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On the Volt-Ampere and Traction Characteristics of Electromechanical Systems

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Abstract. In the article, issues related to the current-voltage characteristics of an electromagnetic vibration exciter for different values of the gap X are considered. In addition, based on the results of calculations and experiments, the traction characteristic was obtained by graphical differentiation of the curve L(X).

INTRODUCTION

In the Republic of Uzbekistan, special importance is attached to ensuring the uninterrupted and high-quality operation of automated electromechanical oscillatory systems, improving their efficiency in converting electrical energy into mechanical energy, and implementing resource-saving technologies at industrial enterprises [1-3].

This article is aimed at fulfilling the assigned tasks stipulated by the Decrees and Resolutions of the President of the Republic of Uzbekistan for 2022–2026 in the area of “Accelerated development of the national economy and maintenance of high growth rates,” which include ensuring uninterrupted energy supply to the economy, actively introducing “green economy” technologies across all sectors, and increasing energy efficiency by 20%. The objectives of the research include the development, modeling, algorithmization, and practical implementation of local intelligent systems for electricity metering and control, as well as measuring, accounting, and monitoring instruments for energy resources, aimed at assessing and improving the efficiency of industrial enterprises [4-6].

These activities are specified in the Presidential Decrees and resolutions of the Cabinet of Ministers of the Republic of Uzbekistan dated January 28, 2022, №UP-60, “On the Development Strategy of New Uzbekistan for 2022-2026”; dated August 22, 2019, №PP-4422, “On Urgent Measures to Improve Energy Efficiency in the Economy and the Social Sphere, Introduce Energy-Saving Technologies, and Develop Renewable Energy Sources”; and №PP-57, “On Measures to Accelerate the Introduction of Renewable Energy Sources and Energy-Saving Technologies in 2023,” dated February 16, 2023, as well as in other regulatory legal documents adopted in this field.

METHODS AND MATERIALS

Static characteristics are understood as the dependence of effective (RMS) values [7-10]:

- The voltage across the coil of the electromagnetic vibrator (EMV) due to the current in the circuit;
- Traction forces and resistance forces depending on the magnitude of fixed gap values.

$$U_1 = f_1(x), \qquad I = f_2(x), \qquad F_T = f(x)$$

with a stationary armature of the electromagnet and constant applied voltage for the given characteristic. Static characteristics include the family of current-voltage characteristics of the system for different values of the gap X (1, 2, 3, 4). When recording the volt-ampere characteristics between the armature and the yoke of the electromagnet, there is a constant air gap, which causes part of the magnetic flux to leak [11-12].

The full magnetic flux linkage and current vary according to a sinusoidal law [13-16].

$$\psi = \psi_m sin\omega t \tag{1}$$

$$i = I_m sin\omega t \tag{2}$$

Then

$$\frac{d\psi}{dt} = \omega\psi_m cos\omega \tag{3}$$

On the other hand, the amplitude of the flux linkage

$$\psi_m = g_{экв} W^2 I_m \tag{4}$$

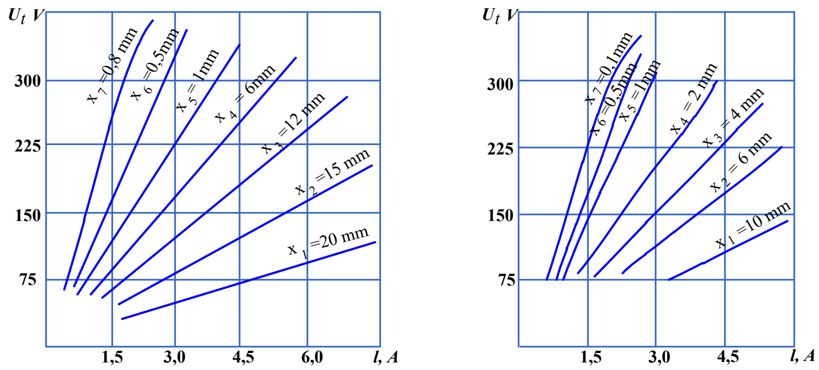


FIGURE 1. Voltage-current characteristics of the U-shaped electromagnetic vibration exciter

Considering this, the voltage across the electromagnet can be expressed as follows [17-20]:

$$U_L = iR + \frac{d\psi}{dt} = RI_m sin\omega t + \omega L I_m sin\omega t \tag{5}$$

Where

$$L = g_{экв} W^2 \tag{6}$$

In the electromagnetic vibrator used, the active resistance is significantly smaller than the inductive one, i.e., it can be assumed that $R<<\omega L_C$, therefore

$$Im = \frac{U_m}{\omega L_c} \tag{7}$$

By substituting the last expression into (4), taking (5) into account, we obtain [21-24]:

$$\psi_m = \frac{U_m}{\omega} = \frac{U_L}{4{,}44f} \tag{8}$$

From here

$$K\psi_m = U_L \tag{9}$$

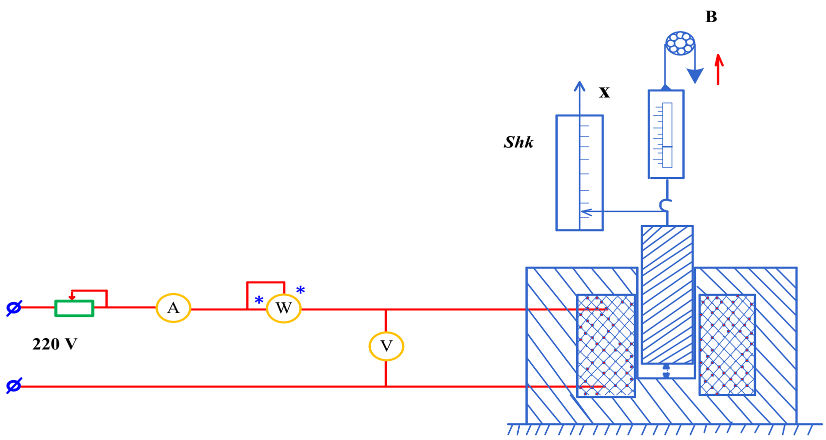


FIGURE 2. Diagram for measuring the traction characteristics of an electromagnetic vibratory exciter

Figure 3 shows the static traction characteristic, obtained by graphically differentiating the *L(X)* curve and multiplying the ordinates $\partial L/\partial X$ by $I^2/2$. The $F_T(X)$ curve, obtained through measurement using a dynamometer, is also presented there. The comparison between the calculated traction characteristic and the one obtained by direct measurement shows good agreement [25-28].

Figure 4 shows the statistical traction characteristics measured using a test bench for various designs of electromagnets used in electromagnetic vibromechanisms [29-30].

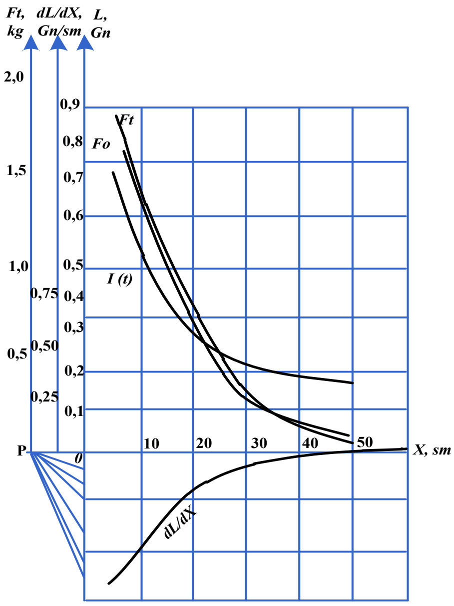


FIGURE 3. The experimental dependencies of inductance *L* and traction force *F* on the gap *X*

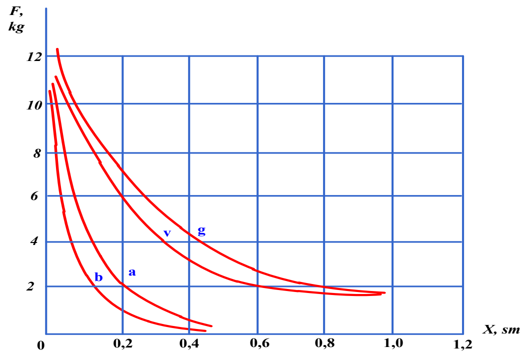
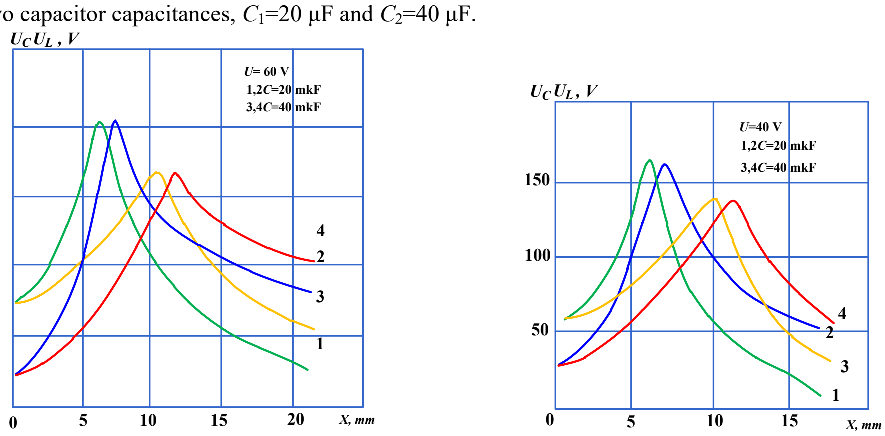


FIGURE 4. A family of static traction characteristics of electromagnets of various designs

When a capacitance is connected to the system, the nature of the static traction characteristics changes abruptly. They acquire a clearly pronounced resonant character. Moreover, in the presence of core saturation, the phenomenon of lag occurs, which is associated with the presence of hysteresis in the magnetic circuit [31-33].

Figure 5 shows the statistical characteristics *U(X)* and *F(X)* for two applied voltage values, U_1=60 V and U_2=40 V, and two capacitor capacitances, C_1=20 μF and C_2=40 μF.



a) b)

FIGURE 5. Static characteristics *U(X)* for two values of the input voltage

The instrument readings were recorded after the transient processes in the circuit had settled, for various values of *X*. As can be seen from the figures, the curves have clearly pronounced maxima. When the applied voltage is changed, the effective values of the current and the pulling force in the electromagnet coil vary; however, the nature of the curves does not change. With the change in the capacitance of the capacitor, X_p shifts. The inclusion of active resistance smooth's the peaks of the static characteristics. When the supply network frequency changes, X_p also changes. Thus, in a static process, control can be exercised by making changes [34-37]:

a) The capacitance *C* of the capacitor;

b) of active resistance;

d) Inductances in the electromagnet circuit;

e) Supply voltage;

f Air gap X_0;

h) the frequencies of the applied voltage.

The analysis of the traction characteristics shows that the dependence on the gap has a nonlinear nature. Consequently, the amplitude-frequency characteristics of the mechanical oscillatory system should differ from the classical amplitude-frequency characteristics inherent to nonlinear systems [38-41].

Equation (7) allows us to assert that, at a given frequency, the characteristic of the electromagnet $U_1(I)$ will reflect the magnetization curve on a different scale. The saturation of the magnetic system of the electromagnetic vibratory exciter can be judged from the appearance of its characteristic. Figure 1 shows a family of voltage-current characteristics for a U-shaped electromagnet with different air gaps and a restrained armature [42-44].

From the given characteristics, it is evident that the magnetic circuit of the electromagnet does not saturate. Saturation occurs at small gaps, when the induction in the iron reaches high values [45-47].

When calculating and determining the static traction characteristics, the saturation of the magnetic circuit is not taken into account, since the volt-ampere characteristics are linear. To determine the mechanical forces acting in a magnetic field, a formula can be used [48-50]:

$$F_T = \frac{i^2}{2}\frac{\partial L}{\partial X} \quad (10)$$

well-known from the course of theoretical electrical engineering (3). This formula is derived from the assumption that the current in the circuit, to which the electrodynamics forces are applied, is maintained constant. However, determining the self-inductance coefficient with direct current presents experimental difficulties compared to alternating current. Therefore, it is easier to verify the specified formula using alternating current. In this case, the average value of the force over the period is determined, which is equal to [51-53].

$$F_{T\,\text{cp}} = \frac{1}{2T}\frac{\partial L}{\partial X}\int_0^T i^2 dt = \frac{I^2}{2}\frac{\partial L}{\partial X} \quad (11)$$

That is, it is equal to half the product of the square of the effective current and the derivative of the self-inductance coefficient with respect to the *X* coordinate. When determining the average value of the force according to (10), it is carried out by directly evaluating the left and right sides of equation (11) [51-53].

The force F_T is determined using a dynamometer, while to determine the right-hand side, the current I is measured and the dependence (X) is recorded, from which the derivative $\partial L/\partial X$ is obtained. In a test rig specially designed for measuring mechanical forces in a magnetic field, there is a large-stroke solenoid electromagnet, the movable part of which is suspended by a metal cable (see Fig.2). Using block E, it is possible to adjust the suspension height and, consequently, the relative position [51-58].

CONCLUSION

In the course of the article on 'Volt-Ampere and Traction Characteristics of Electromechanical Systems,' the following scientific results were obtained:

1. The high level of energy losses and the low level of reliability in the elements of industrial enterprise power supply systems, including vibrational equipment, indicate that the operating mode of these devices is not optimal. As a result of theoretical analyses of the autoparametric oscillations of electromechanical system processes with electromagnetic vibratory exciters and feedback, the possibility of creating controllable vibration devices has been demonstrated.

2. Based on the theory of electromechanical systems, an electromagnetic vibration exciter was developed, enabling the creation of a vibratory concrete compaction unit. As a result, it became possible to develop a design for an electromagnetic vibrating device using continuous vibration technology.

The article presents methods for measuring the statistical and traction characteristics of electromechanical systems (EMS) using an electromagnetic vibration exciter, as well as the possibilities of controlling them by varying the parameters of the electromagnetic vibration exciter.

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