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Development of Hardware and Technical Means of Control and Management for Mining and Technological Research at the Stage of Mining Operations

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***Abstract* — A significant part of the mineral deposits mined by the open pit is represented by rock formations that differ significantly in structural and strength properties. The variability of mining conditions in the development of deposits is a big problem. A hardware-software complex for mining and technological mapping of rock masses is proposed by registering changes in the energy performance of heading and lifting engines. To register changes in the quality of the ledge soles, particle size distribution and shape of the collapse broken mass, the hardware-software complex provides a binding energy performance engine heading, lifting, turning through the position of the bucket in space and time with the operations of the excavation cycle: digging, filling and holding the filled bucket.**

Keywords — intelligent hardware-software complex excavator; mining and technological mapping; dynamic monitoring of energy parameters; robotization of mining processes; operations of the excavation cycle; remote monitoring

I. Introduction

A significant part of the mineral deposits mined by the open pit is represented by rocks that differ in structural and strength properties. Therefore, the specific consumption of explosives for their fragmentation varies widely from 0.3 to 1.55 kg/m3. Heterogeneity and variability massifs of rock within a single Deposit causes difficulties in zoning and practical use of classifications, both prospective and current planning and design of mining operations [1, 2]. Therefore, technological research massifs of rock are an urgent task.

The lack of operational methods for obtaining reliable information on the characteristics of the excavator face inhibits the use of existing reserves to improve the efficiency of mining processes. Therefore, there was a need to measure new parameters and values in production conditions that were not previously measured, but can characterize the efficiency of using mining complexes in different excavator faces. The presence of electromechanical units in the construction of mining excavators makes them convenient objects for remote monitoring.

II. Formulation of the Problem

A number of scientific papers are known[3,4,5,6], which analyzed the energy parameters of the excavation cycle operations. For example, in [3], self-recording wattmeters H-348 with a diagram tape were used as devices for recording changes in the energy parameters of the excavation cycle operations. The device was connected via TPOF-200/5 current transformers and voltages in the circuit of the excavator mains motor. This made it possible to record the total energy consumption per cycle (development of the face, rotation the platform to the transport vessel, unloading and returning the bucket to the face). In other cases, ampervoltmeters N-390 and N-354 were used, which were included in the control circuit of the head and lift engines. Then, the diagram tape clearly recorded the energy costs of the actual face mined. The aim of this work is to substantiate the quantitative relationship of energy criteria, such as the energy intensity of drilling with the explosiveness and difficulty of excavation (the energy intensity of the excavation process) with the speed of propagation of longitudinal waves in the array. Since for different types of rocks there is no single quantitative relationship between the energy intensity of drilling and rock explosiveness, the author [3] emphasizes the use of averaged energy parameters to promote this idea.

At the same time, the greatest value of using the capabilities of dynamic monitoring of energy parameters is represented for mining and technological mapping, when a set of tasks is solved to optimize the algorithms of mining equipment operation, increase the reliability of planning and designing of mining operations, and current management [7,8].

III. RESEARCH METHODS

To solve this problem, a hardware-software complex and a subsystem for remote monitoring of the excavation process were developed. The structural diagram of the subsystem is shown in Fig. 1.

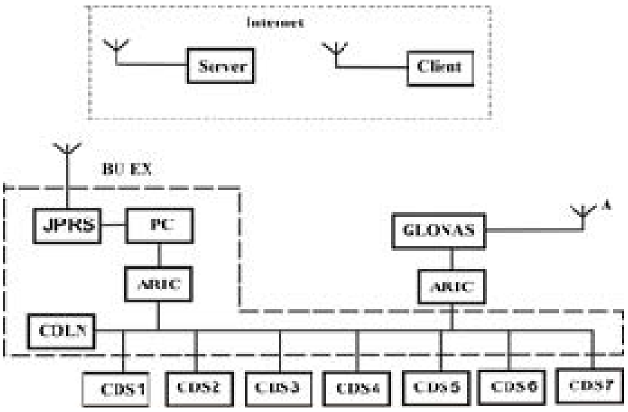

Fig. 1. Block diagram of the subsystem of excavation process remote monitoring: BU EX - excavator control unit; PC - personal computer; COLN - controller of the local network of communication devices with subscribers; CDS - communication device with the subscriber; ARIC - active repeater interface converter; GLONAS - receiver of signals of a navigation system; A - GLONAS antenna; JPRS - JPRS modem.

For the practical advancement of this methodology, a prototype hardware-software complex was created (Fig. 2), the mining of which as part of the EKG-4.6 excavator at the first stage should solve the problem of experimental justification of rational parameters for remote monitoring of excavator units. Through the bucket position in relation to the operations cycle of the excavation in time and in space to provide reference energy performance engines head, lifting, turning to set a minimum sampling frequency of sensors.

Fig. 2. Hardware-software complex based on microcontrollers of the MCX52-x.x series

In the initial version of the hardware-software complex prototype, a design based on a PC with increased computing power was put in place to guarantee an excessive frequency of sensor polling. In addition, to ensure the safe measurement of currents in high-voltage circuits, the use of galvanically isolated ADCs (analog-to-digital converters) was provided. In the circuit of each motor (head, lift, turn), the ADC terminals of a separate microcontroller with galvanic isolation were connected to the shunt terminal. A total of 4 MCX52-x.x series microcontrollers were used.

The basis of the MCX52-x.x. node is the PIC18F2620 microcontroller. It provides communication with interfaces using the basic principles of the MODBUS protocol. In FLASH memory of the microcontroller, in addition to the main firmware of the module, a program for pre-processing ADC signals is loaded. The built-in 10-bit ADC of the PIC18F2620 microcontroller provides conversion time per channel of the order of 10 μs. Galvanic isolation between the interfaces and the I/O lines is no worse than 2.5 kV.

AEDC857B-RS DC voltage converter was used as a voltage sensor.

The structural diagram of the subsystem is shown in Fig.1. Through devices interfacing with the object carried out a survey of the current sensors and voltage of the motors head, lift, and turn. Initially, the ADC polling frequency was adopted after 10 ms, but during the experiments it was found possible to reduce the polling frequency to 50 ms without loss of quality. Moreover, a sample of parameters from every 20 measurements is stored in the database as a single record 50 ms after statistical processing. Thus, per second measurements are saved in the database. Significant reduction in data flow allowed to simplify the design of the hardware-software complex. For Fig. 3. the control unit in the excavator cab of the remote monitoring subsystem based on the USB-24 microcontroller is presented.

Structurally, the subsystem for monitoring and controlling the excavation process consists of two parts: the block for registering the position of the excavator bucket, which is attached with magnets to the connection of the handle with the upper part of the excavator bucket (see Fig.4); the control unit is located in the excavator cab (Fig.3.). The registration unit and the control unit are connected using a Wi-Fi module via Wi-fi access point.

Fig. 3. Control unit in the excavator cab.

Fig. 4. Excavator bucket position registration unit.

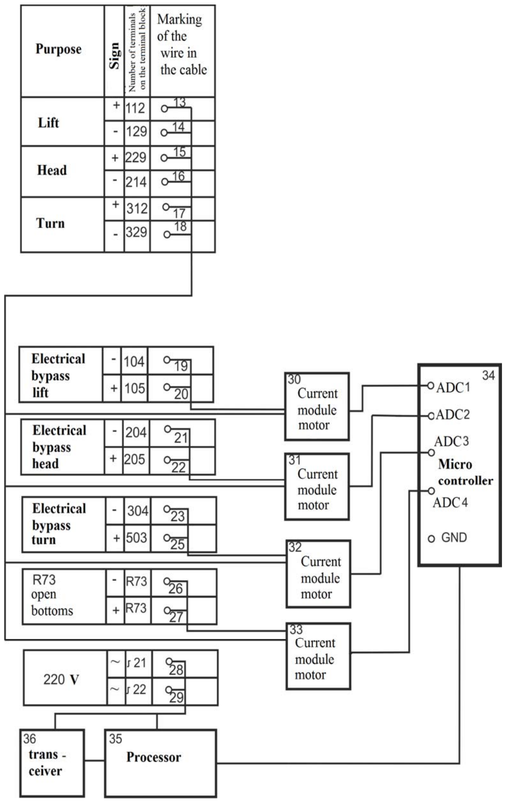

Fig. 5. Block diagram of hardware-software complex integration into the excavator control system.

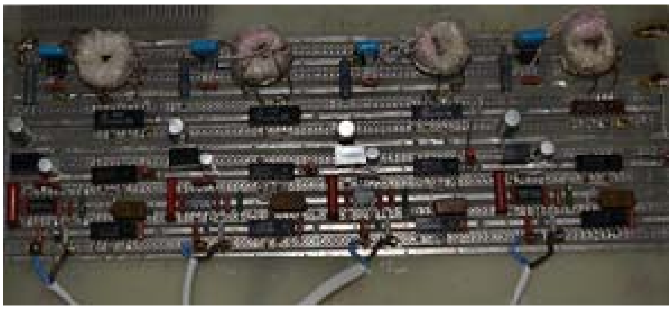

Fig. 6. Galvanic isolation of the ADC.

Fig. 7. Connecting the sensor to the bottom opening relay.

Fig. 8. Connection of galvanic isolation lines in the control cabinet.

IV. FINDINGS

Stable operation of the electric drive of the excavator-engines (lift, head, turn and go) in severe working conditions is provided by the combined action of four control windings of the magnetic amplifier. Start, speed control, choice of direction of rotation and braking of electric motors, lifting, heading, rotation is produced by changing the magnitude and direction of current in nominal control winding of magnetic amplifier with a controller. The voltage and current in the master winding of the magnetic amplifier are changed using a command controller without reversing contactors. When switching the handle or pedal of the foot controller from zero to any other position, the magnetizing force of the setting winding of the magnetic amplifier increases sequentially and the generator voltage increases accordingly. In the scheme, four positions of the command controller are used for each mechanism, which corresponds to four engine speed stages. Table 1 shows the maximum holding currents of the head, lift, and turn motors depending on the position of the controller.

TABLE I. MAXIMUM HOLDING CURRENTS OF THE ENGINES OF THE EKG-4.6 EXCAVATOR, DEPENDING ON THE POSITION OF THE CONTROLLER

Position command controller	**Maximum (holding currents) of engines, Amper**		
	Lift	***Head***	***Turn***
I	950-1100	290-305	250-330
II	1050-1140	300-310	260-350
II	1150-1180	320-340	300-390
IV	1180-1200	340-360	360-400

The excavator works in rock exploded rocks in a mode close to the holded, which is set by the amount of extension of the handle. With the amount of handle extension, the chip thickness, filling time, energy characteristics, and the trajectory of the bucket change. On the other hand, by changing the current of the engines head, lift and turn, one can judge the conditions, the algorithm of work and the skills of the excavator operator.

For example, Fig. 9 shows a diagram of changes in motor currents, lift, head, and turn over two cycles. Judging by the current of the lifting engine and the duration of the excavation cycle operations, the face is not difficult under working conditions. The driver combines filling the bucket and turning to unload, at the same time, there is a rather lengthy operation in the cycle ty - keeping the bucket in the filled state (while the dump truck is approaching). This operation is about 8 seconds, which exceeds the digging time. Energy losses for this period of time, as can be seen from the diagram, range from 25 to 30%.

The many months of testing in production conditions of the subsystem have established the reliability of its operation and allowed us to evaluate the effectiveness of practical use. A client application has been developed and tested in production conditions, which provides the information needed by the chief power engineer and technologist in a convenient form for shift analysis. The ability to display changes in energy parameters per second in the process of performing technological operations of the excavation process, their automated processing allows us to the causes establish of inefficient operation at any time interval.

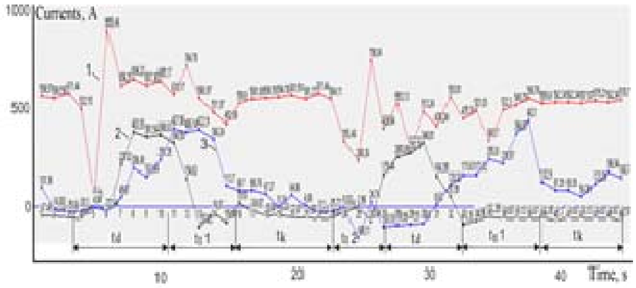

Fig. 9. Diagram of changes in motor currents, lift, head, turn during two cycles: 1-lift engine; 2-head engine; 3-turn engine; td – time of digging; tt1 – time of turning to the dump truck; tk – time of keeping the filled bucket; tt2 – time to turn into the face..

V. CONCLUSION

The greatest value of using the capabilities of energy parameters dynamic monitoring is represented for mining and technological mapping, when a set of problems is solved to optimize the algorithms of mining equipment, increase the reliability of planning and design of mining operations, and current management. Ultimately, the work is aimed at improving modern software and hardware and technical means of control and management for mining.

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