634. Investigation of current parameter in electro-magnettic drive of resonance adaptive vibromachines while using the duopolar latitude-impulsive voltage for its power supply

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Abstract. The analytical relationship between parameters of duopolar impulse-modulated voltage was established which goes through electromagnetic vibrodrive and resonance adaptive technological vibromachines. This analytical relationship is applicable for design of regulated electromagnetic vibrodrives of adaptive vibromachines.

Keywords: regulated vibromachines, electromagnetic vibrodevice, resonant vibromachines, optimal vibromachines, adaptive vibromachines.

Introduction

Problem statement. One of key criteria of any technological equipment is its specific expense of energy. In the case of vibromachines and vibrotechnologies it is the minimal consumption of energy. For a vibrodrive only constant resonance regime of the vibromachine operation is possible. Adaptive systems are used for vibrodrive regulation in order to provide constant resonance regime with variable parameters of a technological process [1]. They ensure minimal expenditure of energy with the specified optimal technological parameters of the vibrofield of the vibromachine. In the case of vibromachines with electromagnetic vibrodrive for regulation of parameters of the vibrofield dual-polarity modulated latitude-impulsed (LI) voltage is employed for power supply of the vibrodrive. Development of new and improvement of existing methods of determination of the geometrical and electrical parameters of the electromagnetic vibrodrive with set parameters of vibrofield of the vibromachine and LI of voltage is an important problem at the present time. Calculated optimal electromagnetic vibrodrive allows to ensure the lowest consumption of energy by virtue of specified optimal parameters of the vibrofield.

Analysis of recent publications. Research work [2] demonstrates the connection between current and LI voltage in electromagnetic vibrodrive. Given connection is not analytical because it was obtained by means of Runge-Kutta numerical scheme with adaptive step. It allows to establish relationship between the main parameters of electromagnetic vibrodrive and LI voltage as well as vibrofield parameters. Work [3] shows more plain due to technology of receiving form of LI voltage for feeding VTM, which does not need high-frequency force keys in control block of the electromagnetic vibrodrive. Refusal of technologies where LI modulation is used due to sinusoidal statue of breadth of orthogonal impulse allows reduction of value of control system of the vibrodrive. At present stage it is reasonable to establish the analytical connection between plain technological LI voltage forms [3] and calculating parameters of electromagnetic vibrodrive.

Investigation

The aim of present study is to establish the analytical relationship between parameters of duopolar widen-impulsed modulated voltage [3] and current. It is implemented in electromagnetic vibrodrives of adaptive vibrational technological machines (AVTM) for further utilization while designing regulating electromagnetic vibrodrives AVTM.

To establish the connection between current *I(t)* and dynamic characteristic of working body *x(t)* AVTM and parameters *U(t)* [3] LI voltage is necessary to lane a view on electromechanical systems (Fig. 1) of duo-weighted AVTM.

$$U(t)=\frac{1.29\cdot U}{\pi}\cdot\arctan\left(K_a\cdot\left(t-\frac{2\cdot floor\left(\frac{\omega\cdot t-\pi}{2\cdot\pi}\right)\cdot\pi}{\omega}-\frac{2\cdot\pi}{\omega}\right)\right)\cdot\arctan\left(K_a\cdot\left(t-\frac{2\cdot floor\left(\frac{\omega\cdot t}{2\cdot\pi}\right)\cdot\pi}{\omega}-\frac{\pi}{\omega}\right)\right) \quad (1)$$

where U – amplitude of voltage nourishment of electromagnetic vibrodrive, ω - frequency of voltage of electromagnetic vibrodrive, K_a – coefficient of approximation, which smoothens right angles of LI voltage, maximally adjusting the mathematical model (1) to the real LI voltage.

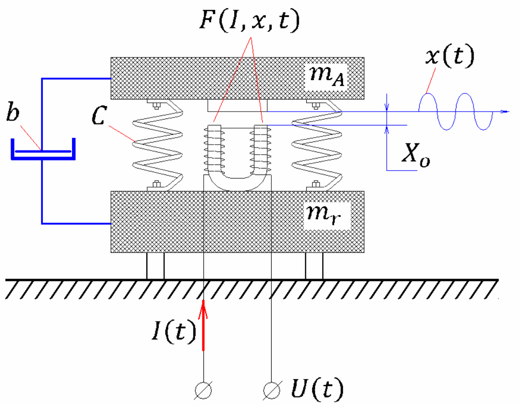


Fig. 1. Structural scheme of fluctuating electromechanical system of duo-weighted AVTM

Differentiation equation system, which describes behavior of varying electromagnetic system of duo-weighted AVTM due to [4, 5] has the following form:

$$\begin{cases} m_a\dfrac{d^2x_a}{dt^2}+b\cdot\left(\dfrac{dx_a}{dt}-\dfrac{dx_r}{dt}\right)+k\cdot(x_a-x_r)=F\left(I,(x_a-x_r),t\right) \\ m_r\dfrac{d^2x_r}{dt^2}-b\cdot\left(\dfrac{dx_a}{dt}-\dfrac{dx_r}{dt}\right)-k\cdot(x_a-x_r)=-F\left(I,(x_a-x_r),t\right) \\ \dfrac{d}{dt}\left(L(x,I)\cdot I(t)\right)+R\cdot I(t)=U(t) \end{cases} \quad (2)$$

where m_a – active weight (working body) of AVTM, m_r – reactive weight (trunk, frame) of AVTM, x_a and x_r – coordinates of active and reactive weight of AVTM, b – resistance coefficient $b= - f / x$ (f – force friction, windage), k – resilient system rigidity of AVTM, $F\left(I,\left(x_a - x_r\right),t\right)$ – forced strength of electromagnetic vibrodrive of AVTM, $L(x,I)$ - electromagnetic vibrodrive inductance, R – coil active resistance of electromagnetic vibrodrive, $I(t)$ – strength of current that passes through vibrodrive winding.

Observing vibration of the working body in the same direction and leading in reduced mass M $\left(M = (m_a \cdot m_r) / (m_a + m_r)\right)$ and relative coordinate x $\left(x = \left(x_a - x_r\right)\right)$ the system of differential equations is obtained. The upper differential equation in (3) describes mechanical processes in AVTM. It is binding the dissipative processes in vibratory system and movement of working body x with forced vibrofield $F(I,x,t)$ strength, which has electromagnetic character and partially is the function of $x(t)$ law of working body transfer. This is stipulated by that change of air gap between kedge and electromagnetic vibrodrive kedge influences the strength F with which they are prosecuted. Lower system's differential equation (3) describes electromagnetic processes in AVTM.

$$\begin{cases} m\dfrac{d^2x}{dt^2} + b\dfrac{dx}{dt} + cx = F\left(I,x,t\right) \\ \dfrac{d}{dt}\left(L\left(x,I\right)\cdot I\left(t\right)\right) + R\cdot I\left(t\right) = U\left(t\right) \end{cases} \tag{3}$$

It is composed on the basis of voltage equilibrium and it accounts for: structure of voltage on vibrodrive coil and electromotive force of self-induction, which appears during the process of inductive change $L(x,I)$ of electromagnetic AVTM vibrodrive. It depends on $x(t)$ of working body transfer. Given equation establishes connection between mechanical parameter of working body $x(t)$, voltage $U(t)$ and current strength $I(t)$, which goes through winding of the electromagnetic vibrodrive. Current strength in the vibrodrive winding $I(t)$ is the basic parameter that influences the $F(I,x,t)$ strength, with which kedge is attracted with burden in electromagnetic vibrodrive. Establishing the analytical connection between the law of working body $x(t)$ and $I(t)$ allows to conduct the calculation of coil parameters of the electromagnetic vibrodrive for ensuring the necessary strength of vibrodrive $F(I,x,t)$ with the aim to receive set technological optimal parameters of working body $x(t)$ of AVTM. To establish this connection it is necessary to look through system equation (3) shown lower. Differentiation yields:

$$L\left(x,I\right)\frac{dI}{dt} + I\,\frac{dL\left(x,I\right)}{dt} + R\cdot I\left(t\right) = U\left(t\right) \tag{4}$$

Electromagnetic inductivity depends on two [6] variables: air gap (Fig. 1) X_0 between burden and kedge and current $I(t)$ which passes through its winding while saturated [6] magnetic drive. To determine the change of inductivity in vibrodrive you should take into consideration two factors: air gap between the burden and the kedge in electromagnetic vibrodrive is not equal to zero ($X_0 \neq 0$); this air gap is always larger than the amplitude of vibration AVTM working body $(x_0 > |x(t)|)$, it is prearranged by the principle of work of the vibrodrive. It means that because of the equality of air gap and vibrational amplitude of working body, the burden will knock on kedge, it will lead to destroying of electromagnetic vibrodrive. Taking into consideration working limitation on maximum current value we can expect [6] satiation magnetic drive of electromagnetic vibrodrive. Taking into consideration constructive particularity of magnetic vibrodrive we can make such conclusion: inductivity of electromagnetic vibrodrive does not depend on current in coil winding $I(t)$. It depends only on change of air gap X_0. Change of air gap X_0 directly depends on law of movement $x(t)$ of working body of AVTM. According to [4, 7, 8] in such case the inductivity of electromagnetic vibrodrive can be described by the following expression:

$$L(x) = L_0 \cdot \left(1 + \frac{x(t)}{X_0}\right)^{-1} \tag{5}$$

where L_0 – inductivity of electromagnetic system with air gap. According to [9, 7] the inductivity of electromagnetic system with air gap is defined:

$$L_0 = \frac{\mu_0 \cdot S \cdot \varpi^2}{X_0} \tag{6}$$

where ϖ amount of coil spire of electromagnetic vibrodrive, μ_0 – magnetic permeability of vacuum, S – area of nucleus intersection of electromagnetic vibrodrive. Inserting expression (6) into (5), and the obtained result into differential equation (4), we obtain the connection between law of working body $x(t)$ of AVTM and electromagnetic vibrodrive of duo-weighted AVTM:

$$\frac{\mu \cdot S \cdot \varpi^2 \left(\frac{d}{dt} i(t)\right)}{X_0\left(1+\frac{x(t)}{X_0}\right)} - \frac{i(t)\cdot \mu \cdot S \cdot \varpi^2 \left(\frac{d}{dt} x(t)\right)}{X_0^2\left(1+\frac{x(t)}{X_0}\right)^2} + Ri(t) = \frac{1}{\pi} \times$$
$$\times \left(1.29 \cdot U \arctan\left(Kap \cdot \left(t - \frac{2\cdot floor\left(\frac{\omega \cdot t - \pi}{2\cdot\pi}\right)\cdot\pi}{\omega} - \frac{2\cdot\pi}{\omega}\right)\right) \left| \arctan\left(Kap\cdot\left(t - \frac{2\cdot floor\left(\frac{\omega\cdot t}{2\cdot\pi}\right)\cdot\pi}{\omega} - \frac{\pi}{\omega}\right)\right)\right|\right) \tag{7}$$

For convenience the differential equation is rearranged into:

$$\frac{1}{\left(X_0 + x(t)\right)^2}\left(\mu\cdot S\cdot\varpi^2\cdot\left(\frac{d}{dt}i(t)\right)\cdot X_0 + \mu\cdot S\cdot\varpi^2\left(\frac{d}{dt}i(t)\right)\cdot x(t) - i(t)\cdot\mu\cdot S\cdot\varpi^2\cdot\left(\frac{d}{dt}i(t)\right) + \right.$$
$$\left. R\cdot i(t)\cdot X_0^2 + 2\cdot R\cdot i(t)\cdot X_0\cdot x(t) + R\cdot i(t)\cdot x(t)^2\right) =$$
$$\frac{1.29\cdot U}{\pi}\cdot\arctan\left(Kap\cdot\left(t - \frac{2\cdot floor\left(\frac{\omega\cdot t-\pi}{2\cdot\pi}\right)\cdot\pi}{\omega} - \frac{2\cdot\pi}{\omega}\right)\right)\cdot\arctan\left(Kap\cdot\left(t - \frac{2\cdot floor\left(\frac{\omega\cdot t}{2\cdot\pi}\right)\cdot\pi}{\omega} - \frac{\pi}{\omega}\right)\right)$$

For calculation of equation (7) we should clarify the movement of working body. It undergoes harmonic vibrations which are described as:

$$x(t) = X \cdot \sin(\omega\cdot t + \phi) \tag{8}$$

where X – the amplitude of vibration of AVTM working body (depends on dissipative characteristics of vibration system and coefficient of dynamics [10] “System’s Deferment”), ω – frequency, φ – phase shift between transfer of working body and forced strength [5, 10].

According to [4, 5, 10] in resonance regime occurs lagging of produced vibration of working body $x(t)$ of AVTM from cycling of obtained strength of vibrodrive in quarter of period. Taking into consideration that the strength phase of electromagnetic vibrodrive is proportional to phase of current strength $I(t)$ in its winding we can see that in our case shift between current $I(t)$ and transfer $x(t)$ will be equal to $\varphi = -\pi/2$.

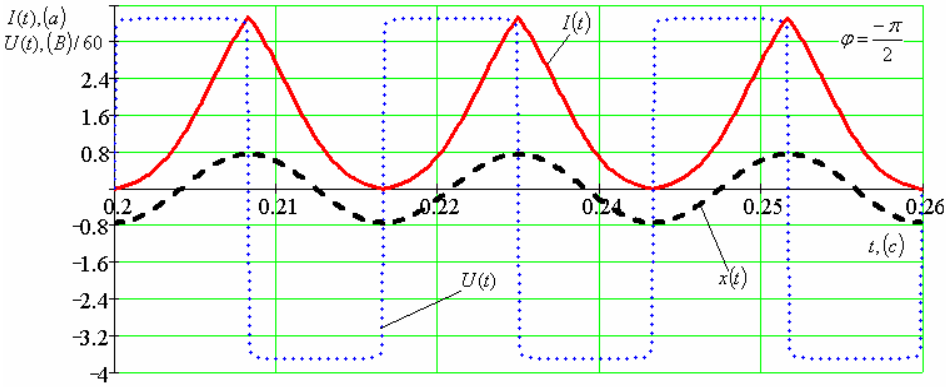


Fig. 2. Connection between current in electromagnetic vibrodrive and LI voltage (1)

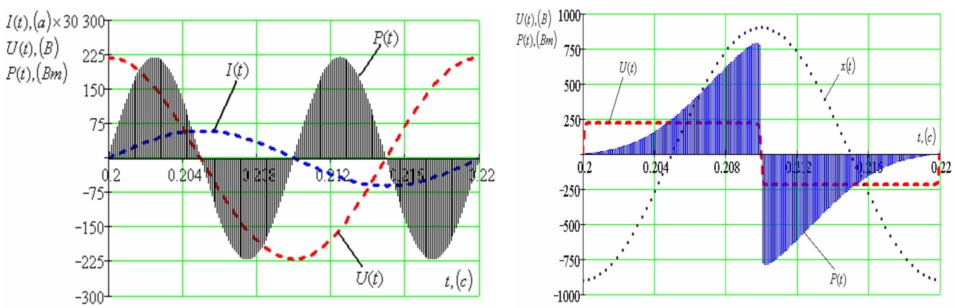
Partial issue of differential equation (7) taking into consideration (8) and the primary clause *I(0)=0* is expression (9). Graphically the set connection is shown in Fig. 2. It indicates that on spread of each half period LI voltage (1) the current handles as in a circle with constant voltage:

$$
\begin{aligned}
I(t) = \Bigg(& e^{-\frac{2\cdot R\cdot\left(X_0+\arctan\left(\tan\left(\frac{\omega\cdot t}{2}+\frac{\varphi}{2}\right)\right)\cdot\tan\left(\frac{\omega\cdot t}{2}+\frac{\varphi}{2}\right)^2+X_0\cdot\arctan\left(\tan\left(\frac{\omega\cdot t}{2}+\frac{\varphi}{2}\right)\right)-X\right)}{\mu\cdot S\cdot\varpi^2\cdot\omega\cdot\left(\tan\left(\frac{\omega\cdot t}{2}+\frac{\varphi}{2}\right)^2+1\right)}} \cdot \left[\int_0^t \left(-\frac{129}{100}\cdot\frac{1}{\varpi^2\cdot\pi\cdot S\cdot\mu}\times\right.\right. \\
& \times\left(U\cdot\arctan\left(\frac{1}{\omega}\cdot\left(Kap\cdot\left(-\omega\cdot\tau+2\cdot floor\cdot\left(\frac{\omega\cdot\tau-\pi}{2\cdot\pi}\right)\cdot\pi+2\pi\right)\right)\right)\right)\times \\
& \left.\left.\times\left|\arctan\left(\frac{1}{\omega}\cdot\left(Kap\cdot\left(-\omega\cdot\tau+2\cdot floor\cdot\left(\frac{\omega\cdot\tau}{2\cdot\pi}\right)\cdot\pi+\pi\right)\right)\right)\right|\cdot e^{\frac{R\cdot\left(2\cdot X_0\cdot\arctan\left(\frac{\sin\left(\frac{\omega\cdot\tau}{2}+\frac{\varphi}{2}\right)}{\cos\left(\frac{\omega\cdot\tau}{2}+\frac{\varphi}{2}\right)}\right)-X\cdot\cos(\omega\cdot\tau+\varphi)-X\right)}{\omega\cdot\varpi^2\cdot S\cdot\mu}}\right)\right] d\tau\times \\
& \times\left(X_0\cdot\tan\left(\frac{\omega\cdot t}{2}\right)^2+X_0\tan\left(\frac{\varphi}{2}\right)^2+X_0+X_0\tan\left(\frac{\omega\cdot t}{2}\right)^2\tan\left(\frac{\varphi}{2}\right)^2+2\cdot X\tan\left(\frac{\omega\cdot t}{2}\right)-\right. \\
& \left.\left.-2\cdot X\cdot\tan\left(\frac{\omega\cdot t}{2}\right)^2\cdot\tan\left(\frac{\varphi}{2}\right)+2\cdot X\cdot\tan\left(\frac{\varphi}{2}\right)-2\cdot X\cdot\tan\left(\frac{\varphi}{2}\right)^2\cdot\tan\left(\frac{\omega\cdot t}{2}\right)\right)\right) \\
& \Bigg/ \left(\tan\left(\frac{\omega\cdot t}{2}\right)^2+\tan\left(\frac{\varphi}{2}\right)^2+1+\tan\left(\frac{\omega\cdot t}{2}\right)^2\cdot\tan\left(\frac{\varphi}{2}\right)^2\right)
\end{aligned}
\tag{9}
$$

where $\tau = 0\ldots t$.

Graphical analysis of expression during different phase shift indicates that connection between current $I(t)$ and shift φ vibrotransfer $x(t)$ has physical content in boundary $-\pi/2 \le \varphi \le 3\cdot\pi/4$. In other values of φ the current behavior will lead to destruction of electromagnetic vibrodrive by means of overheat of constant current. Coming out of physical content [5] of amplitude frequency and phase frequency of AVTM characteristics, such regimes respond in two cases: when frequency ω_U LI of the voltage $U(t)$ will be lower or much larger than the frequency ω_0 of AVTM natural vibrations.

We should separately notice that in the case of electromagnetic vibrodrive supply from network with frequency f=50 Hz the vibrational frequency of working body will be 2 times larger [10]. And in the case of vibrodrive supply by means of voltage $U(t)$ (1) vibrational frequency of working body is equal to frequency LI of the voltage. This situation can be explained as follows. While using sinusoidal voltage as a supply source of electromagnetic vibrodrive it should be examined as a coil with inductivity L_0 (6), and in a circle of alternating sinusoidal voltage with inductive stick exists phase shift between the voltage and the current. According to [11] voltage in the inductive circle lags by $\pi/2$ with respect to the voltage. Considering this fact we can easily determine instant force of electromagnetic vibrodrive $P(t) = U(t) \times I(t)$. Electromagnetic vibrodrive force with supply by means of sinusoidal voltage is indicated in Fig. 3 a).



a) b)

Fig. 3. Connection between AVTM electromagnetic vibrodrive force and voltage

Analyzing this picture we can observe that for each half period there occur two opposite directed splashes of force, during which the transfer of AVTM working body is accomplished. In the case of using as a source LI voltage supply (1) the power in the working body changes according to the law indicated in Fig. 3b). As we can observe the situation here is completely different: during one period there occurs one pair of opposite directed splashes of force during which the transfer of AVTM working body is accomplished. It means that during one period of LI voltage creates one vibration of the working body.

Conclusions

Conducted investigation enabled establishment of analytical connection parameters of duo-weighted LI voltage (1) and current $I(t)$, which flows in the electromagnetic vibrodrive in the resonance AVTM. The proposed relationship allows more effective analysis of electromechanical processes and facilitates the development of new methods for design of regulated electromechanical vibrodrives in the course of creating adaptive technological vibromachines.

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References

[1] **Chubyk R. V.** Adaptive Ruling System of Resonance Vibrational Technological Machines. Candidate of Technological Sciences. – Lviv, 2007. – 266 p.

[2] **Tajanov S. A., Chubyk R. V., Seniv S. B.** Act research of Current Change and Force on Electromagnetic Resonance Vibromachine while its Supply from Latitudinal-Pulsed Modulated Voltage. // Optimization of Production Processes and Technological Control in Machine Building and Instrument Building. Visnyk (Messenger) NU "Lviv Polytechnics". – 2005. - № 535 – P. 119 – 125.

[3] **Chubyk R. V.** Mathematic Models of Duo-Weighted Latitudinal-Pulsed Modulated Signals for Electromagnetic Vibrodrive Supply of Adaptive Vibrational Technological Machines. // Vibrations in Technic and Technology. All-Ukrainian Scientific-Technological Magazine. 2007. - №3 (48) – P. 18 – 22.

[4] **Bauman V. A., Bykhovskij I. I.** Vibrational Machines and Processes in Building. – M., "Higher School", 1977. – 255 p.

[5] **Khaikin S. E.** Physical Basis of Mechanics. – M.: Science, 1971. – 751 p.

[6] **Besekerskij V. A.** (Editor) Problem Receptacle of theory of Automatic Regulation and Operation. – M., Main Editor of Physics-Mathematical Literature, 1972. – 587 p.

[7] **Malkin D. D.** Theory of Electromagnetic Vibrators. // "Technology of Time Manufacture". – 1971. - № 3 (6) – P. 75 – 85.

[8] **Lanets O. S.** Development of Dynamic-Balanced Torus Vibrational Machines with Electromagnetic Vibrodrive: Candidate of Technological Sciences. – Lviv, 2002. – 150 p.

[9] **Bul' B. K., Bul' O. B., Azarov V. A., Shoffa V. N.** Electromechanical Machinery of Automatics. – M., "Higher School", 1988. – 303 p.

[10] **Povidajlo V. O.** Vibrational Processes and Equipment. – Lviv: Publisher NU "Lviv Polytechnics". – 2004. – 248 p.

[11] **Bessonov L. A.** Theoretical Bases of Electrotechnics: Electrical Chains. – 7th Publishing remarked and completed. - M., "Higher School", 1978. – 528 p.