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CHARACTERIZING RADIO EMISSIONS FROM ELECTRONIC SYSTEMS USED IN UNDERGROUND COAL MINES

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ABSTRACT

Electronic systems have been increasingly used in underground mines to improve mine safety. These electronic systems emit electromagnetic (EM) energy which can adversely impact the performance of other electronic systems nearby and thus should be characterized. Researchers at the National Institute for Occupational Safety and Health (NIOSH) characterized the magnetic fields emitted from devices that can potentially interfere with the performance of proximity detection systems (PDSs) and compared the emission levels of these devices to the susceptibility of PDSs. In this paper, we present our measurement results pertaining to this effort. Particularly, magnetic fields emitted from the different orientations of a powered air purifying respirator (PAPR) and two lite trackers are evaluated based on the RE101 protocol specified in the MIL-STD-461G standard. The results show that both devices emit strong magnetic fields which strongly depend on the orientation of the devices. At some frequencies, the maximum emission levels from the two devices exceed both the emission limit given in MIL-STD-461G and the maximum magnetic fields that a PDS can withstand without a failure. The results and findings in this paper can help the mining industry better understand electromagnetic interference (EMI) underground and provide critical scientific data that support mining-specific recommendations to address EMI-related challenges.

INTRODUCTION

Electronic systems have been increasingly used in underground coal mines to improve mine safety. For example, communications and tracking systems are now mandated in U.S. underground coal mines by the Mine Improvement and New Emergency Response (MINER) Act of 2006. Proximity detection systems (PDSs), which use electronic sensors on both mining machines and mine workers are required for place-changing continuous mining machines in underground coal mines (MSHA, 2015). The personal dust monitor (PDM), a belt-wearable, computerized electronic device that measures and displays the amount of respirable coal mine dust is another electronic system that has been mandated recently (in 2016). While these electronic systems function satisfactorily when they operate alone, there might be unexpected performance issues when they work in proximity to another electronic device or system in the same electromagnetic environment, due to electromagnetic interference (EMI). For example, PDSs currently used in underground coal mines are known to be susceptible to EMI from some other electronic systems used in the underground such as PDMs (Li*, et al.*, 2019). There have been a number of other reported EMI instances involving electronic sensors in underground coal mines (Zhou*, et al.*, 2022).

While EMI issues are becoming more noticeable, due to the greater pervasiveness of electronic products in different aspects of mining, the solution to this problem is usually a compromise. First, electronic systems must be able to withstand a certain degree of interference, and then interfering emissions from any device may not exceed a certain level, which normally involves measuring interfering emissions of a device and comparing it to a given limit. This compromise thus outlines the two major elements within the scope of EMI: susceptibility and emission.

This paper mainly focuses on the second part of EMI issues: characterizing radio emissions, particularly magnetic field emissions at relatively low frequencies. Researchers at the National Institute for Occupational Safety and Health (NIOSH) have tested a variety of electronic systems used in underground coal mines that can potentially interfere with the performance of PDSs and the corresponding results will be reported in this paper. It should be noted that currently there is no mining-specific EMI standard, and thus no mining-specific emission limit is given. The emission measurement results in this paper will be compared to a susceptibility limit of PDSs, which represents the maximum emission level that a PDS system can withstand without any failure (Noll*, et al.*, 2018).

METHOD FOR CHARACTERIZING MAGNETIC FIELD EMISSIONS FROM ELECTRONIC DEVICES

EMI issues are not new on the surface and various EMI standards have been developed to address EMI-related challenges across multiple industries (Girman*, et al.*, 2021). These standards generally contain methods and procedures for characterizing radio emissions from different systems. Most of the existing EMI standards, however, focus on EM emissions above 30 MHz and in the form of electric field emission. There are very few standards containing methods for characterizing magnetic field emissions from electronic devices below 30 MHz.

PDSs used in U.S. underground coal mines are magnetic-field-based systems typically operating under 100 kHz. RE101 in the military standard MIL-STD-461G is one of the very few existing EMI standards that can be used for characterizing magnetic field emissions from electronic systems in the frequency range of 30 Hz to 100 kHz (DoD, 2015). Our method for characterizing magnetic field emissions from electronic devices used in coal mines is adapted based on RE101. Fig. 1 illustrates the measurement setup for the results reported in this paper. The major equipment involved are a calibrated antenna and a spectrum analyzer. The antenna (model AL-RE101, Com-Power Corporation) is a 36-turn electrostatic shielded passive loop antenna with a diameter of 13.3 cm which is specially designed for RE101 tests. The spectrum analyzer is used for displaying and recording measured magnetic field emission levels over the frequency band of interest. It should be noted that a distance of 7 cm should be maintained between the equipment under test (EUT) and the center of the loop antenna so that measured magnetic fields can be fairly compared to the given limits in MIL-STD-461G or other similar measurement results obtained following the same RE101 protocol. If the EUT is powered by the line power instead of a battery, then a Line Impedance Stabilization Network (LISN) should be used. “Maximum-hold” is used to record the maximum emissions during the period of the recording time. The other details about measurement procedures can be found in (DoD, 2015).

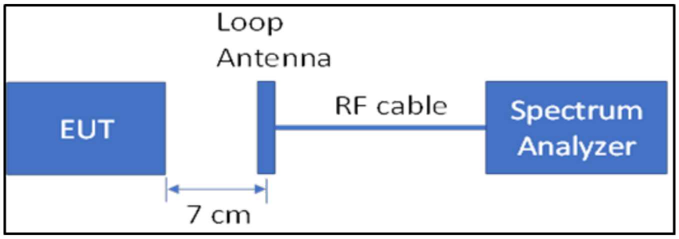

Figure 1. Measurement setup for characterizing magnetic field emissions from electronic devices.

MEASUREMENT RESULTS AND DISCUSSION

Powered Air Purifying Respirator (PAPR): The PAPR (as shown in Fig. 2) is one of the electronic devices currently used in underground coal mines for protecting miners against potential exposure to respirable coal mine dust. Some obsolete models of the PAPR are discontinued and new models are being introduced into underground coal mines (MSHA, 2021). Since PAPRs have electrical components such as pump motors and batteries that can potentially create strong radio emissions, MSHA has required EMI performance of those new models be tested before they can be used in underground coal mines. As documented in (MSHA, 2021), MSHA investigators traveled to an underground mine to test for EMI between PAPRs and electrical devices typically worn, carried, or operated by miners on the working sections. It was found that some of the new models (e.g., 3M VersafloTM TR-800) interfere with the performance of existing PDSs.

Figure 2. A picture of the 3M PAPR (VersafloTM TR-801N) that NIOSH researchers evaluated in terms of its magnetic field emissions.

The use of 3M VersafloTM TR-800 PAPR in particular mines has been granted by the Mine Safety and Health Administration (MSHA) (e.g., in (MSHA, 2021) and (MSHA, 2022)), with the condition that the mine operator shall adhere to the manufacturer's recommendations regarding safe operating distances to prevent EMI between the PAPR and other electrical equipment. It is also required that the operator shall perform testing for EMI between the PAPR and any other additional types of electrical equipment, placed in service at the mine, which have not been previously tested.

The reported EMI testing on the 3M VersafloTM TR-800 PAPR so far has been limited to checking whether the PAPR can cause any interference to the performance of PDSs and other electronic devices. The emission levels from the device for different orientations have not been quantified. To better understand the emission levels of the PAPR, NIOSH researchers started to characterize the 3M VersafloTM TR-800 series PAPR in a laboratory environment. Fig. 2 shows a picture of the PAPR we evaluated which includes three major parts: a helmet, a blower and a breathing tube connecting the two. Ideally, EM emissions should be evaluated under a working condition with the helmet on a user's head. However, our preliminary testing results have shown that there is no significant difference in terms of the magnetic field emissions for with and without the helmet. As a result, the rest of the measurements were conducted without the helmet for convenience.

Magnetic field emissions from all six sides (as defined in Fig. 3) of the PAPR have been evaluated based on the method described in the prior section, and the corresponding results are shown in Fig. 4. The magnetic fields from the ambient environment with the PAPR being powered down is plotted (labeled as "background" in Fig. 4) to show that there is no other significant magnetic field source in the environment. The PDS susceptibility curve is also plotted for reference.

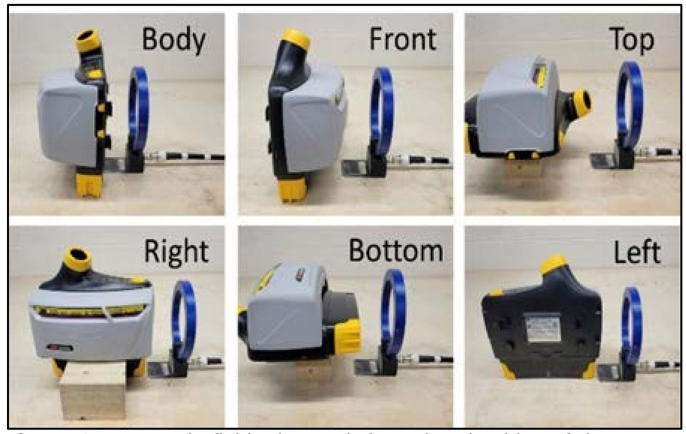

Figure 3. Magnetic fields that emit from the six sides of the PAPR were measured at a distance of 7 cm based on RE101 protocol specified in MIL-STD-461G.

It is shown in Fig. 4 that magnetic field emissions from the PAPR significantly vary (on the order of 20 dB) from side to side. The maximum emission is from the body side and the lowest emission is from the bottom side. In the frequency range between 61.975kHz and 80.35 KHz, the emissions from the body side exceed the susceptibility limits of the PDS, indicating that the PAPR will cause a PDS to fail when the PAPR (body side) is placed 7 cm away (or closer) from a miner-wearable component of the PDS. A closer look of the data in Fig. 4 shows that a small portion of the emissions (around 77.9 kHz) for the front and left sides of the PAPR are also slightly above the susceptibility curve of the PDS.

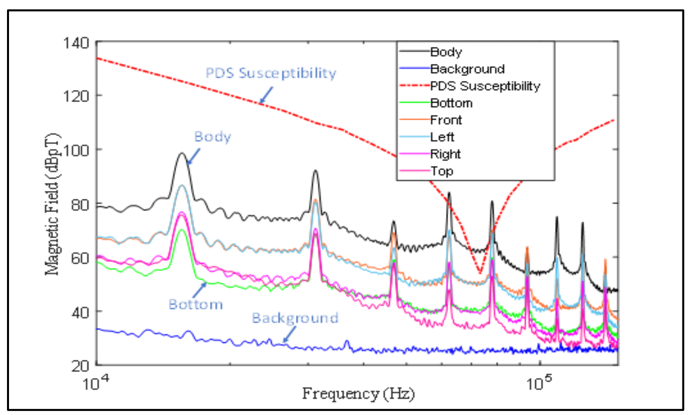

Figure 4. Measured magnetic field emissions from the six sides of the PAPR.

The results shown in Fig. 4 were obtained by setting the PAPR fan speed at the high level. In order to investigate the influence of the fan speed on PAPR magnetic field emissions, the measurement was repeated for different fan speed levels (i.e., low, medium, and high levels) to which the PAPR can be configured. Fig. 5 shows the measured magnetic field emissions for different fan speeds, from the body side (the side with the highest emissions to represent the "worst case"). It can be found from Fig. 5 that, overall, different fan speeds do not seem to cause any significant difference in the magnetic field emissions. At around 73 KHz which is the operating frequency of the PDS from which the susceptibility curve was measured, the high- and medium-speed modes seem to produce slightly higher emissions as compared to the low-speed mode.

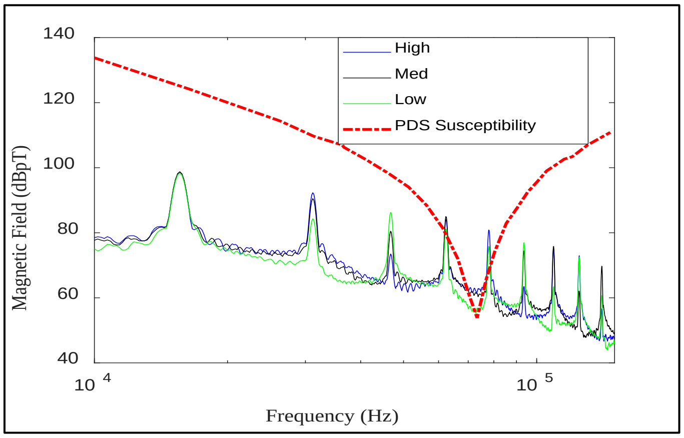

Figure 5. Magnetic field emissions from the body side of the PAPR were measured for different fan speeds.

Lite Tracker: Lite trackers provide a flashing visual indicator that allows instant recognition of personnel and are currently used in some U.S. underground coal mines as a personal safety light. As shown in Fig. 6, the lite tracker evaluated in our lab is an MSHA-approved permissible electronic device (Grace Industries, model 2004M). Similar to the PAPR, magnetic fields emitted from the six-sides (defined in Fig. 7) of the lite tracker were characterized and the corresponding results are presented in Fig. 8. It is shown in Fig. 8 that the front side has the highest emission while the lowest emission is from the right side of the lite tracker. At around 73 KHz, emissions from both the front and back sides of the tracker are above the susceptibility limits of the PDS.

Figure 6. A picture of an MSHA-approved permissible lite tracker (Model 2004M) used in underground coal mines.

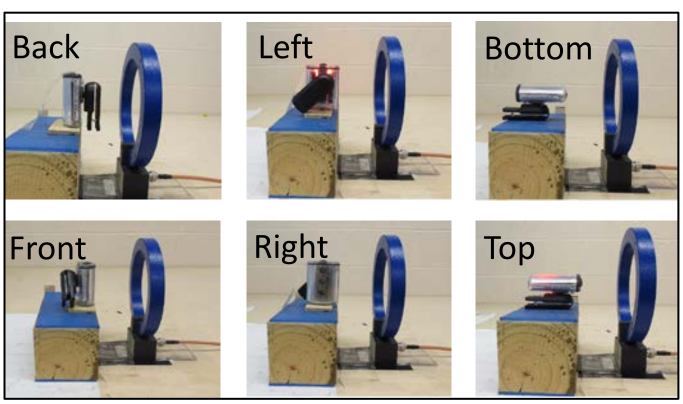

Figure 7. Magnetic fields emitted from the six sides of the Lite tracker were measured at a distance of 7 cm.

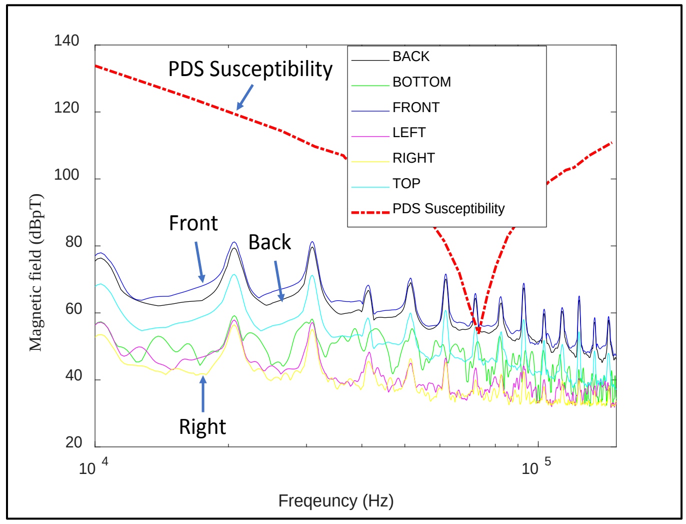

Figure 8. Measured magnetic field emissions from the six sides of the lite tracker (working under the strobe mode).

The results in Fig. 8 were measured under the "strobe" mode which is the only mode that the 2004M model has. To investigate how the magnetic field emissions vary with different operating modes of the device, another model (2013M) from the same vendor was characterized from the front side for three modes: glow, flash, and strobe, and the corresponding measurement results are shown in Fig. 9. It was found that all three modes show strong magnetic field emissions at a similar level. There is one emission peak located around 73kHz which exceeds the susceptibility limits of the PDS and thus can cause PDSs to fail if the lite tracker is placed near (< 7 cm) to the wearable component of the PDS.

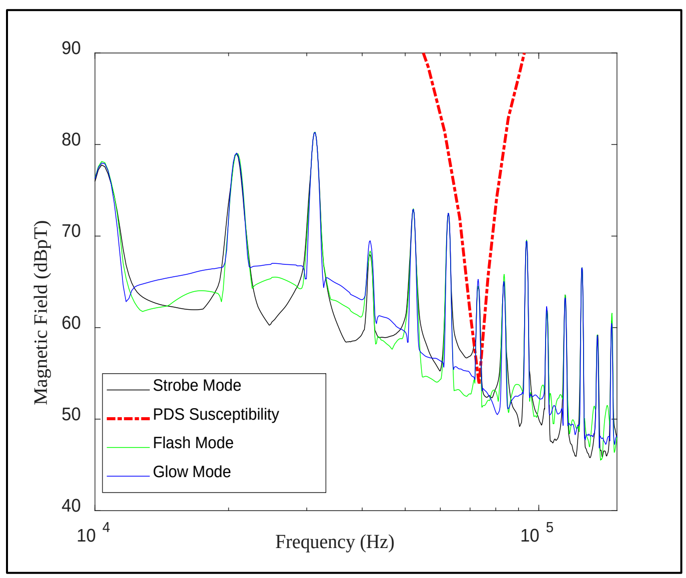

Figure 9. Magnetic field emissions from the front side of the lite tracker for different operating modes.

To gain an insight on how different devices are compared to each other, Fig. 10 shows a comparison of the magnetic field emissions for three different devices (PAPR, Lite tracker and PDM3700 reported in (Noll, *et al.*, 2018)), when measured from the highest emissions side. In addition to the PDS susceptibility limit, the RE101 emission limit for the Navy applications (labeled as "Navy Mask") is also plotted for reference. It is shown that, for certain frequencies, all three devices exceed emission limits specified in the Navy mask. Around 73 KHz, the emissions from the three devices are under Navy mask but exceeds the PDS susceptibility.

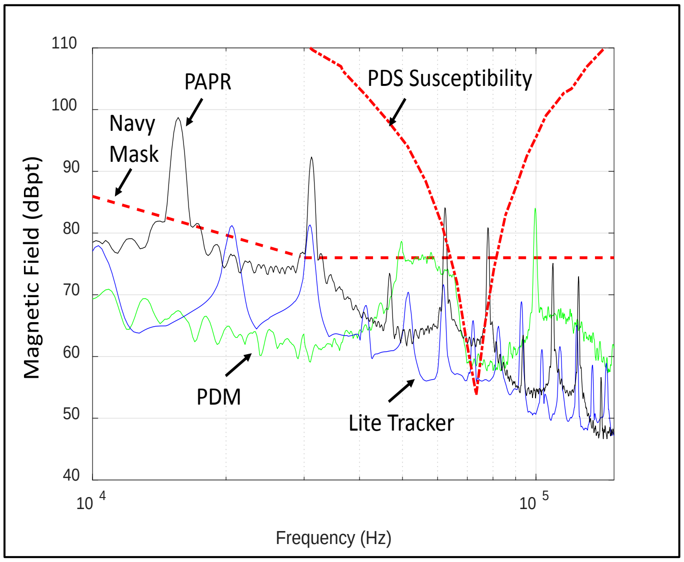

Figure 10. A comparison of the magnetic field emissions from different devices (for the side with strongest emissions).

CONCLUSIONS

This paper provides a practical method for characterizing magnetic field emissions from electronic devices used in underground coal mines. Using a PAPR and two lite trackers as illustrative examples, we show that the suggested method can be used to effectively characterize the magnetic field emissions of different mining electronic devices in a laboratory environment. Measurement results show that at some frequencies, emissions from both the PAPR and the lite trackers exceed the maximum field that PDSs can withstand, as well as the emission limit specified in MIL-STD-461G. It is also shown that the emissions from both devices significantly vary with the orientation of the device but little with the operating mode. The results and findings in this paper can help the mining industry to better understand EMI issues in the underground and provide critical scientific data to support mining-specific recommendations to address EMI challenges.

DISCLAIMER

The findings and conclusions in this paper are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC). Mention of any company or product does not constitute endorsement by NIOSH.

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