Development of an electronic control module and research of dynamic and power characteristics of an electromagnetic hammer for destruction of boulders.

Konstantin Vasin[1,2*], *Yerik* Yedygenov[1], *Nakhypbek* Aldiyarov[2] and *Vladimir* Voronin[3]

[1]D.A. Kunaev Institute of mining, Almaty, Kazakhstan
[2]K.I. Satpayev Kazakh National Research Technical University, Almaty, Kazakhstan
[3]Pacific National University, Khabarovsk, Russia

Abstract. The developed electronic control module of an electromagnetic hammer for destruction of boulders is described and studied in the article. The possibility of using an inductive slot sensor for both controlling electromagnets and for measuring dynamic and energy characteristics is demonstrated. During the research of the possibility of controlling the impact energy of an electromagnetic hammer, the advantage of the method of adjusting the height of the lifting of the armature in relation to the method for controlling the magnitude of the electric current of the electromagnets is clarified.

1. Introduction

Currently, in the mining industry, the mechanization of technological processes is carried out by high-impact machines, mainly hydrohammers, which have a significant drawback associated with the multiple conversion of energy from one type to another.

The research shows that the creation of electromagnetic hammers is perspective way of developing such machines [1,2,3]. The main advantages of electromagnetic hammers in comparison with other types of impact machines are: the simplicity of construction and the absence of high precision parts; transformation of electrical energy directly into the kinetic energy of a rectilinearly moving peen; the possibility of transmitting electricity over significant distances, which is a very important factor in the creation of a number of machines; great opportunities in increasing reliability and efficiency.

[*] Corresponding author: kvas2500@mail.ru

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).

2. The Theory and Methods of Experimental Research

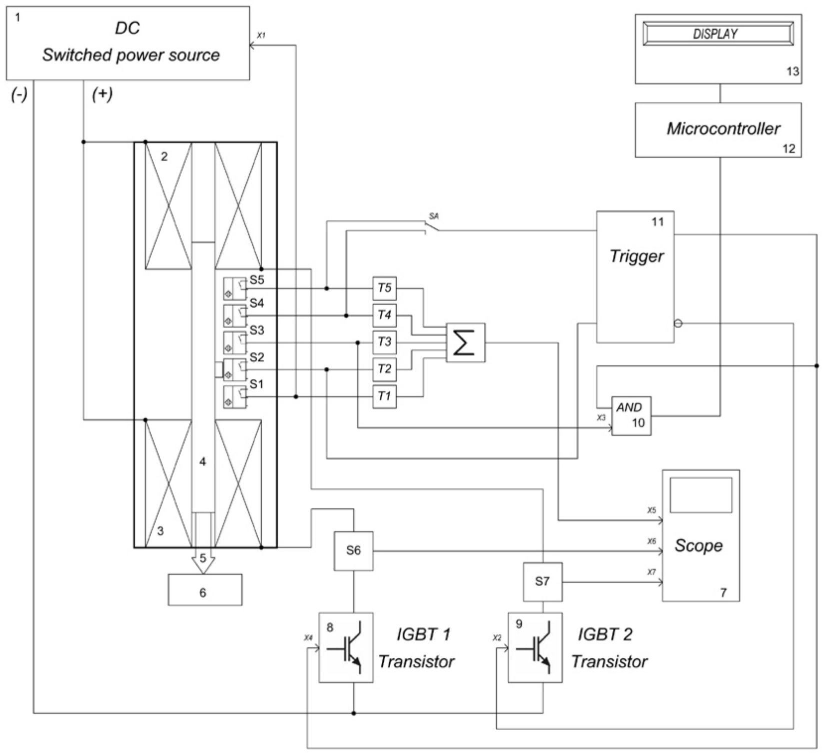

Fig. 1. Electronic control module for electromagnetic hammer.

The developing an electronic control module for electromagnets is very important in developing an electromagnetic hammer. The scientific novelty of this research is the use of an inductive slot sensor for both controlling electromagnets and for measuring dynamic and energy characteristics. Figure 1 shows the circuit diagram of the electronic control module of the electromagnetic hammer.

The simplest electromagnetic hammer has two electromagnets. No.2 is the electromagnet of idling. He draws the armature (No.4) up. No.3 is the electromagnet of the working stroke. He pulls the armature (No.4) down. The armature transfers the energy of impact through the peen (No.5) to the collapsible boulder (No.6). The armature (No.4) has a protrusion for the inclusion of inductive gap sensors as the idle and working motion. In this electronic control module, we have applied five inductive slot sensors (S1-S5). The sensor S1 is used to turn on the electric power of the electromagnets when the peen (5) is pressed against the broken boulder (No.6) and to cut off the electrical supply of the electromagnets when the oversize collapses and the peen (No.5), together with the armature (No.4), fall into the lower position. In this case, the sensor S1 is triggered and the signal X1 turns off the switchable electric power supply (No.1) with a direct current. The sensor S2 is triggered when the electromagnetic hammer is pressed against the next boulder and the peen (No.5), together with the armature (No.4), ascends to the working position. The signal from the sensor S2 switches the trigger control device (No.11) which generates the signal X2 and opens the second power IGBT transistor (No.9). This power transistor turns on the electromagnet of idling and the armature (No.4) rises. The upper position of the armature (No.4) is controlled by the sensors S4 and S5, signals from which through the switch SA, switch the trigger device (No.11). Sensor S5 operates at full idling, i.e. when lifting the armature to full height. Sensor S4 operates at the middle of idle and shortens the height of the armature, thus reducing the working stroke and, accordingly, the impact energy. At the output of the trigger device, the signal X2 is turned off and through the second power transistor (No.9) disconnect the electromagnet of idling (No.2), and the signal X4 is turned on and opens the first power IGBT transistor (No.8). The first power transistor (8) turns on the electromagnet of the working stroke (No.3) and the armature (No.4) accelerates and strikes the peen (No.5). The sensor S2 is triggered and the duty cycle is repeated until the boulder is destroyed.

The S3 sensor is used to measure the speed of an armature. The inductive slot sensor remains in the on state until the armature protrusion travels in the sensor slots 23 mm apart. To isolate the signal from the sensor S3 during the working movement of the armature, the "AND" element of the module (No.10) is applied. The signal is emitted to the microprocessor controller (No.12), where the signal duration is measured, followed by calculating the armature (No.4) speed and the impact energy of the peen's strike (No.5).

The speed of movement of the armature is calculated by the formula:

$$V = \frac{l}{t}; \quad (1)$$

V – the speed of the armature movement (m / sec);
l – the distance of the armature movement (m);
t – the time of the armature movement (sensor signal time) (sec).
The impact energy of the peen is calculated by the formula:

$$E = \frac{m * V^2}{2}; \quad (2)$$

E – the energy of a single impact of the peen transmitted by the armature (J);
m – the mass of the armature (kg);
V – the speed of movement of the armature (m / sec).

Calculated by the microprocessor controller (No.12) energy of a single impact of the peen is displayed on the display, indicated on the diagram (No.13).

In addition to measuring and calculating the signal by the sensor S3, the signals of all inductive sensors are emitted to attenuators, where they are scaled in level and then are emitted through the mixer to a multichannel electronic oscilloscope in the form of the common signal X5. Simultaneously with the signal X5, signals X6 and X7 from the sensors S6 and S7 are emitted to the multichannel electronic oscilloscope carrying information about the change in the electric current in the coils of the working and idling, respectively.

On the oscillogram, the signals from the sensors S1-S5 are separated in time and differ in amplitude. For this reason, they are easily distinguishable. In addition to illustrating the general nature of the armature movement when idling and running, the oscillogram allows to measure the signal duration from the S3 sensor for subsequent manual calculations.

3. Results and discussions

Investigations of the electronic control module for electromagnets were carried out on an experimental electromagnetic hammer, developed in the laboratory "Destruction and Delivery of Rocks" of the D.A. Kunaev Institute of Mining. The electronic control module of the electromagnetic hammer was investigated in three operating modes of the hammer:

1) The work of an electromagnetic hammer with a current of electromagnets is 80 amperes. The total stroke of the idle and working motion, i.e. switching on the signal from the sensor S5;

2) The work of an electromagnetic hammer with a current of electromagnets is 100 amperes. The total stroke of the idle and working motion, i.e. switching on the signal from the sensor S5;

3) The work of an electromagnetic hammer with a current of electromagnets is 100 amperes. Incomplete stroke of idle and working motion, i.e. switching on the signal from the sensor S4.

Figures 2 and 3 show oscillograms of the first two operating modes of an electromagnetic hammer. The upper graph shows the signals from the inductive sensors S2-S5. Sensor S1 is not used, because the experimental hammer is mounted on the stand, and the hammer strikes the metal bar. The average graph shows the electric current's change during the operation of the idling electromagnet, i.e. when the armature moves up. The lower graph shows the change in the electric current when the electromagnet of the working stroke is operating, i.e. when the armature moves down.

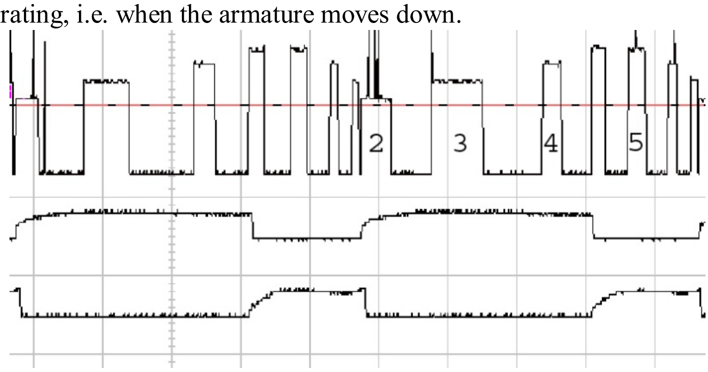

Fig. 2. Operating mode of the electromagnetic hammer No. 1 (80A, S5).

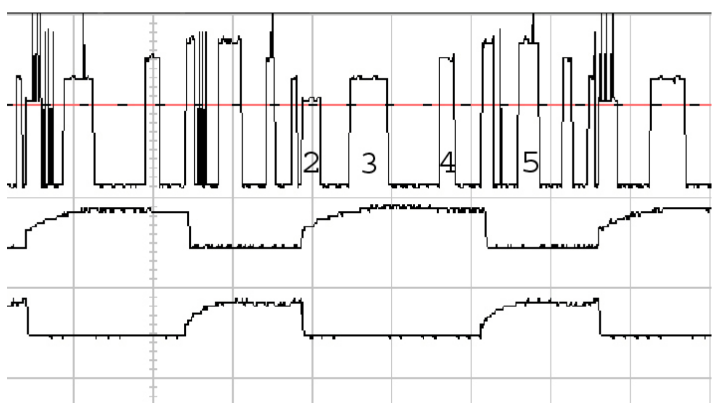

Fig. 3. Operating mode of the electromagnetic hammer No. 2 (100A, S5).

Figure 4 shows an oscillogram of the third mode of operation of an electromagnetic hammer when current of electromagnets is 100 amperes and an incomplete idling and working stroke of the armature. The armature does not go up to the S5 sensor. Therefore, the upper graph shows the signals from the inductive sensors S2-S4.

On the oscillograms of the digital oscilloscope, the periods of the full cycle and the duration of the signal of the sensor S3 were measured during the working stroke of the armature. Then, using formulas 1 and 2 for l = 23mm and m = 90 kg, the armature velocities and the impact energy of the peen were calculated for all three operating modes of the electromagnetic hammer. The results are shown in the table 1.

Fig. 4. Operating mode of the electromagnetic hammer No. 3 (100A, S4).

Table 1— The results of measurements and calculations.

Mode No.	**Period, msec**	**Number of hits per minute**	**Duration of S3, msec**	**Speed, m/sec**	**Hit energy, J**
1	500	120	8	2,875	372
2	380	158	6	3,833	661
3	370	162	8	2,875	372

The results of calculations show that energy of impact of an electromagnetic hammer can be managed both by change of force of an electric current in electromagnets, and by shortening of a working course of an armature. In this case, the method of shortening the working stroke of the armature makes it possible to substantially increase the frequency of impacts at the same impact energy. This is important in the destruction of boulders. In addition, there is no need to use a bulky and expensive voltage regulator of voltage for powering an electromagnetic hammer.

The use of a microprocessor controller for measuring of the duration of the signal from the S3 sensor with subsequent calculations allows you to monitor the impact energy in real time.

4. Conclusions

Therefore, the developed electronic control module of the electromagnetic hammer for the destruction of boulders allows you to change and explore the operating modes of the hammer and can be used for testing new models.

References

1. Electromagnetic hammers. Ed. A.T. Malova, N.P. Riashentseva, Novosibirsk, "Nauka", (1979).
2. E.K. Yedygenov, V.I. Lyashkov, N.N. Neborokova, Electromagnetic strike machine for the destruction of rocks // Scientific and technical support of mining. 80. (2010).
3. Yedygenov E. Lyashkov V. Electromagnetic rock breaker for non-explosive rocks breaking // The 20th International Symposium on Planning of Mining and Selection of Equipment MPES 2011 Almaty (2011).