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Alternative electromagnetic compatibility methods tests of mining equipment

***Abstract**. In the paper author not only mentions the difficulties connected with mining equipment tests and their typical working environment, but most of all presents the results of his many years' research concerning issues connected with non-standard approach to the testing of "difficult" subjects (equipment). The paper presents practical problems of mining equipment EMC testing together with the description of the cases of incorrect or faulty work of mining equipment as the result of not complying with the electromagnetic compatibility requirements.*

***Streszczenie.** W niniejszym artykule autor nie tylko wspomina o trudnościach związanych z badaniami urządzeń górniczych i ich typowym środowisku pracy, ale przede wszystkim przedstawia wyniki swoich wieloletnich badań nad zagadnieniami związanymi z nienormatywnym podejściem do badań „trudnych obiektów (urządzeń). W artykule zaprezentowano praktyczne problemy dotyczące badań EMC sprzętu górniczego wraz z opisem przypadków niezgodności z wymaganiami EMC. (**Badania urządzeń górniczych z wykorzystaniem metod alternatywnych**).*

Keywords: EMC tests, underground mines, large equipment.
Słowa kluczowe: badania EMC, podziemne kopalnie, duże urządzenia.

Introduction

Mining equipment tests carried out by author and National Institute of Telecommunications team since 2006 show that there is well noticeable and confirmed need for the standardization of requirements for the machines and other equipment used in underground mines (what was presented in some of previous papers co-authored by the author of this paper [1, 2]). But not only the standardization of requirements is necessary, but also there is a strong need for specially modified test methods that can be used for EMC testing of the mining equipment.

Accumulation of equipment on a relatively small surface requires them to be relatively high resistant to the disturbances generated in this environment, however, due to the specificity of this environment and its conditions, it becomes necessary to adapt the methods to the tested objects.

Beside the practical problems of mining equipment EMC testing and the description of the cases of incorrect or faulty work of mining equipment as the result of not complying with the electromagnetic compatibility requirements, paper presents the significance of the issue of mining equipment EMC testing. On the other hand it brings the essence of the issue closer to the reader, and points to the need for further work in this area, not only to meet the requirements for the products but primarily to ensure the safety of miners.

The issues described in this article are becoming from year to year even more important, in particular, because of the dynamics of the automation of the extraction processes, which in turn calls out for the significant increase of the data transmission from different sensors. These data should be "certain" (free of errors) one – from the functional and people's safety point of view, and second – from the continuity and permanence of excavation process point of view, which is directly connected with the costs of the mining.

Electromagnetic environment of mines

When conducting electromagnetic compatibility tests of electric and electrical equipment to be used in underground mines, one should consider some general distinctive features of underground environment that can influence both the EMC requirements and the test methods:

- physical parameters (the tunnels of underground mines are very long, and mostly rather narrow and low),
- power grids structure, that runs through those tunnels for very long distances and mainly parallel to each other and parallel (and close) to signal and communication lines which can cause the interference of transmission by the disturbances propagating in power lines,
- type of machines working in mines (typical machines with high power electric engines producing great current and voltage changes during switch on / switch off operations), which generate high levels of disturbances that then propagate for long distances for example through the power grids structure mentioned above,
- physically big machines, that are difficult to test against EMC, while, because of parameters mentioned above, they are the most significant source of disturbances,
- intentional emissions propagated in tunnels (telecommunication systems using radiating cable), that once again propagate for very long distances (for the intentional transmission reasons) and at the same time they can present significant source of disturbances for example for the remote control systems that are using similar working frequencies.

It should be noted here that the mine environment is significantly different from the typical industrial environment conditions that we can find on the surface. This differences are not only important from EMC point of view, but it also plays significant role when you consider the functional safety and people's life safety. Due to the serious risks connected with the equipment that is not immune to EMC disturbance and for that reason can in some circumstances present dangerous malfunction, special attention should be brought to the studies of the underground mines electromagnetic environment. The issues presented here regarding EMC environment of underground mines do not by no means provide full knowledge of the environment and further, more thorough tests are undoubtedly needed – this for example should include more real-life measurements performed in different kinds of excavations of metal ore mines, coal mines etc. Those type of tests are difficult to organize and conduct firstly because of difficult environmental conditions for both the equipment and researchers, and secondly because the test cannot interfere with normal operation of the mine. Nevertheless, the team of National Institute of Telecommunication (NIT) team throughout the years of research data gathered significant amount of data that allow to formulate the thesis mentioned earlier, that electromagnetic environment of underground mines is so significantly different from industrial environment as it is characterized today that it yields for also significantly different approach, and equipment that is intended for mining use needs special approach during the EMC tests of it. Some pictures from the mine environment research tests performed by NIT team are presented on Figures 1 and 2. Those picture give some view into the conditions that we can meet in underground mines – what especially can be seen on these pictures is the close gathering of many electrical and electronic equipment that work in close proximity in tight spaces, which poses the subsequent problem in mine EMC and environmental tests.

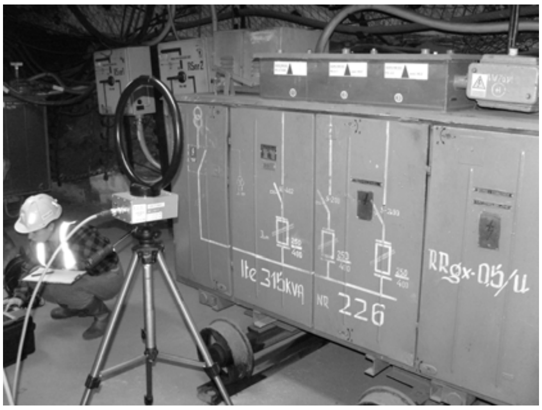

Fig. 1. Test team during measurements in underground mine

The main component of electromagnetic environment description of underground mine is a definition of the disturbances occurring this environment, the correct identification of these disturbances and, which is particularly important for the radiated disturbances, the proper identification and definition of the propagation paths for these disturbances. Taking into account the geological structure of the mine, it should already at the beginning be assumed, that the most significant component of the environment are the conducted disturbances and radiated disturbances in the near field. Therefore it can be assumed that the disturbances that are generated by the mine equipment penetrate the environment through two main paths:

- conducted disturbances, propagating in common power grid and common signalizing cables system (control, supervision, inspection etc.),
- currents/voltages induced in the cables by electromagnetic field, furthermore because of how the power and signal cables are running in the tunnels, the disturbances introduced (for example by the machine being the source of disturbances) to the power cables very easily induce to other parallel cables.

By conducting electromagnetic compatibility tests of some equipment typically used in underground mines, the NIT's team gathered many additional information concerning the electromagnetic environment of the real life working mine. It must be noted here that some of the above mentioned measurements and tests were not performed on isolated installations or in experimental mines – some of those tests were carried out in actual working mines during constant excavation. The main findings confirm the above analysis and can once again be summarized by the statement that in the underground mines the main role in electromagnetic disturbances is played by the conducted phenomena (in opposite to the situation on the surface) due to accumulation of many high power engine machines or machines working in constant switch on / switch off modes [1, 2]. What is particularly interesting and important – other researchers that were working on similar subject in Polish mines came to similar conclusions [4].

Fig. 2. Example of conveyor control room in copper mine

In situ EMC tests

Electromagnetic compatibility standards that define the emission and immunity test methods generally formulate those test methods for use in laboratory conditions with controlled environmental conditions for well-defined test set-ups that guarantee the test results repeatability. In practice, when testing equipment intended for use in special environments, it is often not possible to reproduce those standard conditions and set-ups due to the large dimensions of the devices under test (shearer loaders, continuous miners, conveyor belts etc.) and their operating and power conditions – for example 1 kV power supply – most (if any) EMC laboratories do not have the appropriate power transformers for those, not to mention the problems of where to find suitable test sites and how to transport the machines to those test site if they were somehow available. In such a situation, the in situ device testing is performed, ie. in the place of production, destination or otherwise – where the appropriate working conditions for the machine can be provided [3]. The main advantage of in situ measurements and tests is the ability to check how the device under test will behave in real operating conditions. This is of great importance especially in the immunity tests, since then not only standardized disturbances can be introduced, but also those that actually occur in industrial environments are often present and combined influence of disturbances can be therefore tested. On the other hand it must be remembered that the measurements of radiated disturbances emission from the device under test performed in the in situ conditions are most often not carried out in full compliance with the recommendations given in the EMC standards, especially regarding the following:

- measuring distance – 30 m and even 10 m distances are in many cases impossible to achieve, in those cases measurements must be performed from the 3 m distance, which yield testing from many directions – you cannot rotated the machine under test (you will not be able to cover the whole machine at the 3 m measuring distance with any test antenna anyway), you need to move the antenna around the tests object,
- the electromagnetic environment – other machines are sometimes working not far from test place, therefore the thorough ambient noise measurements are crucial for the measurements results interpretation, furthermore – big metallic planes and surfaces can be present on site and cause significant reflections, that can also influence measurements results and must be dealt with,
- test method – for example for conducted emission measurements AMN/LISN cannot be used because of type of machine powering – most in situ conducted emission

measurement techniques are based on current or voltage probes use.

In spite of the nonstandard measuring set-ups, the in situ tests cannot be ignored even when performed in very difficult conditions, as their thorough analysis allows to estimate, based on their results, the level of disturbances emitted by the device under test. In most cases of big mining equipment it is the only way you can gather those information. One must also remember that the purpose of most in situ tests is not the standard compliance estimation, but the analysis of the ability of the device to work in its target working environment.

To complement the in situ tests, small machines or subassemblies of machinery can be tested under standard laboratory conditions which can provide standard compliant set-ups and standard required repeatability. However, it must be taken into account that special conditions may be present in the environment different than during laboratory measurements and it may still be necessary to examine the whole system or machines that comprise the test equipment / subassembly in the in situ conditions. This is especially true for safety-sensitive equipment, such as a gas sensor. The proper functioning of such a sensor may depend on how and where it is installed on the target product (for example proximity of metal components may play a significant role here) and how the cables are connected, what is the quality of the cables, etc. Because of that, the above mentioned additional in situ measurements may be required in the target operating environment and actual installation conditions. Actual environment disturbances can be much higher than levels defined in typical industrial environment general standards and cannot be lowered by the final user, therefore the device must be capable of operating under such conditions.

For large devices, as it was pointed out before, it is usually not possible to carry out laboratory tests, due to their size, power supply, and auxiliary/associated devices. The in situ conditions, even while deviating from standardized conditions and being less repeatable, are nevertheless necessary for assessing actual hazards in a special environment. During the tests at the production or destination site, the broadest possible range of tests is performed there, with the methods that are as similar to standardized conditions as it can be achieved, always bearing in mind the precise documentation of all activities that were performed during the tests, especially the documentation of the set-ups that were actually used [3].

Through the years of experience in the in situ measurements and tests, the Wroclaw located EMC Testing Laboratory of National Institute of Telecommunications has developed a number of recommendations for the preparation of the test site and the environment of test equipment. The experience that was gathered through all these years demonstrates the importance of cooperation between the testing team and the manufacturer of the device and beside the appropriate competences for big equipment testing for testing lab it also gives the research team of EMC Department of NIT the opportunity and knowledge to advise manufacturers on the modifications to be made to the device to meet EMC requirements.

EMC tests with modified test methods

The most important from the electromagnetic environment of the mine research point of view proved to be conducted disturbances – this comes from the fact that in most mines power network is a "soft" type and the connected devices are generating significant transients.

While studying the electromagnetic environment in such conditions, one should pay particular attention to the fact that the measurement of conducted disturbances in the underground mine medium voltage (LV) power network is only possible with appropriate RF current transformer. The use of artificial network (which is the basic method for the conducted voltage disturbances measurements in the laboratory conditions) for the mine power network (with high operating currents up to hundreds of Amps at a voltage of 500 / 1000 V) is impossible, because there are no artificial mains networks or LISNs available in the market suitable for such a large operating currents and the operating voltage of 500 V, 1 kV or even more. Another factor in favor of the use of the current transformer is the simplicity of the measuring system and the ease of its use in real conditions of the working mine; there is no need to interrupt the cable energy flow, which is necessary in the case of artificial networks. Application of the voltage probe may also be difficult in some in situ conditions, because of the unambiguous determination of the point of the ground reference, especially in the underground mine in situ conditions.

Figure 3 presents the results of the calibration of the current probe that can be used during the in situ measurement. K-factor derived from that calibration allows you to determine the equivalent unbalanced voltage disturbances in the tested wire (or bunch of wires in a three-phase network). The other current probe parameter – the transfer impedance (ZT), see Figure 4, allows you to determine the actual value of the disturbances current.

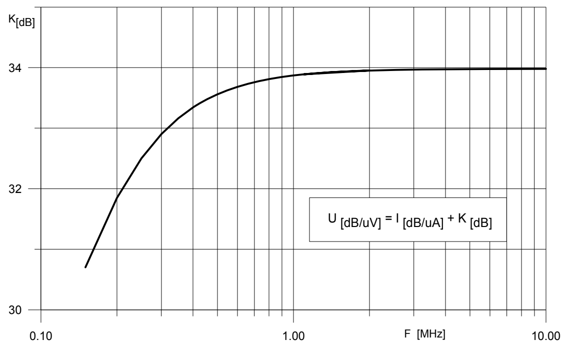

Fig. 3. Coefficient K of current probe used to measure the common disturbance voltage

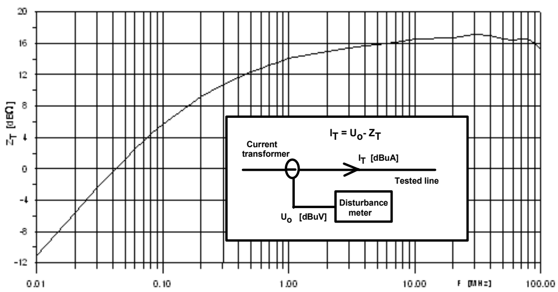

Fig. 4. Transfer impedance of current probes used to measure the disturbance current

The current probe and voltage probe simultaneous use test method for the use in the conducted emission measurement have been recently introduced for the application for example in the EN 55032 standard [5]. Although it is the multimedia equipment standard – nevertheless it proofs the usefulness and recognition of the method. The method presented here has been tested by the author and his colleagues since 2006, ie. since NIT carried out the first works in mines. Repeated application of this method in case of various mining machines has shown that in most cases it is sufficient for this type of device to perform measurement of disturbance emissions by applying the current probe itself. The consistency of the results obtained with this method when compared with the results obtained with the basic method (using the AMN/LISN) for mining equipment show their high repeatability.

Once again a special attention should be brought to the fact that the environment that we are facing with in the case of working underground mine is significantly different from that on the surface (even the industrial one). While the electromagnetic environment of the mining plant in its aboveground part can be regarded as similar to the typical industrial environment (in accordance with EN 61000-6-4 [6]), the electromagnetic environment under the ground is significantly different, especially it can be observed in the differences between being radiated emissions and conducted emissions. In the case of underground mine most important are the components associated with conducted disturbances, which are in this case much more important than the radiated disturbances. In the underground mine there are only very few intentional radiated signals – for communication or machines control, while the National Institute of Telecommunications team has recorded a significant amount of phenomena occurring in the case of conducted disturbances – including the phenomena related to the accumulation of machines equipped with "large" engines, very often working with frequent on / off operations.

Therefore the radiated disturbances measurements of mining equipment tested in the mine environment conditions require a specific approach because of the problems related to the limited space around the device under test. These tests cannot really provide the clear answer if the device fulfils the requirements or not, however they give an approximate knowledge of the disturbances the EUT can generate, that then can influence to a large extent on the features of the other mine equipment, especially safety-related equipment.

For this purpose, the author conducts research regarding using a variety of measurement distances and tries to introduced to the measurement results some adjustments related to the presence of mine walls elements such as metal gates or power cables.

As a part of NITs own research works, in order to better understand the essence of the impact of such elements, a series of studies was carried out that were intended to help in determining the safety margins for measurements in underground mines conditions.

One part of these research works included the radiated emission measurements carried out for the certain (possible to set-up in the mine) receiving antenna heights. Results of those measurements constituted the source of reference for subsequent modifications related to measurements conditions in the real mine environment. In the next steps the ground plane reference was removed and then verified was the effect of the reflection plane located behind the source of disturbances, behind the receiving antenna and at the side of the test set-up.

To compare the results of the measurements on reference test site and on the modified one – simulating the mine conditions site, and to determine the compatibility and repeatability of the results the E_n coefficient was used during the statistical evaluation.

$$E_n = \frac{x - X}{\sqrt{U_{mod}^2 + U_{ref}^2}}$$

U_{mod}^2 is the extended uncertainty of the measurements carried out under the modified measurement conditions,

U_{ref}^2 is the extended uncertainty of the measurements carried out on OATS (reference).

As a result of these studies, it was found that applying an additional uncertainty correction factor for the uncertainty (in this case it was in fact as far as 6 dB) the results of the comparisons carried quite a large uncertainty, but they allowed to carry in situ measurements in the real working underground mine conditions. Results of these tests can be used for rough evaluation of the tested equipment (if it generates extensive disturbance emissions).

Some examples of equipment incompatibility

The author also wishes to present here a few cases of lack of immunity recorded in the study of in mine used devices to present to the recipient the relevance of the problem of compatibility in mines. Due to the disturbances potential for causing safety hazards of large equipment and extensive installations, special attention should be paid to the particularly sensitive parts of their equipment.

During mining locomotives conducted disturbances tests – disturbance voltages induced in the conductors by the radiofrequency field (150 kHz ÷ 80 MHz) – locomotive pantograph was spontaneously lowering down and the system reset was occurring. You must be taken into account that this type of disturbance can be for example caused by a communication or control system working in this frequency range. In this case, the problem that occurred was related to discontinuity of the cable screen. These types of structural errors are a very common case contributing to the lack of compliance with the electromagnetic compatibility requirements.

Another example is a mine diesel locomotive, where the ESD disturbance caused the shutdown of the service monitor (or the occurrence of erroneous random characters), which finished with the complete turn off of the locomotive. For the same object when the RF field was applied there was the shutdown due to the methanometric alarm, and the sensitivity occurred among the others for the operating frequencies used in mines communication system.

The other example of the lack of immunity to the RF field disturbance from communication systems such as DOTRA (system used in copper mines) may be the effect observed during testing of conveyor equipment (ie. large distributed system). When the RF field was applied, the faulty earthing fault was detected, resulting in switch off of the conveyor belt. Please note that this kind of susceptibility to communications signals that are likely to be used in the near vicinity may even unable the device work.

The next example concerns the conducted immunity. During the application of disturbances to the wires in the transformer, erratic indications of supply voltage and grounding impedance were observed. Providing the same disturbances to the intrinsically safe cable caused an incorrect indication of the insulation resistance (less than acceptable – interpreted as insulation break). The effect of these errors was the device turning off.

Incorrect connection of cable screens (so called "hanging" screen), which is the cause of frequent problems when exposing mining equipment to the disturbances, was also the reason for erroneous operation of conveyor sensors. Among the various examples of error indications, the observed belt acceleration can be reported, with absurd readings comparable to 1st cosmic velocity or the temperature indication of the belt of the equally absurd melting temperature of the material from which the belt was made. Correct shielding together with using the ferrite rings on the corresponding wires allowed the elimination of the effects.

Fig. 5. Example of the device under test during RF field immunity tests

Repeated problems in devices with large electronics accumulation – for example electronic control, especially in devices that have a control point distant from the operator panels by several or more meters, are the cases of susceptibility to the conducted disturbances on the signal lines. The NIT team has repeatedly observed examples of erroneous messages in such conditions. In most cases, the reason for the susceptibility is to use of the incorrect (not recommended by the manufacturers) cables, especially unshielded cables. This effect is also observed when the manufacturer of a large or distributed device applies the distance between the devices that is well beyond the distance allowed by the manufacturer of the control system, and the signals that are transmitted by communication lines have levels substantially lower than typical, which results in greater susceptibility to the disturbances [7].

Summary

The article on the one hand shows the importance of the research problem connected with the requirements of electromagnetic compatibility of mining equipment and, on the other hand, gives the reader the essence of the issue of conducting work in this field. An important element is the appropriate adaptation of research methods so that requirements for the product electromagnetic compatibility can be identified and met. In addition, the problems associated with the correct operation of the equipment directly affecting the safety of miners were discussed. The base for those finding is authors own experience with electromagnetic environment of mine research and numerous mining equipment EMC tests performed.

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