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CONTROL AND DATA LOG OF FUNCTIONS FOR PROTECTION IN THE HYDRAULIC EXCAVATOR

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Abstract

In the paper, the results of research for controlling of functions for protection of the hydraulic excavator for mining and loading of ore in mines are given. The main purpose of the paper is the development of an electronic circuit intended to follow some system parameters providing information about the proper operation of the excavator. In the case of anomaly such electronic circuit passes proper output signals to the engine control system which take adequate action. The developed solution is part of an electronic system that manages the overall operation of the excavator. It has practical application in one of the mines in Macedonia. The completing of such electronic module with proper hardware and software allows: 1) visualization of some signals, parameters and features connected with the excavator protection, and 2) creation of data log file. In the solution the latest achievements in hydraulics, mechanics, and electronics are implemented. With designed solution, optimal balance between the basic mechanical structure of the excavator and its overall management is achieved.

Key words: electronic circuit, programmable controller, date log, hydraulic excavator

1. Introduction. The stationary mining machines like excavators, aggregates, and pumps are mainly power-driven by diesel engines [8, 9]. These are off-road working machines with capital importance for the working process in the mines, separators and quarries. Therefore, the proper operation of these machines is imperative and the circuit which manages the functions of the protection is important for the overall operation of the machine. In Figure 1, a temperature diagram of diesel engine is given. Moreover, the diesel engine is the main part on the stationary mining machines, and some important conditions for its functioning are given below. These conditions define the levels of the output control signals which the circuit for protection should generate.

The exposed parts to friction (main axis, gears and cylinders) should be cooled with oil for lubrication with pressure from 3 to 6 bars.

The working power of the engine will stay unchanged, if the components which receive heat (head, block) from the parts exposed to friction are cooled by forced air or water.

The above two conditions ensure that diesel engines will operate in allowed temperature domain, Fig. 1 [6]. In Figure 1, in point *1* the engine switches on. Along line *1–2*, the engine works without a load (low speed). In t_1 (*2*) the engine achieves working temperature of 68 °C. This is a condition for the engine to be capable to operate under a load (work with maximum speed). In t_2 (point *3*) the engine achieves a working temperature of 82 °C. When the engine operates under a load, the temperature of the fluid for cooling moves along the curves *3–4*. When the engine which has been working for some time under load (point *4*) should stop, it is necessary for it to work some additional time with a small number of revolutions (idler) before it turns off. It is point t_4 (point *5*), when the temperature of the fluid for cooling is 68 °C.

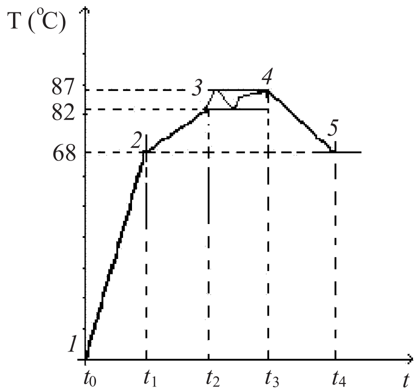

Fig. 1. Temperature diagram of diesel engine

2. Design of electronic circuit for protection. The protection features of the stationary mining machines are usually limited to monitoring of the working state from the operator of the machine [8, 9]. An important disadvantage of this protection method is connected with the tiredness of the machine operator after a certain time and the gradual decrease of his working ability during the work day. This type of protection includes only signalling in the case of high temperature, low pressure of the oil for lubricating (on motor, shaft or hydraulics), and low level of water for cooling in the tank. When any of these variables exceeds allowable range, an alarm occurs on the control panel in the cab of the machine solely. Such protection circuits is not able to stop the engine in the case of incorrect operation. This paper presents a new designed and practically implemented protection circuitry that makes a decision to stop the engine and protects the excavator based on given input variables. The circuitry also gives adequate visualization and keeps a date log of measured variables [5].

2.1. Defining the working conditions. Figure 2 shows a block diagram of the protection circuit for the hydraulic excavator [6].

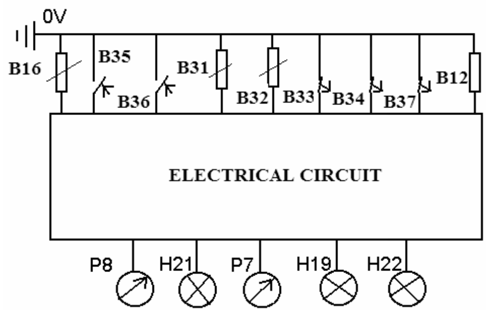

Fig. 2. Block diagram of the circuit for protection of he hydraulic excavator

The elements in Fig. 2 are as follows: B16-temperature sensor, P8-instrument for measuring on the temperature, B35-thermal switch, B36-thermal switch, H21-signal led diode, B31-pressure sensor, B32-sensor for hydraulic pressure, P7-instrument for measurement on the oil's pressure for lubrication, B33-pressure switch, B34-pressure switch, B37-switch the hydraulic pressure, B12-sensor for level on water, H19-signal led diode, H22-signal led diode.

Principle of operation. The temperature sensor B16 and the instrument P8 measure the temperature of the engine. The pressure sensor B31 and the instrument P7 follow the oil's pressure for lubrication of the engine. B35 is a thermal switch which closes when the temperature on the diesel engine is high. Then led diode H21 is activated. B33 is a switch for the oil's pressure for the lubrication of diesel motor. When the pressure is lower than the limited value the led diode H19 is activated. B12 follows the level of water in the tank of the engine. When the level is less than the permissible value led diode H22 is activated.

We said that at the older stationary mining machines circuit for protection is limited only to the control with adequate signalling, when some of the variables exceed over the allowable controlled values. According to the experiences this is a disadvantage of these systems. Namely, in the case of large stationary mining machines with capital importance for manufacturing process, the role of man – handling should be minimized. Because the working process is difficult, operator of the machine after a certain time at work shows signs of fatigue. So his reaction reduces when magnitudes of the variables important for the machine overcome the critical values. This could result with defect of the machine, and cause big material costs (not only machine damage, but also the machine can be excluded from the production provisionally). Therefore, the electronic circuit, which is subject of this paper, enables when some of the variables important for the operation of the machine exceed the allowed values, machine is going to shut down and the data for this to be preserved for future evaluation with date log system.

2.2. Circuit for protection. The circuit for protection is part of the electronic system which manages with the functions of the hydraulic excavator. It is designed as a result of requirements for improving the efficiency of operation on the excavator and for protection of important parts of excavator (motors, shaft). With the electronic system are covered, [6]:

- Electronic circuit for management of the operation and shutting down of the engines.
- Electronic circuit for protection of the engines from small oil's pressure, high temperature.
- Electronic circuit for optimization of the system for loading of the excavator.
- Electronic circuit for lubrication of the shaft of the excavator.

2.2.1. Description of circuit for protection. In Figure 3 a circuit is given for protection. The circuit for protection has a task to monitor the state of the signals for a level on water for cooling in the tank, the temperature of the diesel engine, the temperature of the shaft, the oil's pressure for lubrication of the engine, the shaft and the hydraulic. The circuit for protection sends signal to the circuit for control of the operation of the engines and signal to the PLC (programmable controller) for monitoring the status of the excavator, based on the state of these signals. Incoming signals in the circuit for protection given in Fig. 3, [4, 6], are: signal from sensor B12 for level on water in the tank (PN), signal from thermal switch B35 for temperature of the engine (PT1), signal from thermal switch B36 for temperature of the shaft (PT2), B33 signal from the switch of oil's pressure for lubrication of the engine (PU1), signal from the oil's pressure switch B34 for lubrication of the shaft (PU2) and the signal from the switch of hydraulic pressure B37, (PU3). The circuit for protection activates when any of these sensors set logical 0 on their input. Also the signal Q1 is input to circuit for protection. Q1 is connected in the circuit for protection through opto isolator (circuit 4N26). Q1 is the voltage signal from the alternator G9 of the diesel engine. Q1 is a logical 0 when the engine does not work (then the transistor T' is switched on and the circuit for protection is without voltage). When the engine works, the voltage of Q1 moves in the rang of 24–28 V and it is regulated by voltage regulator of the alternator. The signal Q1 enables the circuit for protection to be activated only when the engine works but not when the motor starts. For example, during the start, the pressure switch B33 provides a logical 0 on the input of circuit for protection, but Q1 is still on 0 V, the circuit for protection will not be activated. Now, we are analysing the operation of circuit for protection (see Fig. 3). When the engine is in operation, Q1 is at 24 V (transistor T' is turned off and the circuit for protection is connected on the supply voltage). Now if one of the sensors set logical 0 in circuit, the voltage at the base of the transistor T_3 will be reduced. This will switch on transistorsT_3. In this case its collector is set to the logical 1. This logical 1 activates monostable multivibrator realized with the circuit IC_7 (NE555). Time member of the circuit IC_7 is determined by condensate C_{22} and resistor R_{18}. The logical 1 of pin 8 and 4 from circuit IC_7 sets output pin 3 to logical 1. This switches on the transistor T_4, so the voltage on its collector is set to logical 0. The collector on the transistor T_4 is connected through the diode D_6 with reset input of the circuit for switching off the diesel engine. Also the collector on the transistorT_4 is connected with the circuit for signaling, realized by the circuit IC_{11B}. After the time T defined by condensate C_{22} and resistor R_{18}, output 3 of he IC_7 is set up to logical 0. This switches off the transistor T_4. Now its collector is set up to a logical 1. This logical 1 disables the circuit for the operation of the engine through the diodeD_6. Thus, in this moment the circuit for switching off the engine is sending a signal for stopping the engine. On the other hand, the occurrence of logical 1 on the collector of transistor T_4 activates the circuit IC_{11B}, setting up its Q output to a logical 1. This logical 1 activates the led diode LD_6. So, finally the engine is turned off and led diode LD_6 is activated. Led diode LD_6 indicates that the engine is turned off because some of the function for protection is activated. Time of quasi stable state of the monostable is:

$$T = C_{22} R_{18} \ln 3, \quad R_{18} = 90\, k\Omega,\ C_{22} = 100\, \mu F \tag{1}$$

$$T = 9.9 \text{ s} \approx 10 \text{ s}$$

The capacitances C_{20}, C_{21} protect the circuit from induced voltage of the alternator. The capacitor C_{23} allows flip-floppy IC_{11B} to be set in the reset state with connecting on the supply voltage. The circuit NE555 in Fig. 3 works in a modified variant. In a classical application pin 2 of the circuit NE555 is set up with a low level of the voltage of the capacitor C_{22} (1/3Vcc). The pin 6 (pin 6 and pin 7 are together) is set up with high level of the voltage of the capacitor C_{22} (2/3Vcc). The pin 7 is connected to the internal transistor in the circuit NE555. Through this transistor the capacitor discharges when NE555 works as a classical multivibrator. In Figure 3 the pin 7 is not connected. Namely by switching on of the supply voltage the pin 2 is on low voltage level (capacitor charges). Output, pin 3 is on high voltage level. When the voltage of the capacitor reaches 2/3Vcc,

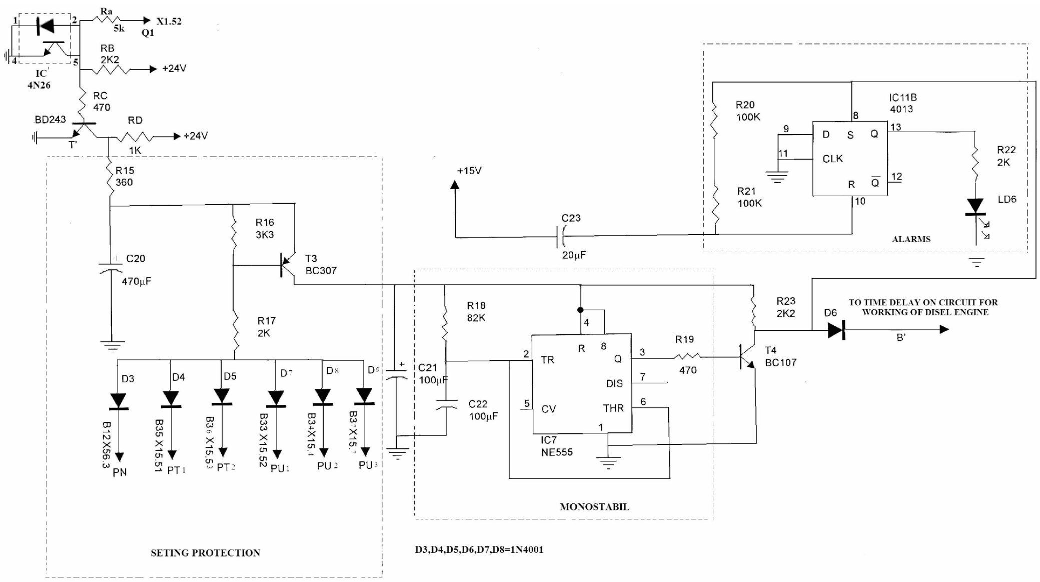

Fig. 3. Circuit for protection

the pin 6 (joins with the pin 2 in Fig. 3) sets the circuit NE555 and its output 3 is set up in logical 0. Now because the pin 7 is not active, the capacitor does not discharge through the internal transistor from the circuit NE555. Such state remains until the circuit is connected of the supply voltage. The capacitor is full and the output 3 from NE555 is logical 0.

2.2.2. Results from simulations of circuit for protection. The computer simulations for circuit of the protection are made in PowerSim programme, [7]. In the circuit for simulation one of the functions of protection (temperature, pressure, level) is simulated with function generator with frequency $f = 0.1$ Hz. The wave forms of voltage on the input in the circuit (point 8, or PN), collector of the transistor T_4 (point 13, or B') and Q (point 16) output the circuit IC_{11B} are given in Fig. 4. Low level of the impulse of the generator simulates that one from the functions of protection is activated (time t_4 in Fig. 4). In that moment logical 1 should appear on the collector of transistor T_4 with time delay defined with C_{22} and R_{18} (time t_5 of Fig. 4). The logical 1 activates the circuit IC_{11B}, which switches on lamp Si connected to his output.

Based on the results of the simulation, we can conclude that the circuit for protection of the excavator as it is constructed works properly. Practically realized circuit for protection of the excavator based on the research, subject of this paper is given in Fig. 5.

2.3. Improving the operation of circuit for protection. The electronic circuit presented in this paper significantly improves the operation of diesel en-

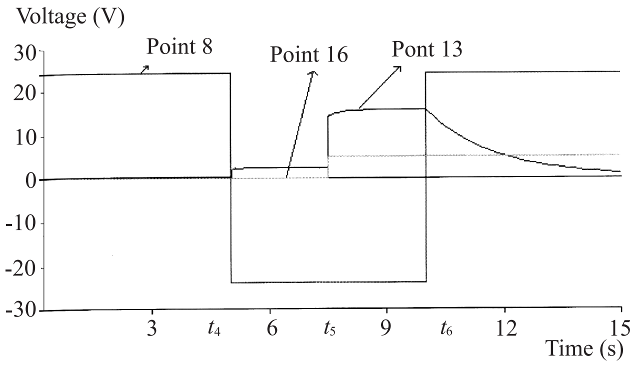

Fig. 4. Wave forms on the voltage in point 8 (PN), 13 (B') and 16

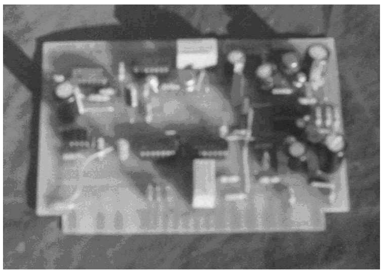

Fig. 5. Practically realized circuit for protection on the excavator

gines. Also the overall functionality of the excavator is increased. With its implementation subjective factor of the handler is reduced and the operation of the machine is followed automatically. But, this solution can also be improved. By installing adequate hardware and software, data valid for the function of protecting of the machine are collected and distributed. This is achieved by introducing a programmable logic controller.

The procedure begins by placing the sensors-transducers on adequate places on the working machine. The transducers receive a signal from the measuring place and they are transforming this signal into electrical one, adjusted for the input of the programmability controller. Measuring locations are: the temperature of engine, the temperature of the shaft, the temperature of air, the oil's pressure on the engine, the oil's pressure on the shaft, the oil's pressure of the hydraulic, the flow of oil for shaft, the flow of water for cooling.

Date log system. The signals from the transducers are connected to the programmable logic controller. The controller has a task: to accept signals from the transducers, to process them, to visualize the numerical values of the received signals with bar graph, to create date log file and to connect it to the computer (notebook) with communication port via adequate protocol. Input and output signals in PLC are from: Analog type, Frequency type and Relay type. The communication between PLC and computer and between PLC and PLC is realized with protocol via connection RS232 or RS485.

3. Conclusion. In the paper is given a solution of circuit for protection of operation of the hydraulic excavator. The solution is practically applied in the hydraulic excavator Orenstein Koppel in one of the mines in Macedonia. With its implementation the overall functionality of the excavator is improved and subjective factor of the operator is eliminated. The primary circuit for protection with small modification can be implemented in other stationary working machines (diesel electrical aggregate, pumps, compressors). Expansion of the circuit for protection by adding date log system enables, the data relevant for the work of the excavator to be gathered, processed and used. It is an important feature in the process of diagnosis of the state of excavator and also facilitates the work of the people for maintenance of the machine.

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