

UNDERGROUND FIELD TESTS OF SECOND-GENERATION PROXIMITY DETECTION SYSTEMS ON CONTINUOUS MINING MACHINES

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ABSTRACT

Since 1984, the date of the first recorded fatality involving a remote controlled continuous mining machine, 38 miners in the United States have been killed when they were struck by a continuous mining machine. Proximity detection is a valuable tool for preventing fatalities, and the use of these systems is expected to significantly improve safety. Proximity detection provides a means to prevent accidents like these. Researchers at the National Institute for Occupational Safety and Health (NIOSH) conducted a series of underground tests to evaluate the accuracy and repeatability of proximity detection systems under a number of conditions such as varying the orientation and height of the personal wearable device (PWD), moving the PWD close to the trailing cable, and activating the machine's mining mode. At the 2014 SME Annual Meeting, results from tests on first-generation proximity detection systems were presented. This paper will provide results from the similar tests performed with second-generation systems. The results show that performance has improved. For example, the negative impact of PWD orientation and the trailing cable has been reduced. However, some inconsistencies remain. Notably, performance changes dramatically when mining mode is activated.

INTRODUCTION

Since 1984 there have been 38 fatalities involving striking and pinning of the operator and other workers by the continuous mining machine (CMM) [1]. In August 2011, the Mine Safety and Health Administration (MSHA) published a proposed regulation that would require proximity detection systems on all continuous mining machines except full-face machines [2]. Proximity detection systems are designed to stop machine motion to protect miners from striking/pinning hazards. Several MSHA-approved proximity detection systems are commercially available.

MSHA estimates that of the 38 fatal striking and pinning accidents that have occurred since 1984 involving CMMs, the use of proximity detection could have been a preventative factor in at least 28 cases [1]. Furthermore, MSHA estimates that proximity detection could prevent 20% of all deaths throughout the industry [3].

NIOSH researchers have been involved in the development and testing of proximity detection technology since creating the HASARD system [4] and have recently conducted research intended to develop more advanced proximity detection technology for CMMs [5,6,7,8]. In addition, NIOSH has also conducted research investigating how the signals of a proximity detection system propagate [9,10] and have developed a novel method for determining the location of a personal wearable device (PWD) relative to the magnetic field generators [11,12].

To evaluate the performance of proximity detection systems implemented in industry, NIOSH researchers conducted tests in 2013 on three systems installed on CMMs at three underground mines in Illinois, and West Virginia. The results of these tests indicated that, while generally consistent performance was observed, there were opportunities for improving performance. These results were presented at the 2014 SME Annual Meeting [13]. Since that time, second-generation systems have become available to the industry and are becoming more commonly used.

Beginning in early 2014, NIOSH researchers conducted underground testing of these second-generation proximity detection systems installed on CMMs. A total of five tests were conducted on four installations of second-generation proximity detection systems, with one installation being tested twice. The tests were conducted at mines located in Illinois, Virginia, and Kentucky with seam heights ranging from 54 inches to 84 inches. These tests were conducted using the same test protocol used during first-generation testing, which is summarized in the following section.

METHODS

The goal of these tests was to assess the performance of the second generation of proximity detection systems in terms of functionality and repeatability. These tests followed a protocol developed with input from industry and the West Virginia Mine Safety Technology Task Force. NIOSH researchers used a custom measurement apparatus to characterize the warning zone and stop zone distances by moving a PWD towards the machine until a PWD alarm was activated. The researchers recorded the distance at which the alarm was activated for the warning zone and continued to move towards the machine until an alarm was activated for the stop zone. This was executed at 10 specific test points around the perimeter of the machine, shown in Figure 1. All measurements taken during these tests were performed in fresh air.

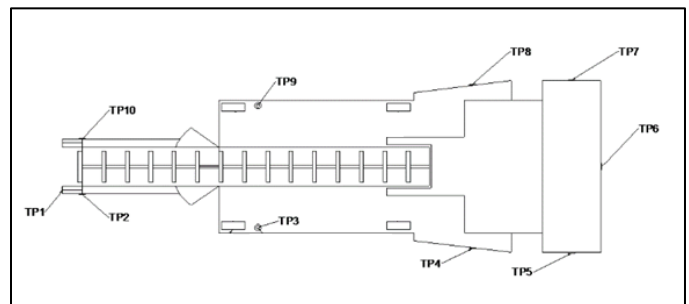


Figure 1. Test point locations.

A scanning laser level was mounted on the mining machine providing a plane parallel to the bottom of the tracks on the CMM. The scanning laser level projected a laser line onto the test apparatus reference pole as shown in Figure 2, and the height of the PWDs was adjusted using this line. This ensured that unevenness or tilt in the mine floor would not affect the results.

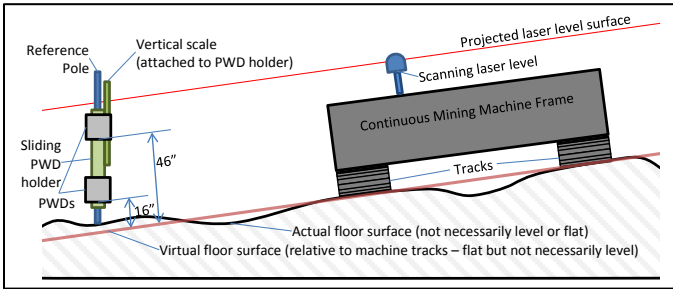


Figure 2. Reference plane projected by scanning laser level.

The reference pole (Figure 3) consisted of a telescoping non-metallic pole with a bubble level attached. Researchers performing the measurements held the pole plumb while advancing slowly toward the CMM. A sliding concentric tube held the PWD at one of two heights: high (46") and low (16"). The high and low positions correspond to the 95th percentile waist height for an adult male in a standing position and the 5th percentile waist height for an adult female in a kneeling position, respectively.



Figure 3. Researcher holding the reference pole while conducting a test (Inset: PWD attached to reference pole).

First, the stop and warning zones were mapped for the 10 test points to create a baseline set of data. The variables listed in Table 1 were then changed to evaluate their influence on system performance. The baseline case was defined by the following conditions: CMM stationary with all motors turned off, PWD at the high position, conveyor boom down and centered, cutter head down, trailing cable positioned away from the PWD, and no shuttle car or other haulage equipment present. The results of the other tests are compared with the results of the baseline test. In addition, the results of the baseline test give an indication of the repeatability of the system.

Table 1. Variables tested.

Conditions/Variables Tested
PWD height
PWD orientation
Multiple PWDs
Trailing cable position
Conveyor position
Cutter head position
Haulage equipment presence
Mining mode
Tramming

All measurements were performed at least twice at each test point. A third measurement was recorded if the first two measurements were more than five inches apart.

RESULTS

The warning and stop zones were mapped out at the 10 test points for each of the five field sites. This was completed first for the baseline case which is considered to represent the typical performance of the proximity detection system. Tests were then completed to determine the influence of each of the variables of interest on this baseline performance. In these results, relative distances are reported for each of the tests as compared to the baseline measurements. These relative distances are calculated by subtracting the relevant baseline distance from the measured value for each test. For example, measurements taken at mine 1, at test point 1, and at the high PWD height are compared to the baseline measurements for mine 1, test point 1, and high PWD height. Stop zone and warning zone measurements are also not mixed in these comparisons. For the relative distances, a positive number indicates that, as compared to the baseline, the zone was activated further from the machine, and a negative number indicates that the zone was activated closer to the machine.

The results for all of these tests are summarized in the following sections. For some of the tests, example results from individual mines are also included to show the typical performance observed.

Baseline Measurements

An example of the baseline measurements is shown in Figure 4. In this figure, the width of the red (stop zone) and yellow (warning zone) bars indicates the range of measurements observed for each test point.

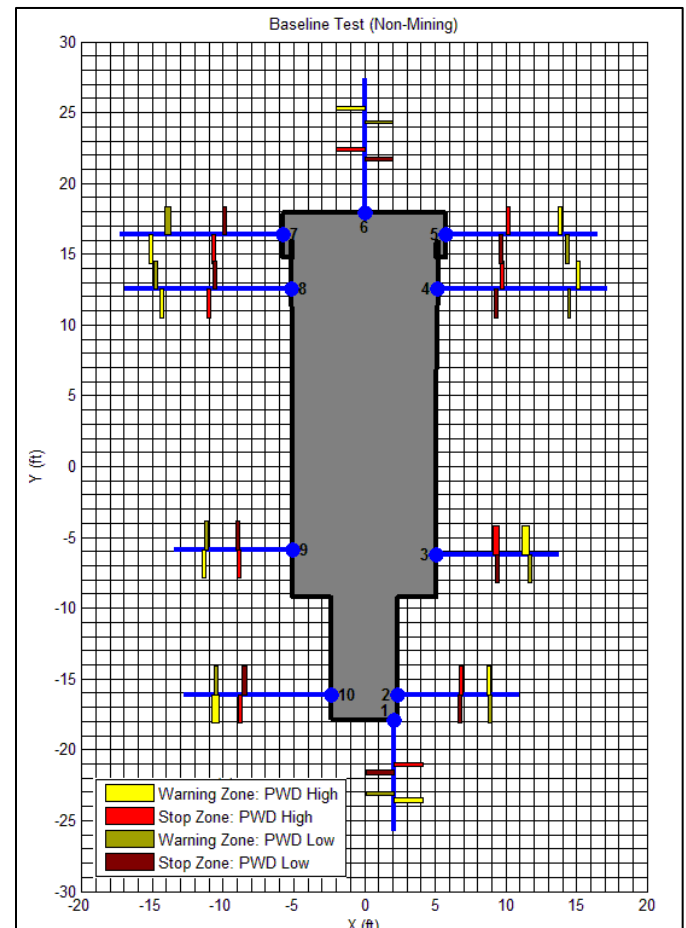


Figure 4, Example of baseline test results.

For most of the measurements taken, the first two measurements were within five inches of each other for both the stop zone and warning zone. This indicates that the technology is consistent and repeatable. The largest variability within a single set of measurements for the baseline test was approximately 24 inches, which occurred at only one of the 10 test points. Typically, the two successive measurements were within five inches of each other.

PWD Height

The height of the PWD can change significantly with changes in posture. With the PWD at the low position, some changes in performance were observed. Measurements were taken at both the low and the high PWD height for all ten test points.

In these tests, the stop zone distance with the PWD at the low height was typically within 6 inches of the stop distance with the PWD at the high height. In the most extreme case, however, a difference of up to 24 inches was observed. Similar observations were made relative to the warning zone.

PWD Orientation

The orientation of the PWD was varied on three orthogonal axes: yaw, pitch, and roll. This test was conducted to determine the effects of the PWD's orientation on the repeatability of the warning and stop zone distances. Due to time limitations, these measurements were performed at only one of the 10 test points. Depending on the ease of access at each of the sites, either test point 3 or test point 9 was used.

The warning zone and stop zone distances showed repeatability comparable to the baseline test for most of the measurements. The variability within measurements tended to be as much as 12 inches but was more typically about 5 inches. Compared to the baseline tests, the relative difference in warning and stop zone distance was 1 inch further from the machine with a standard deviation of about 5 inches. In the most extreme cases, the distances were within 8 inches.

Multiple PWDs

A test was conducted in which multiple PWDs were present to determine whether performance would change when more than one person is near the CMM. This test was conducted at either test point 3 or test point 9 depending on ease of access. Up to three PWDs were placed around the machine, and no significant changes in the stop zone and warning zone distances were observed. Compared to the baseline tests, the relative change in stop zone distance had a mean of 1 inch closer to the machine and a standard deviation of about 3 inches. In the most extreme cases, the zone activated up to 8 inches closer and up to 6 inches further from the machine.

Trailing Cable

A test was conducted to determine the influence of the presence of the CMM's trailing cable near the PWD. This test was conducted at either test point 3 or test point 9 depending on ease of access. First, the trailing cable was pulled along the floor away from the CMM. The PWD was positioned directly over the cable and moved toward the CMM. This test was performed with the PWD at both the high and low heights. In these tests, the individual zones varied up to 12 inches but were typically within 4 inches. The baseline comparison showed the relative distances to have a mean of 4 inches further from the machine and a standard deviation of 5 inches at the high PWD height, with the low position being about the same and having a mean of 1 inch further from the machine with a standard deviation of 7 inches. Example results of a trailing cable test are shown in Figure 5.

Conveyor Position

A test was conducted to measure the influence of the conveyor position on the warning and stop zone distances. For this test, measurements were taken at test points 1, 2, 3, 9 and 10. Both conveyor swing and elevation were varied. The swing positions tested were extreme left, centered (baseline), and extreme right. The conveyor elevations tested were extreme down (baseline) and in the extreme up position.

The repeatability of the stop and warning zone distances was not significantly changed by the conveyor swing. The influence of conveyor elevation was more significant. Measurements taken with the conveyor

up were compared to measurements with the conveyor down. Compared to the baseline tests, the PWD high position mean was 6 inches closer to the machine with a standard deviation of about 17 inches. In the most extreme cases, the zones activated up to 56 inches closer and up to 49 inches further from the machine. The PWD low position mean was 7 inches closer to the machine with a standard deviation of about 15 inches. The most extreme measurements for the PWD low position were 55 inches closer and 40 inches further from the machine. More detailed results and analysis have been communicated to the mine operators and proximity detection vendors involved. Example results of a test with the conveyor raised are shown in Figure 6.

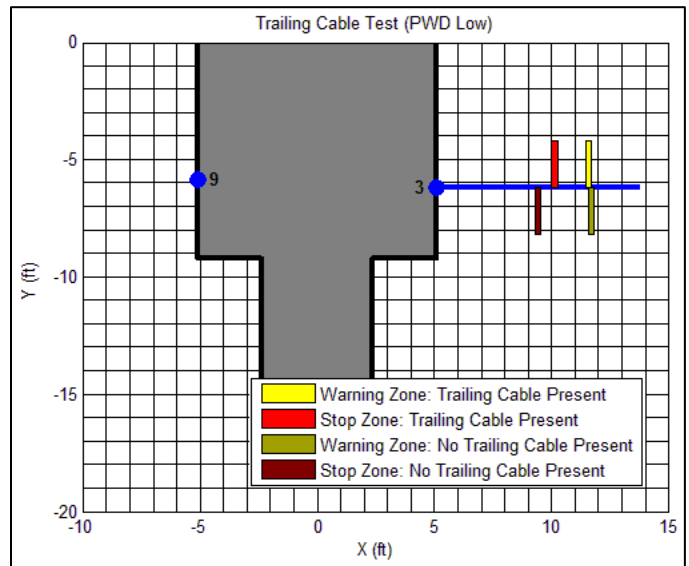


Figure 5. Example of trailing cable test results.

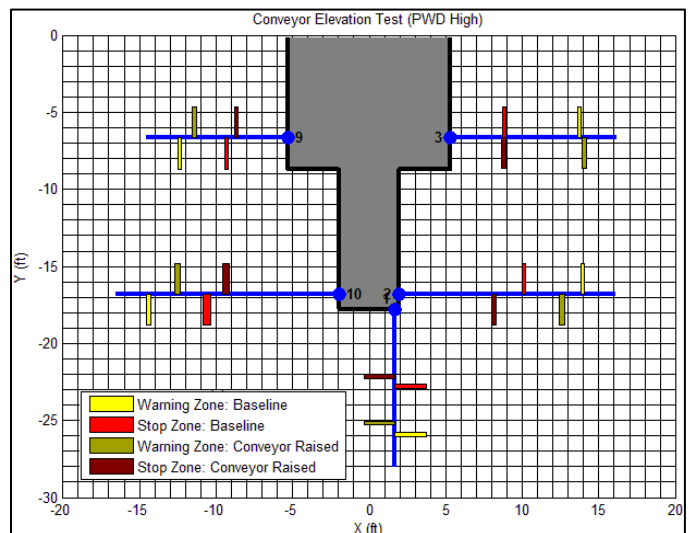


Figure 6. Example of conveyor elevation test results.

Cutter Head Position

In a test similar to that described for conveyor position, measurements were taken with the cutter head at a fully raised position (touching the roof) and compared to the baseline. All tests showed a tendency of allowing the PWD closer to the CMM with the cutter head in the raised position. This effect was minimal at four of the sites, but the stop zone distance was significantly changed at one site where the PWD was able to contact the head when it was raised.

Compared to the baseline tests, the relative zone activation distance for the PWD high position had a mean of 3 inches closer to the machine with a standard deviation of about 10 inches. The most

extreme measurements were 29 inches closer and 33 inches further from the machine. The PWD low position mean was 1 inch closer to the machine with a standard deviation of about 7 inches. The most extreme measurements were 26 inches closer and 13 inches further from the machine. Example results of a test with the cutter head raised are shown in Figure 7.

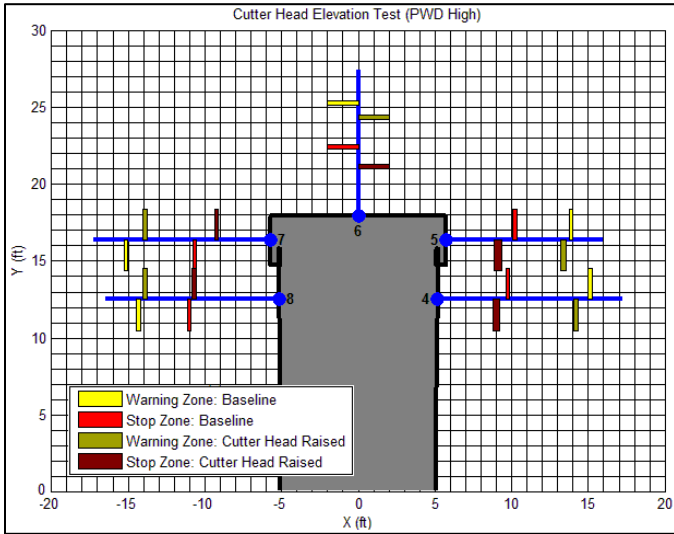


Figure 7. Example cutter head elevation test results.

Haulage Equipment Presence

A test was conducted to determine whether the presence of a shuttle car or other haulage equipment had an influence on the distance at which the stop and warning zones activated. Haulage (if available) was positioned behind the CMM as if coal was being loaded and the zones were measured at test points 3, 4, 8, and 9 along the left and right sides of the chassis. These measurements were compared to the baseline test. No significant change was observed with the haulage equipment present at the two sites where it was available.

Compared to the baseline tests, the relative zone distance for the PWD high position mean was 0 inches with a standard deviation of about 3 inches. The most extreme measurements were 5 inches closer and 4 inches further from the machine. The PWD low position mean was 1 inches with a standard deviation of about 3 inches, and the most extreme measurements were 4 inches closer and 7 inches further from the machine.

Mining Mode

All of the systems tested had a “mining mode” built into them to change their behavior when coal is being cut. The size of the warning and stop zones are reduced, in mining mode, to allow the operator greater mobility around the rear of the machine.

With the reduced zone sizes, miners are allowed to move close enough to come into contact with the machine without activating either the stop or warning zone at points outby the machine’s rear bumper. This was observed at test points 1, 2, and 10 around the conveyor boom as well as at points 3 and 9 on the rear of the CM body. At one site, the PWD was able to contact the CMM at test point 9 and get considerably closer to the CMM at test point 3.

Compared to the baseline tests, the relative zone activation distance for the PWD high position mean was 5 inches with a standard deviation of about 12 inches. In the most extreme cases, the zones activated 48 inches closer and up to 3 inches further from the machine. The PWD low position mean was 4 inches with a standard deviation of about 12 inches. In the most extreme cases, the zones activated up to 49 inches closer and up to 6 inches further from the machine.

Tramming

The proximity detection systems were also tested by tramming the machine toward a PWD and measuring the distance at which the

system stopped the motion of the machine. This type of test was performed with the PWD positioned on a wooden stand first in front of, then behind the CMM, and the CMM was trammed at the highest available speed until it was automatically stopped.

Although the performance was comparable to the baseline test for most cases, a large amount of variability was observed at one of the field sites with the machine in motion. Although it is unclear why this variability was observed, it is clear that mine- or machine-specific conditions may affect performance. In the worst case (PWD at the low height in front of the CMM) the machine stopped in actual contact with the PWD in both the forward and reverse directions where compared to a baseline distance of about 2 feet. In general, the stopped location of the CMM was closer to the machine than the stop zone distance because the CMM has a tendency to coast when shut off—more so in the forward direction than reverse.

Compared to the baseline tests, the relative stop zone distance for the PWD high position had a mean of 4 inches closer to the machine with a standard deviation of about 19 inches. In the most extreme cases, the zones activated up to 25 inches closer and up to 40 inches further from the machine. The PWD low position mean was 8 inches closer to the machine with a standard deviation of about 30 inches. In the most extreme cases, the zones activated up to 25 inches closer and up to 92 inches further from the machine.

Summary Results

The zone activation distances relative to the baseline measurements for all tests were combined into a single data set. The histogram of these relative distances is shown in Figure 8. Select points from the cumulative probability curve are given in Table 2. Figure 9 shows a comparison of all measurements relative to the baseline distances for all five tests. In this figure, tests with an “H” label indicate that the test was conducted at the high PWD position, and an “L” indicates that the test was performed at the low PWD position.

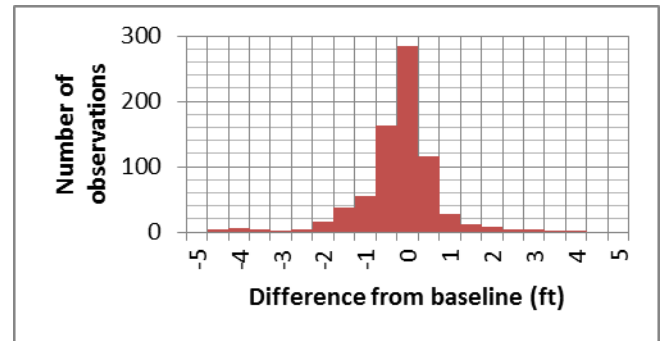


Figure 8. Histogram of all measurements relative to the relevant baseline measurement (754 total measurements).

Table 2. Select points from cumulative probability curve.

Relative difference from baseline	Percent of observations falling within range
±1.5	90%
±2.2	95%
±3.0	97%
±4.1	99%

DISCUSSION

The use of proximity detection technology is expected to drastically improve safety for miners working near continuous mining machines and other mobile equipment underground, and these test results show that the performance of the technology is improving. These tests showed a generally high level of repeatability, with 95% of all warning and stop zone distances falling within 2.2 feet of the baseline measurements and 99% falling within 4.1 feet. Factors observed to most strongly affect system performance were conveyor elevation, cutter head elevation, tramming, and mining mode, as can be seen in Figure 9. In the most extreme cases, the zones activated up to 7.6 feet further from the machine and 4.7 feet closer to the machine.

Although observations this extreme were rare (less than 1% of all measurements taken), they indicate the possibility of unexpected behavior of the system and should be carefully considered.

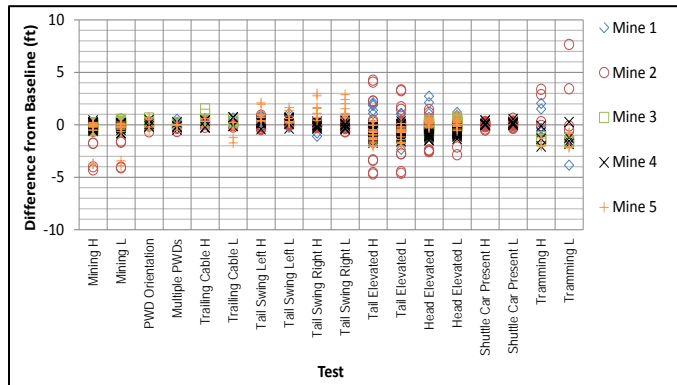


Figure 9. Relative difference from baseline for all tests and all mines (754 total measurements)

Also apparent in Figure 9 is the fact that there is a clear difference between mines. In the figure, a greater number of the more extreme measurements appear to be associated with Mines 1, and 2, although there are also extreme values associated with Mine 5. There are several possible explanations for this; however, in the opinion of the authors, it is due to the timing of the tests. The tests at Mines 1 and 2 were conducted in January 2014, relatively soon after the introduction of second-generation proximity detection systems. Whereas, the other three tests were conducted during the summer of 2014 after the technology may have improved. Regardless of the cause for variation between mines, these results should be considered during the design, installation, and use of a system.

The most concerning results are obviously the cases in which the stop zone distance was moved closer to the machine to the extent that the PWD was able to come into contact with the CMM. This was observed under three conditions: (1) when the cutter head was raised to its highest possible position, the PWD was able to contact the cutter head without the stop zone activating (this was observed at only one of the five mines), (2) while trampling, the proximity detection system stopped the CMM, but it did not come to a complete stop before contacting the PWD (this was also observed at only one of the five mines), and (3) during mining mode, a design feature intended to allow the operators closer during cutting, the stop zone does not activate for any of the points around the conveyor boom (this was observed at all five mines).

It is the opinion of the authors that the first two cases described above are correctable through system adjustments or recalibration. More detailed test results and conclusions have been communicated to the mines involved, and NIOSH continues to work with proximity detection vendors to improve system performance.

The third case described, in which contact with the machine is permitted during mining mode, represents a design decision to change system behavior while cutting coal. Mining mode is a configurable feature that can be enabled or disabled based on the preference of the mine operator. At all of the five tests conducted for this paper, mining mode was enabled. No fatality has ever occurred in the United States where a miner was struck by a remote control continuous mining machine while cutting coal [1], and the proposed MSHA regulation for proximity detection systems on CMMs has separate criteria while cutting as opposed to trampling [2]. It is also reasonable to assume that the CMM will have limited mobility when cutting since it is pressed against the face and/or rib and is limited to low tram speed when in cutting mode. However, the use of mining mode may create the situation that a miner is not protected by the proximity detection system and, therefore, may be struck by the machine. This system behavior should be clearly communicated to machine operators, and no operator should ever become reliant on a proximity detection system to save his or her life.

An alternative to mining mode, developed through NIOSH research, is the Intelligent Proximity Detection system in which miner position is continuously tracked, and only hazardous machine motions are prevented [5,6,11,12]. By only disabling the potentially hazardous motions, operators are still protected but are permitted to stand closer to the working face to see necessary visual cues and to avoid hazards such as approaching shuttle cars or other haulage equipment. It is the opinion of the authors that a system of this type would eliminate the need for the mining mode, which is intended to allow the operators greater mobility while cutting.

CONCLUSION

Test results also showed improvement over previously reported tests. Factors that were previously observed to significantly affect performance, including PWD orientation and close proximity to the trailing cable [13], appear to have minimal effect in the current test results. Researchers at NIOSH intend to continue working with proximity detection manufacturers to further investigate the proximity detection technology characteristics and to improve the performance of proximity detection systems. Proximity detection technology is evolving and system performance should continue to improve. The systems that are currently available provide a solution that will save lives.

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REFERENCES

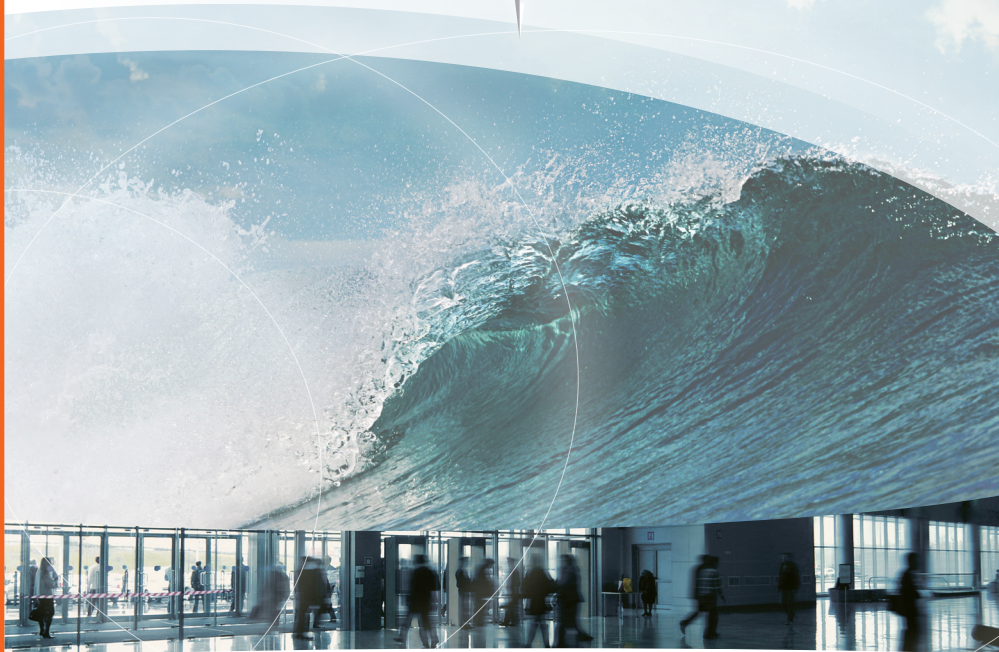
1. Huntley, C. "Remote Controlled Continuous Mining Machine Fatal Accident Analysis Report of Victim's Physical Location with Respect to the Machine." April 5, 2013.
2. Mine Safety and Health Administration. "Proximity Detection Systems for Continuous Mining Machines in Underground Coal Mines." Notice of Proposed Rule Making. Federal Register Volume 76, Number 169. August 31, 2011. pp 54163-54179.
3. Chirdon, D. "MSHA Proximity Detection" February 2, 2009. Retrieved from http://www.msha.gov/Accident_Prevention/NewTechnologies/ProximityDetection/Proximity%20Detection%20Paper.pdf on 5/17/2012.
4. Schiffbauer, W. "Active Proximity Warning System for Surface and Underground Mining Applications." Mining Engineering. 2002.
5. DuCarme, J.P., Carr, J.L., Reyes, M.A. "Smart Sensing: The Next Generation in Proximity Detection." Mining Magazine. July/August 2013. pp 58-66.
6. Jobes, C.C., Carr, J.L., DuCarme, J.P. "Evaluation of an Advanced Proximity Detection System for Continuous Mining Machines." International Journal of Applied Engineering Research. Vol. 7, No. 6, 2012. pp 649-671.
7. Carr, J.L, DuCarme, J.P. "Performance of an Intelligent Proximity Detection System for Continuous Mining Machines." 2013 SME Annual Meeting. February 24-27, 2013. Denver, CO.
8. Carr, J.L., Li, J., Smith, A.K. "Use of Magnetic Proximity Detection Systems in the Presence of Coal." 2013 SME Annual Meeting. February 24-27, 2013. Denver, CO.
9. Li, J., Carr, J.L., Jobes, C.C. "A shell-based magnetic field model for magnetic proximity detection systems." Safety Science. Vol. 50, Issue 3. March, 2012. pp 463-471.
10. Li, J., Jobes, C.C., Carr, J.L. "Comparison of magnetic field distribution models for a magnetic proximity detection system." 2011 IEEE Industry Applications Society Annual Meeting (IAS). October 9-13, 2012. Orlando, FL.

11. Carr, J.L., Jobes, C.C., Li, J. "Development of a method to determine operator location using electromagnetic proximity detection." 2010 IEEE International Workshop on Robotic and Sensors Environments (ROSE). October 15-16, 2010. Phoenix, AZ.
12. Jobes, C.C., Carr, J.L., DuCarme, J.P., Patts, J. "Determining proximity warning and action zones for a magnetic proximity detection system." 2011 IEEE Industry Applications Society Annual Meeting (IAS). October 9-13, 2012. Orlando, FL.
13. Carr JL, Lutz TJ, Reyes MA [2014]. Field Evaluations of Proximity Detection Technology on Continuous Mining Machines. 2014 SME Annual Meeting, February 23-26, Salt Lake City, Utah, Preprint 14-134.

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