Test of manoeuvring haulage unit with battery drive conducted within operational trials in the conditions of the mine working

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Abstract: Suspended manoeuvring haulage units are commonly used for a realization of manoeuvring operations in mine workings. Their application minimizes a necessity of performing manual transportation operations and improves work safety of miners. The PCA-1 battery driven haulage unit, developed at the KOMAG Institute, can be an example of such a haulage unit. Due to lack of experience in using battery-driven equipment of this type in the mine workings, it was indispensable to conduct a series of test, among others, in in-situ conditions. The results of these tests and some observations, made during them, are presented in the article.

1. Introduction
Suspended manoeuvring haulage units are commonly used for conducting manoeuvring operations in mine workings, in material stations or workshops. Their use minimizes a necessity of performing manual transportation operations and improves work conditions of mine personnel. Many solutions of such equipment are available in the market. This equipment, in relation to the drive, can be divided into: electrical, hydraulic, electro-hydraulic, diesel-hydraulic. A novel solution in this group is a battery-driven haulage unit with an electric drive [1, 2].

The PCA-1 suspended battery-driven haulage unit, in which lithium cells LiFePO4 are applied, developed at the KOMAG Institute and produced by the Hellfeier Ltd., is an example of such a haulage unit. This equipment, moving on a suspended monorail track, is treated as an assembly of a suspended monorail and it requires an approval of the Chairman of the State Mining Authority [4].

Due to lack of experience in using battery-driven equipment of this type in mine workings, it was indispensable to conduct a series of test, among others, in-situ tests, in the conditions of the mine working, to confirm an operational safety of the haulage unit.

The tests, mentioned above, were conducted within a trial exploitation in the mine workings of the Rydultowy Coal Mine. The test results as well as some observations concerning these tests, are presented in the article.

2. Object of tests – suspended battery – driven haulage unit
A suspended battery-driven haulage unit (Figure 1) was the object of tests. This haulage unit, developed in four versions marked as PCA-1 and PCA-1/zt, PCA-1/m, PCA-1/zt/m (PCA-1/zt and
PCA-1/ZT/M were subject to tests), is an equipment designed for a transportation of assemblies on a suspended monorail track. The haulage unit can be applied in underground mining plants in the non-methane and methane fields in the workings of “a”, “b” or “c” degree of methane explosion hazard and “A” or “B” class of coal dust explosion hazard and in the mining plants of salt and non-ferrous metal ores.

![Figure 1. Suspended battery-driven haulage unit [2].](image)

The drive car of the haulage unit is equipped with two frictional gearboxes. A pressure of the wheels to the rail track is realized by means of springs. The drive motors are supplied from a battery of cells installed in the MZ-1 supply module. This module has an apparatus enabling charging of cells and controlling of the equipment operation. In the case of the haulage unit operation on the track inclined above 4°, it is indispensable to use a braking car. A braking car is equipped with a mechanical brake of passive action, i.e. in the case when there is no supply from electric divider, the brake blocks are pressed to the rail web. A brake release is performed in a hydraulic way, using a manually operated pump. An activation of the brake and braking the haulage unit are performed by switching on the emergency switch or automatically in the case of an excessive speed increase, while moving (e. g. at self – rolling down). In the case of haulage units, marked as PCA-1 and PCA-1/M, a collaboration of the brake with the transportation assemblies, equipped with manually operated hoists is foreseen, but in the case of the PCA-1/ZT and PCA-1/ZT/M haulage units a collaboration with the transportation assembly with electric hoists is foreseen [2].

Basic technical parameters of the haulage unit are presented in Table 1.
Table 1. Haulage unit technical data [2].

| Parameter                                      | PCA-1 and PCA-1/ZT | PCA-1/M and PCA-1/ZT/M |
|------------------------------------------------|--------------------|------------------------|
| Haulage unit power(track assembly), kW         | 2.2 (2x1.1 kW)     |                        |
| Maximal pull force, [kN]                       | 2.7                | 4.2                    |
| Maximal speed, [m/s]                           | 1                  | 0.5                    |
| Motor type                                      | Electric self-braking motors |
| Motor supply voltage, [V]                      | 3x230              |                        |
| Realization of pressure force of drive wheels  | By a spring, with a manual control of pressure force |
| Battery capacity of MZ-1 module, [Ah]          | 100                |                        |
| Possibility of charging batteries              | Charging of batteries directly from the flameproof transformer assembly |
| Maximal suspended weight on one hook of electric hoist [t] | 2.1 |

The battery driven haulage unit is a solution, in which a zero – emission battery drive, based on lithium LiFePO4 cells, is used. An application of the integrated charger in this solution enables to charge the battery from any spot in the external mine network, using a flameproof connector being a part of the haulage unit equipment.

It does not require an additional external charger. The battery management system (BMS) supervises an operational safety of the battery cells. The haulage unit was designed in such a way that it enables an adaptation of its composition to the user’s needs. In the standard version the haulage unit is equipped with the wire control or optionally with the radio control.

3. Method of conducting tests during the trial operation

Tests in the framework of trials were conducted in the roadway working at the Rydultowy Coal Mine. The tests were conducted on horizontal and inclined segments of the suspended monorail track. The programme of these included four stages [5.6].

- Stage I. Test at standstill.
- Stage II. Operational tests on the horizontal segment.
- Stage III. Operational tests on the inclined segment.
- Stage IV. Tests connected with battery charging.

3.1. Stage I. Tests at haulage unit standstill

Within Stage I of the tests, checking of a possibility of conducting maintenance activities, described in the operational manual, were planned in in-situ conditions. All the activities, made by the operator before starting the work as well as the maintenance operations, were checked. Among others the following activities were checked: an operational correctness of control buttons, switches, circuit – breakers and limit switches.

During the tests the following tasks were to be accomplished:

- a verification of the information in the technical and operational documentation in the scope of check – ups, overhauls and possibilities of acting according to the technical and operational documentation,
- a determination of indispensable time for an everyday overhaul in underground conditions,
- a determination of the method for checking protections,
a check – up of the correctness of ground – fault protections activation before starting the tests,
• a check – up of charging level of supply batteries,
• a check – up of operation correctness of motor’s brake assemblies working as parking and emergency brakes. The tests were conducted for the following cases: a decay of supply voltage, an activation of emergency switches and an activation of limit switches,
• a check – up of operational correctness of the manoeuvring brake (to the minimal speed) using the V button. The test is aimed at a determination of the minimal time indispensable for the machine braking till it is stopped and a determination of the braking distance,
• a check – up of a possibility of the brakes mechanical release,
• a check – up of operational correctness of individual radio control function,
• a check – up of chain hoist assemblies – a chain hoist at static load equal to 1.25 x nominal load,
• a trip along a horizontal segment with load on the hook equal to 1.1 x nominal load.

3.2. Stage II. Operational tests on horizontal segment
The tests, conducted on the horizontal segment included checking of operational parameters and of the functionality on the horizontal segment of the suspended monorail track. Within this stage of tests an operation without any load and an operational with a maximal foreseen load were conducted.
During this stage the following check – ups were performed among others:
• a check – up operation of the control, interlocking and information systems on the LED display against the operational manual,
• a check – up of electric cables to be sure that they will not be subject to any danger hazard during the haulage unit operation,
• a check – up of lighting in the motion direction, the result should be the arithmetic average from 5 tests (the level of visibility/lighting intensity in the distance of 30m),
• a check – up of static breaking force,
• a check – up of pull force (statically), the result should be the arithmetic average from 5 tests.

3.3. Stage III. Operational tests on the incline segment
The tests conducted within Stage III were aimed at checking the functionality of the haulage unit on the inclined segment of the suspended monorail track. During this stage the following tests were conducted among others:
• a trip on the inclination without any load,
• a trip on the inclination with maximal load,
• a check – up of parking brakes during a standstill on inclination,
• a check – up of braking efficiency using the emergency brake (braking car) on inclination,
• a trip with load on the inclined segment.

3.4 Stage IV. Tests connected with battery charging
Within this stage it was planned to perform battery charging using the transformer assembly of the output voltage 3x230V, equipped with the ZW-40 socket. During these tests the following measurements were taken:
• a temperature measurement of cell battery housing during the charging process,
• a temperature measurement of the flameproof housing on the spot of the converter installation.

4. Test results within the trials at standstill
During the trials conducted in Stage I the activities performed by the operator, before switching the supply were recorded. The operator checked a technical condition of: wires, limit switches, lighting, brake blocks and of oil level in the brake car tank. These activities were performed during one passage
around the haulage unit and did not last more than 1 minute. After switching on the supply, the operator additionally checked battery charge level (on the display), lighting condition, an operation of limit switches and of emergency switch. He conducted a test of ground – fault protections, he checked an operation and tightness of the braking car hydraulic installation as well as an operation of control buttons on the control panel of the haulage unit and of the chain hoists. During the observations no possibility of non – performing the activities, specified in the technical and operational documentation, to be done by the operator, was noticed. All the process of everyday overhaul does not require more time than 10 minutes and it is possible to conduct it in underground conditions. During the tests some check – ups of the leakage protection, using the “test” button, installed in the MZ-1 supply module, were conducted. After pressing it, the CZU, BZ1, BZ2 and BZ3 diodes illuminate. The next start – up of the haulage unit required a reset of the control system, using the reset button. A test of the protections efficiency was finished with a positive result. In the further part of the trials the test of lighting was conducted. After having selected the drive direction in the haulage unit, the white lighting was illuminated automatically in the selected direction and the red one – in the opposite direction. The lighting intensity was measured at two distances of 15 and 30 m from the haulage unit. The intensity of the white light was checked and determined as the average result of 5 measurements. The intensity in the distance of 15 m was 7.9 lux, and in the distance of 30m – 1.0 lux. During the tests, when the haulage unit was illuminated at the distance of 30 m, it was possible to see only the outline of a moving silhouette [7,9]

The following tests concerned operational parameters such as: pull force and static force, braking force. First, these tests were conducted for the haulage unit marked as PCA-1/ZT and after its modernization also for the haulage unit marked as PCA-1/ZT/M (modernization and a development of the PCA-1/ZT/M haulage unit resulted from the observations and test result obtained during the operational trials).

4.1. Measurement of static braking force and of pull force of PCA-1/ZT haulage unit
The tests were conducted with use of a dynamometer installed in a catch of the braking car. The force value was measured in the peak. The measurements were taken in two versions:

- dynamically – without an elimination of clearances in the measurement system,
- statically – eliminating clearances in the measurement system.

The pull force in the dynamic version was 3.380 kN. It was the value obtained for the haulage unit marked as PCA-1/ZT. This haulage unit is characterized by the mechanical ratio i=40. The measurement was also taken at the initial tension of the measurement system, aiming at eliminating an impact of dynamic forces. A measured value of the force, in the static version, was 2.7 kN. Static measurements of the pull force were conducted until the protections were activated and the haulage unit was switched off automatically. The measurements of the static braking force were conducted separately for the braking car assembly and for the drive car. A dislocation of these assemblies, during the measurements, was realized by means of a manual chain hoist. During the measurement a tension of the springs was increased to determine the tension enabling to obtain the braking force exceeding 1.5 x pull force. The obtained braking force for the braking car and for the haulage unit exceeded 4.05 kN [8].

4.2. Measurement of static braking force and of pull force of PCA-1/ZT/M haulage unit
During a realization of the pull force measurement in the ‘dynamic’ version, the haulage unit advanced about 40 mm till the measurement system was tensioned. In this case the pull force varied within the scope from 4.5 to 4.8 kN till the drive system was automatically switched off by the protective system.

During the static measurement, the system was initially tensioned to eliminate an impact of dynamic forces on the measurement results. The value of the recorded pull force was 4.42 kN. The measurement of the pull force in static conditions reflects a situation of a start – up on an inclination uphill after stoppage. A measurement of the static braking force was realized as for the PCA-1/ZT haulage unit, however, in this case maximal, possible to be obtained braking force, was searched.
additionally. The obtained braking forces were: for the drive car – 9.05 kN, for the braking car – 6.9 kN. The obtained values enable to state that for the finally accepted pull force, in the case of PCA-1/ZT/M haulage unit, which equals 4.2 kN (Table 1), it is possible to obtain the static braking force which equals 6.3 kN. The method of conducting measurements is shown in Figure 2.

![Figure 2. Measurements of pull force and of static braking force.](image)

5. Test results within operational trials on horizontal segment

The tests, realized within this stage, were connected with the haulage unit trip on the horizontal segments of the suspended monorail track. It was observed that a drive with the maximal haulage unit speed of 1 m/s (foreseen for the PCA-1/ZT/M haulage unit), may cause problems to the operator, who moves along the roadway working, to observe the advancing haulage unit and the transported weight and simultaneously the track on which it moves. An adaptable possibility of speed control enables the operator to adjust the trip speed to the conditions on the transport track. During the trip, efficiency tests of the emergency braking system were conducted in the conditions of: the dead-man’s handle release, an activation of the emergency switches. An operational correctness of the control function, using the wire and radio control, was tested as well. The result was positive. There were tests aimed at a determination of the braking path length in the case of manoeuvring braking. The manoeuvring braking is realized by pressing and maintaining the pressure of the V button on the operator’s panel. In such a case a speed reduction of the drive motors, by the converter controlling their operation, is caused. Such braking does not stop the haulage unit but only reduces its speed to the minimal value. A complete stop happens after releasing the dead-man’s button on the control panel. On the base of these measurements, the braking path was determined, starting from the maximal speed developed by the haulage unit, which varies from 5.5 m to 6 m. An exact determination of the path length was not possible due to the fact that the operator assessed the point of reaching the minimal speed by the haulage unit subjectively. During the observations of the haulage unit operations, conducted by the mine personnel, frequent stops of the haulage unit, due to a release of the dead-man’s button, which caused their instant stop using the brakes installed on the drive motors, were noticed. Braking, due to a reduction of the rotational speed of the motors during a normal haulage unit operation, requires the operator’s appropriate earlier reaction. During operational tests temperature measurements on the surface of the battery housing in the MZ-1 supply module, on the motor frame and on the gear-box frame were conducted. The measurements were taken during a half – hour haulage unit trip along a trial segment. The test result were as follows: battery housing – 32.9°C, gear – box frame – 27.4°C, motor frame – 34.2°C. The hottest surface was the motor frame. In the framework of these trials chain hoist assemblies were subject to testing as well (Figure 3). The tests consisted in hanging the weight of 1.25 x nominal load on the hook and observing if a self – lowering of the weight happens during the tests of raising and lowering the weight equal to 1.1 x permissible load. In both cases no abnormalities were seen [7,8].
6. Test results of operational trials conducted along inclined track segment
Trials on the inclination were conducted for the PCA-1/ZT/M haulage unit on two inclined rail track segments of 2 m length, in which the inclination angle of individual rails was not constant and varied from 8° to 12°. The trip tests without any load were conducted first. During a trip downhill possibilities of trip speed change and of a stop, including an emergency stop, were checked. No events, indicating an incorrect operation, were observed. During the tests with load on the hooks of the electric hoists a flameproof contactor circuit – breaker of the weight about 290 kg was hung. The conducted tests aimed at checking the haulage unit operation at a start – up uphill after having stopped. During a standstill on inclination, the haulage unit was maintained by the parking brake installed on the motor, which, through the drive system, generated the braking torque on the drive wheel. While setting the haulage unit in motion the voltage was applied to the motor winding and simultaneously the brake was released. In the case of the excessive loading of the haulage unit, the motor was not capable of generating the torque on the transfer shaft fast enough which might cause that the shaft would rotate in the opposite direction than the applied one. During the tests of the start uphill, in the first stage the haulage unit moved in the opposite direction at the distance of max 10 mm, then it advanced uphill.

7. Test results of operational trials connected with battery charging
The MZ-1 supply module of the haulage unit was equipped with the charger integrated with the converter and the flameproof connector, which enabled to charge the battery in any place, from the flameproof transformer assembly, equipped with the connecting socket compatible with the plug. Due to the fact that the heat was released while charging the battery, the conducted tests consisted in temperature measurements of the MZ-1 external surfaces during the charging process. The temperature of the MZ-1 module external surface was 33.5°C before starting to charge on the spot of the battery installation, and on the spot of the converter it was 33.4°C. During the tests the battery of the MZ-1 module was charged with the voltage of 225V and the current of 2.5A from the OZTK 0632 assembly. After 45 minutes of charging, the temperature of the measured surface stabilized on the level of 39.5°C for the battery housing and 43.2°C for the module surface on the spot of the converter installation. The conducted measurements enabled to identify the MZ-1 module surface which was heated most [7].
8. Summary

The tests of the suspended battery driven haulage unit were conducted within a trial exploitation required by a decision of the Chairman of the State Mining Authority and it was indispensable for obtaining an approval for an application in mine workings. According to the above mentioned decision the mover, Hellfeier Ltd. together with the KOMAG Institute elaborated a programme of trials, which was approved by the OBAC Certifying Body. The tests, within the trials, were conducted in the Rydultowy Coal Mine workings.

The conducted tests delivered a lot of information concerning a functionality and operational possibilities of the haulage unit. They enabled to verify the operational parameters of the haulage unit as regards its use. Due to that a determination and a verification of, among others, pull force, transportation capabilities, degree of heating external surface of the haulage unit and lighting efficiency in mine conditions were possible. The tests confirmed a possibility of a safe application of battery supply based on the LiFePO4 cells, which were installed in the MZ-1 module. The information, obtained from the mine personnel operating the haulage unit, turned out to be valuable. Among others, basing on this information a design modernization of the haulage unit, consisting in increasing the mechanical ratio in the drive system, was introduced. In the haulage unit, marked as PCA-1/ZT/M, the pull force was increased to 4.2 kN at a simultaneous reduction of the maximal speed to 0.5 m/s and at maintaining the same power as in the PCA-1/ZT haulage unit. The conducted tests also delivered a series of other pieces of information which will enable a further development of the equipment.

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