

## USE OF MAGNETIC PROXIMITY DETECTION SYSTEMS IN THE PRESENCE OF COAL

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### ABSTRACT

Every year, severe injuries and fatalities occur when a miner is struck or pinned by a continuous mining machine, shuttle car, scoop or other piece of mobile mining equipment. Proximity detection systems offer a means to prevent these types of injuries and fatalities by sensing the presence of a miner and disabling machine motion. Although hundreds of these systems are installed and in use in operating coal mines, the influence that coal has on the electromagnetic fields associated with these systems has never been rigorously quantified. NIOSH researchers have conducted tests to measure whether the proximity of coal has a significant influence on a popular design of proximity detection system. The system tested utilizes a low frequency magnetic field generator that would be mounted on the mining machine. At the NIOSH Safety Research Coal Mine in Pittsburgh, researchers measured the performance of a simplified proximity detection system of this type first on the surface then underground at varying distances from a coal face. Analysis of these measurements shows that the presence of coal does not have a measurable impact.

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### INTRODUCTION

Machine related injuries and fatalities continue to be a major safety concern within the mining industry. This problem is particularly severe in underground coal mining, which accounts for roughly half of the United States coal production [1]. To reduce underground coal mine worker injuries and fatalities, proximity detection systems have been developed for continuous mining machines and other equipment. In 2011, the Mine Safety and Health Administration (MSHA) published a proposed regulation that would require the use of proximity detection systems on all continuous mining machines, except full face continuous mining machines, and there are currently three systems approved for use in underground coal mines [2, 3]. These systems stop certain hazardous machine functions when an operator enters into a predetermined hazardous zone.

Magnetic proximity detection systems measure electromagnetic fields to estimate the distance between a miner-wearable component and a machine-mounted component. One of the first systems to effectively demonstrate this technology was the NIOSH Hazardous Area Signaling and Ranging Device (HASARD), which was tested on a number of mining machines including continuous mining machines [4]. In HASARD, ferrite-core magnetic field generators were placed on the mining machine and used to generate a magnetic field at approximately 75 kHz. The strength of this field was measured by a Personal Alarm Device (PAD) worn on the miner's belt. Through laboratory and field trials, this design was shown to provide robust and reliable performance in an underground mine environment [4]. In addition, researchers at NIOSH have developed the Intelligent Proximity Detection (iPD) system to provide enhanced protection while minimizing false alarms [5].

Previously, NIOSH researchers developed a mathematical model for variation in measured field strength with respect to PAD position relative to the generator [6]. This model describes the shape and size of magnetic "shells," defined as all points around a generator having the same field strength reading. This model is useful in predicting the distances at which a proximity detection system would alarm and was used by NIOSH in the iPD system, which calculates the position of miners by measuring field strength from multiple generators and finding the intersection of the modeled shells [7].

The use of VLF electromagnetic systems is preferred for underground mining applications over systems operating at other frequencies due to the fact that it is affected to a much lesser degree by the presence of physical obstructions such as the coal ribs. However, the degree to which the technology is affected by coal has never been directly and rigorously measured. The presence of coal or any other material changes the electromagnetic environment in which the magnetic fields of the system are being generated. Although this is expected to have a small influence on the performance of the technology, it is important to quantify to what degree the environmental change will alter the propagation of the fields. This paper will present findings from experiments that were conducted to understand and quantify this concern.

### UNDERGROUND TEST BED

The Safety Research Coal Mine (SRCM) is located at the NIOSH Office of Mine Safety and Health Research (OMSHR) in Pittsburgh, PA. Along with the connected Experimental Mine, this two-mine complex consists of approximately 4 miles of underground workings in the Pittsburgh seam, and has been used by the US Bureau of Mines and NIOSH to conduct safety and health research for over a century. The average entry dimensions in the SRCM are 6.5' high by 14' wide, and the average seam thickness is 5.5'. Experiments were conducted at two locations in the SRCM labeled on Figure 1.

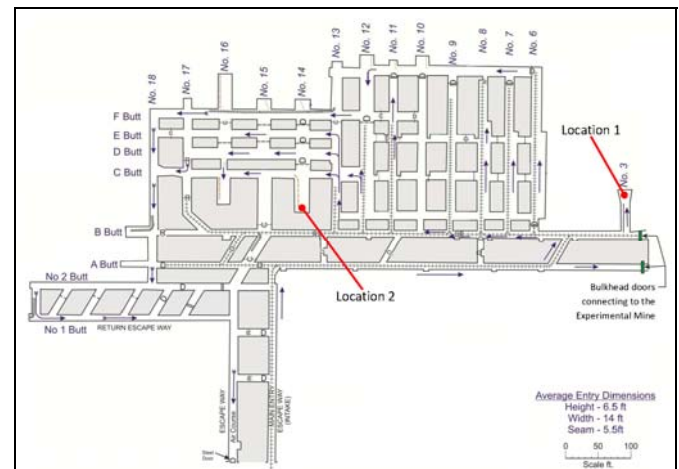


Figure 1. Map of Safety Research Coal Mine (SRCM).

**DATA COLLECTION**

To determine whether the performance of a proximity detection system is significantly affected by the presence of coal, two experiments were designed and completed. In the first experiment, the shape and size of several magnetic shells were mapped. This was done first on the surface in a laboratory setting without coal present, then underground in the SRCM with the generator in close proximity (approximately 1 inch) to a coal face. In the second experiment, a generator and a probe were rigidly mounted on a test fixture and the measured field strength at the probe was recorded as the distance between the test fixture and the coal face was varied. In both of these experiments, a custom-built proximity detection system was used in order to provide superior laboratory control. A magnetic field generator was created by wrapping 64 turns of wire around a 12"-long piece of ferrite with a 1"-square crosssection. This generator was supplied with current at 75 kHz to generate the magnetic field. This field strength (magnetic flux density) was measured using highly accurate magnetometers in place of the PAD that would be used in a proximity detection system.

**Experiment 1: Shell Size and Shape Measurement**

To map the shape and size of the magnetic shells, the generator was placed at the center of a polar coordinate system as shown in Figure 2. This coordinate system was laid out on a table as shown in Figure 3. The generator was powered by a Krohn-Hite Model 7500 amplifier, which produced a 75 kHz signal at up to 125 V. Using a VLF IDR-200 magnetometer connected to an isotropic magnetic probe, the field strength was measured at numerous locations around the generator. To account for minor changes to the reading based on the orientation of the probe, at each measurement location, the probe was rotated until a maximum reading was observed.

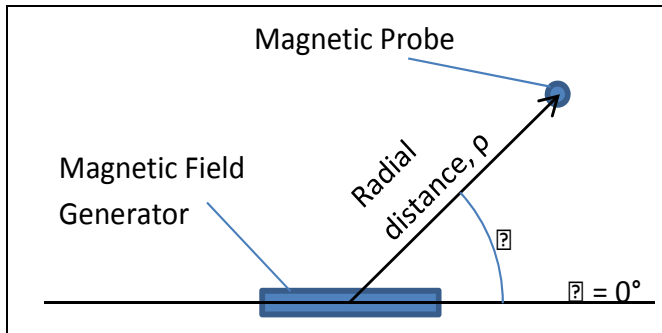


Figure 2. Polar coordinate system used to map magnetic fields.

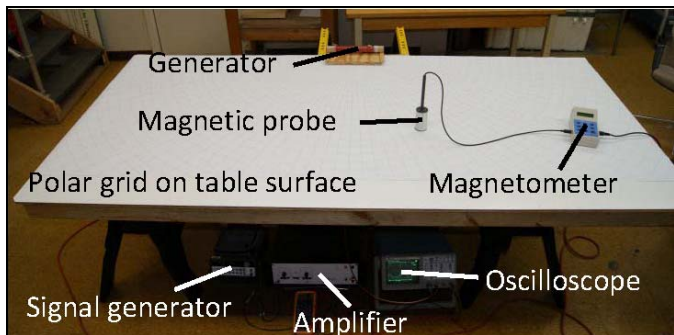


Figure 3. Experiment 1 set up in a laboratory on the surface.

A total of 13 magnetic shells were mapped. Each shell begins at a given distance along the  $\phi = 0$  axis as shown in Figure 2. The measured field strength at this point was recorded. The probe was then moved around the generator in 6° increments through 180°. At each angular increment, the probe was moved radially toward or away from the generator until the same field strength reading was observed. The distance between the generator and the probe was recorded at this point. Shells were mapped in 5-cm increments along the  $\phi = 0$  axis from 40 to 100 cm.

Once the shells had been mapped on the surface in a laboratory setting, the test was repeated underground in the SRCM. This repeat test was performed at Location 1 labeled on Figure 1. A photograph of the underground test is shown in Figure 4.



Figure 4. Experiment 1 set up underground in the SRCM.

**Experiment 2: Variation with Distance to Coal**

During mining operations, the distance between the coal rib and a magnetic field generator mounted on the side of a continuous mining machine would constantly vary. It is therefore important to test whether the generated field would change significantly as the machine moves relative to the rib. To do this, the magnetic generator was mounted rigidly on a plastic board along with an isotropic magnetic probe as shown in Figure 5. In this experiment, the generator was powered by an Agilent E4980A LCR meter which provided a 75-kHz signal at up to 20 V. An isotropic magnetic probe was connected to a Narda ELT-400 magnetometer. The equipment was changed from the first experiment to allow greater portability and convenience when moving the test apparatus from place to place. It would also be easy to take this apparatus into other mines to test other conditions.

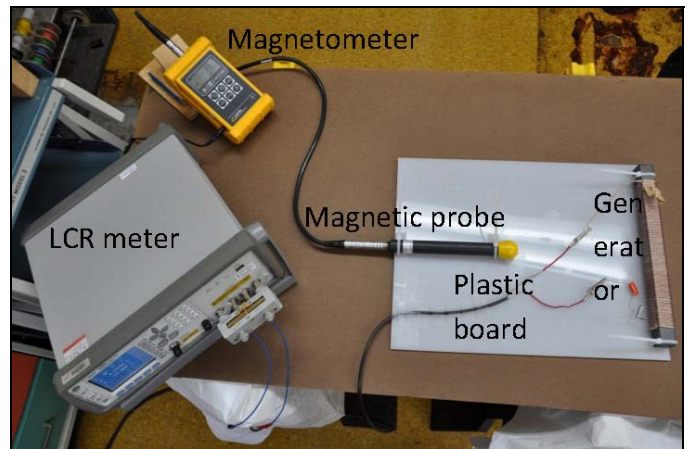


Figure 5. Experiment 2 set up.

The plastic board was placed near the coal rib on a horizontal table. The fixture was then slid along the table top to vary the distance between the coal face and the generator from 18" to touching in 1-inch increments. At each position, the magnetic flux density measured by the magnetometer was recorded. This experiment was performed twice in the SRCM: once at Location 1 and once at Location 2 labeled on Figure 1. These locations were selected to evaluate whether moisture would have an influence on the results; Location 1 is a relatively dry place in the mine, and Location 2 is relatively wet.

**RESULTS AND ANALYSIS**

**Experiment 1: Shell Size and Shape Measurement**

Figure 6 shows three example magnetic shells mapped both on the surface and underground near a coal face. Visually, it is clear that

the shells are very close to being identical. Slight differences exist between the shells mapped on the surface and underground. This is due, in major part, to fluctuations introduced by the signal generator and amplifier used. The performance of these components changes with temperature, humidity and other factors. In addition, measurement errors result in very slight differences between the two data sets. These slight differences are therefore considered to be insignificant.

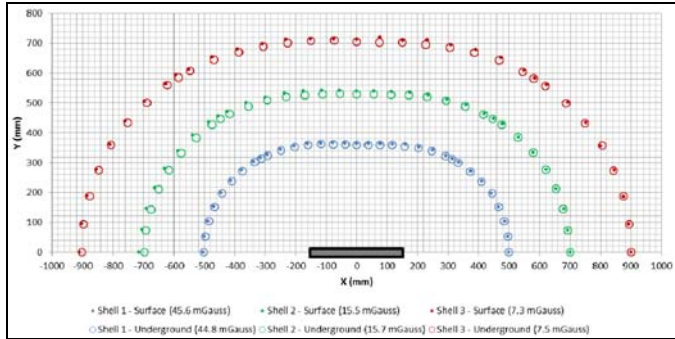


Figure 6. Examples of magnetic shells mapped on the surface and underground near a coal face.

Figure 7 shows the results for all 13 shells mapped on the surface and underground. In this figure, the radial position of the probe underground is plotted with respect to the corresponding measurement on the surface. If these measurements were identical, all points on this plot would fall on a line with a 1:1 slope. All 429 measurements taken were within  $\pm 3.5\%$  of being identical. Again, this small difference is considered to be insignificant and, given the equipment used, is within the measurement error.

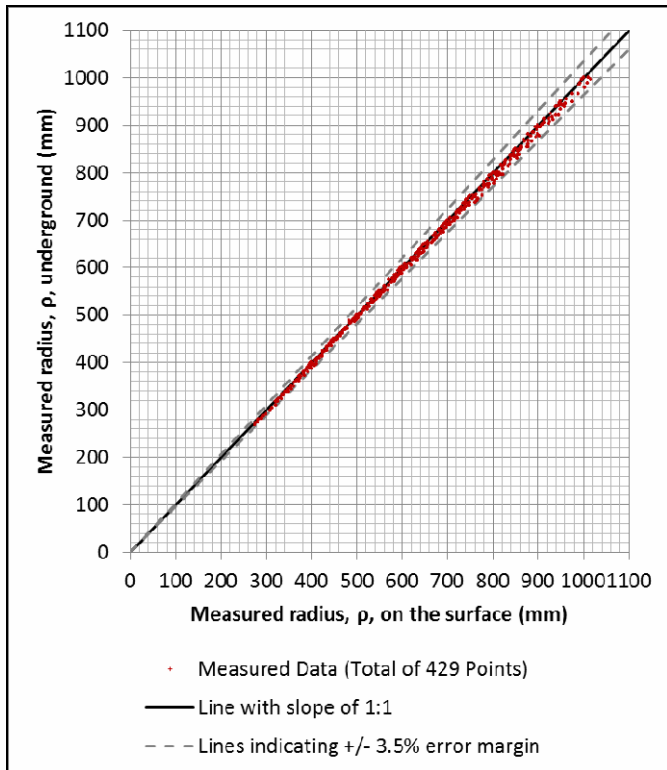


Figure 7. Comparison of measurements taken on the surface and underground.

**Experiment 2: Variation with Distance to Coal**

Since the LCR meter used in the experiment was able to provide a more stable signal to the generator, this experiment provides a much more controlled and accurate measure of the influence of coal on the magnetic field. As an example, the measurements recorded at Location 1 are shown in Figure 8. With 18 measurements taken at 1-

inch increments from the coal face, the standard deviation of all measurements was equal to 0.1% (i.e. 1 in 1000) of the mean. At Location 2, similar results were obtained with a standard deviation equal to 0.08% of the mean.

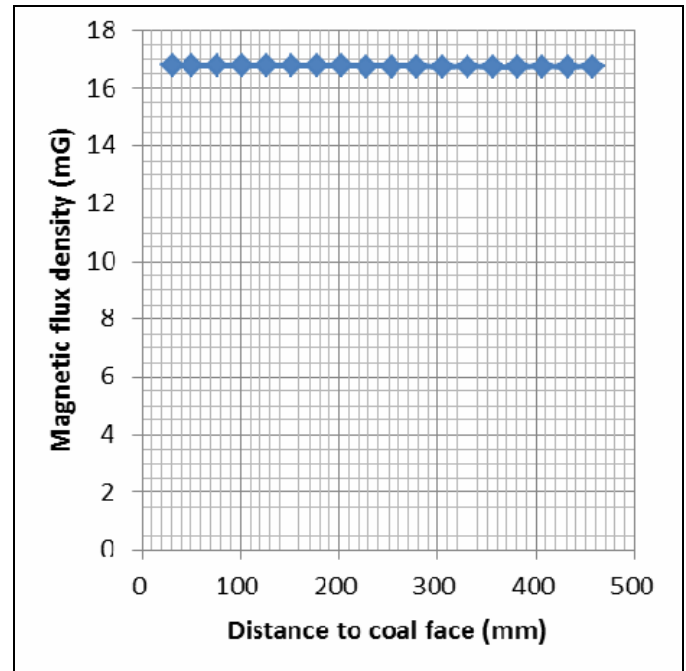


Figure 8. Variation in measured magnetic flux density with distance between the coal face and the generator.

To demonstrate how small this variation is, a test was conducted in which the same test apparatus was set up in a controlled environment in a laboratory on the surface. Over the course of several days, 25 measurements were taken with this system at various times of the day. For all of these measurements, the apparatus was not moved. The standard deviation seen with these measurements was equal to 0.16% of the mean. This indicates that the variation in readings introduced by the presence of coal is smaller than the natural variation introduced by temperature, humidity and other factors, and is therefore immeasurably small with the equipment used.

**CONCLUSIONS AND DISCUSSION**

The experiments described in this paper have shown that positioning a magnetic field generator of the type used in this experiment near in-situ coal, does not significantly change the shape or size of the magnetic field generated. In an underground mine setting, this would mean that the performance of a proximity detection system utilizing similar generators would not experience significant changes in performance as the mining machine moved closer to the coal rib. It must be noted, however, that these experiments were conducted at a single frequency of 75 kHz. Systems operating at a different frequency will not necessarily have similar results. It should also be noted that other environmental differences such as other rock types or other materials in the mine may have an impact on the accuracy of the system.

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