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An Environmentally Robust Proximity Warning System for Hazardous Areas

William H. Schiffbauer
Electronics Technician
National Institute for Occupational Safety and Health (NIOSH)
Pittsburgh, PA 15236

Gary L. Mowrey, Ph.D.
Electrical Engineer
National Institute for Occupational Safety and Health (NIOSH)
Pittsburgh, PA 15236

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ABSTRACT

Proximity warning devices can improve workplace safety by alerting workers when they are in a hazardous area near moving equipment. Industrial work sites often present extreme challenges to safety-based proximity warning devices. Many commercially available types of proximity warning sensors and systems can be rendered useless when covered with mud, ice, snow, ore, rock, and other material. The list includes radar, ultrasonic, capacitive, and visual types of sensors and systems. Addressing these shortcomings, NIOSH personnel have developed a patented active proximity warning system called HASARD (Hazardous Area Signaling and Ranging Device) which employs low-frequency, low-power magnetic fields which are quite impervious to severe environmental conditions. A shapeable wire loop antenna which provides the marker of dangerous work areas, has been mounted on a continuous mining machine and was mounted inside 1.3-cm thick angle iron. This loop antenna was exposed to more than six months of active underground coal production, which included being covered by and scraped over with tons of rock, sprayed by a continuous stream of water, and immersed in thick mud. After six months the loop antenna showed signs of wear, but was still capable of performing its intended function. The HASARD system is now being applied to other industrial applications and is showing much promise, especially in harsh environments. This paper details the system, describes the tests that have been done, and mentions other areas where it can benefit the safety of industrial workers.

INTRODUCTION

Researchers at the Pittsburgh Research Laboratory (PRL) of the National Institute for Occupational Safety and Health (NIOSH) have been investigating methods and equipment that will provide for the safety of workers near moving vehicles and other industrial equipment. Their work was based on a need identified from statistical data that highlighted many accidents and fatalities in industrial work settings where employees were struck or pinned by moving equipment. The Mine Safety and Health Administration (MSHA) database showed that there were a high number of surface and underground personnel that were killed when working near machinery and powered haulage (1). For example, between 1992 and 1997, there were 24 fatalities just involving continuous mining machines (CMs). Another example is that 45 fatalities occur annually with forklifts in the United States. Also, in highway construction, between1992 and 1998, 318 vehicle and equipment-related fatalities occurred within work zones, where a worker on foot was struck by a vehicle. The victims were as likely to be struck by a construction vehicle or a piece of construction equipment as by a passing traffic vehicle. These statistics are a small sampling of data that identifies the need for proximity warning systems for protecting workers near vehicles and equipment. Many of these fatalities may have been avoided if a reliable proximity warning system was employed.

Addressing the needs of worker safety, NIOSH personnel obtained and tested a variety of different types of proximity warning systems to determine their reliability and effectiveness under varying conditions. The first tests were focused on underground coal mining. Coal mines have extremely harsh working conditions, especially in the coal production area called the face. The primary machine causing injuries and fatalities in that environment is called a continuous miner (CM) (figure 1.) First the various proximity warning systems were installed and evaluated on a CM and some associated mining equipment at the Pittsburgh NIOSH surface test facility. The systems tested were commercial products and also one called HASARD that was developed in-house by NIOSH. The HASARD system was found to be the most reliable in the underground coal mining environment. Consequently it was chosen to be tested under actual coal production conditions in an underground mine near Pittsburgh, PA. The system was exposed to water sprays; falling debris, including mud, coal and rocks; sliding sheets of rock; extreme vibration; and collisions with walls, and other vehicles B these exposures are normal in a coal production section. A few structural changes were made to ensure the integrity of the system and the loop antenna. The final HASARD system survived for six months under typical coal production conditions (2).

FIG. 1 – CONTINUOUS MINER

BACKGROUND

NIOSH personnel reviewed relevant statistics, accident reports, and verbal descriptions for situations which have led to worker injury and death caused by moving vehicles and equipment. Some commonalities surfaced which could benefit from the application of a properly selected proximity warning system.

Vehicle blind spots

Most vehicles have blind spots that obscure the driver=s vision. This is particularly true in large construction vehicles and haul trucks (3), but it is also very true in much smaller vehicles. Mirrors and cameras have been used to minimize the problem, but accidents still occur -- the vehicle operator must first see the problem and then react accordingly. Dirty mirrors and lenses, poor lighting conditions, fog, and driver fatigue can cause the driver to not see other vehicles and people on foot. An additional warning system could be beneficial.

Vehicle operator unaware of the presence of workers on foot

Around underground mining machines the work area is very dark and cramped. The operator and his helpers have to work in close proximity to the machine. It is normal for the operators to use the walls to help to steer the vehicle. Additionally, the vehicles commonly bump into one another when loading and unloading ore or coal. Operators are not always aware of the position of their helpers, and/or any other person who may be in the work area. A marker on each worker, which is activated as they approach a dangerous area, could alert the operator and prevent a potential injury or fatality.

Vehicle operator unaware of edges of roads

Accidents sometimes occur when an equipment operator inadvertently contacts the berm along the edge of a haul road. The problems have to do with poor visibility and blind spots. A road edge marker could provide improved safety.

Worker fatigue

Worker fatigue certainly has been a factor in many fatalities. The worker may see the impending hazard, but it may not register in his mind. A Awake-up@ call from a warning system may help.

Improperly marked hazardous areas

Fork lifts have been involved in many workplace fatalities. Some cases have been attributed to improperly marked work areas. Additionally, commonly applied back-up alarms tend to be ignored after long-term exposure. Another level of warning needs to be applied.

Repetition of tasks causing the worker to be unaware of new hazards

When workers perform a task over and over again it becomes so automatic that the work no longer requires concentration. Their minds can drift leaving them unresponsive to dangerous events that could occur.

Each of the cited cases could benefit from a proximity warning system. However, it is very important that the proper system is selected for the job, and that the system is reliable in the environment in which it is used. It is also imperative that proximity warning systems provide fail-safe features to ensure that if the safety device fails, the worker is warned of the failure. If a worker gains confidence in a safety system and it fails, the worker and co-workers can be put in jeopardy. An alarm that is always going off (nuisance alarms) can also be a major source of danger. It could cause workers to ignore the alarms. Maintenance and testing of proximity warning systems should occur on a regular basis to ensure confidence in the safety system.

The first NIOSH application of a proximity warning system was developed for the protection of operators and workers around a CM. A number of different types of commercially available proximity systems were considered and tested for the job. They included radar, ultrasonic, capacitive, and visual types of sensors and systems. Testing proved that for the underground mining application, none of these devices were appropriate due to the following and generally common reasons. Any object which got into the detection zone would cause the alarm output to trip. This would include the walls of the mine and other vehicles which normally come in close proximity to, or in contact with, the machine. Additionally, falling coal, rock, and even the water sprays, would set off the alarms. Each of these systems could be described as a passive type of proximity system, in that any object in its detection path would set off an alarm. Hence NIOSH developed an active type proximity based system (HASARD) since no commercially available active type systems could be found at the time. NIOSH has been granted a U.S. patent for the HASARD system, Patent No. 5,939,986 (Aug. 17, 1999).

HASARD DESCRIPTION

HASARD is an active system. The active feature is very important and is somewhat unique since most proximity warning systems (4) are of the passive type. Passive types of systems are triggered by all objects they detect within their range which is not always desirable. In surface mining operations large haul trucks frequently run over large pieces of earth, rock, and other debris. If the system triggered with every large piece of material it detected, it would quickly become a nuisance to the driver of the truck, causing him/her to tend to ignore it. In contrast, HASARD, being an active system, can minimize or even eliminate nuisance alarms.

HASARD requires a transmitter on one object and a receiver on another object. In this way, objects to be avoided are positively identified and are avoided. In construction sites a HASARD transmitter on a large haul truck and a receiver on a worker on foot (WOF) could effectively prevent an accident. A transmitter and receiver combination could be put on a wide range of objects such as people, edges of roads, poles, etc. HASARD includes a number of accessories to provide remote alarms, data logging, and shut-down features. The transmitter creates a current through a properly tuned loop antenna, producing a magnetic field about the loop. Figure 2 shows how a magnetic field is produced around a conductor. The loop acts like any low-frequency transformer. The magnetic field generated is held constant due to its constant current design. The loop antenna is usually constructed of one to three or more turns of 14 gauge wire. It must be tuned in place to account for the metal in the machines and the antenna housing. The magnetic field produced by the antenna is generally referred to as the magnetic moment (*m)* (5). *m* is the product of the current (I), the number of turns in the loop (N) and the area (A) of a current carrying loop. By measuring the resultant magnetic field with a calibrated 3-axis receiver, the distance between the transmitter loop antenna and the receiver can be determined. These properties are the essence of the HASARD system. The receiver can be made to provide some action (e.g., sound an alarm, shut down the equipment, etc.) whenever a magnetic field signal of a certain level is detected. From the HASARD perspective, as soon as a person enters a potentially dangerous zone around a vehicle, some warning signal or action can be triggered.

HASARD UNDERGROUND TESTS

Figure 3 shows a top view of the HASARD system as it was applied to a CM. The HASARD transmitter puts a signal into a loop of wire (the antenna) that is positioned around the periphery

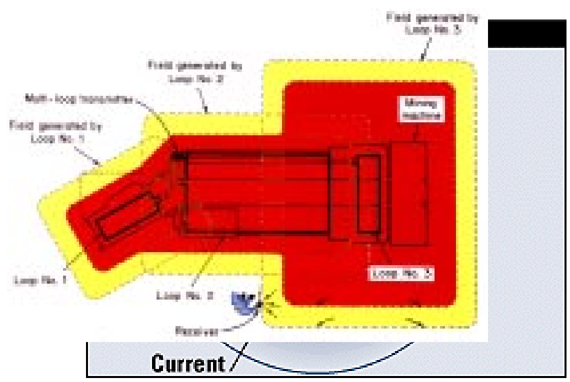

FIG. 2 – MAGNETIC FIELD

FIG. 3 – HASARD TOP VIEW

of the machine. A HASARD receiver is being held by a worker. As shown, the magnetic field generated by the loop conforms to the shape of the loop. The zone indicated is defined by a certain level of magnetic signal generated by the transmit loop antenna. The receiver contains circuitry for two threshold detectors which are calibrated to trip at signal levels which are relative to specific distances from the transmit loop antenna. These threshold detectors are calibrated to identify the zones around the CM. The receiver (figure 4) includes a vibrating motor. The motor is triggered by the output of one of the threshold detectors when a signal of a certain amplitude is received, which causes the entire receiver to vibrate, thereby alerting the wearer. Figure 5 shows how the HASARD system is typically used with a CM. Included in the receiver design is a short-range UHF (ultrahigh frequency) transmitter that can convey the status of the receiver to a remote data collection point. The data conveyed includes radio status, as well as safe, caution, and risk signals. This data can be used to shut down a machine and/or turn on the brakes, if required.

Designing transmit wire loop antennas for HASARD for coal mine use was particularly challenging because the antennas had to be protected from much abuse. In order to provide strength and protection, 1.3 cm thick metal covers were specially constructed. The antenna shown in figure 6 survived six months of intense coal production.

HASARD SURFACE FIELD TRIALS

The HASARD system was tested for use in surface mining operations. In one case it was evaluated in combination with researchers at the Spokane Research Laboratory (SRL) of NIOSH. SRL researchers were investigating various sensing and warning system technologies (6) that could be used to detect the presence of on obstacle in the blind spot of a large haul truck. The obstacle to be avoided in the SRL evaluation was a small pickup truck. HASARD was compared with other types of systems including radar, and Radio Frequency Identification Systems (RFID). The SRL study was limited to radio

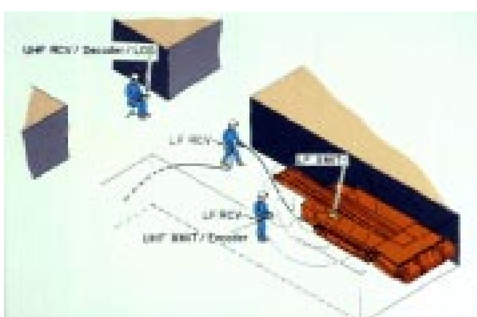

FIG. 4 – RECEIVER **FIG. 5 –**
TYPICAL HASARD SYSTEM

FIG. 6 – ANTENNA

frequency devices. For purposes of comparison, this study classified HASARD as an RFID type of system, although it might have been more appropriately identified as a magnetic sensing system. The testing centered on a 50-ton Komatsu 210 M Haulpak at an SRL surface test facility. While this truck was much smaller than most trucks used in surface mining operations, it provided an adequate platform for these tests.

The system configuration for underground applications of HASARD consisted of putting the transmitter and antennas on the CM and placing the receiver on the person. For the surface tests, the transmitter was placed on a small truck, and the receiver was placed on the large haul truck. The experiment consisted of placing a rectangular loop antenna on the roof of the small truck (figure 7). The antenna was encased in PVC pipe. The receiver (figure 8) incorporated a simple LED bar graph display that indicated the signal strength from 1 to 10, with 10 indicating the strongest signal. The receiver was used to map the detection area. The results of the tests showed that a very uniform detection zone of about 30 feet could be provided at each corner of the large haul truck. In retrospect, if the transmitter and antenna were placed on the haul truck and the receiver was placed on the small truck, the range of operation would have increased substantially due to the fact that a larger antenna generates a bigger magnetic envelope. The selected test configuration proved that HASARD could be used as an effective warning system for surface mining operations.

FIG. 7 – SMALL TRUCK LOOP

FIG. 8 - RECEIVER

HASARD has been also employed on a highwall-mining application. A manufacturer contacted NIOSH for help in locating an appropriate proximity warning device for their system. The company had tried other proximity devices but were unsuccessful in finding one that was reliable. Their system consisted of a CM , multiple-car haulage, and a large launch vehicle (figure 9). The problem addressed by HASARD was on the launch vehicle. The vehicle included a 40-foot long and five foot wide conveyor belt that ran through the center of the machine and was located just below worker foot level (figure 10). In most cases the conveyor belt area was covered by a stacked conveyor section, but there were times when that was not so. There was a danger that an operator may be injured by contacting the moving belt, or by tripping or falling on to it. To address the problem, a transmit loop antenna was placed below the belt and along the length of the launch vehicle. The loop antenna established a danger zone over the whole length of the belt. Workers on the launch vehicle were required to wear a receiver. The system was designed so that if anyone got close to or fell on the conveyor belt, a radio remote switch would be activated via the workers receiver and the belt would be shut off. HASARD=s success resulted in the patent being licensed by the company so they could use it on other mining systems.

OTHER APPLICATIONS

Industrial work sites experience many fatalities each year. The fatalities are wide ranging and involving many different pieces of equipment. NIOSH data has shown that forklifts trucks are one major cause of fatalities. Presently most, if not all, fork-lift trucks have back-up alarms. However, accidents are still occurring. Perhaps the workers have become oblivious to back-up alarms. The driver of the fork-lift can only be sure of avoiding a worker he sees. It=s mainly up to the WOF to avoid the danger. The unseen worker could use another level of protection. Implementation of the HASARD system would require each WOF to be outfitted with a receiver and a transmitter would be installed on the fork-lift. The WOF would receive a vibratory alert when a fork-lift was approaching. The fork-lift operator would be alerted to a WOF in close proximity. HASARD could also be used to apply the brakes.

FIG. 9 – LAUNCH VEHICLE

FIG. 10 – CONVEYOR BELT

In construction work zones, two-thirds of WOF fatalities, from 1992- 1998 did not involve traffic vehicles (7). Of those fatalities, over half involved a backing construction vehicle. Recent events indicate an increasing number of fatalities. On June 9, 1998, President Clinton signed into law a federal transportation bill called TEA-21, The Transportation Equity Act for the 21st Century (referred to as TEA-21). TEA-21 authorized $217 billion in funding over six years. Road construction projects are expected to increase by 40%. Addressing their concerns NIOSH recently started a NORA-based (National Occupational Research Agenda) research project entitled AEvaluating Roadway Construction Work Zones Interventions@ which will focus on minimizing work zone fatalities. HASARD will be employed as part of this project. It will be installed and tested on a variety of construction vehicles, and will be evaluated for its effectiveness.

CONCLUSIONS

NIOSH has created an innovative safety-based proximity warning system called HASARD that has the potential to not only warn workers around dangerous vehicles and machinery, but also to shut down the vehicle or machine should it pose a danger to the worker. The system was installed in a very harsh production environment where it survived for the duration of the project. HASARD has been tested and compared to other warning systems and has demonstrated its ability to provide a uniform and reliable marker in blind spots around heavy trucks. HASARD has also demonstrated that it can be applied to heavy equipment where a uniform marker and machine shutdown capability is needed to keep workers out of harms way. HASARD was so successful in this effort that a company licensed the patent for use on its other equipment. Other applications to which HASARD could provide a safety benefit include use on fork-lifts, and work zones on construction sites. HASARD will soon be tested on haul trucks inside of a construction work zone.

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