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«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

Х А Б А Р Л А Р Ы

ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК РЕСПУБЛИКИ КАЗАХСТАН»

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JUSTIFICATION FOR CHANGES IN THE DESIGN OF THE ROCK-BREAKING ELECTROMAGNETIC HAMMER FOR ITS ENHANCED EFFICIENCY

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Abstract. In the mining industry, when breaking rocks, oversized pieces are formed that exceed the dimensions of the technological equipment. To carry out secondary rock fragmentation in quarries, it is proposed to use an electromagnetic hammer. At the D.A. Kunayev Institute of Mining, a prototype of a medium-class electromagnetic hammer with an impact energy of up to 6000 J has been developed. The use of the electromagnetic hammer for breaking oversized pieces in the mining industry will increase the efficiency, environmental friendliness, and automation of the technological processes of rock and ore fragmentation. To develop a competitive prototype of a rock-breaking hammer, it is necessary to justify its dynamic parameters. A microprocessor-based measurement system was developed to measure the dynamic parameters of the prototype of the electromagnetic hammer, followed by the calculation of the energy characteristics of the prototype using the software “Matlab.” A digital sensor “HC-SR04” and a microprocessor controller “Arduino Mega 2560” were used to measure the height of the moving part of the electromagnetic hammer. To eliminate measurement errors, calculate the dynamics of the plunger’s velocity, acceleration and impact energy values, and plot the dependency graphs, the “Matlab” program version R2021b was used. Experiments were conducted by supplying the power voltage to the upper coil with a current value of 120 amperes, while the lower coils received the power voltage with current values of 70, 100, and 120 amperes. The data obtained, after processing in the “Matlab” software, allowed for the construction of dynamic parameter graphs for the prototype. The analysis of the graphs revealed the design flaws of this prototype, the elimination of which will improve the technological characteristics of new developments.

Keywords: rock breaking, dynamic parameters, electromagnetic hammer, microprocessor measuring system, digital sensor, acceleration, impact energy.

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ТИІМДІЛІКТІ АРТТЫРУ ҮШІН ТАУ ЖЫНЫСТАРЫН БҰЗАТЫН ЭЛЕКТРОМАГНИТТІК БАЛҒАНЫҢ ДИЗАЙНЫН ӨЗГЕРТУ НЕГІЗДЕМЕСІ

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Аннотация Тау-кен өнеркәсібінде тау жыныстарын бұзу кезінде технологиялық жабдықтың өлшемдерінен асып түсетін көлемдегі ұсақталмаған кесектер пайда болады. Тау-кен карьерлерінде тау жыныстарын екінші рет бұзу үшін электромагнитті балғаларды қолдану ұсынылады. Д.А. Қонаев атындағы тау-кен институтында 6000 Дж дейін соққы энергиясы бар орташа класты электромагнитті балғасының тәжірибелік үлгісі жасалған. Электромагнитті балғаны тау-кен өнеркәсібінде ұсақталмаған кесектерді бұзу үшін қолдану технологиялық процестердің тиімділігін, экологиялық тазалығын және автоматтандырылуын арттыруға мүмкіндік береді. Бәсекеге қабілетті тау жыныстарын бұзу балғасының үлгісін әзірлеу үшін оның динамикалық параметрлерін негіздеу қажет. Электромагнитті балғаның тәжірибелік үлгісінің динамикалық параметрлерін өлшеу үшін микропроцессорлық өлшеу жүйесі жасалып, «Matlab» бағдарламалық жасақтамасы арқылы прототиптің энергетикалық сипаттамалары есептелді. Электромагнитті балғаның қозғалмалы бөлігінің биіктігін өлшеу үшін «HC-SR04» цифрлық сенсоры мен «Arduino Mega 2560» микропроцессорлық контроллері қолданылды. Өлшеу қателіктерін жою, плунжердің қозғалыс жылдамдықтарының динамикасын есептеу, үдеу мен соққы энергиясының мәндерін және тәуелділіктер графиктерін құру үшін «Matlab» бағдарламасы R2021b нұсқасы қолданылды. Эксперименттер барысында жоғарғы катушкаға 120 ампер ток мәнінде қоректендіру кернеуі берілді, ал төменгі катушкаларға 70, 100 және 120 ампер ток мәндерінде қоректендіру кернеуі берілді. «Matlab» бағдарламалық жасақтамасында өңделген деректер динамикалық параметрлер графиктерін құруға мүмкіндік берді. Графиктерді талдау осы үлгінің конструктивтік кемшіліктерін анықтап, оларды жою жаңа әзірлемелердің технологиялық сипаттамаларын жақсартуға мүмкіндік береді.

Түйін сөздер: тау жыныстарының бұзылуы, динамикалық параметрлер, электромагниттік балға, микропроцессорлық өлшеу жүйесі, сандық датчик, үдеу, соққы энергиясы.

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ОБОСНОВАНИЕ ИЗМЕНЕНИЯ КОНСТРУКЦИИ ПОРОДОРАЗРУШАЮЩЕГО ЭЛЕКТРОМАГНИТНОГО МОЛОТА ДЛЯ ПОВЫШЕНИЯ ЕГО ЭФФЕКТИВНОСТИ

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Аннотация. В горнодобывающей промышленности при разрушении горной породы образуются, негабаритные куски превышающие размеры технологического оборудования. Для вторичного разрушения породы в карьерах предлагается применять электромагнитный молот. В Институте горного дела им. Д.А. Кунаева изготовлен опытный образец электромагнитного молота среднего класса с энергией удара до 6000 Дж. Применение электромагнитного молота для разрушения негабаритов в горнодобывающей промышленности позволит повысить эффективность, экологичность и автоматизацию технологических процессов разрушения горных пород и руд. Для разработки конкурентного образца породоразрушающего молота необходимо обосновать его динамические параметры. Для измерения динамических параметров опытного образца электромагнитного молота была разработана микропроцессорная система измерения с последующим расчетом энергетических характеристик прототипа с использованием программного обеспечения «Matlab». Для измерения высоты подвижной части электромагнитного молота были применены цифровой датчик «HC-SR04» и микропроцессорный контроллер «Ардуино Мега 2560». Для устранения погрешности измерения, вычисления динамики скоростей движения плунжера, значений ускорения и энергии удара, а также построения графиков зависимостей была использована программа «Matlab» версии R2021b. Были проведены эксперименты при подаче питающего напряжения на верхнюю катушку при величине тока равном 120 ампер, а на нижние катушки подавалось питающее напряжение при величине тока равном 70, 100 и 120 ампер. Полученные данные после обработки в программном обеспечении «Matlab», позволили построить графики динамических параметров опытного образца. Анализ графиков выявил конструктивные недостатки этого образца, устранение которых позволит повысить технологические характеристики новых разработок.

Ключевые слова: разрушение горной породы, динамические параметры, электромагнитный молот, микропроцессорная измерительная система, цифровой датчик, ускорение, энергия удара.

Introduction. In the mining industry, there is the problem of secondary breaking of rock in quarries. In particular, oversized pieces of rock must be destroyed to a size adequate for processing equipment. To destroy brittle rocks, mechanical impact methods are used by means of pneumatic, hydraulic and electromagnetic hammers (EMH). The EMH has significant competitive advantages, since the electromagnetic drive can operate in severe weather conditions (low temperatures) and has higher efficiency due to the direct conversion of electrical energy into impact energy. In addition, the EMH is more suitable for automation, is less demanding in terms of precision in manufacturing, is more reliable and environmentally friendly, since it does not need oil stations, high-pressure hoses, etc. (Deniz, et al., 2016; Wu, et al., 2017; Lemos, et al., 2018; Zh, et al., 2023).

The Mining Institute after D.A. Kunaev works on creating mining machines with electromagnetic power pulse systems, where electrical energy converted into magnetic field energy performs mechanical work (Yedygenov, et al., 2011; Yedygenov, 2018; Vasin, et al., 2018; Vasin, et al., 2019; Yedygenov, et al., 2021). Currently, a prototype of a midrange electromagnetic hammer with a 6,000 J impact energy has been manufactured (Yedygenov, et al., 2020; Vassin, et al., 2020). The relevance of the EMH creation results from the need to destroy rocks in the severe weather conditions of Kazakhstan and the development of domestic mining engineering and reduction in import supplies of mining equipment.

The developed EMH is unique in that it can work as an attachment on any type of excavators (electric, hydraulic). The novelty of the technical solution embodied in the EMH is confirmed by copyright protection documents for intellectual property (Patent of the Republic of Kazakhstan No. 34351) (Yedygenov, et al., 2020).

Figure 1 shows the EMH units as attachments on the HYUNDAI 210 wheeled excavator and on a test bench equipped with a hydraulic lift.

Fig. 1 - Photos of the EMH units as attachments on the HYUNDAI 210 wheel excavator and on a test bench equipped with a hydraulic lift

The EMH includes three electromagnetic drives designed for the reciprocating movement of three anchors and a striker attached to them. Two drives are designed for forward (operating) stroke and one for reverse (idle) stroke.

To assess the real energy characteristics of the EMH prototype, it was necessary to study its dynamic parameters.

Materials and methods. To conduct scientific research into the dynamics of motion of the EMH moving part and to improve the accuracy of measurements, a microprocessor system for measuring dynamic parameters was developed that ensures the subsequent calculation of the energy characteristics of the prototype using the Matlab software.

The microprocessor system for measuring dynamic parameters of the electromagnetic hammer prototype consists of the Arduino Mega 2560 microprocessor controller and the HC-SR04 digital sensor measuring the height of the EMH moving part, which are shown in Figure 2.

Fig. 2 - Photos of the Arduino Mega 2560 microprocessor controller and the HC-SR04 digital sensor

The Arduino microcontroller and HC-SR04 digital sensor have been used in many projects (Aitimov, et al., 2017; Abdulkhaleq, 2020; Buktukov, et al., 2020; Turnip, et al., 2020; Abreu, et al., 2021; Sukri, et al., 2021; Buktukov, et al., 2023).

This sensor is mainly designed to estimate distance using a principle similar to that of radar distance measurement, which is shown in Figure 3.

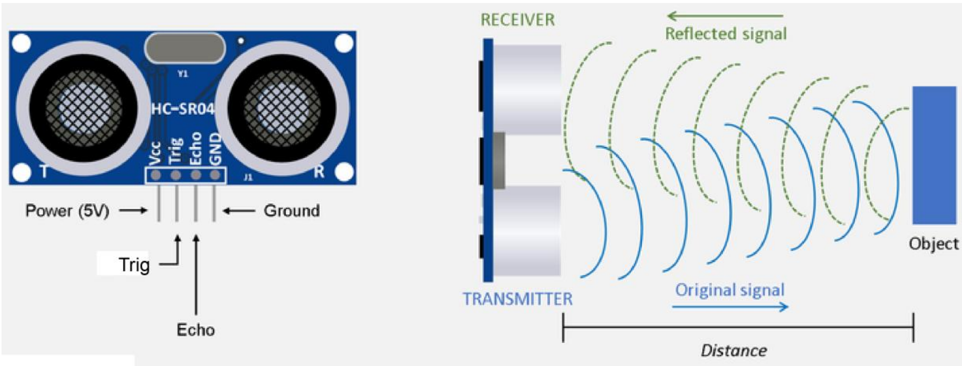


Fig. 3 - Diagram of the radar distance measuring principle

Figure 4 shows the installation of the Arduino Mega 2560 microprocessor controller and the HC-SR04 digital sensor on the electromagnetic hammer prototype.

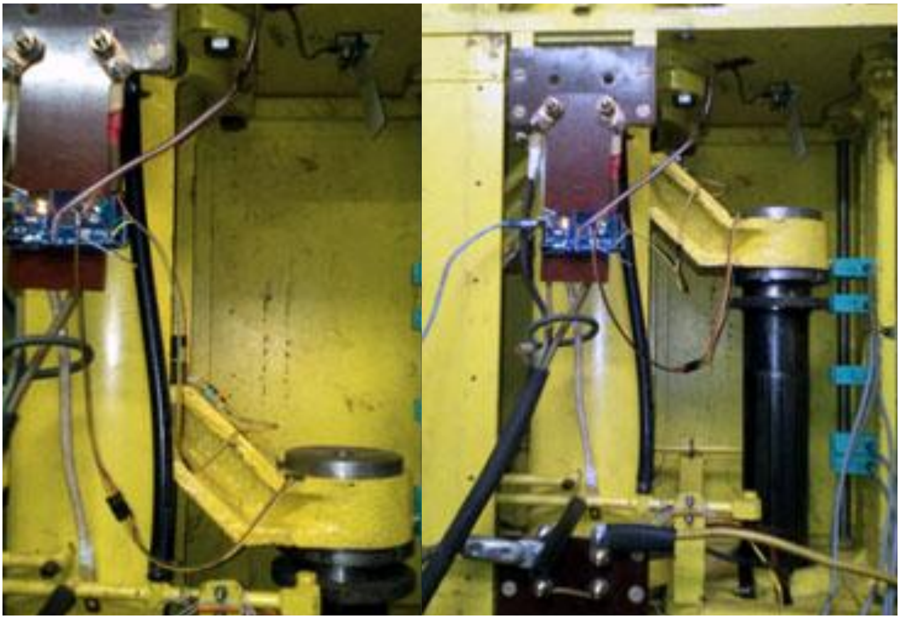


Fig. 4 - Photos of the installation of the Arduino Mega 2560 microprocessor controller and the HC-SR04 digital sensor on the prototype of the electromagnetic hammer.

Below is given the program code for measuring and transmitting the current time (in milliseconds) and plunger height (in millimeters) to the computer:

```
const int Trig = 12; const int Echo = 11; long t=0; // time in msec
void setup(){ pinMode(Trig, OUTPUT); pinMode(Echo, INPUT); Serial.begin(19200); accel.initialize();}
unsigned int time_us=0; unsigned int distance=0;
void loop()     {
digitalWrite(Trig, HIGH); // We send a signal to the output of the microcontroller
delayMicroseconds(10); // Hold for 10 microseconds
digitalWrite(Trig, LOW); // Then we remove
time_us=pulseIn(Echo, HIGH); // We measure the pulse length
distance=time_us/5.8; // Convert to millimeters
t=millis(); Serial.print(t); Serial.print("\t"); Serial.print(distance); // Output to serial port }
```

A serial port monitoring program was run on the computer. Next, the microcontroller and EMH prototype were switched on. After a series of impacts, the equipment was turned off. The result of the experimental data was loaded into the Matlab program to construct a graph of the dynamic movement of the plunger, which is shown in Figure 5.

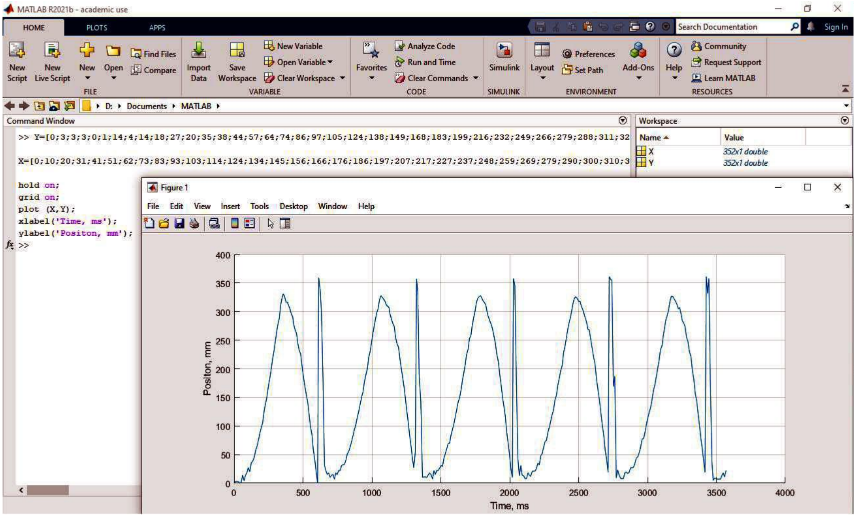
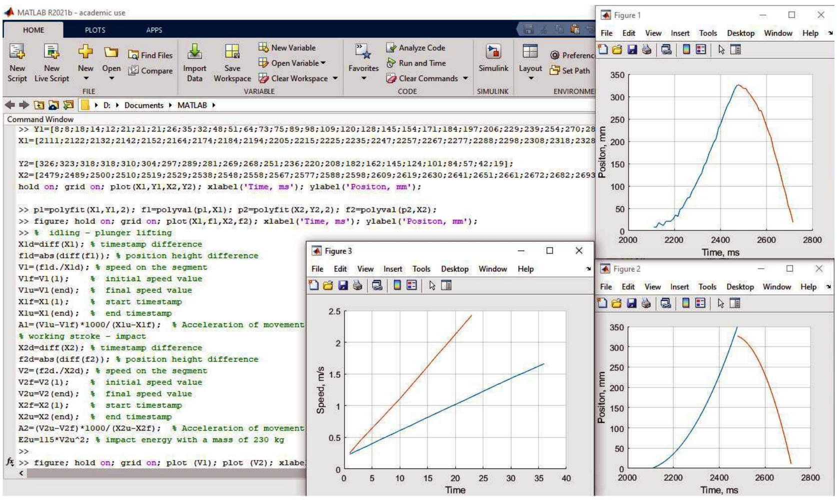


Fig. 5 - Plotting the graph of the dynamic motion of the EMH prototype's plunger

Figure 5 shows the up and down movement of the plunger and the moment of impact as a peak signal. The peak burst of the sensor signal occurs at the moment when vibration of the EMH metal structure reaches the piezoelectric elements of the sensor.

Figure 6 shows a snapshot of the Matlab software window after processing data arrays of the rise and fall of the EMH plunger in a single impact.



1 - Plotting the graphs of changes in plunger height (mm) versus time (ms); 2 - Plotting the graphs of approximated dependences of the change in plunger height on time; 3 - Plotting the graphs of the rate of change of plunger height versus time

Fig. 6 - Snapshot of the Matlab software window after processing data arrays

Figure 6 shows the Matlab software window with the results of measurements using the microprocessor system in the form of data arrays and plotting the dependency graphs of the change in plunger height (mm) versus time (ms):

Y=[8;8;18;14;12;21;21;21;26;35;32;48;51;64;73;75;89;98;109;120;128;145;154;171;184;197;206;229;239;254;270;281;289;302;315;324;326];

X1=[2111;2122;2132;2142;2152;2164;2174;2184;2194;2205;2215;2225;2235;2247;2257;2267;2277;2288;2298;2308;2318;2328;2339;2349;2360;2370;2381;2391;2401;2411;2422;2431;2440;2450;2460;2470;2479];

Y2=[326;323;318;318;310;304;297;289;281;269;268;251;236;220;208;182;162;145;124;101;84;57;42;19];

X2=[2479;2489;2500;2510;2519;2529;2538;2548;2558;2567;2577;2588;2598;2609;2619;2630;2641;2651;2661;2672;2682;2693;2703;2714];

hold on; grid on; plot(X1, Y1,X2,Y2); xlabel('Time, ms'); ylabel('Positon, mm');

Y1, X1 – arrays of the idle stroke. Y2, X2 – arrays of operating stroke. Y – the plunger's Haight in mm. X – time marks in ms.

The graphs in Figure 6.1 show that the plunger height measurement sensor has random errors. To eliminate them, data arrays are processed using the approximation function by a 2nd order polynomial:

p1=polyfit(X1, Y1,2); f1=polyval(p1,X1); p2=polyfit(X2,Y2,2);
f2=polyval(p2,X2);

Next, graphs of the approximate dependences of the change in plunger height on time are plotted, which are shown in Figure 6.2:

figure; hold on; grid on; plot(X1, f1,X2,f2); xlabel('Time, ms'); ylabel('Positon, mm');

The data arrays are then processed to calculate changes in plunger speeds as well as acceleration and impact energy values:

```
% idling - plunger lifting
X1d=diff(X1); % timestamp difference
f1d=abs(diff(f1)); % position height difference
V1=(f1d./X1d); % speed on the segment
V1f=V1(1); %  initial speed value
V1u=V1(end);  %  final speed value
X1f=X1(1);    %  start timestamp
X1u=X1(end);  %  end timestamp
A1=(V1u-V1f)*1000/(X1u-X1f);  % Acceleration of movement
% working stroke - impact
X2d=diff(X2); % timestamp difference
f2d=abs(diff(f2)); % position height difference
V2=(f2d./X2d); % speed on the segment
V2f=V2(1);    %  initial speed value
```

V2u=V2(end); % final speed value
X2f=X2(1); % start timestamp
X2u=X2(end); % end timestamp
*A2=(V2u-V2f)*1000/(X2u-X2f); % Acceleration of movement*
*E2u=115*V2u^2; % impact energy with a mass of 230 kg*
figure; hold on; grid on; plot (V1); plot (V2); xlabel('Time'); ylabel('Speed, m/s');

Figure 6.3 shows the graphs of the rate of change in plunger height versus time.

Results. The following experiments were done:

1st — the idle stroke operated at the supply of voltage to the upper coil at a current value of 120 amperes, and during the working stroke, the voltage was supplied to the lower coils at a current value of 70 amperes;

2nd — the idle stroke operated at the supply of voltage to the upper coil at a current value of 120 amperes, and during the working stroke, the voltage was supplied to the lower coils at a current value of 100 amperes;

3rd — the idle stroke operated at the supply of voltage to the upper coil at a current value of 120 amperes, and during the working stroke, the voltage was supplied to the lower coils at a current value of 120 amperes.

For each experiment, the data for five impact cycles was selected and loaded into the working window of the Matlab program. The calculation results are shown in Table.

Table - Calculation results

№	Acceleration UP, m/s^2					Acceleration Down, m/s^2					Impact energy , J				
	Up1	Up2	Up3	Up4	Up5	Down 1	Down 2	Down 3	Down 4	Down 5	Imp1	Imp2	Imp3	Imp4	Imp5
1	5,4	4,0	3,4	3,9	4,2	7,2	9,3	9,3	9,3	9,2	580	660	710	678	669
2	5,3	2,6	3,2	3,4	2,9	9,1	13,4	12,4	13,4	13,5	712	956	949	940	1007
3	5,8	2,8	1,3	2,4	2,1	10,3	14,7	14,4	13,9	15,3	759	1090	1102	1031	1092

Using the obtained data and Matlab software, graphs of the dynamic parameters of the prototype were constructed, which are presented in Figure 7.

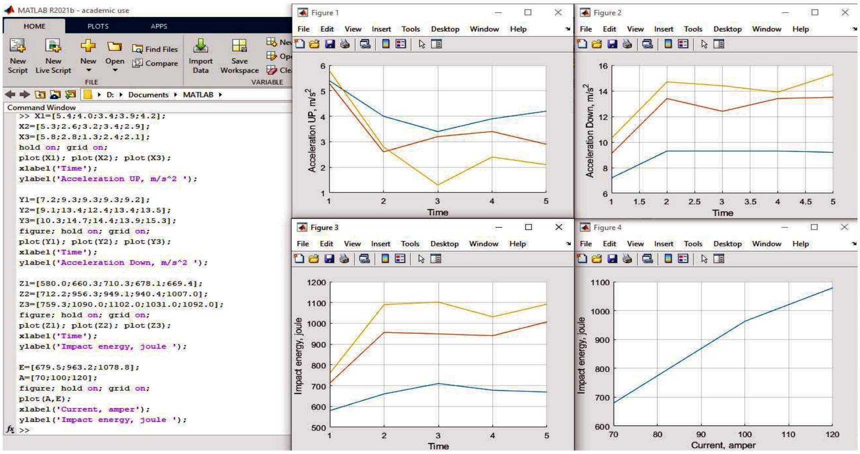


Fig. 7 - Plotting the graphs of dynamic parameters of the prototype of the electromagnetic rock-breaking hammer

Figure 7.1 shows the changes in the acceleration of the plunger rise during the first five impact cycles in different experiments.

Figure 7.2 shows the changes in the acceleration of the plunger fall during the first five impact cycles in different experiments.

Figure 7.3 shows the changes in impact energy during the first five impact cycles in different experiments.

Figure 7.4 shows the dependence of the average energy from the second to the fifth impact cycles on the current value in the electrical windings of the electromagnetic coils of the operating stroke.

Discussion. The graph in Figure 7.1 shows that the acceleration of the plunger during the idle stroke of the first impact cycle has an almost equally high value, and during the rest of the impact cycles the value decreases in proportion to the current increase in the windings of the electromagnetic motors of the operating stroke. This is due to the magnetization of the armatures of the lower electromagnetic motors. The higher the current in the electromagnetic coils, the higher the residual magnetization.

From the graph in Figure 7.2 it follows that the acceleration of the plunger during the operating stroke of the first impact cycle has a low value; and during the rest of the impact cycles the value increases in proportion to the current increase in the windings of the electromagnetic motors of the operating stroke. This is due to the magnetization of the armatures of the lower electromagnetic motors. Residual magnetization increases the traction force of the armatures in the electromagnetic coils.

The dependence shown in Figure 7.3 suggests that the impact energy of the first technological cycle has a low value, and during the rest impact cycles the value increases in proportion to the current increase in the electrical windings of the coils of electromagnetic motors of the operating stroke. This is due to the magnetization of the armatures of the lower electromagnetic motors. Residual magnetization increases the traction force of the armatures in the electromagnetic coils.

From the graph in Figure 7.4 it is clear that the dependence of the average energy from the second to the fifth impact cycles on the current value in the electrical windings of the electromagnetic coils of the operating stroke increases, but having reached 100 amperes the growth in value decreases.

Conclusion. The results obtained show that the magnetization-demagnetization time of electromagnetic motor armatures exceeds the duration of the production operating cycle. This is connected with the armature material, which has a large hysteresis loop. To increase the efficiency of the EMH, the selected armature material should have a minimum hysteresis loop value. In addition, the decrease in the impact energy growth as the current in the electrical windings of the electromagnetic coils of the operating stroke increases and the nonlinearity of accelerations of the plunger from the second to the fifth impact cycles give evidence that the influence of the lateral attraction of the armatures on the friction forces in the moving unit of the impact element.

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