Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 36
ISSUE 2
October
2009

Use of a virtual prototyping in construction of a mining machine's control system

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Received 12.08.2009; published in revised form 01.10.2009

Analysis and modelling

ABSTRACT

Purpose: Possibilities of state-of-the-art information and automation systems in the process of construction and testing the machine's control system are the project objectives. The concept of virtual prototyping of a roadheader's control system consisting in coupling the real PLC controller, made by WAGO, with the virtual machine with its surrounding was presented in the paper. Such a solution enables testing the functions of the control system before its installation on a real object, what can significantly reduce the time of the system implementation. Data concerning .NET simulation application made in the Visual Basic language as well as the method of communication between PLC controller and MODBUS TCP simulation application were given. The work also contains a description of basic functions of the roadheader control system as well as assumptions concerning construction of an adaptive control system – which uses the methods of artificial intelligence for analysis of conditions that are around the machine.
Design/methodology/approach: Virtual prototyping of a roadheader's control system consisting in coupling the real PLC controller, made by WAGO, with the virtual machine and with its surrounding.
Findings: Trends in the world mining industry indicate for necessity of development roadheader control systems to improve operations associated with roadways driving. Use of a virtual prototyping method will enable to speed up implementation of the system.
Research limitations/implications: Building the adaptive system for roadheader control using artificial intelligence will be the next step of the project.
Practical implications: The solution presented in the paper is a part of the project aiming at a development of the system for visualization and control of roadheader. The system will be installed in a roadheader manufactured in Poland.
Originality/value: Use of the method for virtual prototyping to develop the control system of a mining machine.
Keywords: Numerical techniques; Roadheader; Virtual prototyping; Control system

Reference to this paper should be given in the following way:
J. Świder D. Jasiulek, Use of a virtual prototyping in construction of a mining machine's control system, Journal of Achievements in Materials and Manufacturing Engineering 36/2 (2009) 160-167.

1. Introduction

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 [3]. 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 proper ventilation at increasing temperatures and at production rate increase,
- increase of rocks compactness and their strength to uniaxial compression.

Implementation of new solutions as regards control systems is associated with a necessity of conducting long and expensive tests. New approach in implementation of the system consisting in using the virtual prototyping method enables to reduce maximally costs and time [8]. The virtual 3D model of a roadheader together with a surrounding roadway has been coupled with the real PLC controller (making a test rig). The virtual model of roadheader working area, among others, will enable changing the properties of mined rock and simulating reaction of the machine. Simulation tests carried out on the model will enable to verify and correct the algorithm and software that control roadheader operation, significantly reducing time of implementation of the control system on a real machine.

The described method is included to Hardware-in-the-Loop Simulation (HILS) [4,15] technique and consists in replacement of a mechanical part by the simulation application.

Test rig consisting of the following was built for the project purposes:

- simulation application, made in Visual Basic .NET environment together with EON Studio module for graphical visualization of roadheader operation,
- WAGO IPC 758-850 controller, which realizes the control algorithms of machine operations. CoDeSys environment is used for programming the controller.

Results of initial field tests, carried out on R-130 roadheader, to prepare for the roadheader main in-situ tests in mine underground were also presented. The results of those tests will be an intelligent control system built for a roadheader.

2. R-130 Roadheader

3D model of REMAG's R-130 roadheader was used in the project (Fig. 1).

For the project purpose the simplified model of the roadheader was applied, where model's geometry refers to the real roadheader, but all elements that have no direct impact on cutting proves were neglected. These additional elements would slow down the operation of simulation application.

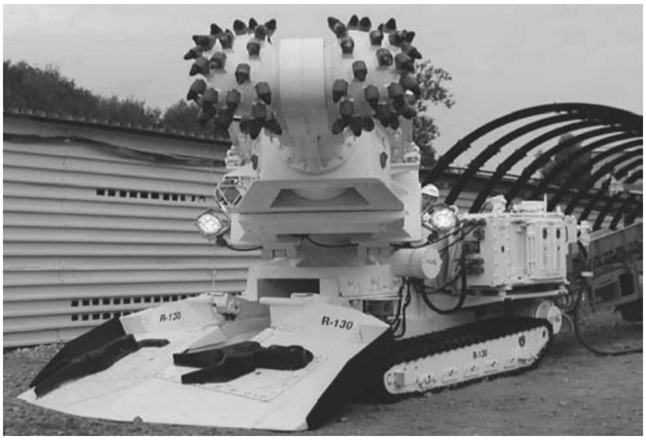

Fig. 1. R-130 Roadheader [19]

3. Simulation application

Simulation application consists of three main modules:

- Module of selection of mining-and-geological parameters
- Communication module,
- Graphical visualization module,
- PLC controller software.

Each component of the simulation application was described in chapters below.

3.1. Module of selection of mining-and-geological parpameters

A module of selection of mining-and-geological parameters and simulation of measuring signals will play a basic role in the whole simulation system. This module will include algorithms describing, in a simple way, phenomena present in a roadway. Values of parameters, which were recorded in a real cutting process, will be used during the simulation. These values will have impact on measuring signals introduced to a PLC controller. Measuring signals will be generated in a form corresponding to signals from real sensors installed on a roadheader.

The module will be created in the Visual Basic .NET environment.

The module will simulate, among others, such parameters as follows [5]:

Pressure:
- in under-piston and over-piston chamber of cylinders of boom lifting,
- in under-piston and over-piston chamber of cylinders of boom rotation,
- in travel system.

Current intensity:
- motor of cutting drum,
- motor of hydraulic pump.

Temperature:
- motor of cutting drum,
- motor of hydraulic pump,
- hydraulic medium.

Parameters describing location of hydraulic cylinders and roadheader.

3.2. Communication module

MODBUS TCP protocol is used for communication between the PLC controller and the simulation application. All geometric data connected with roadway driving process as well as simulated loads of machine's drives are exchanged between the simulation application and the controller.

Etherent (MODBUS TCP) is a hardware layer of communication between the PLC controller and the simulation application. Such a solution makes the simulation significantly easier – the controller is connected to a local Ethernet grid and does not require any additional wiring system for communication.

The MODBUS protocol defines universal content of PDU (Protocol Data Unit) (Fig. 2) data frame that does not depend on a transferring method.

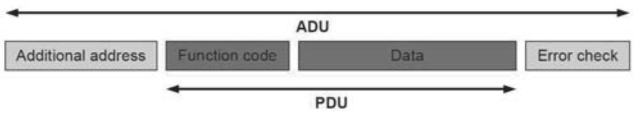

Fig. 2. MODBUS data frame [17]

				Function Codes code	Sub code	(hex)	Section
Data Access	Bit access	Physical Discrete Inputs	Read Discrete Inputs	02		02	6.2
		Internal Bits Or Physical coils	Read Coils	01		01	6.1
			Write Single Coil	05		05	6.5
			Write Multiple Coils	15		0F	6.11
	16 bits access	Physical Input Registers	Read Input Register	04		04	6.4
		Internal Registers Or Physical Output Registers	Read Holding Registers	03		03	6.3
			Write Single Register	06		06	6.6
			Write Multiple Registers	16		10	6.12
			Read/Write Multiple Registers	23		17	6.17
			Mask Write Register	22		16	6.16
			Read FIFO queue	24		18	6.18
	File record access		Read File record	20		14	6.14
			Write File record	21		15	6.15
Diagnostics			Read Exception status	07		07	6.7
			Diagnostic	08	00-18,20	08	6.8
			Get Com event counter	11		OB	6.9
			Get Com Event Log	12		0C	6.10
			Report Slave ID	17		11	6.13
			Read device Identification	43	14	2B	6.21
Other			Encapsulated Interface Transport	43	13,14	2B	6.19

Fig. 3. MODBUS function code [17]

A Client/Server structure is used to exchange data in real time between: two control devices, a control device and other device, HMI/SCADA devices, PCs. In the case of using the Ethernet as a hardware layer, additional information - ADU (Application Data Unit) [17,18] is added to the (podbas???? - MODBAS) standard data frame.

A structure of data frame of MODBUS TCP protocol is presented in Figure 2. The MODBUS function code is one of components of the data frame. Standard function codes are presented in Figure 3. The simulation application uses mainly codes associated with reading and recording memory registers of the controller.

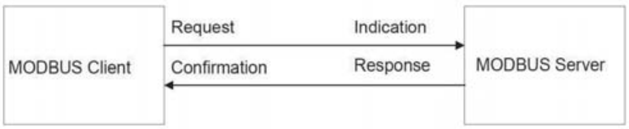

Fig. 4. Client/Server data exchange [18]

Communication in the MODBUS TCP network is based on a Customer/Server structure (Fig. 4) [18]. A Customer/Server model is based on the following four types of information:
- MODBUS Request – message sent by the Customer to the network to start a transaction (inquiry),
- MODBUS Confirmation – confirmation of receiving the answer by the Customer,
- MODBUS Indication – confirmation of receiving an inquiry by the Server,
- MODBUS Response – answer sent by the Server.

3.3. Graphical visualization module

Graphical part of simulation application enables, first of all, recreation of a position of the cutter head and other elements of the roadheader (loading table) in the roadway space. The simulation application can visualize a position of the cutter head in the roadway's face cross-section – 2D and a position of the whole machine with all its elements in 3D space. Work connected with a development of 3D graphical part of the simulation application that would enable visualisation of cutting process can be divided into three stages:

- preparation of spatial models of each roadheader assembly,
- preparation of animations of each roadheader assembly (movements of turning base, cutter jib, cutter drum and the whole machine),
- development of simulation software in EON Studio and the transfer of developed animation to the EON software to simulate the cutting process (Fig. 5).

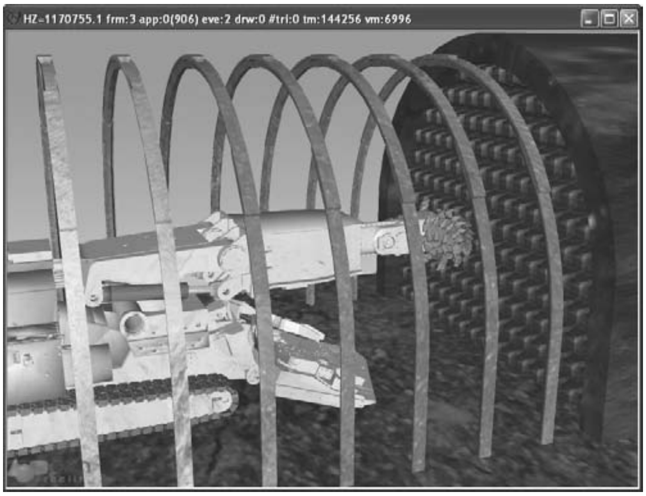

Fig. 5. 3D model of roadheader

3.4. PLC controller software

Testing the maximal number of control functions before implementation of the system on a real machine is the purpose of using the method of virtual prototyping of roadheader control system.

The control functions of roadheader were divided into two categories:

- basic functions,
- advanced functions.

All basic functions can be tested on a virtual model of a machine as they refer to the maintenance of basic roadheader's devices – mainly two-mode ones. Processing of values from analogue and digital sensors, maintenance of basic alarms as well as calculation of current values of local and global coordinates are also realized within the basic functions.

There are the following advanced functions:

- function limiting the movement of the cutter head outside the programmed outline,
- function generating the cutting trajectory,
- function selecting the cutting parameters (circumferential speed of cutter jib) depending on current mining-and-geological conditions and the machine condition.

IPC WAGO 758-850 controller was used in a control system (Fig. 6). The WAGO IPC 758-850 controller has implemented functions of the MODBUS [16] network client. Area of the memory that can be used to read out and save by the MODBUS protocol has been defined in the controller specification, to use this function the variables should be properly addressed. Variables of MW (Memory Word) types are used for communication between the PLC controller and the simulation application.

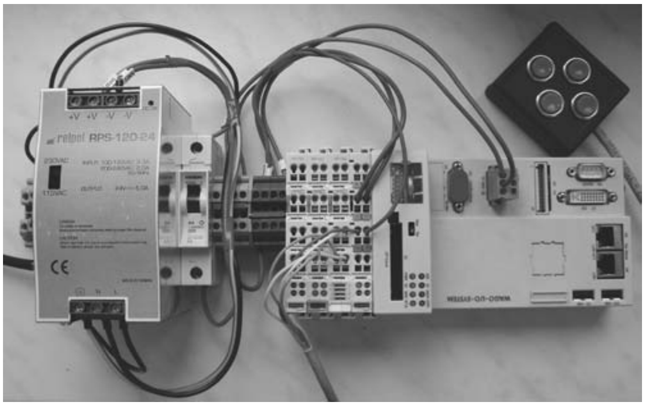

Fig. 6. IPC WAGO 758-850

Function limiting the movement outside the programmed outline

Coordinates of the cutter head centre in the working area are the input parameters of a function. The function includes currently selected type of working and it switches on/off the interlocks of movement in each direction (input parameters). In a target control system the function will operate in the following two variants:

- it will make the movement of cutter head outside the programmed outline impossible,
- it will signalize the movement of a cutter head outside the programmed outline acoustically or by light.

Catalogue dimensions of yielding arch support (Fig. 7) were used during development of the function. Geometrical relationships present in the roadheader-working system were used for calculations of interlocks.

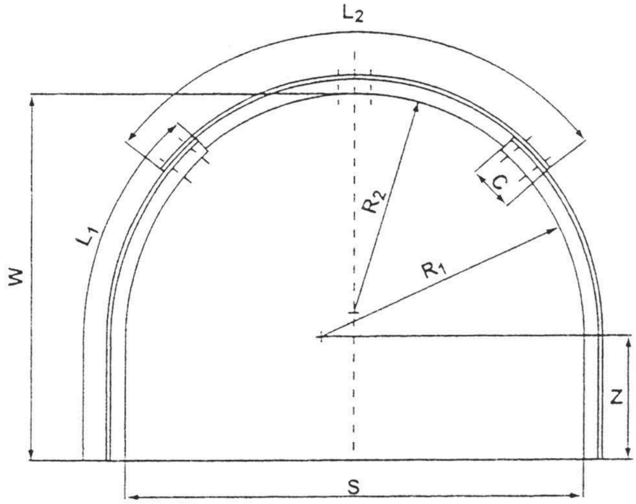

Fig. 7. Yielding arch support

A simplification, which assumes that a roadheader is in the working's axis, was made at the current stage of the project.

Function selecting cutting parameters

This is the function responsible for cutting efficiency and for trouble-free operation of the machine. The function is under development and it will be completed with the use of artificial intelligence (adaptive selection of cutting parameters). We assume constant revolution of the cutter head, constant web *he* and height cutting drum trajectory *av* (movement of the cutter head vertical plane Fig. 5). Circumferential speed of the cutter jib is the parameter that will decide about machine safety and output.

Markings used in Fig. 8:

A – cross-section in the plane perpendicular to advance direction
he – cutter head pushing in (z)
av - movement of the cutter head vertical plane (h)

Work on using an artificial intelligence in testing cutting bits and cutting heads has been undertaken [2,9,10,11,12]. Test results were used for identification of cutting bits condition with use of artificial neural networks. Apart of identification of cutting bits condition it is planned to use an artificial intelligence method in the process of selection of cutting parameters. To develop the control algorithms it is necessary to acquire time characteristics of each parameter (it is indispensable to carry out tests in real conditions).

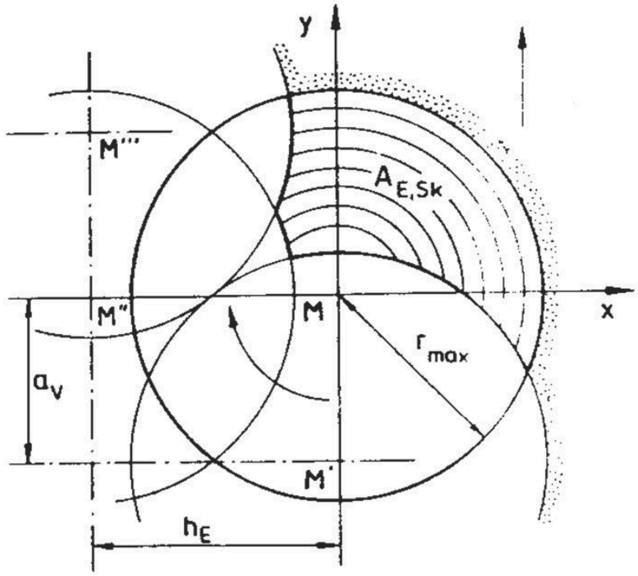

Fig. 8. Technological parameters of a cut layer

Selection of roadway dimensions

Database of standard types of arch yielding support will be entered to the controllers' memory. An operator will have a chance to select a type of a roadway from the visualization screen and after it is accepted the software will select parameters associated with cutting geometry in relation to the selected type of the roadway. Dimensions of the roadway will be included in a function that limits movements outside the operational area as well as in the function that generates a cutting trajectory [5, 6] (the function is not described in the paper).

Function that determines roadway dimensions has two input parameters like a type of a roadway and overburden thickness as well as output parameters referring to those given in Fig. 9. Input parameters of the function are selected from the level of the computer application and transferred to the PLC controller. In a targeted final control system the input parameters will be entered from the operator's panel placed on the control panel.

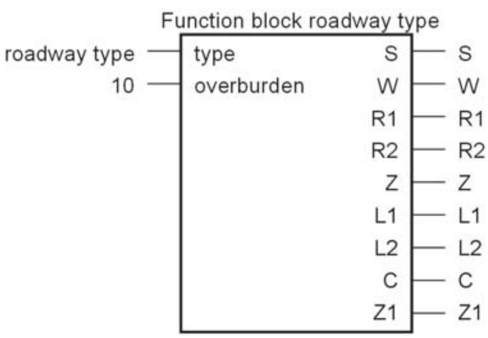

Fig. 9. Function block roadway type

4. Field tests

In the Polish mining industry tests on roadheaders were carried out in the end of 1990ties. The tests were carried out by the Silesian University of Technology [13,14]. Electric parameters of the roadheader and the cutter head position were recorded during tests.

Field tests of cutting operations with R-130 roadheader on a rock block were carried out in March 2009. The tests were made in REMAG S.A by the specialists from KOMAG Institute of Mining technology and from P.U.P SOMAR (supplier of measurements recorder). The tests were aimed at testing specified sensors before installation the roadheader in mine underground – then the main test will be carried out.

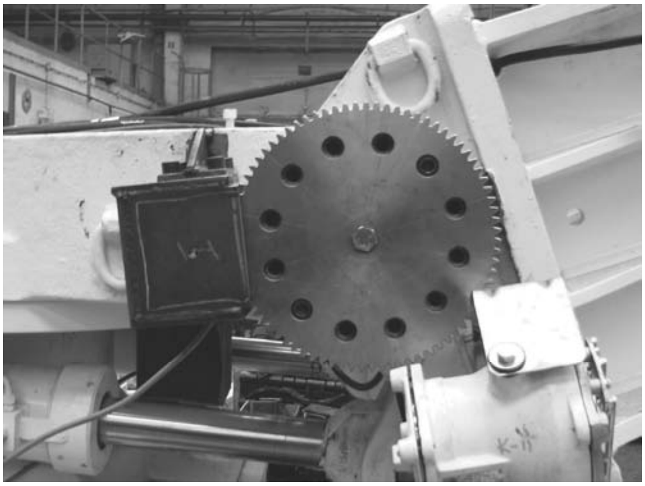

Fig. 10. Installation of jib position sensor

Fig. 11. Installation of loading table position sensor

The roadheader has been equipped, among others, with sensors of cutter jib vertical and horizontal position (Fig. 10), a sensor of loading table position (Fig. 11), vibration sensors installed on the cutter head (Fig. 12), an inclinometer to determine the position of the whole machine (inclination in x and y axes) as well as with pressure sensors in the hydraulic system.

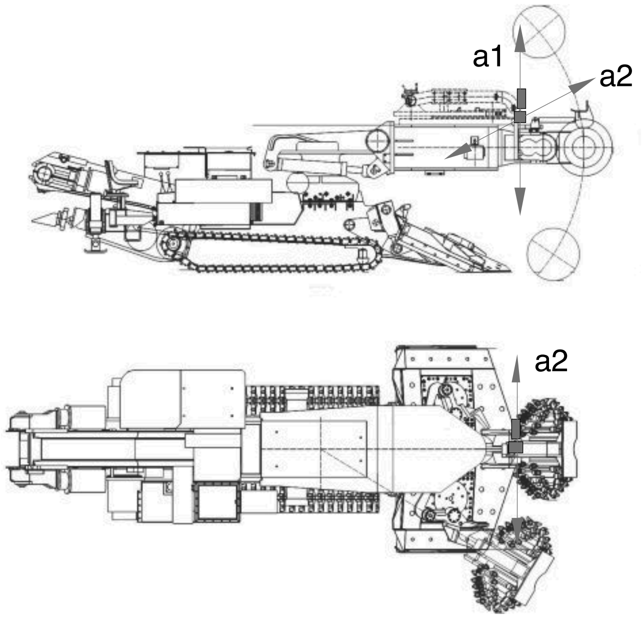

Fig. 12. Arrangement of transducers and direction of mechanical vibrations measurements

The results of initial cutting tests carried out with the R-130 roadheader on a concrete block of the strength uniaxial compression of about 40MPa has enabled to draw the following conclusions:

- R-130 roadheader can be classified as the small one. During cutting process the whole machine is moving, what makes interpretation of results significantly difficult. During tests the effective vibrations were recorded. It is important that during the main tests, carried out in mine underground, data processing is more advanced (to realize that some changes in a measuring recorder will be implemented).
- Installed encoders would enable to recreate the position of the jib in a given moment. The initial tests showed that in the targeted system it is necessary to install the sensors of extensions of hydraulic cylinders, which would replace currently used encoders. Exposure of encoders to mechanical damage is the reason of sensors replacement. Installation of the sensor inside a cylinder will significantly reduce failure risk caused by mechanical damage.
- The film was made during tests to combine the recorded values with the actual operations realized by the machine operator (it is possible to find out what the operator has exactly done and how each operation can be transferred into the measurement results). During the main tests, an observation of cutting process will be also required, but all events will be recorded in a daily log, as there is no possibility to make a video recording.
- During testing also electric amounts were recorded – current in roadheader motors. Measurements of cutter head drive motor current are most important. Combination of current cutter head vibrations and present pressure in a jib system will enable to determine a load of the machine.
- Tests carried out on the concrete block will be used as the reference point – they were made on a new machine with new cutting tools. Then the recorded vibrations will be compared with the measurements taken during machine operation in mine underground.

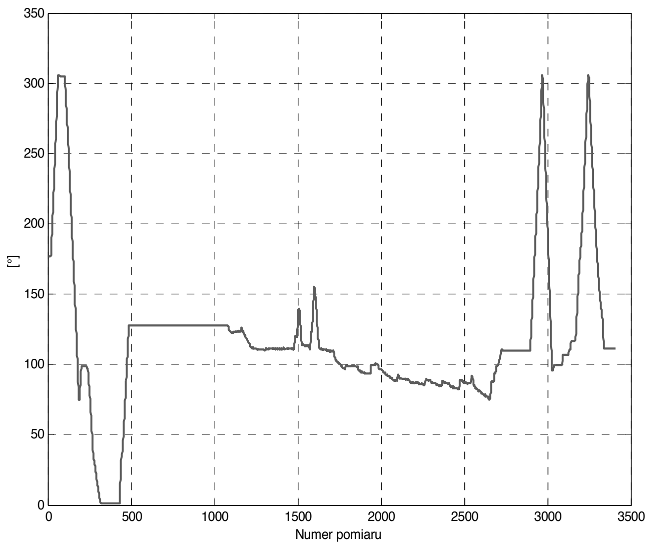

Fig. 13. Diagram of jib articulation [1]

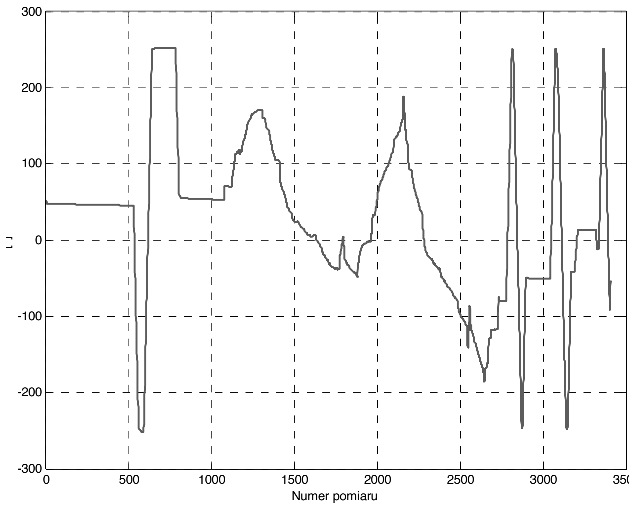

Fig. 14. Diagram of turning base position [1]

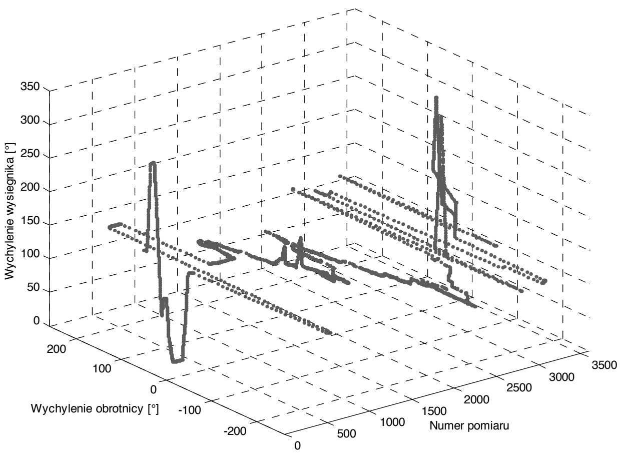

Fig. 15. Position of cutter head [1]

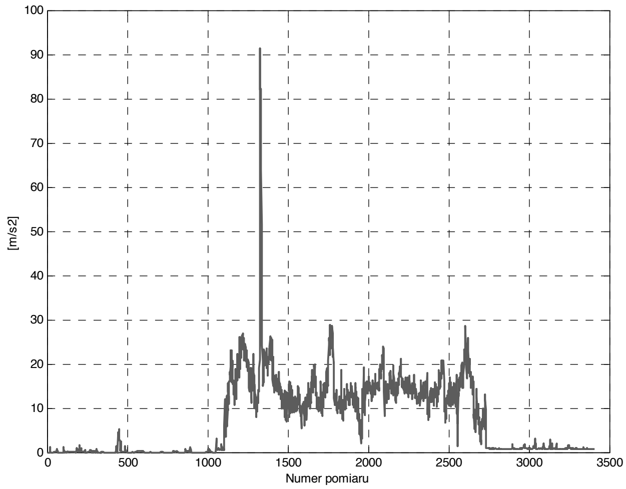

Fig. 16. Mechanical vibration of jib and cutter head (a1) [1]

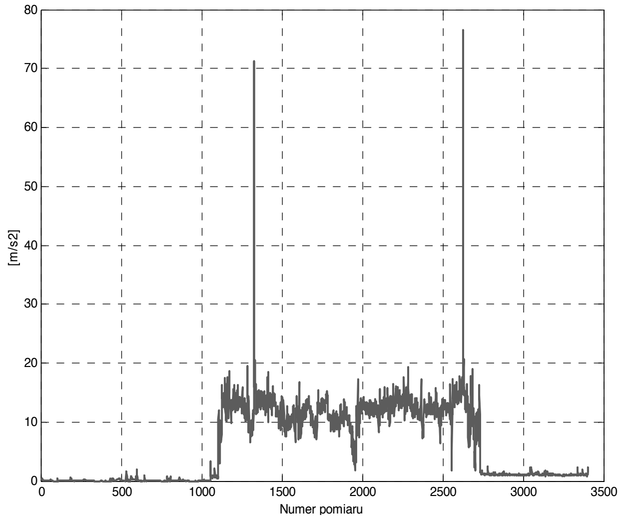

Fig. 17. Mechanical vibration of jib and cutter head (a2) [1]

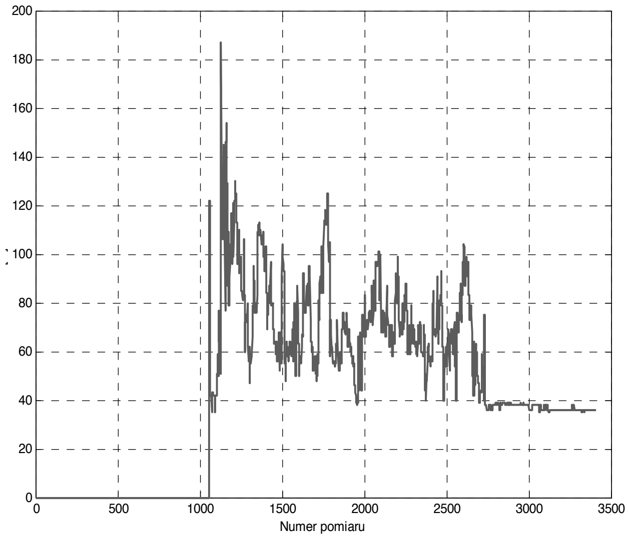

Fig. 18. Current of cutter head motor [1]

Time processes of the parameters recorded during initial tests were given in Figures from 13 to 18. In Fig. 13 position of the jib in a vertical plane was shown, in Fig. 14 its position in a horizontal plane, and in Fig. 15 cutter head position in a form of 3D diagrams were presented. In Figs. 16 and 17 time process of efficient vibrations values were given (in a1 and a2 axes according to Fig. 12), while time processes of current were presented in Fig. 18.

5. Conclusions

Trends in the world mining industry indicate for a necessity of development of control systems for roadheaders [7], to improve operations associated with driving of roadways. Due to specificity of those operations we can say that total removal of men from the zone of machine operation, is not possible, for example due to activities connected with roadway support assembly. Implementation of automation of the system, which would control operational parameters of a roadheader and which would support profiling of the roadway outline should give the advantages like [5,6]:

- making exceeding of permissible loads of drives impossible, increasing their life and reducing number of failures,
- increase of driving efficiency,
- reduction of machine power consumption,
- increase of precision in realization of the required roadway profile,
- increase of work safety in the face.

Simulation tests on the model enable verification of the software that controls a roadheader in a simple and cheap way. Simulation results will enable making corrections in the software and will reduce time of implementation of the control system in a real machine.

Results of tests carried out on a real object (both initial ones described in the paper and the main ones carried out in mine underground) will enable to verify the control procedures. After completion of testing the results will be entered to the simulation application and tests of the controller, using real data, will be carried out.

Results of initial tests on R-130 roadheader cutting [1], presented in the paper, will enable for proper preparation to the main tests which are planned to be carried out in mine underground.

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