used. All too often, designers do not recognize that the system consists of humans, machines, and the environment that must interact effectively. The successful outcome is to achieve a goal that could not be accomplished by these components independently.

In this paper, various ergonomics principles of workstation design, as well as practical examples of ergonomics interventions in the mechanized mining environment, will be discussed. The potential for enhancing existing health, safety and productivity levels through the application of these principles will also be highlighted.

Definition of ergonomics

Ergonomics is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.

Ergonomists contribute to the design and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with the needs, abilities and limitations of people.

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Ergonomics is a systems-oriented discipline, which extends across all aspects of human activity, and promotes a holistic approach in which considerations of physical, cognitive, social, organizational, environmental and other relevant factors are taken into account.

Legislation

The Mine Health and Safety Act (Act 29 of 1996) makes pointed reference to ergonomics. Section 21(1)(c) of the Act states that *any person who designs, manufactures, erects or installs any article for use at a mine must ensure, as far as reasonably practicable, **that ergonomic principles are considered and implemented during design, manufacture, erection or installation***.

From the above it is evident that it is a legal requirement that human capabilities and limitations must be addressed when designing mining equipment.

Workstation design

A workstation is generally referred to as any location on a mining machine where one or more operators routinely control the machine functions. Within the workstation there is the human-machine interface area and includes displays, controls, the layout of these and how they relate to human information processing. The workstation is also concerned with the support provided to the operator (e.g. seating) and the posture required for task execution. The technical components of the 'human-machine system' (the 'machine') are capable of high speed and precision, and can be very powerful. The human, in comparison, is sluggish and releases only small amounts of energy, yet it is more flexible and adaptable. Human and machine can combine to form a very productive system, provided that their respective qualities are sensibly used[3].

An analysis of tasks is usually required to precede optimum workstation design. Such an analysis will provide information about the different tasks and sub-tasks that are performed and the equipment involved. Data on the physical characteristics as well as the cognitive capabilities and skills level of the user is important; the last-mentioned two in view of their impact on processing information[4].

Basic ergonomic principles to be considered in the design of work systems are described in the international standard ISO 6385 that was developed by the International Organization for Standardization[5]. The design of the workstation has to take into account constraints imposed by body dimensions (anthropometry), with due regard to the work process. Sufficient space is required to ensure a correct body posture in order to avoid unnecessary or excessive strain in muscles, joints, ligaments, and in the respiratory and circulatory systems. Strength requirements have to be within physiologically desired limits and prolonged static tension in the same muscle should be avoided.

Signals and displays have to be designed and laid out in a manner compatible with the characteristics of human perception. Where displays are numerous, it is important that they be laid out in such a way as to furnish reliable orientation clearly and rapidly. Their arrangement may be according to a function of the technical process or of the importance and frequency of use of the control actions. It is of importance, that the nature and design of signals and displays ensure unambiguous perception. This principle applies especially to danger indicators and alarms. In this regard the intensity, shape, size, contrast, prominence, and the signal-to-noise ratio are important aspects to consider.

Controls should be designed in such a way as to be compatible with the characteristics of that body part by which they are operated. Travel of controls and control resistance have to be selected taking into account the nature of the control task and of biomechanical and anthropometric data. Critical controls need to be safeguarded against inadvertent operation. Controls should have appropriate labels, showing the function controlled and the mode of operation, to enable rapid, accurate, and safe operator performance. Coding of control knobs for colour recognition requires adequate illumination. Problems with low illumination, general wear, and soiling of control knobs in the mining sector limits recommended colour coding to emergency equipment only.

The designer's most important consideration when designing displays, controls and workstation layouts is to make decisions that are consistent with the user expectations. With controls, for example, some direction-of-motion expectancies seem almost natural (movement stereotypes): pushing a throttle forward to increase forward speed or turning a wheel clockwise to turn right. Unexpected direction-of-movement relationships should be avoided.

Practical ergonomics interventions

This section of the paper deals with three examples of ergonomics interventions on mining equipment used for mechanized mining operations.

Dragline operation

An operator controls the dragline used in surface coal mining operations by means of a pair of force-controlled joysticks. The actual task activity requires the operator to push or pull on the left-hand controls with his forearm/hand to 'payout' the shovel or to 'drag' it in. The operator uses his right hand to lower and hoist the shovel as well as to swing the boom to the left or right with hand and wrist movements.

Operators of the dragline experienced extreme fatigue from approximately halfway through their shift, as result of manipulating the joysticks. They also perceived operating one dragline as being more exhaustive as another, identical dragline.

The forces required to operate the joysticks on the draglines in question were measured and compared with the recommended standards. Results obtained indicated that the force required operating the joysticks of both of the draglines were in excess of the recommended standards (Figure 1). Furthermore, the force requirements on the one dragline were more than double that of the other dragline. This information not only confirmed the observations made by the operators, but also explained the vast difference in production between the two draglines.

The force requirements of the joysticks of the draglines were adjusted to meet acceptable standards. The ergonomics intervention not only resulted in improved productivity and job satisfaction, but also reduced maintenance cost

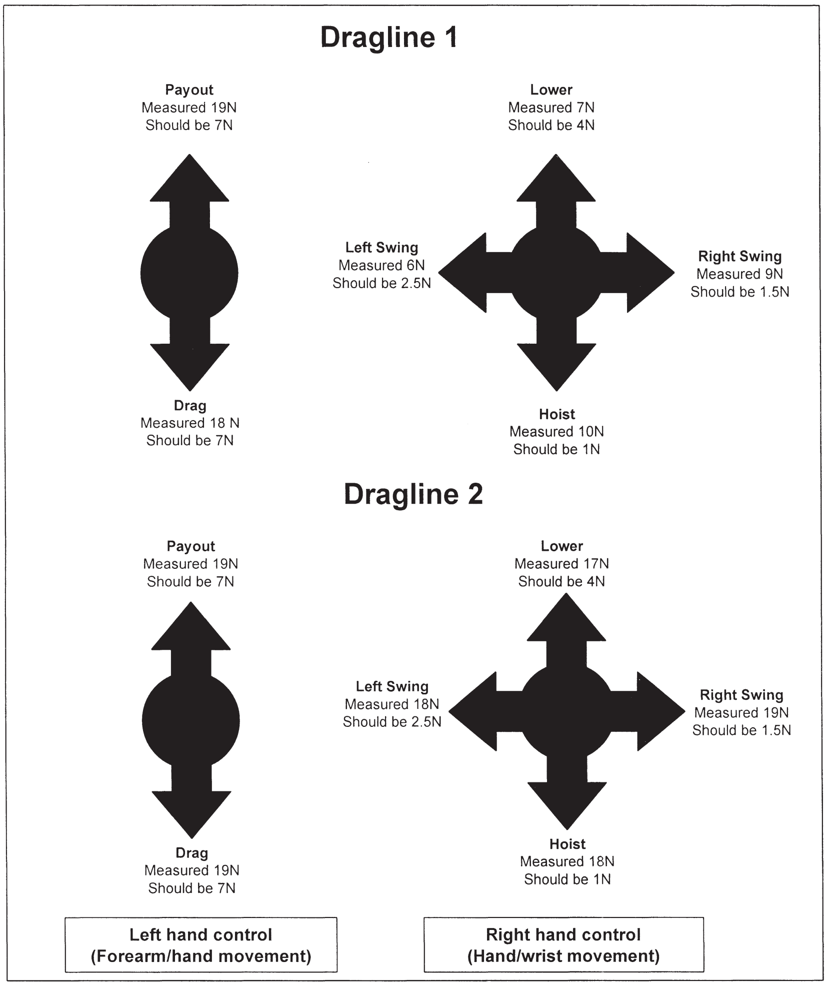

Figure 1—Dragline control forces

considerably. In addition the risk of work-related musculoskeletal disorders was significantly reduced.

Locomotive design

A recent study[6] on the ergonomics of locomotives used in the gold and platinum mines highlighted ergonomics deficiencies for seating, storage space for equipment and tools, physical protection, visual access, control activation, body posture and body orientation.

Three-dimensional computer aided design assessments were used to evaluate cab layout with regards to operator accommodation, seating, reach to control, field of view, unnatural body posture and body orientation. Figures 2 and 3 show the 5th and 95th percentile South African male operating a battery powered locomotive typically used by the mining industry. From these Figures it is evident that the 95th percentile operator has a restricted workspace, while the view of the 5th percentile operator is physically obstructed by the battery of the locomotive.

Proposed ergonomics interventions to improve the current design of the existing locomotives include:

- access to the cab of the locomotives
- forward visual access
- seating and posture
- communication and warning systems
- labelling of controls and displays
- equipment storage
- pre-operational safety and mechanical checks, and
- modification of the park brake.

The ideal design of a locomotive is depicted in Figure 4. Unique features to facilitate operator efficiency include the following:

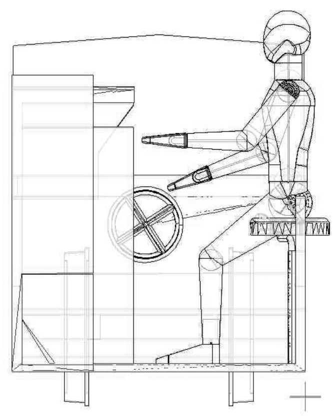

Figure 2—5th percentile South African male

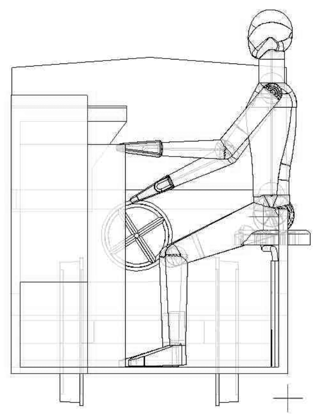

Figure 3—95th percentile South African male

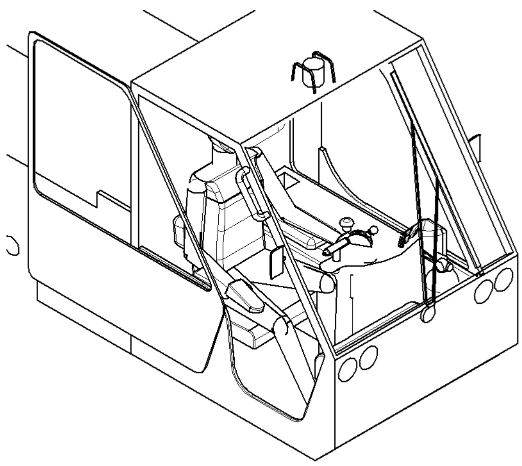

Figure 4—Ideal locomotive cab design

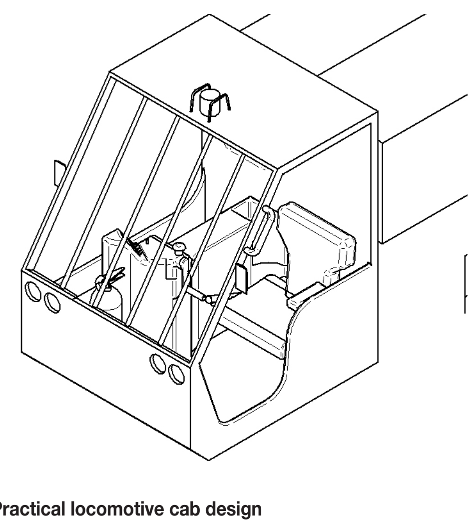

Figure 5—Practical locomotive cab design

Easy access to the cab and seat. An emergency exit is also provided and with adequate cab space provisions for the 95th percentile South African. A T-shaped backrest makes provision for back support while allowing space for wearing the cab lamp battery and self-rescuer on the waistbelt. Mechanical or pneumatic suspension is included in the seat configuration to reduce whole body vibration levels.

Both hand and foot controls are used as primary control elements. A 'deadman's' directional controller with foot operated service brake, hand operated park brake and locomotive direction sensitive automatic head and tail light switching are provided. The combination of controls allows the locomotive operator to effectively and accurately control the train movement while necessary visual aids and safety related controls are activated automatically. The design provides excellent forward visual access with operator body orientation in the direction of travel.

Additional warning devices in the form of an amber flashing light on the locomotive at the non-operator's end of the train and personal red flashing cap-mounted lights for locomotive driver and guard were indicated to improve situational awareness of workers.

This design also makes provision for two locomotives per train, one at each end that not only have ergonomics advantages but also the added advantage of the potential increase in ore tonnage per train.

Practical considerations frequently influence the 'ideal' design concepts to ensure safe as well as cost-effective workable solutions. This approach can be done while still incorporating sound ergonomics. A practical design for a locomotive includes an enclosed cab, the use of current rail bound stereotypes (i.e. hand control of direction and speed), and as far as the train is concerned, a single locomotive with a guard car at the other end. The guard car replicates the controls and the control system of the locomotive, but is not self-propelled.

Figure 5 depicts the practical locomotive design. This design is also suitable for retrofitting to the existing fleet of locomotives.

Table I presents a number of ergonomics guidelines for the design of locomotives. The guidelines are based on the anthropometry and biomechanics of the South African population and to accommodate the 5th percentile to the 95th percentile male and female user[7].

Conclusions

The South African mining environment, especially when underground, presents the designers and manufacturers of mining equipment with unique challenges. As mining equipment grows in sophistication, it is imperative to incorporate ergonomics principles in the design of new mining equipment from the conceptual design phase. This approach, besides being from a legal requirement, will facilitate efficiency and effectiveness of operating and maintaining the systems, with the concomitant reduction in health and safety risks.

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Table I

Some ergonomics guidelines for mine locomotive design

Parameter	Range of values	Preferred
Access		
Surface to entrance level height	380 mm (maximum)	
Entrance level to floor height	0 mm – 200 mm	0 mm
Entrance width	500 mm – 760 mm	760 mm
Entrance level to roof line		1300 mm (minimum)
Workspace		
• leg clearance (forward horizontal distance from SRP to cab panel)	910 mm – 1000 mm	1000 mm
• head clearance (vertical distance from SRP to roof line)	Erect seated stature of the 95th percentile man +100 mm	1070 mm
Seating		
Type	Cushioned seat with backrest that can accommodate the personal protective equipment, no sharp edges	T-back cut out
Vertical adjustment range from recommended midrange	0 mm – 40 mm up and down	80 mm
Horizontal adjustment to the fore and aft positions	150 mm – 200 mm	150 mm
Seat base:		
• cushion thickness	25 mm – 50 mm	38 mm
• width	485 mm – 510 mm	
• depth	420 mm – 445 mm	
• height (SRP to floor)	300 mm – 550 mm	350 mm
• Slope down towards the SRP	5° - 8°	
Seat back:		
• height (from SRP)	300 mm – 650 mm	600 mm
• width	480 mm – 510 mm 200 mm minimum only in area where provision for personal protective equipment at waist level is required	485 mm
• Angle from vertical plane	6.5° - 30°	
Arm rest:		
• SRP to top surface of the armrest		235 mm
• width	50 mm – 120 mm	75 mm
• length	210 mm – 300 mm	220 mm
• spacing	480 mm – 510 mm	480 mm
Viewing angles		
Eyeview above 0° horizontal	15°	
Eyeview below 0° horizontal	30°	
Eyeview to either side	90° / 90°	
Distance obscured in front of the vehicle	1500 mm (maximum)	
Body orientation	in direction of movement	

Mintek embarks on Adopt-a-School project*

Mintek, as part of its active participation in a national programme to help rectify the problem of the poor teaching, perceptions and results in Science, Engineering and Technology (SET) at secondary schools, has confirmed that it is 'adopting' the Kwadeda Ngendlale High School in Zola North, Soweto.

A list of over 100 schools to be dedicated to improved teaching and results in maths and science were announced by the Department of Education in September 2001. Of these, the eleven in Gauteng province, were investigated by Mintek, with the four schools located closest to Mintek being targeted for visits. Kwadeda Ngendlale was subsequenly identified as the school most amenable to the sustainable upgrading of its maths and science learners. There are currently just under 1500 learners at the school.

The project will see Mintek rendering assistance in the following areas:

- donation of excess and obsolete equipment—Mintek has excess laboratory equipment which can be used in science laboratories
- donation of IT equipment—so far, 25 computers have been identified as absolete and suitable for learners
- raising the SET awareness of learners: An important part of these specialist schools' activities will be to encourage promising learners to attend part-time workshops, and, besides intensive SET coaching, expose them to other science-related activities. Mintek is currently setting up a programme to lecture and demonstrate various concepts and technologies which will include visits both to the schools by Mintek technologists and scientists, and visits and tours of Mintek's facilities by the learners. ◆

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Schümann Sasol targets solvent extraction market*

Schümann Sasol, the world's leading synthetic wax manufacturing company, has extended its focus on the solvent extraction industry by launching the high-performance SSX™ range of aliphatic diluents.

The move follows extensive research by Schümann Sasol into the requirements of the solvent extraction industry, which uses diluents largely as carrier solvents in minerals extraction processes.

Schümann Sasol Paraffins business unit manager, Petrus van Dyk, said that the SSX™ range of aliphatic diluents had been designed to suit the requirements of customers operating in sub-Saharan Africa, among them leading resources companies.

'SSX™, a product of the low temperature Sasol Fischer-Tropsch process that uses coal as a feedstock, is exceptionally pure.

'The new product has a high consistency, and, because it is manufactured in South Africa, can be reliably supplied to customers in sub-Saharan Africa,' Mr Van Dyk said.

He is confident that SSX™ will meet and exceed the requirements of local customers.

'The benefits of using the SSX™ range of diluents are numerous. SSX™ exceeds specifications related to loading capacity, extraction isotherms and kinetics of extraction of various metals, and resists oxidation by cobalt.'

Three different variations suitable for mineral extraction processes—SSX™ 150, SSX™ 210 and SSX™ 250—have been developed.

SSX™ 150 is an ideal organic diluent for the extraction of uranium and SSX™ 210 is suitable for the extraction of, among others, copper, cobalt, zinc and nickel. SSX™ 250 is a substitute for SSX™ 210 in applications where a high flash point and low evaporation rate are required, which are experienced in areas with high ambient temperatures.

Mr Van Dyk said that another advantage to sub-Saharan African customers was the convenience of local supply.

'The SSX™ range is produced in Sasolburg specifically for African customers. Full technical and sales support is close-at-hand for all operations in sub-Saharan Africa.'

Schümann Sasol South Africa is a wholly owned subsidiary of Schümann Sasol International AG, the world's leading supplier of synthetic wax and wax-related products, in which Sasol Ltd has a majority shareholding. ◆

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