Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 49-20 (2016) 031–036

Functional Safety and Mean Time to Fail for Underground Mining Proximity Detection Device in No-Go-Zones

N. Sifferlinger * **G. Rath** *

* *Montanuniversität Leoben, Leoben, A-8700 Austria*
(e-mail: Nikolaus-August.Sifferlinger, gerhard.rath@unileoben.ac.at)

Abstract: Due to the inevitable proximity of heavy machinery and human workers in mining and tunnelling the risk of severe accidents is high. The paper describes recent worldwide efforts to increase occupational safety in this industry. The major problems and approaches are discussed using the example of the development of proximity detection systems. Due to the hard environmental conditions, guards and protective devices cannot be used in many cases. Consequently functional safety is gaining importance in mining and tunnelling. The standards for functional safety are well-developed for manufacturing industry, but some issues cannot be applied directly in mining and tunnelling. One of these problems is the mean time to fail, which is a condition to reach a required safety integrity level. Small samples of data make statistical conclusion difficult. A method based on Markov chains is presented for this purpose and is compared with a standard method.

Keywords: Mining, automation, functional safety.

1. INTRODUCTION AND BACKGROUND

The restricted space in underground work sites in mining and tunnelling always entails the potential of collisions between men and machinery. Despite work rules and safety training, accidents of this category are still too frequent and therefore technical safety systems to avoid such collisions have been asked for and developed. Figure 1 shows the darkness and the proximity of machinery and persons in underground operation. In this case a service technician has just left the roadheader and walks beside the truck out of the tunnel.

In the United States the Mine Safety and Health Administration (MSHA) has analyzed all accidents for Underground Coal Mining since 1984. For radio-remote controlled Continuous Miner, where the operator works close to the machine with his radio-remote console, 38 fatal accidents were identified. Reason for the fatalities was that the victims working close to the machine were caught either by unplanned machine movements and/or were in the wrong spot and have been crushed, Huntley (2015). For mobile transport machines in underground coal mining in the same timeframe 42 fatal and 179 infringing accidents were detected, which could have possibly avoided if a technical protection system detecting persons in danger zones and stopping the machinery if necessary would have been available and installed, MSHA (2015).

Based on this high accident rate the National Institute for Occupational Safety and Health (NIOSH) started in 1998 with the development of a proximity detection system for persons too close to mining machinery in so called No-Go or Red Zones, Ruff (2015), and also got a patent filed, Schiffbauer and Ganoe (1999). Based on this patent several companies developed Proximity Detection Systems, which are available to the mining industry since about 2009. After positive operational results of the tested system the Mine Safety and Health Administration (MSHA) has announced in March 2015 the final rule that will strengthen protections for miners on the working section of underground coal mines by reducing the potential for pinning, crushing, or striking accidents involving continuous mining machines, MSHA (2016).

Fig. 1. Close proximity of persons and machinery in underground space

Also in South Africa the use of Collision Avoidance Systems between persons and machinery become compulsory in 2015, Department of Mineral Resources (2015). So worldwide there are at the end of 2015 over a thousand systems in operation. Although the existing systems are

2405-8963 © 2016, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All rights reserved.
Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.10.092

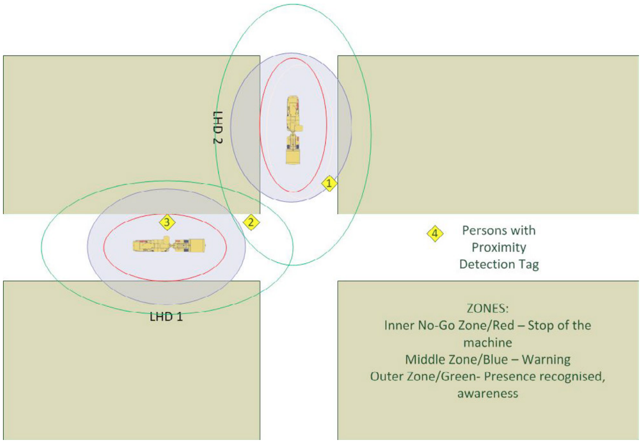

Fig. 2. Overview Proximity Detection System

a big step forward for the safety of mine operators, operational experience shows that further development and improvement of the systems is possible.

One of the topics is Functional Safety of the control part of the Proximity Detection Systems and this is also in focus of this paper.

2. BRIEF DESCRIPTION OF A PROXIMITY DETECTION SYSTEM

For close range detection of persons in underground condition so far a combination of a low frequency magnetic field and Radio Frequency Identification (RFID) has brought the best results and are the most common devices in operation worldwide. It consists of one or more magnetic field generators onboard, depending on the size and form of the machine, which can be dangerous to others. Each person in the underground area is equipped with a tag, which measures the magnetic field strength, which is an indicator for the distance. This tag reports the measured field strength to the machine and communicates with the proximity detection system on-board.

Figure 2 shows a Proximity Detection System based on the combination of a low frequency magnetic field and RFID. The person with Tag No. 3 is within the No-Go-Zone of the loader LHD 1 and stops the machine. The person with Tag No. 1 is on the boarder to the Warning Zone of LHD 2 and will activate warnings both for the loader driver and the person wearing the tag. The person with Tag No. 2 is in the Awareness Zones of both LHD 1 and LHD 2, no action will happen but the systems of LHD 1 and LHD 2 will be aware of the presence of a person in the area.

3. OPERATIONAL EXPERIENCE AND IDENTIFIED AREAS OF FURTHER IMPROVEMENTS

Reports from South Africa show that the Proximity Detection Systems in use have saved lives and avoided collisions, but also that systems, which failed undetected, could not avoid accidents. This shows the importance that the safety system has a Mean Time to Failure (MTTF) longer than the intervals between testing of the system. And calculating the MTTF is in the centre of the later part of this paper. MTTF is the predicted elapsed time until a failure of the system during operation.

The National Institute for Occupational Health has evaluated all existing Proximity Detection Systems for Continuous Miner in the USA, Jobes et al. (2012), and Nikolaus A. Sifferlinger has participated in the system tests and evaluation of the Collision Avoidance System of the Australian company Infotronix Design Pty in 2013, InfoTronix (2012).

For Proximity Detection Systems of Persons in No-Go-Zones two types of faults are very critical:

(1) if a person is not detected in the No-Go-Zones, because - malfunction of the system - no tag at the person under protection - the magnetic field gets distorted.
(2) if false alarms shows persons in positions where they are not. If this happens too often the system will be switched off.

Safety that depends on a control or protection system operating correctly in response to its inputs is called functional safety. So for the protection system Proximity Detection for further development the inclusion of functional safety has been proposed by several sources, e.g. Bentham (2013), Neumann et al. (2015), or Punch (2010). Therefore concept work for functional safety for Proximity Detection has been begun.

4. FUNCTIONAL SAFETY

In Europe the DIRECTIVE 2006/42/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 May 2006 on safety of machinery the corresponding list on harmonized standards (HARMSTDS) presents IEC (2005), *Safety of machinery - Functional safety of safety-related electrical, electronic and programmable electronic control systems*. For the design of complex subsystems EN IEC 62061 refers to IEC (2010), *Functional safety of electrical, electronic and programmable electronic safety-related system*, which is based on the Safety Integrity Level (SIL). Figure 3 explains the relationship of IEC 62061 to the other relevant standards in regards of safety of machinery and functional safety in detail.

The Safety Integrity Level is defined as a relative level of risk reduction provided by a safety function of an Equipment under Control.

4.1 Estimation of functional safety requirements by using the risk graph

To understand the later implications on the functional safety requirements a first estimation of the needed SIL is done by using the risk graph in case of a failure of the Proximity Detection System.

The risk graph qualitative method based on a risk graph is described in IEC 61508:5 Annex E. The method enables the safety integrity level to be determined from knowledge of the risk factors associated with the EUC and the EUC control system. A number of parameters are introduced which together describe the nature of the hazardous situation when safety related systems fail or are not available. One parameter is chosen from each of four sets, and the selected parameters are then combined to decide the safety integrity level allocated to the safety