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Research on mechanical tests applied to mining electric cables for certification in the voluntary field

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Abstract. The underground and surface mining industry are a complex sector of activity in which the workers involved face difficult working conditions, manifested by high temperatures, high humidity, risks of collapses, explosions and toxic gases, which requires ensuring a high level of occupational safety. In the case of the use of cable networks in underground and surface mining operations, in order to reduce the risk of explosion and increase the level of occupational safety, they must include electrical cables manufactured in accordance with the requirements of specific standards and which must be checked and certified for this purpose. In order to be certified in the voluntary field, power cables intended for use in the underground and surface mining industry must have a robust construction to withstand the mechanical stresses of exploitation, be able to provide appropriate electrical and thermal protection, and be made of materials that prevent the spread of fire.The danger represented by the use in areas endangered by the presence of gray dust of electrical power cables made of poor-quality materials and with an inappropriate construction for the respective environment, is materialized by the possibility of short circuits that generate heat, electric arcs and metal splashes, resulting in the initiation of fires and/or explosions.
This paper presents the safety requirements, test methods and test stand for mining electrical cables for their certification in the voluntary field.

1 Introduction

The technological processes that take place within the mining industry are complex activities that involve the extraction and processing of mineral resources, this being done through underground and surface mining operations. Although essential to the global economy, the extractive mining industry presents numerous risks and challenges, both for the environment and for ensuring the health and safety of workers involved in technological processes specific to the extractive industry.

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To reduce these risks to a minimum acceptable level, in underground and surface mining operations, strict safety measures must be adopted and implemented, environmental protection regulations must be respected, and the necessary framework must be provided for the use of modern technologies for a more sustainable and safer extraction of the useful mineral substance from the deposit.

Regarding the explosion hazard existing in the extractive mining industry, it is generally associated with the materials and products involved in the production process itself, as well as with the substances used by or released by technical equipment. On the other hand, the risk of ignition of a combustible explosive atmosphere is associated with the presence of equipment and technical installations that are capable of generating an ignition source that can initiate the existing combustible explosive atmosphere.

Due to these aspects, it is of particular importance that, in the process of assessing existing risks, the possibility of possible ignition sources from installations, technical equipment - electrical and non-electrical - and even from associated connection devices be taken into account, as shown in Figure 1. [1]

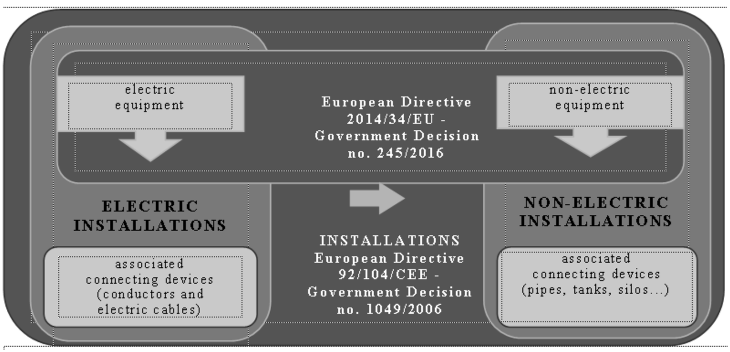

Fig.1. Overall installation analysis

The risk of explosion can be defined as the probability of the occurrence of an explosive atmosphere at the same time as the occurrence of an effective ignition source and the effects caused by it. [2]

An explosive atmosphere is defined as a mixture of flammable substances in the form of gases, vapors, mists or dusts with air, under atmospheric conditions, in which, after ignition has occurred, combustion spreads throughout the unburned area. [3]

The use of electrical power cables in underground and surface mining operations is an essential aspect for ensuring the supply of electrical energy to equipment and technological installations in the underground mines and on their surface. In this context, power cables must be made in such a way that special requirements are met in terms of safety and operational strength, as well as their reliability, taking into account the extreme operating conditions to which they are subjected.

Thus, for the electrical power supply of technical equipment used in technological processes in underground and surface mining operations and operating in areas with explosion hazard, the power cables used must be certified by notified bodies, corresponding to the group and hazardous area in which they are installed.

On the other hand, the installation of electrical cables and their accessories must be carried out in such a way as to avoid, as far as possible, their damage due to mechanical stress, corrosion or exposure to chemical substances. Also, power cables used in gritty mines must not be affected by high temperature values and be made with increased resistance or resistance to flame propagation.

In situations where exposure of power cables to mechanical stress or highly corrosive substances cannot be avoided, it is recommended to install them in protective conduits or choose shielded, armored electrical cables with aluminum sheath or cables with semi-rigid sheath or mineral insulation, suitable to withstand the respective stresses.

2 Requirements for electrical cables intended to operate in gritty mining operations

Due to the difficult operating conditions to which the electrical cables used in the underground and surface mining industry are subjected, they must, from a constructive point of view, be made in such a way that they have a robust construction that allows them to withstand the mechanical stresses specific to the mining industry, to have the possibility of controlling the insulation resistance, to reduce the influence of electromagnetic fields coming from outside or inside them, and to be resistant to the spread of fire.

Considering these aspects, in order to be used in maximum safety conditions in the mining industry, electrical cables must comply with the specifications of the Low Voltage Directive, as well as the specific requirements of the standards SR 11388:2000, SR EN 60811:2012, SR EN 60332:2015. Moreover, in order to be certified in the voluntary field, in order to be admitted to underground mining works endangered by the presence of gray dust, as well as in surface mining operations, electrical cables must also comply with the specific requirements set out in STAS 10411-89. [4, 5, 6, 7].

Regarding the specific requirements of SR 11388:2000 and SR EN 60811:2012, they refer to the performance of type tests and verifications of mining electrical cables, which cover the following aspects:

- dimensional checks and constructive characteristics of cables;
- electrical checks and tests, aimed at checking insulation resistance, electrical resistance, dielectric strength, etc.;
- mechanical checks and tests, such as: temperature shock test, outer sheath tear test, alternating bending test, etc.

The specific requirements included in the SR EN 60332:2015 series of standards refer to the flame propagation behavior of electrical cables intended for the mining industry. Thus, all electrical cables intended for the mining industry, depending on the way they are laid in the mining works – individually or in groups – must be subjected to specific fire tests, necessary to prove the resistance or increased resistance to flame propagation of the cables in question.

Within the existing energy, signaling, telecommunications and telemechanics installations in underground and surface mining works, both flexible mining electric cables are used, in which the insulation is made of natural or synthetic rubber, and reinforced mining electric cables, whose insulation is made of cross-linked polyethylene or PVC, and the sheath is made of PVC. In order for these cables to be certified in the voluntary field, they must be subjected to type tests and verifications in accordance with the requirements of STAS 10411-89, namely: static crushing test, dynamic crushing test, simultaneous torsion and bending test.

3 Test stands and methods used for testing for voluntary certification of mining electrical cables

Due to the difficult operating conditions and extreme mechanical stresses – static crushing, dynamic crushing, torsion and simultaneous bending – to which the electrical cables used in the mining industry are subjected, they must be mechanically tested, in accordance with the test methods provided in STAS 10411-89, which is necessary for the voluntary evaluation and certification of mining electrical cables by the certification body within NIRD INSEMEX Petrosani. In order to be able to perform these tests, a high-performance test stand was created and entered the equipment of the ENExEMEIP laboratory within the NIRD INSEMEX Petroșani, equipped with measurement, notification, control and recording systems for test cycles, connected via an interface to specialized programs used by the PC.

The assembly principle diagram for the test stand used to perform the dynamic crushing test, respectively static crushing, is presented in Figure 2. [1]

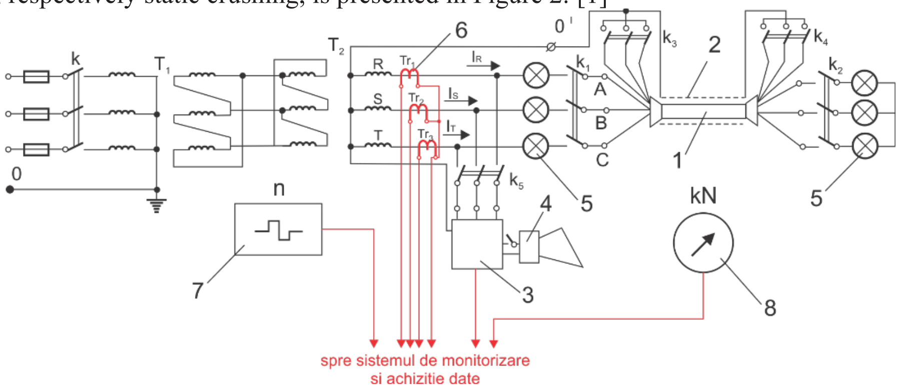

Fig.2. Basic assembly diagram

where:

1 – cable sample
2 – cable screen
3 – insulation control relay
4 – visual signaling lamp
5 – lamps for checking conductor continuity
6 – current transformers
7 – system for measuring blows or twists
8 – digital manometer
$K_1...k_5$ – circuit breakers
T_1 – transformer 380/127 V
T_1 – transformer 127/380 V

Through this test stand, with the help of an AGILENT TECHNOLOGIES system included in the stand, it is possible to monitor the height of the weight drop on the cable sample being tested, the number of successive blows that the tested cable withstands until a defect occurs, the static pressure applied to the cable sample, as well as the detection and warning in the event of defects on the tested cable sample, such as: insulation defect, short circuit or phase interruption.

3.1 Static crushing test

To perform this test, an installation is used that consists of a hydraulic press that can apply a maximum force of 108 kN, a railway rail and a half-wheel of a trolley whose profile is shown in figure 3. This installation is interconnected with the test stand whose assembly diagram is shown in figure 2.

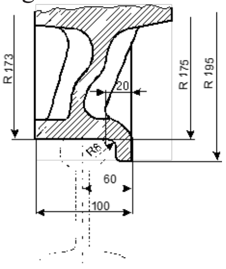

Fig.3. Wagon wheel profile

Fig.4. Installation and test stand

Depending on the nominal cross-section of the phase conductors and the nominal voltage of the cable, crushing forces having the following values are applied to the tested cable sample under voltage:

- 14.7 kN in the case of cables where the phase conductors have a section of maximum 16 mm^2 and the nominal voltage is maximum 1.2 kV;
- 29.4 kN for the cables with phase conductor cross-section greater than 16 mm^2 and nominal voltage of maximum 1.2 kV;
- 49 kN for cables with a nominal voltage of over 1.2 kV.

The main purpose of performing this test is to ensure that no insulation defects, phase interruptions or short circuits occur when applying the static force values presented above, depending on the nature of the cable. It is also necessary that the preventive disconnection coefficient is in accordance with the product standard, which is determined according to relationship 1.

$$k' = \frac{P_1'}{P_2'}, \quad (1)$$

in which:

$$P_1' = \frac{\sum_{i=1}^{5} P_{1i}}{5} \quad (2)$$

P_1' - the average crushing force at which an insulation fault occurs, detected by the insulation resistance control relay

$$P_2' = \frac{\sum_{i=1}^{5} P_{2i}}{5} \quad (3)$$

P_2' the average crushing force at which a short circuit between phases or a phase interruption occurs.

3.2 Dynamic crushing test

Applying the dynamic crushing test to a cable sample involves the use of an installation shown in Figure 5, which includes a ram with a mass of approximately 20 kg and a cylinder with a diameter of 80 mm made of a copper-zinc alloy, on which the cable sample is placed, interconnected to the test stand whose assembly diagram is shown in Figure 2.

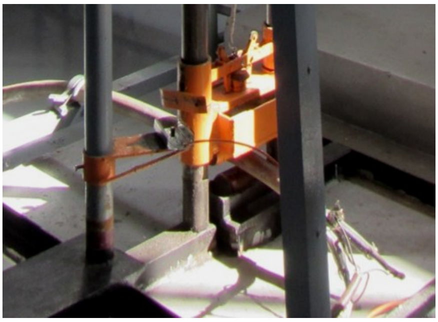

Fig.5. The installation as part of the dynamic crushing test stand

Depending on the nominal cross-section of the phase conductors, the ram is dropped onto the live cable sample from a height of 0,75 m for cables with phase conductors with a cross-section of up to 16 mm^2, and from a height of 1,5 m for cables with phase conductors with a cross-section of over 16 mm^2.

By performing this test, the aim is to ensure that no insulation defects, phase interruptions or short circuits occur as a result of the application of a standardized crushing force. Also, for the test to be considered appropriate, it is necessary that the preventive disconnection coefficient is sub-unit, this being determined according to relation 4.

$$k = \frac{n_1^{'}}{n_2^{'}}, \tag{4}$$

in witch:

$$n_1^{'} = \frac{\sum_{i=1}^{5} n_{1i}}{5} \tag{5}$$

$n_1^{'}$ - the average number of blows at which an insulation fault occurs, detected by the insulation resistance control relay

$$n_2^{'} = \frac{\sum_{i=1}^{5} n_{2i}}{5} \tag{6}$$

$n_2^{'}$ - average number of blows at which a short circuit between phases or a phase interruption occurs

3.3 Simultaneous torsion and bending test

This test is applicable only to flexible mining electrical cables and its main purpose is to check these cables for the possibility of insulation defects, phase interruptions or short circuits when the cable sample under consideration is subjected to a number of "n" forward-reverse cycles and one twist per translation cycle. Also, the preventive disconnection coefficient must be within the limits established by the product standard, this being calculated with relation 7.

$$k^{''} = \frac{n_1^{''}}{n_2^{''}}, \tag{7}$$

in witch:

$$n_1 = \frac{\sum_{i=1}^{3} n_{1i}}{3} \tag{8}$$

n_1- the average number of cycles at which an insulation fault occurs as detected by the insulation monitoring relay

$$n_2 = \frac{\sum_{i=1}^{3} n_{2i}}{3} \tag{9}$$

n_2- the average number of cycles at which a short circuit between phases or a phase interruption occurs.

This test is performed using the test stand whose assembly diagram is shown in figure 6, which is interconnected with the stand shown in figure 2. [7]

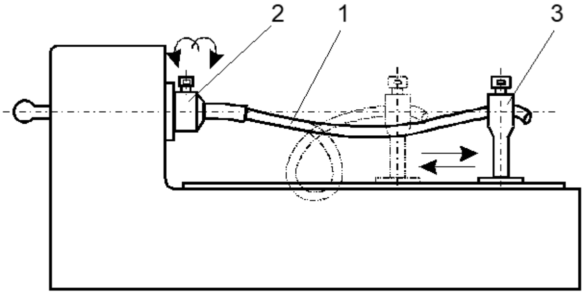

Fig.6. Simultaneous torsion and bending test stand

where:

1 – cable sample
2 – device intended for performing rotational movement
3 – device intended for performing rotational movement

From a functional point of view, the test stand ensures a number of 7÷8 forward - backward cycles through the existing translation device in its composition, simultaneously with 3 rotations to the right and 3 rotations to the left, through the existing twisting device.

4 Conclusions

The electrical power, signal and telecommunications cables that are part of the cable networks present in underground and surface mining operations must be designed to ensure a high level of protection against the danger of electric shock, as well as against the danger of initiation and propagation of a fire and/or explosion.

In order to be used in mining operations endangered by the presence of gray dust, mining electrical cables must comply with the provisions of the legislation in force, the Low Voltage Directive and the specific general applicable requirements provided for in HG 1049 / 2006. In addition, in order to be certified in the voluntary field, mining electrical cables must be subjected to laboratory tests in accordance with the requirements set out in STAS 10411-89, this being the Romanian standard in which the specific technical safety requirements for these cables are regulated.

In order to be able to perform these tests, accredited by RENAR, a high-performance test stand for mining electrical cables was created and entered the equipment of the ENExEMEIP laboratory within the NIRD INSEMEX Petroșani, equipped with measurement, notification, control and recording systems for test cycles, connected via an interface to specialized programs used by the PC.

This high-performance stand can quantify and record the number of blows applied in the dynamic crushing test, as well as the crushing force applied to the cable sample tested in the static crushing test. Also, in the event of short circuits between the cable conductors, insulation defects or phase interruptions, there is an acoustic and optical warning system.

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