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Disturbances generated by locomotives in underground mines

Abstract. The paper presents some of the experience gained by team of National Institute of Telecommunication, EMC Department, regarding the disturbances generated by mining locomotives. It focuses mainly on the disturbances being the effect of the spark between the pantograph and the catenary, but other disturbing phenomena are also mentioned. Some test results are also discussed.

Streszczenie. W artykule zaprezentowano przykłady zaburzeń generowanych przez kopalniane lokomotywy trakcyjne uzyskane podczas badań prowadzonych przez zespół z Zakładu Kompatybilności Elektromagnetycznej Instytutu Łączności – PIB. Zwrócono szczególną uwagę na zaburzenia będące efektem wyładowania pomiędzy pantografem a linią zasilającą. Pozostałe rodzaje zaburzeń również zostały opisane i omówione w artykule. (Zaburzenia generowane przez lokomotywy w kopalniach podziemnych).

Keywords: EMC; mining locomotive; spark discharge; radiated disturbances; conducted disturbances.
Słowa kluczowe: EMC, lokomotywy kopalniane, wyładowanie iskrowe, zaburzenia promieniowane, zaburzenia przewodzone.

Introduction

Electromagnetic phenomena generated by locomotives in mines make them very specific sources of electromagnetic disturbances. These disturbances have the nature of a spark, however, due to the environment in which they are generated, the type of propagation and preservation / duration of the pulses differ from the typically observed electromagnetic phenomena originating from the typical locomotive used in the railway traction.

This article presents one of the sources of the disturbance which exist in the mines traction locomotive. It also identifies how the disturbances appear and are generated resulting from discontinuities of the slip of the pantograph on the catenary (power/traction line). The nature of the spark discharge described in this article, including amplitude and elementary pulse repetition frequency (within the package), is random. Due to the imperfect shape and size of the pressure surface between the catenary and pantograph, they do not cling perfectly. Level of the disturbances associated with the spark discharge represents a pseudo-random distribution, close to normal. The average value of these disturbances, and the dispersion (standard deviation), depend on the type of locomotive and the system with which it forms a power supply circuit and, as is the case with the mine environment, show great variability along the traffic routes of electric locomotive. In this article only the major source of disturbance (ie. pantograph to catenary) is considered, but in other works of the authors there can also be found the analysis associated with other sources of disturbance coming from mining locomotives. The disturbance presented here is an interesting subject for both the numerical analysis and the measurements. Therefore, the second part of the article highlights the environment in which the disturbance is created and the possibilities of carrying out the calculations.

The article shows the important issue of propagation paths of the disturbances coming from the locomotives in a narrow and long tunnels of underground mines. Due to the unusual disturbance propagation in the environment of underground tunnels, the attempt of an analysis requires not only the use of basic modeling procedures but it is also necessary to use other solutions, such as beam tracking. The transmission ducts that are formed in the tunnels cause that wave extinction due to the distance rules do not apply, but more often these signals are amplified and repeated through the reflections. The authors would like to draw attention to the feasibility of the analysis of propagation of the disturbances resulting from excitation which is a spark caused due to imperfect cling between the pantograph and catenary. The authors would also like to share with the audience the problems that are associated with this unusual underground mines environment as well as the structure of the walls of underground corridors that can also affect the obtained results.

Identification of the sources of disturbances

An important element of the disturbances generated by mining locomotives is electromagnetic phenomena associated with the discharge on the contact between the pantograph and the catenary. This problem is widely raised in Europe (particularly in Scandinavia) and globally (advanced work in Japan) with respect to the big speed rail. In the case of mining locomotive which of course do not develop such speeds, resulting disturbances are slightly different and, above all, propagate in a totally different environment as far as the propagation conditions are concerned.

Disturbance source consisting of the pantograph contact with a catenary can be described as a generator of pulse disturbances characterized by variable pulse power and complex impedance of components. Usually, such disturbances are generated while the locomotive is passing places where the total or partial detachment from the trolley wire may occur. The emerging gap becomes the source for the generation of high-frequency phenomena, and the disturbance that has been generated is propagating through the wire along the sidewalks of the mine for a long distance and may result in malfunctions of the devices placed along the tunnels, in which the electric traction is led.

The discharge at the pantograph - traction junction for railway equipment is an issue which, according to research conducted for many years by the Railway Institute [1, 2], is defined as the main source of disturbances coming from rolling stock. Considering the analogy between rolling stock used on the surface of the ground, especially dc traction supplied urban transport devices, it can be assumed that this type of disturbance is also a crucial issue when considering interference from mining traction locomotives.

Spark discharge – the nature

Amplitude and repetition frequency of the single pulse (within the package) are accidental. Due to the imperfect shape and size of the gripping surface between the catenary and the pantograph, they are not adjacent to each other in an ideal manner. Level of the disturbances associated with spark discharge is pseudo-random of near normal distribution. The average value of these

disturbances, and the dispersion (standard deviation) depends on the type of the locomotive and the feed circuit it forms and, as is the case with the mine environment, they present high variability along the route of movement of the electric locomotive.

Presented below is the method of spark discharge modeling [3].

Instantaneous discharge power: $p = v_a \cdot i$
where: v_a – discharge voltage, a i – current
The average value of the discharge power during the process T is calculated from the following relationship:

$$p = \frac{1}{T}\int_0^T p\, dt = \frac{1}{T}\int_0^T v_a \cdot i\, dt$$

Exemplary discharge voltage and current in case of AC power supply has a shape similar to the one shown in Figure 1. The discharge voltage (in the first approximation it is the supply voltage), V_a is constant. The above relationship can therefore be written as:

$$p = V_a \cdot \frac{1}{T} \cdot \int_0^T i\, dt$$

In this case, what is left to do is to evaluate the waveform of the spark discharge current in the time domain and equivalent waveform in the frequency domain, as shown in Figures 1 and 2.
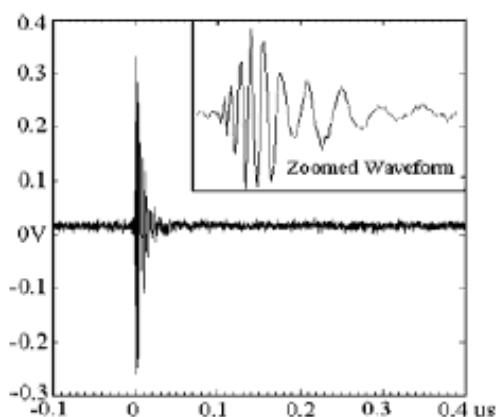

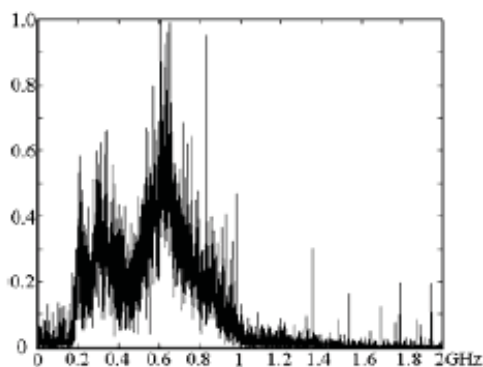Fig. 1. The shape of a single spark discharge pulse [4]

Fig. 2. Frequency spectrum of a single spark discharge pulse [4]

One problem that remains is to determine the current waveforms during the spark continuance. The effect of the spark formation and propagation can be treated (to a first approximation) as a voltage source with a shape corresponding to the single incremental jump. This simplifying assumption allows to determine the shape of the spark discharge current depending on parameters of the circuit, which is a load of the said source. Of course, this

requires careful consideration of the impact of all factors associated with voltage breakdown resistance value (R), equivalent to the load impedance (Z_{o1} and Z_{o2}), the length of the relevant sections of the transmission line (l_1 and l_2) and their equivalent wave impedance (see Figure 3). These parameters can be determined based on the measurements and on the basis of reasonable theoretical assumptions.
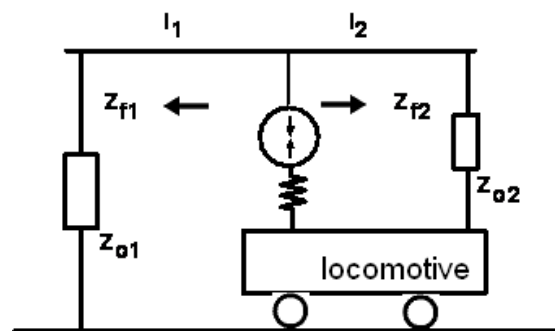

Fig. 3. The equivalent circuit of the load for the source of the discharges

Calculation of the current waveforms is carried out by means of operator method for solving linear differential equations, based on Carson - Laplace transformation and on the basis of equivalent Fourier transformation.

One should therefore proceed as follows:
For specific parameters of individual transmission line (l_1, l_2, Z_{f1}, Z_{f2}) and load impedance (Z_{o1}, Z_{o2}) current waveform equation along the transmission line has the general form [5, 6]:

$$I(p,x) = \frac{U_1(p)}{Z_f(p)} \cdot \frac{Z_o(p) \cdot sh\gamma(l-x) + Z_f(p) \cdot ch\gamma(l-x)}{Z_o(p) \cdot ch\gamma l + Z_f(p) \cdot sh\gamma l}$$

l – equivalent wire length of the transmission line (l_1 or l_2),

x – the distance from the considered point to the spark gap,
Z_f i γ – equivalent characteristic impedance of the transmission line and its transmission factor,
U_1 – input voltage of the transmission line (flashover voltage),
p – Laplace operator.
Then the current flow in the gap of the spark is obtained for $x = 0$.
The resulting expression is converted into a form which allows the transition to the description of the current waveform in time domain, using the appropriate tables given in [5].
The equation describing the complex spectral density of the discharge current is obtained directly from the current operator table as follows:

$$I(j\omega) = [\frac{I(p)}{p}]_{p=j\omega}$$

Propagation phenomena
When considering propagation in the mines, as mentioned earlier, one should be aware of the formation of waveguide along the corridors, as well as sudden and very rapid attenuation of signals in the corridor concerned. The studies on propagation issues [7, 8, 9, 10, 11, 12] are mostly associated with frequencies much higher than those deemed to be significant from the point of view of harmful phenomena, for example of such products as arcing between the pantograph and the catenary.
Moreover, to describe the phenomenon concerned here it is necessary to identify potential routes of disturbance

propagation. As it was already mentioned, we are dealing with two main modes of propagation for disturbances that arise at the pantograph - catenary contact point:
• disturbances conducted to the catenary – disturbance currents,
• radiated disturbances generated around the locomotive in the near field.

Both conducted and radiated disturbances, due to non-linearity of the source generating these disturbances and the uniqueness of their occurrence, are particularly dangerous for devices operating in the close vicinity.

While in the case of radiated disturbances we are talking mainly about the effects occurring in the near field and at a distance up to 20 m from the locomotive, then in the case of conducted disturbances we have to deal with the transfer of signals at the distances that are much bigger.

During the works carried out by National Institute of Telecommunications, EMC Testing Laboratory a strong dependence was observed between electromagnetic field disturbances occurring in the near field and disturbances current generated by the locomotive. Therefore, when considering and testing this phenomenon taken into consideration was the correlation between the disturbance current in the catenary and the field strength present in the close vicinity of the locomotive.

Mining locomotive tests results

As a result of the works that were carried out by the team from the National Institute of Telecommunications, EMC Department measured were the disturbances generated by mining traction locomotives.

The knowledge gained during these measurements indicate that when describing the electromagnetic environment the main thing is to correctly identify and appropriately determine the direction of propagation of disturbances in this environment, wherein in the case of the radiated disturbances it is of particular importance the direction of the disturbance propagation. Environmental studies in underground mines are particularly difficult because of the limited space, the long, narrow and low corridors and the accumulation of a large amount of electrical equipment on a small area, while most of this equipment is interconnected through the common supply network and a complicated network of signal lines. It should also be noted that the mine is a specific object, where in the narrow corridors many cables run in parallel over long distances, including high and medium voltage cables, signal cables as well as traction cables.

Particularly significant difference between mine environment and terrestrial environment can be observed in terms of the emissions of radiated and conducted disturbances.

In the case of underground mining the conducted disturbances are much more important than the radiated disturbances. In terrestrial environments radiated disturbances in the far field are taken into account, whereas in the case of underground mines environment radiated disturbances in the near-field can be very important, generated for example by traction locomotives. These disturbances may affect the machines located near the locomotive tracks, but they can also propagate to greater distances as current disturbances induced on the catenary and the signal lines guided along the walls of the corridor and, above all, by penetration into the overhead line. Among other radiated disturbances there also occur here some radiated signals associated with the desired emissions associated with communication or control machines, but those are, however, much less important.

Fig. 4. Traction locomotive, loop antenna for magnetic field measurements in front.

On Figure 5 presented is the example of conducted disturbances coming from mining traction locomotive. The conducted emission measurements were performed on catenary using the current probe. The disturbances measured are quite significant (the 7 dB attenuation of current probe is not taken into account in the picture) and can easily exceed the allowed levels defined in the emission standards for industrial environment. It must also be remembered that these disturbances can propagate in catenary for some considerable distance.
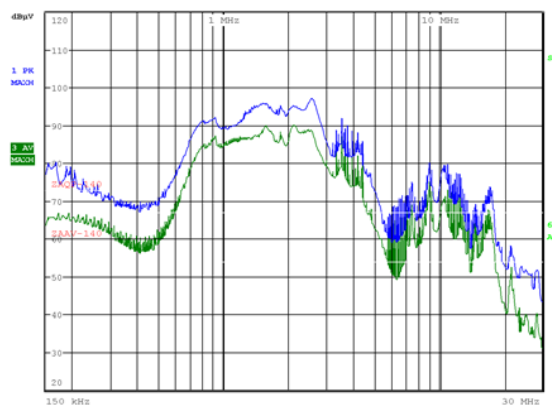

Fig. 5. Example of conducted disturbances (disturbance voltage) from the locomotive, measured in catenary.

Summary

As it was shown in this article, the phenomena related to the propagation of the disturbances coming from mining locomotives are very important issue when analyzing the electromagnetic environment in the mine. Stimulation that has been analyzed may constitute not only a source of disturbances. It can be a potential problem not only in local terms (ie. with a locomotive passing), but also, as it was presented above, can be propagated along tunnels (especially when induced on power or signal lines) and can generate problems even tens or hundreds of meters away.

Further considerations are required regarding the phenomena correlated to the changing dimension of the gap between the catenary and the pantograph. Different gap between catenary and the pantograph can be a premise to analyze the disturbances generated for different frequencies. During the analyses, depending on the dimension, the gap can be transformed on the capacitor with different distance between the capacitor plates. The convolution of these signals will constitute complex spectrum of electromagnetic disturbances.

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