

Suspended battery drivetrain as an example of advanced control and safety system of li-ion battery pack technology in mining industry

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Short Abstract

Description of special design of large 160kWh battery pack with its unique advanced battery management and thermal management system destined for suspended drivetrain for coal mine operation is presented in this paper. Battery has to be designed to meet strict rules and standards of mining industry and fit into anti-explosion tight enclosure without possibilities of liquid cooling circuits. A special active cooling based on Peltier heat pumps has been designed and implemented. Together with battery a special underground charging station has been design with additional safety circuits allowing additional redundancy of supervision during charging process.

1 Introduction

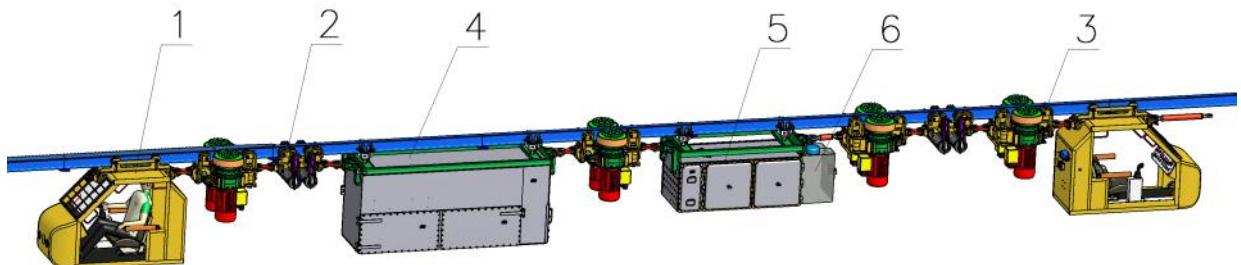
The underground mining industry is one of the largest and most significant branches of heavy industry in Poland. The underground transportation would not be possible without properly operating transportation systems. Transportation of people as well as materials and run-of-mine is mainly realized with use of machines, which move on the rails. We can distinguish floor-mounted locomotives as well as suspended diesel or electric drivetrains. Worsening ventilation conditions in underground mine workings as well as deeper and deeper mining cause the necessity to reduce the number of machines using diesel drives and to make more use of electric drives. Transportation machines driven by electric motors use alternating current grid (traction machines) or direct current (battery machines). Traction machines have a significant disadvantage, i.e. short range resulting from the length of supplying cable. That is why the use of machines, which are supplied from own source of energy, is the only reasonable solution. All battery driven machines, which have been used so far, have conventional acid batteries. These were mostly rail File requirements However, in the case of suspended machines the weight of acid batteries was a serious disadvantage causing limitation in transportation possibilities

2 System Description

Work realized at the KOMAG Institute of Mining Technology showed that ensuring at least 8-hour operation without change of pack of batteries, maintaining the lowest possible weight of a drivetrain, is the condition of successful implementation of drivetrain with battery supply [1]. Due to limited density of energy of traditional acid battery cells, the use of new generation cells and energy recovery during transportation in the working inclined downwards, when electrical motors operate as generators, playing the role of brakes, is the only way to reach the assumed objective. On the basis of the above assumptions it was decided to design and to make the prototype of suspended battery drivetrain for operation in the underground mining industry. The consortium consisting of Impact Clean Power Technology, KOMAG, NAFRA and KOMEL was established for that purpose. The battery prototype, presented during the International Fair of Mining, Power Industry and Metallurgy in Katowice, is given in Figure 1, while its 3D model is shown in Figure 2.



1 Fig.1. GAD-1 battery drivetrain during the fair in Katowice [1]



2 Fig.2. View of 3D design of suspended battery drivetrain [2]

The developed machine was named GAD-1 (Gentle Accumulator Drive). The drivetrain consists of two operator's cabins (1), two double braking systems (2), four drive trolleys (3), set of 160kWh of li-ion batteries with special supervision system (4), supply module, i.e. system of inverters and control system (5), the hydraulic unit to power trolleys braking and handling beam transport (6). Each of the four driving trolleys (fig.3) is equipped with two (identical) drive units consisting of motor (1), gear (2), the friction wheel (3) and toothed wheel (4). Depending on the railway track, which may be conventional, made only

on the basis of parallel-flange beam 155, and additionally equipped with a toothed rack, integrated with the upper beam flange, the truck can operate in rack-and-pinion drive system or frictional drive system. During friction operation, the friction wheels are pressed against the track path (part of beam flange) with the actuator (5), whereas the gear rack wheels are not pressed at all. The change of the friction drive system to the rack system is used mainly in the area, where roadway inclination changes from smaller slope to larger one. For example, for slope less than 15 ° friction system is used and for the slope above 15 ° rack and pinion system is used.

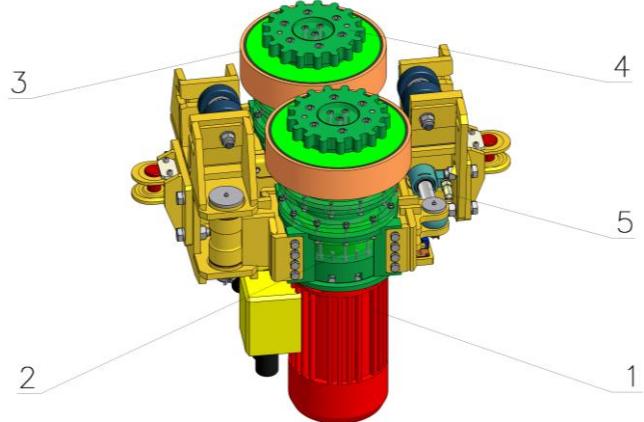


Fig.3. Design of the drive trolley [2].

Existing solutions of horizontal battery powered transportation equipment concern mainly floor-mounted railway drives, where heavy cells are in a sense the advantage, because of a need to ensure frictional contact between wheels and rails. In the case of a suspended drives heavy mass of cells is a disadvantage and it is not acceptable. Suspended GAD-1 drivetrain, was required for a more efficient cells with a higher energy density [2]. To solve the problem, modern lithium cells were applied, which have not been used in the mining industry before, but are successfully used in the automotive industry worldwide. Examples include electric vehicle drives manufactured by BOBRME Komel like Re-Volt car, electric glider, electric quad, and a newly designed BLDC motor drive with changeable number of coils. Lithium - ion batteries have been successfully used in the GAD-1 drivetrain and they give a great prospective for development of this technology in the future. The use of cells with lithium can significantly improve electrical parameters of the cell (Tab.1), while reducing the weight. Four battery units, consisting of a group of 68 cells which are connected together in series, forming a battery with a voltage of 250V DC are the power source for suspended GAD-1 drivetrain. Blocks of batteries of total energy 150 kWh are placed in one of the chambers, inside a special flame-proof box. Each of the four blocks of batteries is an independent power supply for a single drive trolley (consisting of two electric motors). In addition, one of the battery packs is used to supply the induction motor of hydraulic pump [3] and the control-measurement circuits of GAD-1.

Tab1. Parameters of power lithium cell battery

Capacity	150 Ah
Type	Kokam NCM
Rated voltage	3.7 V
Discharge voltage	3 V
Max. charging voltage	4.15 V
Max. charging current	150 A
Max. discharging current	300 A
Weight	3.2 kg

Energy from each of the battery packs, is supplied through a flameproof connector and conductors to the transmission apparatus (power module), which powers each of the eight drive motors via eight inverters with 3-phase voltage of adjustable frequency and amplitude. Brushless synchronous motors with permanent magnets are used in the drive trolleys [2]. The challenge for engineers was to develop an electric PM motor (Permanent Magnets), which would enable to meet the parameters required for the GAD-1 drive while keeping the smallest dimensions and meeting the mining standards for machines intended to be used in potentially explosive atmosphere of the mine. Electric, 10.8 kW permanent magnet synchronous motors with flameproof frame were manufactured and designed in BOBRME KOMEL Institute. The electrical parameters presented in Tab.2.

Tab.2. Parameters of SMwsPA132M6 motor

Rated power	10,8 kW
Rated voltage	152 V
Rated current	45 A
Rated torque	114,6 Nm
Rotational speed	900 rpm
Efficiency	91 %

This type of engine, because of its advantages and opportunities to work as a generator that transmits energy to the battery offers new opportunities in the mining industry. Permanent magnet motors have high efficiency, compared to the induction motor and also the vector control of torque in eight drive motors is accurate [2]. The electronic equipment is also equipped with the ninth inverter, which is used to supply the induction motor of hydraulic pump with a voltage of 188 V and a frequency of 50 Hz. The central unit,

located in the electric apparatus box with security systems, is supplied through DC / D converter with auxiliary voltage of 24V DC while, all intrinsically safe devices such as LED lamps, control panels or electrohydraulic distributor are supplied with 12V DC. The whole control process is realized from the control panel located in one of the cabins (depending on drive direction), after its authorization by the machine operator. Master control system for GAD-1 drivetrain (Fig. 4) was designed on the basis of dispersed structure, which combines all the components of control system through the CAN bus. Due to sending the data in a form of low-voltage differential signal, digital CAN bus (connected in series) is of high resistance to disturbances coming from peripheral devices, and thus of high reliability. The CAN bus protocol was not commonly used in the mining industry so far. It has been used in cars, from which the concept of control was taken.

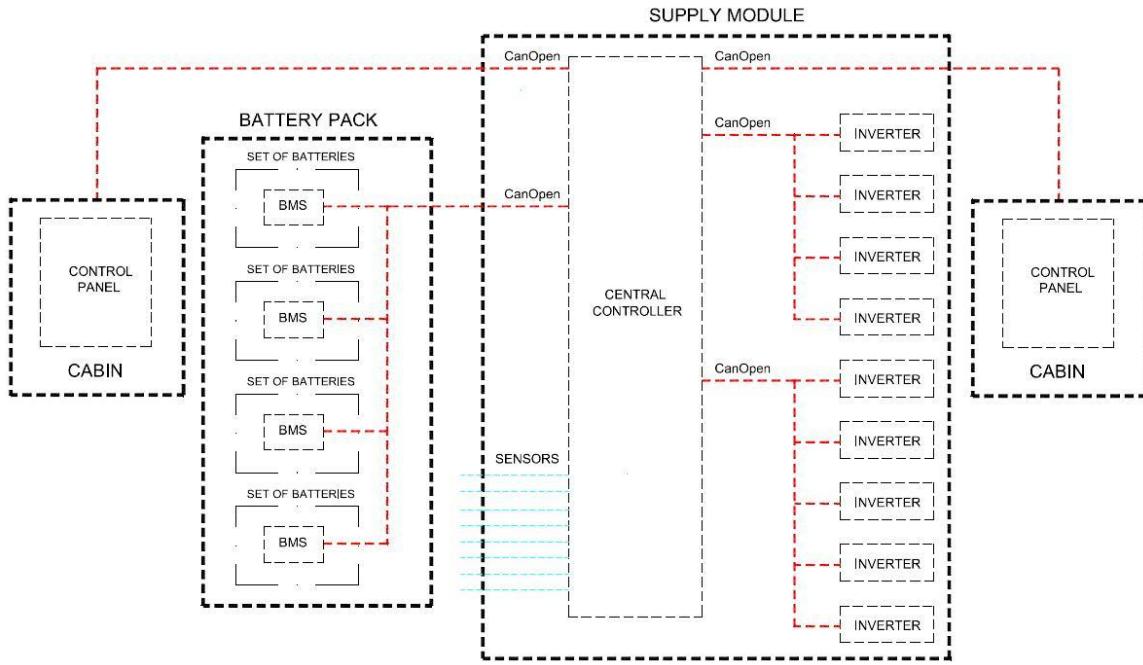


Fig. 4. Block diagram of master system for control of GAD-1 drivetrain [1]

Versatility of used CanOpen protocol allows communication of sub-systems, made by different manufacturers, and switching between applications for diagnosis and configuration of CAN bus. Due to the use of vector control for multi-motor system, intelligent control enables precise management of power distribution, depending on present mode of machine operation. A possibility of energy recovery to the pack of batteries during braking process is a big advantage of the GAD-1 drivetrain [2]. During braking each motor operates as a generator. Generated current is transferred through the inverter to the power pack. Thus it is necessary to maintain some reserve of power pack's capacity to store additional energy. Energy balance associated with a direction of transportation of loads on inclinations is associated with that problem. A situation, in which energy balance during transportation is positive, is rather unrealistic but possible. Such case can take place when heavy loads are transported on big inclination downwards and drivetrain without a load returns upwards.

The drivetrain was designed and made as an explosion-proof version. The casings of modules were designed as flame-proof to make it possible. However, advanced system for supervision of pack of batteries, i.e. Battery Management System (BMS), had to be developed and built to ensure maximal safety.

3 Battery System

It is the first attempt to use the lithium cells of high capacity in the underground mining industry. In order to introduce such a large pack of li-ion battery into operation in coal mine, a special battery management systems had to be designed. There are a lot of strict rules dedicated specially to mines industry which should be applied to li-ion battery in order to get mining approval. A special Battery Management System and thermal management was designed to fulfill the requirements.

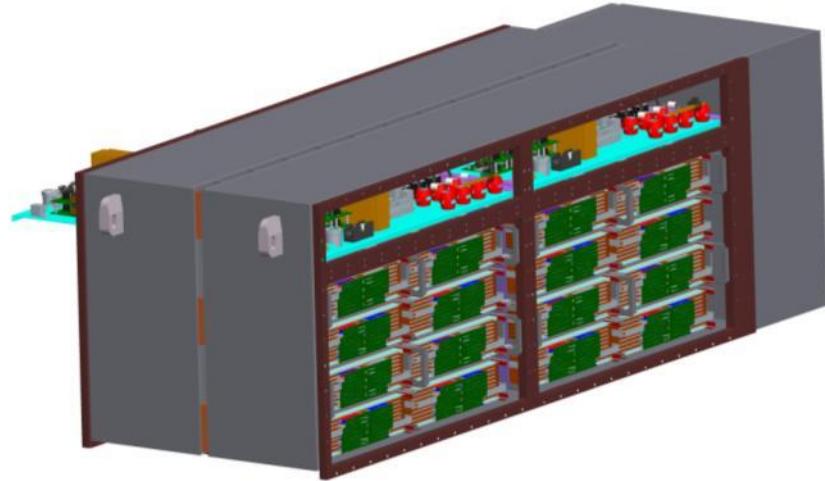


Fig 3. Overview of battery pack in anti-explosion enclosure

Battery pack consists of 4 independent strings having 72 cells in series of 150Ah. Cells are grouped in 9-cell modules which are independent managed electrically and thermally.

Each battery module is equipped with active small heat pump consisting of thermoelectric Peltier modules managed by advanced control circuits. Heat exchangers are part of mechanical frame of whole enclosure so battery has no liquid circuit. System stabilizes the temperature of cells within given values allowing to operate the battery with limited possibilities of cooling in coal mine environment and provides safety features in case of overheating.

Very advanced BMS has been designed to fulfil very strict rules for additional redundancy circuits and intrinsically safe operation. BMS consists of several units realizing different algorithms of cell's management.

Security protection system consists of five independent paths which contribute directly to energy storage protection. These systems work with top priority and no behaviour derived from an algorithm is allowed to override them

Monitoring boards are mounted directly on modules of cells in order to avoid cables connection. Control and management units are located in separate IP68 enclosures providing safe operation of contactors and communication with master system and external charging station.

Additionally dedicated charging station has been designed to operate underground which add additional level of protection for overcharging cell by constant communication with BMS during charging process.

Whole system has unique design providing very high safety level allowing operation underground in coal mine and meeting very strict mining standards.

4 Conclusions

GAD-1 is an innovative mining electric drivetrain of suspended monorail track, with an up-to-date propulsion system supplied by new generation of li-ion batteries with advanced BMS system.

The propulsion system together with an intelligent traction control system and large capacity li-ion battery pack enables energy recovery operation during braking. This solution is congruent with current environmental trends and, additionally, it makes it possible for the train to perform long-lasting work without charging battery from an external source.

Due to emission-free functioning, low level of heat release, and relatively noiseless work, this solution shall be competitive with any classic combustion propulsion products. The exclusion of exhaust fumes emission enhances mine crews' working comfort.

Lithium-ion battery employment, advanced 5-levels protection equipped BMS, permanent magnet mining type motors, dual (frictional and rack) driving system and the involvement of numerous partners altogether account for the project emergence and ultimately for the construction of prototype mining train.

The monorail train has a possibility of frictional and rack-and-pinion drive, which was rare so far, even in conventional diesel driven solutions. It is a result of many signalized problems, which should be solved to make use of dual driving system possible. It is possible due to technically advanced control system of GAD-1 drivetrain.

Innovative character of GAD-1 drivetrain and large interest during international mining fair suggests that this Polish mining drive will soon support the transportation operations in mines, both in Poland as well as in other parts of the world.

5 References

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