

Linear electromagnetic drive of impact machines with retaining striker

V Yu Neyman, A V Markov

Novosibirsk State Technical University, 20, Karla Marksa Av., Novosibirsk, 630073, Russia

E-mail: nv.nstu@ngs.ru

Abstract. The problems of creation and improvement of linear electromagnetic machines of impact action used in mining and construction, geological exploration, immersion of anchors, piles and other special impulse technologies are considered. The expediency of using the operating mode in the work cycle ensuring the initial supply of magnetic energy at the stage of starting the striking mass of the striker is shown. It is proved that the use of this mode makes it possible to increase the impact energy and the efficiency of an impact electromagnetic machine.

1. Introduction

Carrying out mining and construction work, geological exploration, immersion in the anchor ground, piles and other special impulse technologies is connected with the use of impact machines [1-3].

The use of electromagnetic pulse machines for these purposes simplifies the process of shock interaction with a deformable surroundings [4-7].

Experience in the operation of machines and mechanisms with electromagnetic drive shows a relatively high reliability, increased service life, low costs in production and operation.

Methods for calculating and engineering systems with electromagnetic drive are widely known and continue to be improved [8-13].

One of the promising areas of research in this area is the creation and improvement of impact machines with high impact energy due to the use of new control methods. One of these methods of control is the momentary retention of the striker when the voltage is applied to the winding of the electromagnetic motor.

As you hold the striker, the starting time and the touching current increase, and the movement time decreases. The analysis of the LEMD work processes with spring return allows one to increase to some degree the dynamic efficiency of the engine by increasing its speed of movement and mechanical energy at the output by increasing the counteracting force.

One of the effective methods we developed for boosting power electromagnetic motors is the accumulation of magnetic energy in our own system of inductances during the operating cycle.

Practical realization of the accumulation of magnetic energy in the inductances of the engine during the operating cycle consists in the artificial retention of the striker with a counter-acting force. An experimental test on physical models (Figure 1) showed that an increase in the counteracting force at the start-up stage in linear electromagnetic motors makes it possible to improve their specific power and energy characteristics.



The implementation of such device can be most simply carried out on the basis of the functional diagram shown in Figure 1. The device (Figure 1) includes the following nodes: DC power supply 1, control pulse generating unit 2, thyristor converter of working coil 3, control panel 4 and linear electromagnetic motor comprising a magnetic circuit 5, an excitation winding 6, a striker 7, a return spring 8. An arm restraint device is made on the basis of an electromagnet 9 with an external pulling armature 10. The electromagnet is controlled by means of a power supply and control device 11 by applying a voltage pulse, a specific duration to the excitation winding 12.

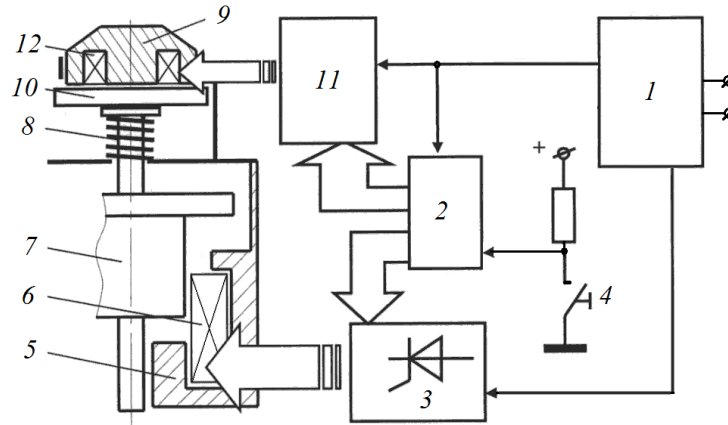


Figure 1. Electromagnetic shock actuator with retaining striker

2. Methods of analysis

To determine the influence of the retaining force of the striker on the energy and time characteristics of a pulsed electromagnetic motor, let us consider the equations of the balance of forces acting on the firing striker. In the period of touching, when the mobile system is at rest, the equation of the balance of forces of the mechanical system is described by equations:

$$\left[F_{em}(x) - F_{cf}(x) \right] \Big|_{t_{fr}=t_1} = 0 ;$$

$$m \frac{d^2 x}{dt^2} \Big|_{t_{fr}=t_1} = 0 ,$$

where m – striker mass, x – current coordinate of displacement, $F_{em}(x)$, $F_{cf}(x)$ – electromagnetic and opposing forces.

After the beginning of the movement, the equation of the balance of forces is described by the equation of motion of the mechanical system:

$$m \frac{d^2 x}{dt^2} = F_{em}(x) - F_{cf}(x) . \quad (1)$$

The efficiency of converting electromagnetic energy into mechanical work during the movement of a striker is determined by the characteristics of the flux linkage and the working gap.

For a linear magnetic system, the mechanical work of the engine is represented in the form of an area of an elementary magnetic cycle that determines the mechanical work in the form:

$$A = \frac{1}{2} (i_1 \psi_2 - i_2 \psi_1) , \quad (2)$$

where i_1, ψ_1 – initial value of current and flux linkages corresponding to the moment of starting; i_2, ψ_2 – the values of these same quantities at the time of the end of the movement.

During the motion, the electromagnetic engine overcomes the opposing force $F_{cf}(x)$. The current at which the pulling force $F_{em}(x)$ becomes equal to the opposing $F_{cf}(x)$, determines the beginning of the movement of the striker and determines the starting current. When the current is lower than the starting current, the striker is at rest.

Let us imagine the current and flux linkage at the moment of starting in the form:

$$i_1 = \sqrt{2F_0 x_1 / L_1} \quad (3)$$

$$\psi_1 = \sqrt{2F_0 x_1 L_1} \quad , \quad (4)$$

where L_1 – initial inductance corresponding to the initial working air gap x_1 , F_0 – force resistance to movement of the striker at the time of starting.

Let us assume that the reaction force is changed as follows:

$$F_i = \begin{cases} F_0 & \text{at } t \leq t_0 \text{ and } x = x_1 \\ F_{cf}(x) & \text{at } t \geq t_0 \text{ and } x \leq x_1 \end{cases} \quad (5)$$

The equation of the energy balance of a mechanical system during the movement of a striker will have the form:

$$\int_{v_1}^{v_2} mv dv = \int_{x_1}^{x_2} F_{em}(x) dx - \int_{x_1}^{x_2} F_{cf}(x) dx, \quad (6)$$

where v_1 , v_2 – initial and final speed of the striker.

The first term on the right-hand side of (6) determines useful mechanical work, which is equal to the area bounded by this characteristic on the displacement interval $x_1 \dots x_2$ and the abscissa axis at a certain current value:

$$\int_{x_1}^{x_2} F_{em}(x) dx = \frac{1}{2} (i_1 \psi_2 - i_2 \psi_1). \quad (7)$$

Under the electromagnetic force $F_{em}(x)$ in equation (7), static force $F_{cf}(x)$ is understood. The kinetic energy of the striker at the end of the stroke is taken equal to zero $m \frac{d^2 x}{dt^2} = 0$.

Then equation (6) takes the form:

$$\int_{x_1}^{x_2} F_{em}(x) dx = \int_{x_1}^{x_2} F_{cf}(x) dx. \quad (8)$$

In this case, the entire energy of the magnetic field is converted into mechanical work. It follows from (8), with the greater force $F_{cf}(x)$, there must be more strength $F_{em}(x)$.

If equality (8) is not satisfied, then at the end of the stroke the anchor acquires a certain speed v_2 . In this case, the driving force will be equal to some dynamic thrust force. In this case, the expression (6) after integrating the left-hand side can be represented in the form:

$$\frac{mv_2^2}{2} - \frac{mv_1^2}{2} = \int_{x_1}^{x_2} F_{em}(x) dx - \int_{x_1}^{x_2} F_{cf}(x) dx.$$

According to the initial conditions $v_1 = 0$, then:

$$\frac{mv_2^2}{2} = \int_{x_1}^{x_2} F_{em}(x)dx - \int_{x_1}^{x_2} F_{cf}(x)dx. \quad (9)$$

After replacing the first term on the right-hand side of (9) by substituting (7) into it after the transformations, taking into account (3) and (4), we obtain:

$$\frac{mv_2^2}{2} = \frac{1}{2}\sqrt{2F_0x_1} \left(\psi_2 \sqrt{\frac{1}{L_1}} - i_2 \sqrt{L_1} \right) - \int_{x_1}^{x_2} F_{cf}(x)dx. \quad (10)$$

When $i = \text{const}$, $i_1 = i_2$, $\psi_2 = L_2 i_2 = L_2 i_1$ equation (10) takes the form:

$$\frac{mv_2^2}{2} = F_0 x_1 (k_L - 1) - \int_{x_1}^{x_2} F_{cf}(x)dx, \quad (11)$$

where $k_L = \frac{L_2}{L_1}$.

The first term on the right-hand side of (11) determines the work of the electromagnetic forces performed when the striker moves from the initial position to the final position.

This work is spent on overcoming the strength of resistance to movement and the accumulation of kinetic energy. If you take a striker from the x_1 to x_2 , that $F_{cf}(x)=0$, then all the work of electromagnetic forces expended to the movement of the kinetic energy of the striker:

$$\int_{x_1}^{x_2} F_{em}(x)dx = \frac{mv_2^2}{2} = F_0 x_1 (k_L - 1). \quad (12)$$

From equations (7), (11) and (12), it is evident that the greater the resistance to movement of the striker F_0 at the moment of starting, the greater the energy concentrated in the volume of the electromagnetic machine.

The increase in energy at the end of the energy conversion process is associated with an increase in the starting current and the energy accumulated in the magnetic field by the moment when the striker begin to move. From equation (12) it is possible to determine the final speed of the striker:

$$v_2 = \sqrt{\frac{2F_0 x_1 (k_L - 1)}{m}}. \quad (13)$$

Assuming that the movement of the anchor is uniformly accelerated, its travel time is defined as:

$$t_m = \frac{x_1 - x_2}{v_2} = x_1 / \sqrt{\frac{2F_0 x_1 (k_L - 1)}{m}} = \sqrt{\frac{x_1 m}{2F_0 (k_L - 1)}}. \quad (14)$$

It follows from expression (14) that when the holding force is increased at the moment when the striker starts, the time of its movement decreases, which ensures a high final speed v_2 and kinetic energy.

3. Conclusions

Analysis of the expressions (13) and (14) obtained allows us to formulate the basic requirements for electromagnetic machines with holding the striker. The striker holding devices must provide a significant resistance to movement at the beginning of the stroke and a minimum resistance to movement on the rest of the stroke. It allows the possibility of adjusting the resistance force to the movement at the beginning of the stroke and consuming a small source energy for its work.

In the development of this direction, effective ways of accumulating magnetic energy in electromagnetic shock machines of various designs and purposes have been developed, carried out with a stationary firing striker, allowing one to significantly increase power and energy performance. The impact energy for individual experimental electromagnetic machines increased from 2 to 4 times and amounted to 9 ... 10 J/kg. The efficiency of electromagnetic machines has doubled and has approached 50%.

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