SELECTED, STATE-OF-THE ART MECHATRONIC SYSTEMS IN POLISH UNDERGROUND MINING INDUSTRY

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ABSTRACT

Projects as regards state-of-the-art mechatronic systems aiming at increase of safety in the mining industry and at improvement of coal production technologies, which have been completed at the KOMAG Institute of Mining Technology, are presented. These projects cover automation, monitoring and visualization systems, systems for implementation of artificial intelligence techniques, and database recording systems.

iRIS system for electronic marking, identification, and recording of components of powered roof supports, which was implemented in 31 Polish mining enterprises, is presented as an example of the work directly associated with an increase of operational safety. Specialists from KOMAG, ELSTA, Ltd., and Silesian University of Technology in Poland, have developed flexible, configurable, and scalable system for data management, which refers to all fixed assets of mining enterprises, meeting the requirements of users as regards marking and identification of fixed assets.

The system for control of roadheaders using intelligent algorithms, based on artificial intelligence techniques is also the example of innovative actions. This system aims at increasing the safety and effectiveness of teamwork due to a possibility of remote, semiautonomous operation. Introduction of artificial intelligence technology enables adaptation of roadheader mining system to the present mining-and-geological conditions.

Moreover, work aiming at implementation of state-of-the-art system for control of mine jig's beneficiation node, integrating machines and equipment in one system, is carried out as regards automation, information integration, and visualization in coal beneficiation process.

Work on recovery and conversion of thermal energy, which is a by-product during operation of machines and equipment, especially mine diesel drives, is presented. Systems for energy recuperation are more and more important due to the necessity of continuous increase of power production efficiency.

KEYWORDS

Mechatronics, Control, Automation, Monitoring

INTRODUCTION

State-of-the-art mechatronic systems, intended for the mining industry should, first of all, solve the problems in securing the safe and efficient winning of minerals. However, when designing the system, it is very important to identify main technical and organizational hazards affecting proper and efficient winning of minerals.

Lack of knowledge about the method of machinery use and operation is one of important dangers to work safety. Technical condition of powered roof support components and its assessment are the key issues in ensuring safe work and operation. Monitoring the technical condition enables elimination of damaged components and lessens the risk to the components that are especially liable to damage. Such components should be marked permanently. Traditional marking of roof support components is not resistant to harsh environmental conditions, as well as it does not provide their clear identification.

From the other side, development of state-of-the-art computer technology of hardware and software encourages dynamic extension of using advanced control techniques. Due to complexity of the described processes, artificial intelligence techniques should be used, including artificial neural network as well as fuzzy logics. When it is implemented in the control systems, it will improve effectiveness of roadways development and it will increase operational safety. Preliminary model tests have been carried out at the KOMAG Institute of Mining Technology. In the result the algorithms, based on the presented technology, have been developed. Possibility of implementing the developed algorithms in the existing control devices, designed for operation in underground mining plants, is an important advantage.

Coal processing is another problem investigated at KOMAG. In many cases, pulsating water jig is the main machine used in that process. The system for selection of optimal parameters of compressed air generating pulsating movement of water, as well as for automatic control of heavy product particles, discharged according to their quantity, has been developed.

Increasing hazard to people and environment, resulting from using the diesel driven machines in underground mining industry encouraged development of intelligent system for energy control with recovery of thermal energy. The system enables optimal adaptation of operational parameters adequately to the energy demand, reducing volume of emitted exhaust gases containing toxic substances, at the same time reducing loss of thermal energy in exhaust gases. We can also benefit from reduction of diesel oil consumption.

Mechatronic systems, which enable reducing the mentioned above hazards and increasing the efficiency of coal mining, are presented.

SYSTEM FOR ELECTRONIC IDENTIFICATION AND RECORD OF MINING PLANTS CAPITAL ASSETS

The system enables recording of all information, indispensable to assess technical condition of the components from their manufacture till the moment of scrapping. In the result of current R&D projects the Electronic Record of Powered Roof Support Components has become a part of integrated hardware-software solution called iRIS (Figure 1), which consists of five modules used for marking, identification, and supervision of the following capital assets:

- PECM – machines, equipment, and components used in underground workings,
- PEUBP – machines and equipment of intrinsically safe design,
- PEST – transportation means,
- PEMP – machines, equipment, and subassemblies used on the surface, and
- PESTB – office equipment.

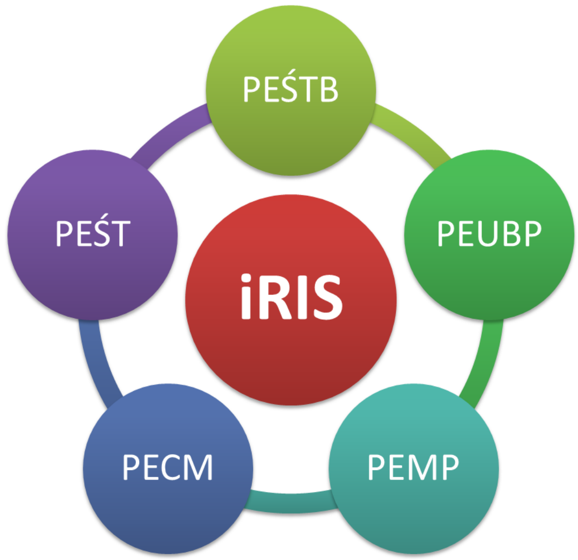

Figure 1 - Structure of iRIS system (own source)

iRIS system is also the basic software tool implemented in Polish mines, which allows assessing the technical condition of powered roof supports. Reliable information about the previous operations and operational conditions of powered roof support enables technical assessment of its components as regards their withdrawal from operation, due to high probability of damage caused by fatigue stress and corrosion (Jaszczuk, Jenczmyk, Pieczora, & Rogala, 2009; Rogala-Rojek, Piecha, Szczurkowski, Kozubek, & Siedlaczek, 2010; Stankiewicz, Warzecha, Rogala-Rojek, Piecha, Loboda, & Midura, 2009). Safe operation of powered roof support is associated with technical maintenance of the equipment according to timetable and with periodical inspection of technical condition, which requires collection and processing of great amount of information.

The systems for identification of powered roof support components used so far in hard coal mines in a form of data plates, welding of codes, or paint marking have not ensured durability of marking in harsh environmental conditions in underground mine workings. This makes reliable assessment of technical conditions and inspection of machines difficult and even impossible. In the developed system the main components of powered roof support are identified in an unequivocal way by use of RFID transponders. Entering the logic relationships between identification number of transponder and attributes of roof support components enables automation of logistic processes associated with e.g. repair or replacement of key components, which is important in the management of the capital assets. The developed system for identification of powered roof support components can operate in a single mine or in a group of mines.

The main advantages of the system are as follows:

- unequivocal identification of each powered roof support component,
- providing the reliable information on previous operations of the support and its each component,
- rational management of powered roof support components,
- use of state-of-the-art databases for collecting and processing the information as regards operation of powered roof support components as well as quick access to the required data,
- fastness of marking (at least 10 years), and
- reliability of identification codes reading in harsh environmental conditions.

ADAPTIVE CONTROL SYSTEM OF ROADHEADER

Development of roadways with use of roadheaders is one of the main types of work carried out in mine underground to open new seams. Drivage of workings at great depths in high temperature, as well as increasing level of hazard are crucial factors for starting the investigation on comprehensive automation of roadway development without people working in the face. This process has not been automated so far due to many factors of unspecified impact, as well as due to complexity of the cutting process with use of the roadheader's cutter head.

In the process of control of machines such as roadheaders there are many elements that make creation of classical mathematical model difficult. That is a direct reason of using the artificial intelligence techniques in modeling of phenomena that occur during roadways development (Jasiulek, Rogala-Rojek, & Stankiewicz, 2011; Swider, Jasiulek, & Stankiewicz, 2010; Jonak, Prostanski, Jasiulek, Rogala-Rojek, & Puchala, 2010; Clarke-Hackston, Belz, & Henneker, 2007). Experimental model of intelligent system for roadheader control, verified in operational conditions, was developed within the project entitled: "Intelligent system for roadheader control", realized by KOMAG and financed by the Ministry of Science and Higher Education. The control system increases the work safety as well as efficiency of roadway drivage with use of roadheaders in a result of increased automation and by determination of operational parameters that better match the cutting conditions (Kahraman, Altun, Tezekici, & Fener, 2006).

Functions of Intelligent Control System

It is assumed that the target roadheader control system has a modular structure as regards the hardware. The functionality of the system is closely linked with the installed hardware (proportional control, automatic positioning of roadheader in the face, cutter jib position sensors). Functions of the control system, which include maximally equipped version of the control system, were developed and they realize the following functions:

- calculation of coordinates of cutter head's geometric centre in the accepted coordinate system,
- limitation of cutter head movement outside the programmed outline of the roadway,
- correction of cutter jib's angular speed set by the operator, and
- generation of cutter head trajectory.

Depending on the roadheader version (roadheader positioning system in a roadway face) the coordinates of the geometric center of cutter head are calculated in a local coordinate system - in relation to a given point of the roadheader or in the general coordinate system - in relation to the roadway. The calculated value of the coordinates is the basis for introduction of other automation functions associated with generation of cutter head's trajectories. Equipping the roadheader with cutter jib's position sensors, installed inside the jib's lifting rams and in turning base, is required.

The current cutter head centre's coordinates in a roadway space are the input parameters for the function limiting cutter head movement outside the programmed outline of the roadway. The function includes selected type of the roadway, and it will switch on/off blockade of jib's movement in each direction (input parameters). In the target control system, it works in the following two variants:

- it limits cutter head movement outside the programmed outline of the roadway,
- it generates acoustic and light signals informing about exceeding the programmed outline of the roadway by the cutter head.

During calculations, the function uses information about the selected type of roadway support with required technological changes. Basing on artificial neural network, the function selecting cutter jib's angular velocity determines cutting resistance, which is the basis for calculation of angular velocity. During preliminary model tests the module, which identifies cutting resistance basing on the artificial neural network, was designed. The network was prepared using the MATLAB software and taught using available data collected during roadheader tests in in-situ conditions.

AUTOMATIC SYSTEM FOR VISUALIZATION AND CONTROL OF JIG OPERATION

Coal beneficiation is the process, which is important as regards each mining plant economy. In the Polish mining industry, coal beneficiation is often realized in pulsating jigs. Separation in water pulsating jigs is based on difference in particles settling rate, depending on their specific gravity. The beneficiated material is cyclically loosened in a pulsating water stream, what causes its stratification and transportation on the screen deck surface towards the area of products' separation. The following two main operations can be distinguished during minerals processing in jigs: stratification of the material and separation of stratified material together with received products (Jendrysik, Jasiulek, Kowol, Lagodka, Rogala-Rojek, & Woszczynski, 2011; Gawlinski, Jendrysik, Kowol, Rogala-Rojek, Stankiewicz, & Woszczynski, 2011; King, 2001; Jonkers, Lyman, & Loveday, 1998; Callen, Patel, Zhou, & Galvin, 2006).

Fed material can be separated e.g. by use of compressed air or by water movement in an operational chamber. During water movement upwards the material, lying on the screen, is thrust upwards and then the particles settle to the screen bottom. After many cycles of water pulsation the material becomes separated into layers where the particles of highest rate of settling are on the screen bottom, and the particles of lowest rate of settling are on the surface of the processed material. Separated material moves constantly towards separation zone at the end of jig's operational chamber.

Structure of the Jig Control System

KOMAG Jig Control System is always adapted to the client's requirements and to the local conditions. Depending on a situation, the feed and receiving system as well as the system for air control can also be added to the jig's control system. The structure of the system is presented in Figure 2.

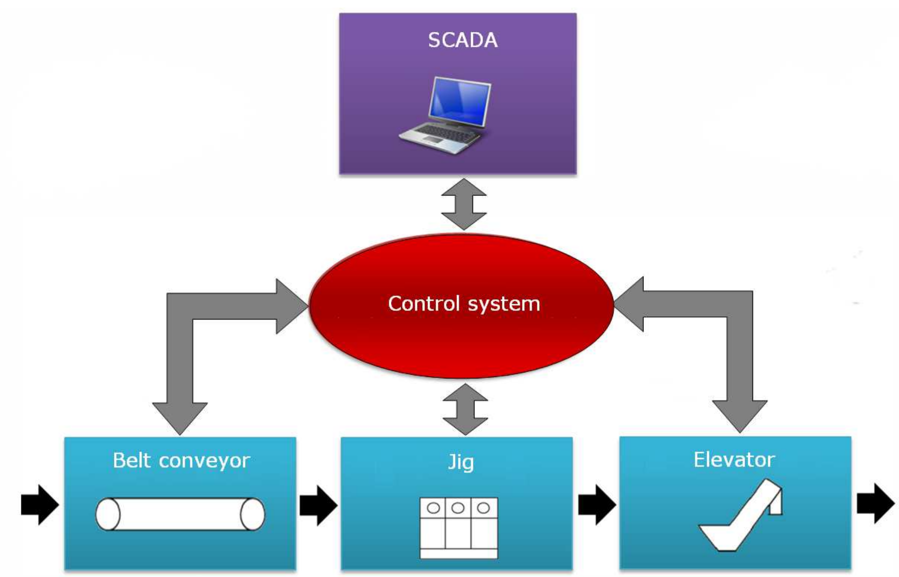

Figure 2 - Structure of jig control system (Jendrysik et al., 2011; Gawlinski et al., 2011)

The components are as follows:

- central unit of the control system, which bases on PLC controller, cooperates with jig's actuating components, collects data from the sensors and communicates with the operator's interface devices realizing the adjustment and control loops,
- operator's panel on the jig visualizes the main parameters of beneficiation process and enters current settings of the parameters, and
- operator's station in the dispatcher room of the processing plant, which enables a full visualization of the process and equipment technical condition .

Control System

Jig control system realizes the following functions:

- maintenance of actuating devices,
- pulsation control,
- passage control, and
- switching the installation on operator's demand or automatically.

SCADA

Operator's station, which includes the following: computer, color monitor, keyboard, and printer, is located in the dispatcher room. It ensures manual remote control of each device and enables making changes to the settings of control loops and to main constants of the process. It also provides alarm signalization, archiving the measured parameters, generates the reports, presents time curves of the parameters (especially the process of valves pulsation and pressure in a form of oscilloscope diagrams), and visualizes current jig operation in a form of synoptic screen, windows of devices, and measuring instruments. Author's tool software, operating the station, results in significant reduction of cost at full adaptation to the tasks of the system.

The system has been implemented in the "Budryk" Colliery and it has been operating without any breakdowns for two years. Due to the regular contact with the software user, the product is up-graded and it is extended by additional functions. Control and monitoring algorithms can be modified according to the user's needs.

INTEGRATED CONTROL SYSTEM OF ELECTRIC POWER WITH HEAT RECUPERATION AND CONVERSION IN MINING APPLICATIONS

Analysis of the prospects for development of the Polish mining industry in the next years, analysis of the fuel price, interest of manufacturers and users of mining machines in a development of state-of-the-art control techniques and obligation of taking care of the environment were the reasons of undertaking the problem of designing the heat recovery and conversion unit, which is a part of the power control system for the mining machines with internal combustion engines. Development of the system will help to implement state-of-the-art energy recovery techniques in mining machines, which can reduce the cost of mining and increase the energy efficiency (Fairbanks, 2008). It can also narrow the technological gap between the solutions used in state-of-the-art vehicles and those used in mining machinery.

The main advantages of the proposed system are as follows (Meisner, 2010):

- increased electric power system performance,
- reduced load to the alternator,
- reduced fuel consumption,

- reduced heat loss to the environment,
- reduced emissions of harmful substances to the environment,
- improved engine's cooling,
- constant monitoring of power distribution, and
- possibility of using in any machine in which there is a significant heat loss.

The purpose of the control system is to integrate the operation and management of three sources of energy for vehicles powered by combustion engines - alternator, battery, and innovative heat recuperation and conversion system. A recuperator is designed to recover thermal energy and to transform it into electrical energy with use of thermocouples.

The developed control algorithm enables supplying the electrical energy required to maintain the battery charge level, and sending extra energy to the receiver, depending on demand. Electrical machine subsystems are monitored in real time in terms of energy requirements.

The structure of an electric power control system of the mining machine is given in Figure 3. This system allows to integrate the existing power systems and alternative energy sources in vehicles and to control them.

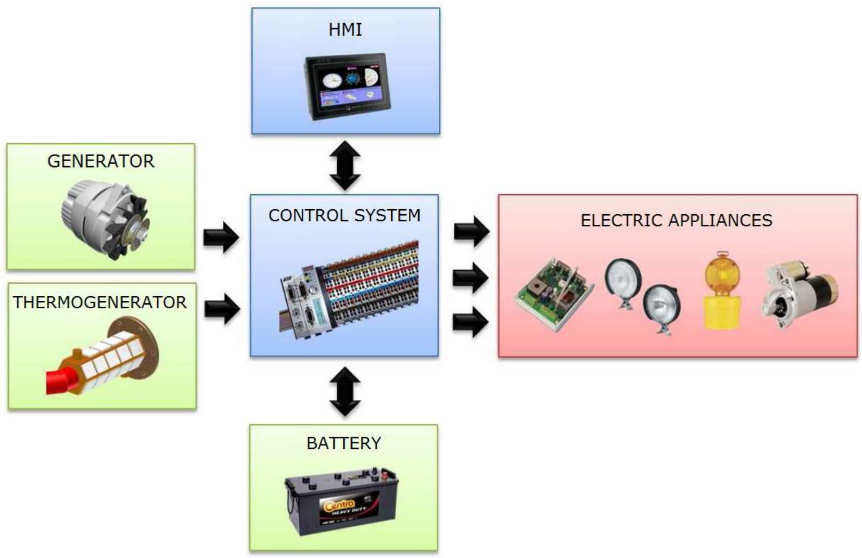

Figure 3 - The structure of an electric power control system based on thermocouples (Stankiewicz & Woszczynski, 2010)

CONCLUSIONS

Trends in the global mining industry clearly indicate the need for development of automated and autonomous machinery control systems, information engineering of management and logistics processes, as well as for integration of various systems in a global platform aimed at coordinated control and supervision of the ongoing technological processes. KOMAG realizes many projects on innovative solutions as regards industrial automatic control. The presented three sample areas, in which state-of-the-art mechatronic systems are used, perfectly illustrate their implementation potential and expectations of the mining industry.

Intelligent control systems are implemented in roadheaders to improve and to rationalize the work associated with drivage of roadways. However, due to specificity of work, withdrawal of all people (operators) from the area of machinery operation is not possible (and not justified). From tests carried out in one of mines it results that time required for installation of one arch of the support is equal to 30% of time needed for one drivage cycle. Implementation of automation system, which enables to withdraw personnel for the rest of the cycle, will significantly increase safety and effectiveness of the cutting process. Implementation of the system, which controls operational parameters of the roadheader in roadway profiling, should also give other important advantages such as:

- prevention against overload of drives increasing their life and reducing the number of failures,
- increase of roadway drivage effectiveness,
- reduction of energy consumption of the cutting process,
- increase of precision of roadway profiling, and
- increase of work safety in the face by withdrawal of the personnel form dangerous zones.

The presented iRIS system with the module for identification of powered roof support components that uses RFID technology aids capital assets management in hard coal mines. Developed solutions and the software enable automation of work and delivery of reliable information about technical conditions of each component. The problems of intrinsic safety, as well as the problems of remote reading and ergonomics were considered during designing the control system. Database author’s PECM software, which plays a role of supervising software recording and processing the identification data as well as information about each component of powered roof support, is an indispensable part of the iRIS system.

The presented system for control of jig’s beneficiation node is a part, which enables full integration of processing plant subassemblies. It provides monitoring and control of jig operation, automatic emergency switching off, as well as remote and manual sequential stopping and starting the jig and equipment cooperating with that system. System operation is monitored with the visualization application, which allows full review of data from all sensors installed in the system, including the float movement, passage, threshold and pressure in the pulsating chambers. The system can be used not only in coal mines, but also in other industries where minerals are processed.

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