INNOVATIVE SOFTWARE SOLUTION FOR COAL MINES

Summary. Organisational measures and research projects performed at the KOMAG Institute of Mining Technology in the scope of mechatronics and information technology are presented in this paper. Results of chosen, implemented scientific research project results are given. Developed solutions, e.g. identification system of powered roof support unit components, a roadheader smart control system and a longwall shearer vibrodiagnostics system. Showed solutions are examples of innovative software solutions implemented in the hard coal mining industry.

Keywords: roadheader smart control system, vibrodiagnostics, RFID

1. Introduction

Polish Energy Policy assumes the use of coal as main energy source for power engineering to guarantee an appropriate level of national energy security. In the current
economic situation, mines are looking for the solutions, which may increase production efficiency and improve safety and work conditions of mining personnel.

In the KOMAG Institute of Mining Technology, projects in electronics, computer science, robotics and telematics are focused on development of solutions aiding the production processes of mineral raw materials.

The article presents three innovative software solutions along with a description of the mechatronic systems they are part of. The vibrodiagnostics system of longwall shearer and the electronic system for the identification of mining machine components have been developed, implemented and tested. The adaptive system for controlling the roadheader operation is in the real-estate testing phase.

2. Adaptive system for controlling the roadheader operation

Drivage of roadways with use of roadheaders is one of the main operations in underground mining industry, which makes the deposit open and prepares it for being mined. In the Polish mining industry over 92% of roadways are currently driven by a selective mechanical cutting method using jib roadheaders. Forecasts for coming years anticipate the necessity of driving from 500 to 700 km of roadways per year [7, 8, 15].

Necessity of opening coal seams on more deep levels causes an increase of driving problems due to: requirement of driving roadways of greater cross-sections, what is indispensable to ensure a proper ventilation at increasing temperatures and at production rate increase, increase of rocks compactness and their strength to uniaxial compression.

High concentration of mining depends on using the roadways development technology with high advance. High drivage advance depends on comprehensive mechanization of operations and proper selection of parameters of the machines that are used in the process [11]. However, the operations have not been fully automated so far, what is associated with large number of factors having impact on these operations, complexity of mining with use of cutter head and difficulties in mathematical description of the process [1, 2, 5, 10, 12].

At present large share of costs of roadways drivage in coal production results from large number of employed people and high costs of materials. Low level of mechanization and automation of operations, many of which are still manual, is one of the reasons of such situation. For example, control of operation of cutter head is manual, what causes that mining is often ineffective or leads to critical exceeding the operational parameters of drives, e.g. rated current of motor of cutter head drive. It results in frequent failures and breakdowns of
machines to repair them, what generates further costs. Moreover, according to the reports of the State Mining Authority, many accidents, including fatal and severe accidents, still happen during these operations.

Currently, in the scope of operations to develop innovative, adaptive control system for a roadheader, the following control and diagnostic algorithms are developed:

- estimation of cutting resistance,
- selection of cutting parameters,
- selection of parameters to the mined layer,
- selection of cutting trajectory and limiting the cutter head movement beyond the working outline,
- positioning the cutter head in the working.

Estimation of cutting resistance is a stage of determining the angular velocity value of a roadheader arm. During model pre-testing, a cutting resistance identification module based on an artificial neural network has been developed. The network was prepared using MATLAB software and was thought with the use of available data collected during roadheader tests in real operation conditions [9, 15].

The results of performed simulations indicate that cutting resistance estimation by that artificial neural network is possible. The following input parameters of artificial neural network were selected on the basis of analysis of measuring data obtained during the tests of roadway development [15]:

- current of cutting drum motor $I_D$,
- efficient value of acceleration of mechanical vibrations $A$,
- under-piston pressure of turning base ram $P_{On}$,
- over-piston pressure of turning base ram $P_{Op}$,
- angular speed of the cutter $jib \ \omega$.

The results obtained by means of the artificial neural network are shown in the cutting trajectory. In Fig. 1a cutting resistance when cutting arenaceous shale in the working upper part is shown, and in Fig. 1b cutting resistance when cutting of coal in the working lower part is shown [15]. Fig. 2 shows the response of the artificial neural network in the scope of estimated cutting resistance to the selected set of real data registered during mine tests. The developed algorithms will be implemented in components of KOGASTER control system [6].

At the KOMAG Institute of Mining Technology, within the tests on an adaptive roadheader control system, an attempt to synthesize the fuzzy system was taken, for the purpose of generating control surfaces, which can be used for an automatic generation of a roadheader operating parameters controlled with the use of PLC group equipment [9, 13].
A structure of adaptive automatic control system of one process parameter is proposed as in Fig. 3. In the presented structure, several modules can be distinguished. In the ANFIS module generating of control surfaces is performed on the basis of collected measurement data concerning the roadheader operating parameters, depending on cutting parameters and strength of the rock mass (in the case of cutting conditions change, on the basis of collected data, a new control surface generation is possible). In the next module, an analysis is performed, aimed at a generation of an optimal combination of roadheader operation parameters. Those parameters are automatically entered into PLC controller, supervising the roadheader, cutting process according to the set trajectory. Feedback in the form of current arm position angle values, its extension etc. is generated by roadheader sensors (encoders, callipers, etc.). This information is further subject to a transformation to obtain for example a real arm deflection value. This value is further compared in an adaptive controller, where rock mass strength parameters are also updated (as well as other parameters). In the result of adaptation procedures, a generation of new set values for the PLC controller is performed. [9].
3. Vibrodiagnostics system of longwall shearer

The analysis of coal deposits in Poland showed that 18.5% of them are the coal seams of thickness up to 1.5 m. Those seams, so-called “thin seams”, are located within the majority of Polish mines. However, coal extraction from those seams is marginal. Development of mining machine of new generation designed to low-wall mining has become an urgent need.

Within the initiative of National Centre for Research and Development named IniTech, between January 2010 and December 2014, the consortium composed of KOMAG Institute of Mining Technology, KOPEX Machinery S.A. and KOPEX Electric Systems S.A. completed the project: “Innovative solutions of mining machines increasing the national energy security” (acronym INERG), which resulted in development of KSW-800NE shearer [16, 17].

Within the project, the KOMAG Institute of Mining Technology developed a vibrodiagnostics system, the idea of which is early detection of gear element damage and identification of its location. The vibrodiagnostics system consists of two basic components:

VITO vibrodiagnostics hardware module, designed for installation on the machine for data collection in the form of signals, their pre-processing and transfer to the software module (Fig. 4).
Software module, which enables the analysis and expert’s opinion for identification and location of possible failure or malfunction.

The vibrodiagnostics system is based on analysis of vibration signals for monitoring and diagnostics of gear components of operating machines. The characteristic feature of the said vibrodiagnostics system is the possibility of automatic operation under varying load conditions during underground mining, what differs it from other diagnostic systems. The structure of vibrodiagnostics system of the shearer is shown in Fig. 5.

![VITO vibrodiagnostics module, intrinsic safety manufacture](image)

**Fig. 4.** VITO vibrodiagnostics module, intrinsic safety manufacture [4]

**Rys. 4.** Iskrobezpieczny moduł wibrodiagnostyczny VITO [4]

Information about gear state are mainly acquired on the basis of analysis of the received signal parameter from the vibration sensors. Ten vibration sensors are installed on an arm and advancing unit of the shearer. In the vibrodiagnostics module, the analysis aiming at determination of trends indicating the technical condition of those subassemblies is performed. An example of a signal of vibration acceleration, recorded on the gear arm during operation of the shearer, is shown in Fig. 6.

Changing operational conditions in a mine result in increase or decrease of the analysed signal parameters, which are strongly dependent on momentary load of cutting drums. Neglecting that fact in analyses and calculations leads to wrong interpretation of measured diagnostic indicators. Momentary load parameters were recorded to make the system independent from the operational conditions. That is why rotational speed sensors of the gear were used, as the load of drums directly depends on their rotational speed. Additionally, load to the gear of the tested subassemblies is also identified on the basis of currents in wires that supply the motors. This information is taken from the machine’s control system.

“InergDiag” managing software (Fig. 7) is the basic controlling element of the vibrodiagnostics system. It controls launching each task and sub-programmes in a specific time and order, and it has the following functions:

- Parameterize of the hardware module,
- Collect data through the hardware module (in cooperation with the communication “InergVibroComm” software), including information about vibration from installed acceleration sensors and other information specific to the machine,
• Predict damages of the selected components of the mining machine with cooperation of expert system,
• Visualise condition of the mining machine and generate messages about potential risks,
• Enable edition, deletion and creation of new expert rules, used by expert sub-system to predict damages,
• Enable observation of archival analyses.

“InergVibroComm” communication software is intended to communicate between the vibrodiagnostics module and the computer of the roadheader. This software is not equipped with graphic user interface (GUI) and communicates directly with the hardware, saving received data in a database.

Fig. 5. The structure of vibrodiagnostics system of KSW-800NE shearer [3]
Rys. 5. Struktura systemu wibrodiagnostyki kombajnu KSW-800NE [3]

Fig. 6. Vibrodiagnostics signal of the KSW800-NE shearer arm in a function of time (a) and frequency (b) [4]
Rys. 6. Przebiegi drgań zarejestrowane na ramieniu kombajnu KSW800-NE w funkcji czasu (a) i częstotliwości (b) [4]
Studies on implementation of RFID (Radio Frequency Identification) technology in the mining industry were initiated at the KOMAG Institute of Mining Technology in 2004. System for electronic identification of powered roof support components was developed in a result of collaboration between KOMAG, Silesian University of Technology and ELSTA Group. The system has been implemented, commercially or on a test level, in nearly thirty hard coal mines in Poland as well as in companies manufacturing the powered roof supports [13, 18].

In the developed system the basic components of powered roof support are identified unequivocally with the use of RFID transponders (Fig. 8). Introduction of logic relationships between transponder identification number and a series of support’s attributes enables automation of logistic processes associated e.g. with repair or replacement of responsible components, what enables rational management of the capital assets [13].

Due to environmental conditions (high humidity, dust, possibility of methane and/or coal dust explosion), the use of RFID technology was not an easy task. Main requirements included in ATEX Directive should have been taken into account during designing of electronic system for identification of powered roof support components [3]. Assessment of conformity conducted by the notified certifying body is the basis to mark the equipment with CE mark and to issue a conformity declaration by the manufacturer, i.e. ELSTA Group [13].

The advantages of implementation of RFID-based system have granted in increased interest from further manufacturers and users of machines and equipment. Therefore, a project aimed at a development and commercial implementation of a complex hardware and
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A software solution for identification of machines, equipment, fixed assets and transportation means was started.

Work aiming at a development of IT-system iRIS (intelligent Rapid Identification System), compatible with previous hardware solutions, and aimed at comprehensive identification and control of fixed assets, was carried out at KOMAG [12, 13]. The iRIS system consists of the following platforms:

- PECM (for machines, equipment and components used in underground workings, Fig. 9),
- PEUBP (for explosion-proof machines and equipment),
- PEŚT (for transportation means),
- PEMP (for machines, equipment and components designed for surface use),
- PEŚTB (for office equipment).

Devices of new generation manufactured by Intertex presented in Fig. 10 cooperate with this software program.

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**Fig. 8.** Components of electronic system for identification of mining machines components [13]

**Rys. 8.** Składowe systemu elektronicznej identyfikacji komponentów maszyn górniczych [13]

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**Fig. 9.** PECM software (for machines, equipment and components used in underground workings)

**Rys. 9.** Oprogramowanie PECM (dedykowane do maszyn, urządzeń i komponentów używanych w podziemiach zakładów górniczych)
5. Summary

Development possibilities of mechatronic systems are now increasing due to the fact that most of designed machines and equipment require innovative control as well as monitoring and diagnostic systems. Those machines and equipment must comply with the regulatory requirements. Hence, mechanical solutions must be integrated with security and control systems starting already at the designing stage.

KOMAG industry partners constantly indicate their needs within the scope of mechatronic systems, due to that joint research, developmental and targeted projects are carried out. A continuous improvement of personnel qualification as well as development of research and testing infrastructure in the domain of mechatronics are visible. In the mining industry implementation of smart diagnostic systems for machines and equipment takes place.

A realization of research projects in close cooperation with industry representatives allows for increasing the innovation level. Possibilities of supporting those projects with national or European funds. It facilitates a realisation of project objectives oriented onto an innovative and safe project.

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Omówienie

Możliwości rozwoju systemów mechatronicznych są obecnie coraz większe ze względu na fakt, że większość projektowanych maszyn i urządzeń wymaga innowacyjnych układów sterowania, monitorowania i diagnostyki. Wytwarzane urządzenia i maszyny muszą być zgodne z wymogami przepisów. Stąd już na etapie ich projektowania należy integrować rozwiązania mechaniczne z systemami bezpieczeństwa i nadzoru. Realizacja prac rozwojowych przy ścisłej współpracy z przedstawicielami przemysłu pozwala na podniesienie poziomu innowacyjności.

W artykule przedstawiono wyniki projektów badawczych zrealizowanych w Instytucie Techniki Górniczej KOMAG z zakresu mechatroniki i technologii informacyjnych. Przedstawione rozwiązania: system identyfikacji elementów ścianowej obudowy zmechanizowanej, inteligentny system sterowania kombajnu chodnikowego oraz system wibrodiagnostyki podzespołów kombajnu ścianowego, stanowią przykłady innowacyjnych rozwiązań oprogramowania zrealizowanego na potrzeby górnictwa węgla kamiennego.

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