Technique of visualization of dynamic characteristics of electromagnetic strike machines

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Abstract. At present, the use of pulsed linear electromagnetic engines in the drive of strike machines for immersing rod elements in soil, percussive drilling of shallow wells and dynamic sounding of soils is recognized to be quite effective. The transient time in linear electromagnetic engines of such devices is not more than 0.25 s, which makes it difficult to obtain the most complete information about their characteristics. The solution to this problem with the help of traditional technical means is found difficult. Experimental studies of the working processes of pulsed linear electromagnetic engines of strike machines were carried out. The study of work patterns, the development of recommendations for the rational selection of individual design and operating parameters allow for maximum mechanical energy at the engine output with the greatest possible efficiency. The technique of visualization of the dynamic characteristics of strike machines with pulsed linear electromagnetic engines using a multifunctional analog-to-digital converter board is considered.

1. Introduction

At present, the use of pulsed linear electromagnetic engines (LEME) in the drive of strike machines for immersing rod elements in soil, percussive drilling of shallow wells and dynamic sounding of soils is recognized to be quite effective [1, 2, 3, 4].

The transient time in LEME of such devices is not more than 0.25 s, which makes it difficult to obtain the most complete information about their characteristics. The solution to this problem with the help of traditional technical means is found difficult [5, 6, 7, 14].

The article discusses the technique of visualization of the dynamic characteristics of strike machines with LEME using a multifunctional analog-to-digital converter board (ADC).

Experimental studies of the working processes of LEME of strike machines are carried out in order to obtain complete information about the characteristics of the tested machine. The study of work patterns, the development of recommendations for the rational selection of individual design and operating parameters allow for maximum mechanical energy at the engine output with the greatest possible efficiency [8, 9, 14].

The studies were carried out with the help of experimental installations, equipped with a complex of instrumentation equipment, allowing registering physical quantities of interest [10, 11, 12, 13].

2. The object and method of research

The functional diagram is shown in Fig. 1.
**Figure 1.** The functional diagram of the stand for the study of working processes of LEME

The installation contains a strike machine with a linear electromagnetic engine (SM); impulse electric converters: EC1, connected directly to the alternating-current power supply (PS) and EC2 with a capacitive energy storage [13, 14] (Fig. 1). Measurement and registration of values of physical quantities of interest are carried out with a set of control equipment (CE).

The strike machine with LEME is mounted on the driven rod 1, which is the load. A potentiometric displacement sensor 3 is rigidly attached to the engine armature through the coupling sleeve 2 to remove the dependence of the armature on time (Fig. 1).

The design of the block of sensors (SQ1 and SQ2) of the position of the striker, installed directly in the machine body and controlling the operation of the electrical converters, provides the possibility of their independent displacement in the axial direction. The coordinates of the sensors relative to the limiting positions of the striker of SM are controlled on the scale (S) (Fig. 1).

A set of control equipment (CE) includes devices for direct evaluation, which are used for visual control of electrical parameters: ammeters, voltmeters and the recording device which is a personal computer with an analogue-digital converter LA-2M5.

The electric circuit of the stand, including the elements of the LEME control systems and the measurement of physical quantities when powering of the winding is carried out from the utility pulse converter, is shown in Fig. 2.

The power part of the electric converter (Fig. 2) is a half-wave three-phase controlled rectifier on thyristors VS1…VS3, loaded with winding LM of LEME, and a pulse shaper (Fl) [2].

For a detailed identification of the features of the electrical interaction of a pulsed load (LEME) with sources and electrical converters, the dynamic characteristics of the LEME under study were simultaneously recorded. They are the instantaneous values of voltage $u(t)$ and current $i(t)$ flowing through its winding, as well as the displacement of the armature $\delta(t)$ as a function of time. Simultaneous recording of the indicated values was made on a personal computer connected to the system under study through a multifunctional analog-to-digital converter (ADC) board.

Voltage control $u_1$ on the engine winding is carried out through the divider $R1$, $R2$ (Fig. 2), which serves to match the input voltage of the ADC with the measured one. The true voltage value is:

$$u = k_1u_1$$

where $k_1$ – conversion factor depending on resistor ratings $R1$ and $R2$. 

\[ u = k_1u_1 \]
Figure 2. The scheme of registration of dynamic characteristics of LEME.

The current was monitored using a standard regular shunt $RS$, the voltage signal from which $u_2$ was fed directly to the ADC. The true value of the current flowing through the winding is:

$$i = k_3 u_2$$

(2)

where $k_3$ – conversion factor depending on the value of the shunt.

Calibration of the potentiometric displacement sensor $R_6$ is performed according to the method [2]. The true displacement value is:

$$\delta = k_3 u_3 - k_4$$

(3)

where $k_3, k_4$ – conversion factors depending on sensor properties.

The computer registers and records the data received from the ADC into an Excel spreadsheet (Microsoft Office application software for Windows operating systems), which is used to process the results and build time diagrams. The following formulas to calculate the required values are used in the program. The energy consumed from the source in the $t_{opr}$ interval is:

$$W_{el} = \int_0^{t_{opr}} u(t)i(t)dt$$

(4)

where $u(t), i(t)$ – instantaneous values of voltage and current in the winding at time $t$. Energy loss in the winding of LEME is:

$$Q = \int_0^{t_{opr}} i^2(t)Rdt$$

(5)
where $R$ – active winding resistance. Magnetic energy:

$$ W_{mag} = \int_{t_0}^{t_{res}} e(t)i(t)dt $$  \hspace{1cm} (6)

where $e(t)=u(t)-Ri(t)$ – engine emf. Flux-linkage:

$$ \psi = \int_{0}^{t} e(t)dt $$  \hspace{1cm} (7)

Mechanical energy output of LEME:

$$ A_m = \frac{mV^2}{2} $$  \hspace{1cm} (8)

where $m$, $V$ – mass and final speed of the armature. Magnetic efficiency:

$$ \eta = \frac{A_m}{(W_m + W_{res})} $$  \hspace{1cm} (9)

where $W_{res}$ – residual magnetic energy in the engine at the end of the movement of the armature.

$$ W_{res} = \int_{0}^{\psi_f} i(t)d\psi $$  \hspace{1cm} (10)

where $\psi_f$ – the instantaneous value of the final flux-linkage. Magnetic energy ratio:

$$ K = \frac{W_{res}}{(A_m + W_{res})} $$  \hspace{1cm} (11)

The integrals in these expressions are found by the formula:

$$ \int f(x)dx = \sum_{i=0}^{n} 0.5\left[f(x_i) + f(x_{i+1})\right]\Delta x $$  \hspace{1cm} (12)

where $\Delta t$ – time interval with a step corresponding to the poll period of the ADC board, which was $\Delta t=1ms$.

The impact velocity $V$ was determined by the formula $V=\delta(t)$, where $\delta(t)$ – armature displacement curve. The formula $\delta(t)=(\delta(x_2)-\delta(x_1))/(x_2-x_1)$ is used to calculate the derivative at some point $x$ on the interval $(x_1, x_2)$ of the armature stroke, the relative error of which is arbitrarily small at rather small $\Delta x=(x_2-x_1)$.

3. Conclusion

Fig. 3 and Fig. 4 show, as an example, the dynamic characteristics of LEME with different duration of current flow through its winding. From the diagrams, in particular, it follows that such electric converters allow adjusting the mechanical energy of the engine in the range of 4 ... 46 J.

![Figure 3](image-url)

**Figure 3.** Dynamic characteristics of LEME with three-phase power supply ($A_m=4$ J): $t_{dis}$ – disengaging time, $s$; $t_{mov}$ – time of movement, $s$; $t_{res}$ – response time, $s$. 


The relative error in determining the energy $W_{el}$ does not exceed 2%. The total relative error in determining the efficiency does not exceed 3%. The number of measurements that provide the specified accuracy does not exceed 5.

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