Tests of flame-proof properties of supply-control system for a mining floor-loader

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Abstract. Tests of flame-proof properties of supply-control box for a floor-loader operating in underground mine workings, where methane and/or flammable dust explosion hazard occurs are presented. The tests included, among others, a determination of the explosion pressure, the enclosure strength to the pressure and the test of non-transfer of internal explosion. The tests enabled to localized the components, which required some improvements regarding their mechanical strength but also confirmed safety of the final design. The enclosure of the supply-control equipment of a floor-loader is designed within the HYDKOM 75 project co-financed by the National Centre for Research and Development.

1. Introduction
Floor-loaders are mobile machines installed on a caterpillar chassis, equipped with electrohydraulic drive, in which all the control functions are realized hydraulically. They serve, among others, for removal from the floor the waste rock generated at driving the roadway workings by means of blasting technique, for pulling materials and ripping the floor [1, 2, 3]. The hydraulic pump is driven by an electric motor. Due to the fact that the motor is supplied from an unwinding cable connected to the mine power network, the equipment mobility is limited and the supply cable is subjected to damages [2, 4]. A floor-loader with a battery drive, developed within the project entitled: “Innovative mobile machine with an universal electric drive system increasing the technical safety level” HYDKOM 75 within the Operational Programme Intelligent Development 2014–2020 eliminates all the above mentioned limitations. The project objectives include designing, manufacture and testing the battery driven floor loader to be operated in mine workings where a potential explosion hazards of methane and/or coal dust occurs.

The article presents the problems of the tests aimed at confirmation of a safe use of the state-of-the-art, innovative floor-loader, designed at KOMAG, in the workings of methane and/or coal dust explosion hazard.

2. “d” flameproof enclosure
The “d” flameproof enclosure is one of the methods for protecting the equipment to be operated in the areas, where an explosion hazard occurs potentially. This is the enclosure in which the components which may cause ignition of flammable gases are installed and which can withstand the pressure generated during an internal explosion of the explosive mixture and which protects against transfer of the explosion to the potentially explosive atmosphere surrounding the enclosure [5].
So-called flameproof connector or fire path is a characteristic component of such flameproof enclosures. This is a place, where two surfaces of enclosure components are contacted or where two enclosures are connected to eliminate transfer of internal explosion to the potentially explosive atmosphere [5]. Flange, cylindrical, flange-cylindrical as well as threaded connectors are most often used types of flameproof connectors. Examples of the selected connectors are presented in Figure 1, where L is a length of flameproof connector in the case a) and b) and in the case c), L is a sum of c and d assuming that \( f \leq 1 \text{ mm} \).

![Figure 1. Examples of flameproof connectors a) flange, b) cylindrical, c) cylindrical-flange; 1 – internal enclosures, L – length of flameproof connector [5].](image)

Seals made of compressive material are used sometimes to obtain the required IP protection level. In this case the seal is not taken into consideration in determining the length of flameproof connection and it cannot divide it. The examples of determination of flameproof connection in the case of using the seals are presented in Figure 2.

![Figure 2. Examples of determination of flameproof connections in the case of using the seals; 1 – enclosure interior, 2 – seal, L – length of flameproof connection [5].](image)

The flameproof connection has to extinguish a flame between the flameproof enclosure and the surrounding atmosphere. A flammable fuel, oxygen and high temperature are indispensable for ignition and sustaining the flame/explosion propagation. Elimination of one of these three components causes the flame extinguishing or lack of ignition possibility. Flameproof connection due to its proper design (e.g. length and roughness) causes reduction of temperature of a flame generated inside the flame enclosure so it can be distinguished. In the case of non-threaded connections, due to the elasticity of the screws connecting the two surfaces of the flameproof connection, during explosion inside the enclosure, the clearance between the enclosure surfaces increases slightly. Therefore, in the resulting clearance, gases formed during explosion / combustion are released and the pressure inside the enclosure drops.
3. Testing object and place of testing
The two-chamber flameproof enclosure of the supply-control module, designed and manufacture within the HYDKOM 75 project was the testing object (Figure 3). In the designed, battery powered floor-loader, “d” flameproof enclosure consisting of two separated flameproof chambers was used. One of the chambers had supplying cells with the Battery Management System (BMS), and in the second compartment there was a control system consisting of cells charger, power-electronic transducer or control-switching equipment.
All the tests of the flameproof box were conducted on the special test stand in the KOMAG Laboratory of Applied Tests.
During testing the flameproof, the box chambers were filled with the components simulating the final components.

![Figure 3. Tested enclosure for the power supply-control module.](image)

4. Testing the flameproof box

4.1. Test objective
Verification of design assumptions of the developed box for the supply-control module as well as a possibility of its use in the underground mine workings of the hard coal mining plants was the tests objective.

4.2. Scope of tests
Scope of the flameproof box verification tests regarding its flameproof ability included the following tests:
- Checking the flameproof connectors for conformity with the technical documentation and with the requirements of the PN-EN 60079-1:2014-12 Standard (before and after the pressure strength tests),
- Determination of the explosion pressure,
- Tests with overpressure,
- Tests for not transferring the internal explosion.

4.3. Testing procedure and the test results

4.3.1. Determination of a reference pressure. Determination of the reference pressure consists in determination of the maximum pressure that arises in the tested flameproof enclosure / chamber during
the forced explosion of the adequate explosive mixture. Adequate explosive mixture is a gas / gas concentration in the air that is characteristic for a given explosion group. For the first explosion group, which concerns mining plants threatened by the presence of methane and or combustible dust, the test mixture used to determine the reference pressure is a mixture of methane (9.8 ± 0.5)% in the air. When determining the reference pressure, three tests were performed for each chamber.

According to the project assumptions, the flameproof enclosure was equipped with O-ring seals or with glued rubber cord on all flameproof cylindrical and flange connections. Due to the above, the determination of the reference pressure was carried out with a set of seals installed. Assuming that the tested enclosure is intended for operation at temperatures above -20° C, tests were carried out at a pressure of the mixture equal to atmospheric pressure. The arrangement of pressure transducers and sources of ignition is presented in Figure 4, while Table 1 presents the recorded maximum reference pressures. The highest measured pressure for each chamber is the reference pressure.

![Figure 4. Arrangement of the measuring instruments during determination of the reference pressure (top and front view of the tested enclosure).](image)

| Item | Type of the tested chamber | Ignition source | Pressure [bar] |
|------|---------------------------|----------------|---------------|
|      |                           | Cz1 | Cz2 | Cz3 |
| 1    | Power cells chamber       | 1   | 4.65 | 6.03 | - |
| 2    |                           | 2   | 5.93 | 4.49 | - |
| 3    |                           | 3   | 3.98 | 5.55 | - |
| 4    |                           | 1   | -   | 4.40 | 4.54 |
| 5    | Control chamber           | 2   | -   | 4.53 | 4.64 |
| 6    |                           | 3   | -   | 4.28 | 4.40 |

Pressure curve for the cells chamber for the ignition source No. 1 is presented in Figure 5.
4.3.2. Test with overpressure. The test is aimed at checking the resistance of the tested enclosure to pressure. The test may be carried out by one of two equivalent methods, static or dynamic. In the static method, for safety reasons, it is recommended to use an incompressible liquid. The test chamber is filled with a liquid at the appropriate pressure which is kept for at least 10 s. The dynamic method uses an explosive mixture which is ignited to obtain the required pressure 1.5 times the reference pressure during the explosion.

The tested enclosure obtains a positive result if, in a result of the overpressure test, none of the enclosure components is permanently deformed or damaged changing the protection level, and the flameproof connections are not permanently enlarged. After testing the control box under overpressure, a positive result was obtained, confirming the required strength of this chamber. In the case of the cells chamber, both front covers were permanently deformed (bulged). Design assumptions included, among others, strictly defined external dimensions of the entire device (enclosure) and the number of power cells to be installed in the box. Meeting the design requirements forced, among others the thickness and profile of the covers, which were deformed, and thus affected their strength.

The above requirements were translated into the thickness of the designed covers and thus their strength.

As part of the improvements, the material from which covers were made, instead of S355JR, the new covers were made of S690QL steel. The new steel has a yield strength of ReH ≥ 690 MPa compared to 355 MPa for S355JR steel.

Due to the introduced changes, after making and installing new covers in the cells chamber, it was necessary to re-determine the reference pressure for this part of the cover. The results of the repeated tests are shown in the Table 2.

| Item | Type of the tested chamber | Ignition source | Pressure [bar] |
|------|----------------------------|----------------|---------------|
|      |                            | Cz1 | Cz2 | Cz3 |
| 1    | Power cells chamber        | 1   | 4.99 | 7.7 | - |
| 2    |                            | 2   | 5.01 | **8.6** | - |
| 3    |                            | 3   | 6.97 | 4.17 | - |

Table 2. Results of the reference pressure measurements in the case of new covers for the cells chamber.
Higher explosion pressures were recorded in relation to the first tests.

The pressure resistance test for the cells chamber, with new installed covers, was performed by a static method. Due to experience with previous covers, apart from checking the flatness before starting the test, during the tests it was decided to install an additional displacement transducer. The transducer was installed in such a way that it was possible to measure the bulge in the midpoint of a larger front cover. The displacement measurements \( l \) were presented on one time axis with the pressure \( p \) exerted on the internal surfaces (forced inside) of the cells chamber. The time processes recorded in this way are presented in the form of a graph \( l = f(p) \) and presented in Figure 6.

![Characteristics l=f(p) recorded in a central point of the biggest cover of the cells chamber during the overpressure test.](image)

After the test, no permanent deformation of any component of the checked chamber was found (this applies to both new covers and the rest of the structure being checked). No permanent enlargement of flameproof connections was found, which ultimately resulted in a positive result for the cells chamber.

4.3. Test for not transferring the internal ignition.

The test for not transferring the internal ignition consists in placing the tested cover in the test chamber and filling both the tested enclosure and the test chamber with an explosive mixture. Then the mixture is ignited inside the tested enclosure and it is checked whether the explosion from the tested enclosure is not transferred to the test chamber. As in the case of determining the reference pressure, also in this case, the explosive mixture depends, among others from the explosive group to which the tested enclosure is intended.

Preparation of the object for tests includes removal of all gaskets, removal of excess grease protecting flameproof connections and obtaining the flameproof connections clearance equal to at least 90% of the maximum structural clearance. Mixture of hydrogen and methane \([(58\pm1)\% \text{ and } (42\pm1)\% \text{ hydrogen}]\) in amount of \((12.5\pm0.5)\%\) in air was the test mixtures used during the tests.

After 10 tests of the cells chamber and 5 tests of the control chamber, there was no transfer of internal ignition for any of the chambers of the tested enclosure, what means obtaining the positive result of this test.

5. Conclusions

Tests of various types of flameproof enclosure designed at the KOMAG Institute of Mining Technology within the HYDKOM 75 project was discussed. In a result of the research work, it was necessary to introduce constructional corrections related to the mechanical strength of the designed flameproof enclosure. The effectiveness of the introduced changes was confirmed by the repeated verification tests.
The tests carried out in the Laboratory for Applied Tests finally confirmed the safety of the flameproof enclosure designed at the KOMAG Institute of Mining Technology and manufactured at Hydrotech S. A. within the HYDKOM 75 project for a set of power cells and the control part of the new floor-loader.

References
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