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Dynamic Characteristics of New Transformer Converters and its Measurement of Angle Slips Differences

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ANNOTATION: The article developed a parametric structure diagram for the dynamic modes of measuring devices in the formation of operator-type algebraic equations that reflect the electromechanical and electromagnetic processes occurring in the dynamic modes of the electromechanical measuring transducer, which measures the difference of angular displacements. In determining the dynamic properties of the elements in the measuring device, their inputs are given jumping variable mechanical moments and sinusoidal variable mechanical moments, the laws of change of the output size of the element over time are determined.

KEY WORDS: inductance, capacitive force moments, mechanical resistance, mechanical stiffness, mechanical inductance, parametric structure diagram, excitation coil, current source, magnetic flux, electric capacitance.

INTRODUCTION

The mode in which the output and input magnitudes of a measuring device (MD) change over time is called its dynamic mode [12, p. 46; 13, 8 p.]. The MDs under study, like other types of electromechanical measuring transducers, contain inertial elements such as inductance and capacitance of mechanical, electrical and magnetic nature that store energy. Under the influence of these elements, the instantaneous value of the output magnitude in the dynamic mode of MD depends not only on the change in the instantaneous value of the input magnitude, but also on its derivative changes [7, 21-22 p.]. The inertial properties of MDs are studied and evaluated using their dynamic characteristics. The dynamic characteristics of MDs are formed using differential equations, transmissions or complex frequency functions that reflect the dynamic processes that take place in them. [14, 123-124 p.].

As mentioned earlier, the MD under study is an electromechanical measuring transducer, the structural composition of which consists of a set of elements of mechanical, electrical and magnetic chains.

METHODS

Figure 1 shows a schematic diagram of an electromechanical MD mechanical chain with a transformer measuring the difference in angular displacement under study.

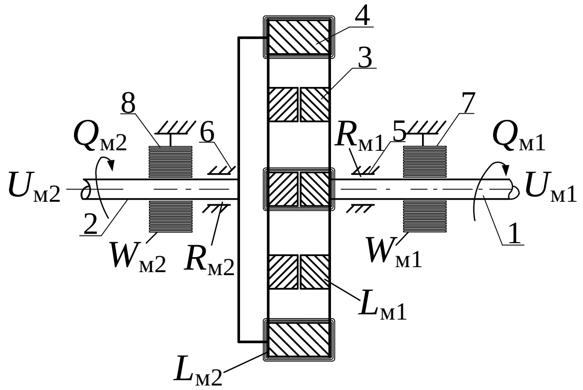


Figure 1. Constructive scheme of electromechanical MD magnetic circuit with transformer measuring angular displacement difference: 1, 2 – bars; 3, 4 - moving parts; 5, 6 - friction bearings; 7, 8 - spiral springs.

In the scheme: $U_{м1}$, $U_{м2}$, $[N \cdot m]$ and $Q_{м1}$, $Q_{м2}$, $[degri]$– the moments of force transmitted by the controlled objects to the rods fixed to the moving parts and the angles of rotation of the rods under the influence of these forces; $R_{м1}$, $R_{м2}$ - mechanical resistance of friction bearings, $[Pa \cdot s \cdot m^3]$; $L_{м1}$, $L_{м2}$ – mechanical inductance of each moving part, $[kg \cdot m^2]$; $W_{м1}$, $W_{м2}$ - mechanical stiffness of helical springs, $[(N \cdot m)/degri]$.

In the formation of operator-type algebraic equations necessary for the study of the dynamic properties of the studied MDs and reflecting the electromechanical and electromagnetic processes occurring in their dynamic modes, it is expedient to use the method of PSD for dynamic modes of MDs. [6].

Theoretical study of the dynamic characteristics of the created MDs PSDs are shown in Figures 2 and 3.

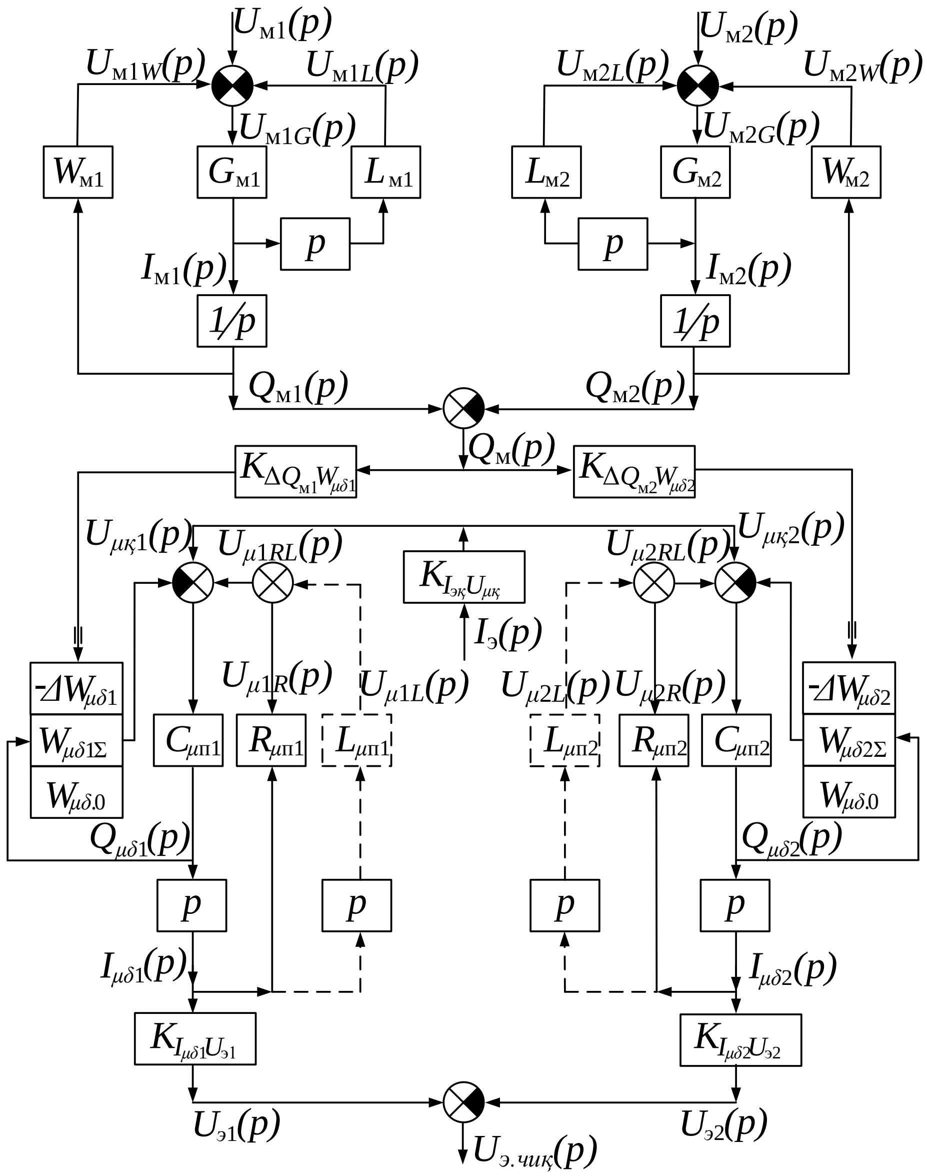


Figure 2. Theoretical study of the dynamic characteristics of the created MD is a structured parametric structure scheme

The theoretical study of the dynamic characteristics of one of the created MDs is considered in the example of MD shown in PSD Figure 3. In order to simplify the calculations to a certain extent, we introduce the following conditions for the MD under study, taking into account the conventional limitations in the analysis of magnetic chains:

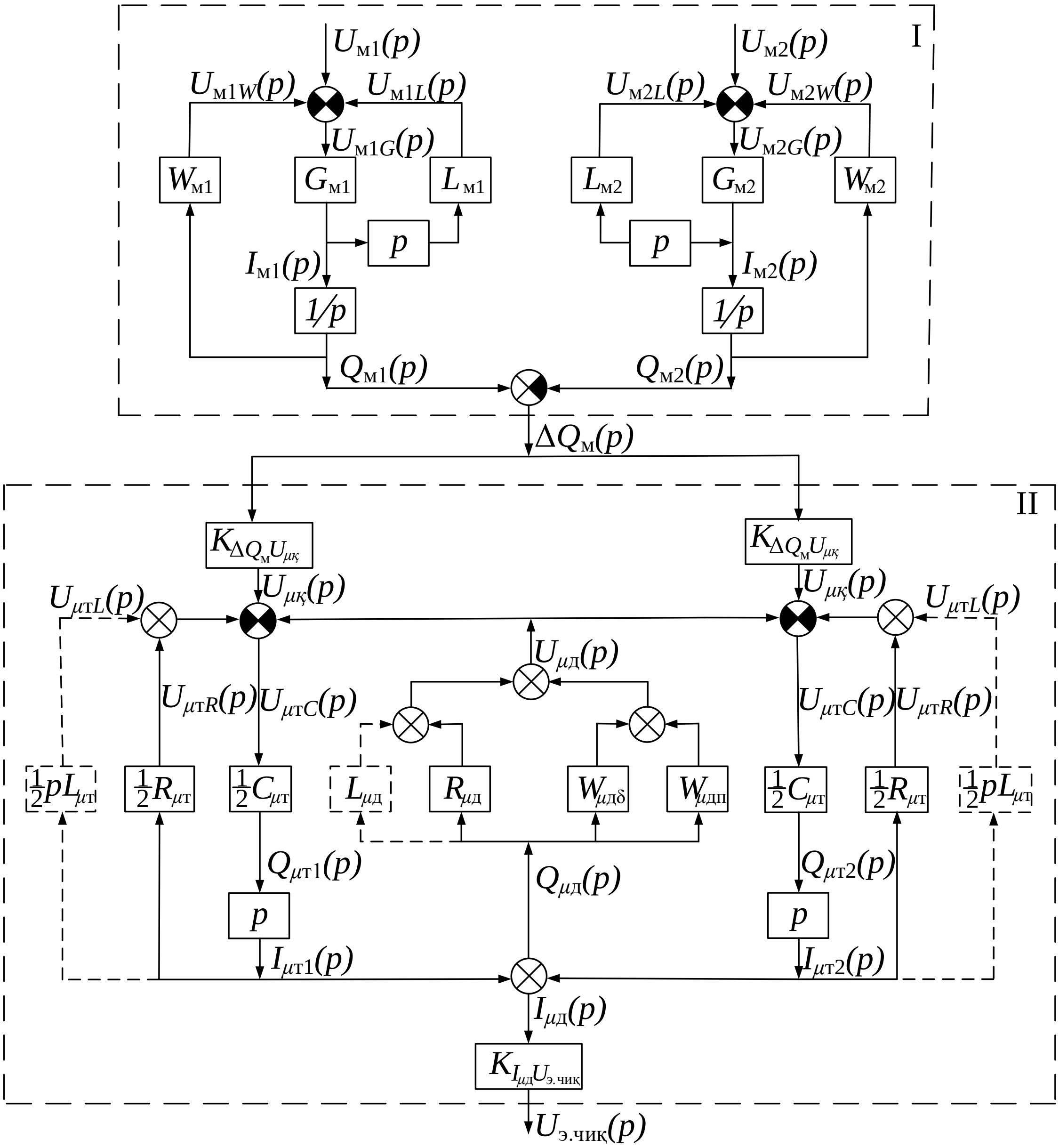


Figure 3. A simplified parametric structure scheme based on a theoretical study of the dynamic characteristics of the generated MD

$R_{м1} = R_{м2} = R_{м}$; $L_{м1} \neq L_{м2}$; $W_{м1} = W_{м2} = W_{м}$; $W_{эқ} \approx 0$ ($W_{эқ}$ – a parameter that is inversely proportional to the electrical capacitance between the excitation windings); $L_{\mu т} \approx 0$ ($L_{\mu т} = C_{эт}$ – electric capacity in the path of alternating currents generated by alternating magnetic flux in a toroidal ferromagnetic core). $W_{эқ}$ and $L_{\mu т}$ The values of are taken to be zero because they are so small.

Operator image of the electrical voltage in the parts of the measuring instrument with the output size based on the constructed PSD $U_{э.чиқ.}(p)$ An operator image of the difference in mechanical moments applied to moving parts with an input size of MD $U_{м1}(p)$ and In order to make it easier to derive the operator equation for the dependence of mechanical, electrical and magnetic parameters on MD, we divide the PSD into four parts (these parts are delimited by dashed lines in Figure 3 and are denoted by Roman numerals.) [8].

The following equations can be written for the elemental converters in the left branch of the PSD I-section:

$$\Delta Q_{м}(p) = Q_{м1}(p) - Q_{м2}(p); \qquad (1)$$

$$Q_{м1}(p) = \frac{1}{p} I_{м1}(p); \qquad (2) \qquad\qquad I_{м1}(p) = G_{м1} U_{м1G}(p); \qquad (3)$$

$$U_{м1G}(p) = U_{м1}(p) - U_{м1L}(p) - U_{м1W}(p); \qquad (4) \qquad\qquad U_{м1L}(p) = pL_{м1} I_{м1}(p); \qquad (5)$$

$$U_{м1W}(p) = (1/p) W_{м1}\, I_{м1}(p). \qquad (6)$$

(2) Substituting (3) - (4) into the equation, respectively, after less complex substitutions and taking into account the above conditions, $Q_{м1}(p)$ we find as follows [3]:

$$Q_{м1}(p)=\frac{C_{м}U_{м1}(p)}{L_{м1}C_{м}p^2+R_{м}C_{м}p+1}=\frac{K_{м1}U_{м1}(p)}{p^2+2\delta_{м1}p+\omega_{м1}^2}, \tag{7}$$

Where is $K_{м1}=1/L_{м1}$, $[1/(kg\cdot m^2)]$; $\delta_{м1}=R_{м}/2L_{м1}$, $[s^{-1}]$; $\omega_{м1}=\sqrt{1/C_{м1}L_{м1}}$, $[s^{-1}]$

For the right branch of the PSD section I compose the equations in the same order as above and create the following result equation:

$$Q_{м2}(p)=\frac{C_{м}U_{м2}(p)}{L_{м2}C_{м}p^2+R_{м}C_{м}p+1}=\frac{K_{м2}U_{м2}(p)}{p^2+2\delta_{м2}p+\omega_{м2}^2}. \tag{8}$$

Substituting equations (7) and (8) into (1), we obtain the following expression:

$$\Delta Q_{м}(p)=\frac{K_{м1}U_{м1}(p)}{p^2+2\delta_{м1}p+\omega_{м1}^2}-\frac{K_{м2}U_{м2}(p)}{p^2+2\delta_{м2}p+\omega_{м2}^2}. \tag{9}$$

We write the following equations for the elemental converters in Part III of the PSD:

$$U_{э.чиқ.}(p)=K_{I_{\mu д}U_{э.чиқ.}}I_{\mu д}(p); \tag{10}$$

$$I_{\mu д}(p)=I_{\mu т1}(p)+I_{\mu т2}(p); \tag{11}$$

$$I_{\mu т1}(p)=pQ_{\mu т1}(p); \tag{12}$$

$$Q_{\mu т1}(p)=\tfrac{1}{2}C_{\mu т}U_{\mu тC}(p); \tag{13}$$

$$U_{\mu т1C}(p)=U_{\mu қ}(p)-U_{\mu т1R}(p); \tag{14}$$

$$U_{\mu т1R}(p)=\frac{1}{2}pR_{\mu т}Q_{\mu т1}(p) \tag{15}$$

$$U_{\mu д}(p)=\left(pR_{\mu д}+p^2L_{\mu д}+W_{\mu д\delta}+W_{\mu дп}\right)Q_{\mu д}(p); \tag{16}$$

$$Q_{\mu д}(p)=Q_{\mu т1}(p)+Q_{\mu т2}(p); \tag{17}$$

$$I_{\mu т2}(p)=pQ_{\mu т2}(p); \tag{18}$$

$$Q_{\mu т2}(p)=\tfrac{1}{2}C_{\mu т}U_{\mu т2C}(p); \tag{19}$$

$$U_{\mu т2C}(p)=U_{\mu қ}(p)-U_{\mu т2R}(p); \tag{20}$$

$$U_{\mu т1R}(p)=\tfrac{1}{2}pR_{\mu т}Q_{\mu т2}(p); \tag{21}$$

$$U_{\mu қ}(p)=K_{\Delta Q_{м}U_{\mu қ}}\Delta Q_{м}, \tag{22}$$

Where is $K_{\Delta Q_{м}U_{\mu қ}}=w_{қ}I_{эқ}/\Delta Q_{мmax}$, $[A/degri]$.

(13)-(17) and (19)-(22) equations $Q_{\mu т1}(p)$, $Q_{\mu т2}(p)$ and $Q_{\mu д}(p)$ together with respect to magnetic fluxes, we obtain the following expressions:

$$Q_{\mu т1}(p)=Q_{\mu т2}(p)=\frac{K_{\Delta Q_{м}U_{\mu қ}}C_{\mu\Sigma}\Delta Q_{м}(p)}{R_{\mu\Sigma}C_{\mu\Sigma}p+1}=\frac{K_{\Delta Q_{м}U_{\mu қ}}G_{\mu\Sigma}\Delta Q_{м}(p)}{p+\frac{1}{T_{\mu}}}, \tag{23}$$

$$Q_{\mu д}(p)=\frac{2K_{\Delta Q_{м}U_{\mu қ}}C_{\mu\Sigma}\Delta Q_{м}(p)}{R_{\mu\Sigma}C_{\mu\Sigma}p+1}=\frac{K_{\Delta Q_{м}U_{\mu қ}}G_{\mu\Sigma}\Delta Q_{м}(p)}{p+\frac{1}{T_{\mu}}}, \tag{24}$$

Where is $G_{\mu\Sigma}=1/R_{\mu\Sigma}$, $[\Omega]$; $T_{\mu}=R_{\mu\Sigma}C_{\mu\Sigma}$, $[s]$.

Substituting (12) and (18) into (11) and the result into (10), we obtain the following equation:

$$U_{э.чиқ.}(p)=\frac{2K_{I_{\mu д}U_{э.чиқ.}}K_{\Delta Q_{м}U_{\mu қ}}pG_{\mu\Sigma}\Delta Q_{м}(p)}{p+\frac{1}{T_{\mu}}}. \tag{25}$$

$\Delta Q_{м}(p)$ Substituting (9) into (25), we obtain the following equation of the dynamic characteristics of the studied MD in operator form:

$$U_{э.чиқ.}(p)=\frac{2K_{I_{\mu д}U_{э.чиқ.}}K_{\Delta Q_{м}U_{\mu қ}}G_{\mu\Sigma}K_{м1}pU_{м1}(p)}{\left(p^2+2\delta_{м1}p+\omega_{м1}^2\right)\left(p+\frac{1}{T_{\mu}}\right)}-$$
$$-\frac{2K_{I_{\mu д}U_{э.чиқ.}}K_{\Delta Q_{м}U_{\mu қ}}G_{\mu\Sigma}K_{м2}pU_{м2}(p)}{\left(p^2+2\delta_{м2}p+\omega_{м2}^2\right)\left(p+\frac{1}{T_{\mu}}\right)}. \tag{26}$$

It is known that [1; 2, pp. 27-29], in transformer measuring converters, the excitation coil can be supplied from an alternating voltage or current source with sinusoidal regularity. If the excitation coil of the MD under study is supplied from a current source, then the static characteristic of the MD retains its linearity even when it is operating in load-connected mode. This is why it is the driving force in the study of the dynamic properties of MD $i_{эқ}(t)=I_{эқm}cos\omega_{э}t$ we consider the case connected to a sinusoidal source.

Analysis of Equation (26) shows that a new transformer converter supplied from a current source can be described as a real differentiating link given the difference between the output magnitudes of the two oscillating links at the input of the automatic control system to which it is applied [5, pp. 56-61].

Therefore, equation (26) gives the coefficient $K_{\Delta Q_{м}U_{\mu қ}}$ in the image of each additive $w_{қ}i_{эқ}(t)/\Delta Q_{мmax}=K_{I_{эқ}K}i_{эқ}(t)$ in order to simplify the finding of the original of the equation (26) in the form of the operator, we write in the following form:

$$A(p)=\frac{U_{э.чик.}(p)}{\mathrm{L}\left\{\frac{d}{dt}i_{эк}(t)\right\}}=\frac{K_1U_{м1}(p)}{(p^2+2\delta_{м1}p+\omega_{м1}^2)\left(p+\frac{1}{T_\mu}\right)}-$$

$$-\frac{K_2U_{м1}(p)}{(p^2+2\delta_{м2}p+\omega_{м2}^2)\left(p+\frac{1}{T_\mu}\right)}, \quad (27)$$

Where is $\mathrm{L}\left\{\frac{d}{dt}i_{эк}(t)\right\}=pI_{эк}(p)$; $K_1=2K_{I_{\mu д}U_{э.чик.}}K_{I_{эк}K}G_{\mu\Sigma}K_{м1}$, $[degri^{-1}\cdot\Omega\cdot(kg\cdot m^2)^{-1}]$; $K_2=2K_{I_{\mu д}U_{э.чик.}}K_{I_{эк}K}G_{\mu\Sigma}K_{м2}$, $[degri^{-1}\cdot\Omega\cdot(kg\cdot m^2)^{-1}]$.

We know from the theory of automatic control [10, pp. 77-79] that in determining the dynamic properties of elements in control and management systems, their input is usually given by sample effects of value jump and harmonic variable, determining the regularity of change of element output size over time. We also study the reaction of the MD under study to these sample input effects [4, 9].

RESULTS AND DISCUSSION

1. *1. The condition in which the mechanical moments of the jump are given by jumping to the MD inputs, that is* $U_{м1}(t)=U_{м10}=const$ *and* $U_{м2}(t)=U_{м20}=const$. Their operator images $U_{м1}(p)=\frac{U_{м10}}{p}$ and $U_{м2}(p)=\frac{U_{м20}}{p}$ Substituting (16), we obtain the following operator equation:

$$A(p)=\frac{K_1U_{м10}}{p(p^2+2\delta_{м1}p+\omega_{м1}^2)\left(p+\frac{1}{T_\mu}\right)}-$$

$$-\frac{K_2U_{м20}}{p(p^2+2\delta_{м2}p+\omega_{м2}^2)\left(p+\frac{1}{T_\mu}\right)}=\frac{F_1(p)}{F_2(p)}-\frac{F_3(p)}{F_4(p)}. \quad (28)$$

(28) equations characteristic equations $F_2(p)=0$ and $F_4(p)=0$ we find the following roots of:

$$p_1=0;\quad p_{2,3}=-\delta_м\pm\sqrt{\delta_м^2-\omega_м^2};\quad p_4=-\frac{1}{T_\mu}. \quad (29)$$

(28) from the image of the operator of the function (29) to the original of its time according to the roots we pass by the following distribution theorem:

$$A(t)=\sum_{k=1}^{4}\frac{F_1(p_k)}{F_2'(p_k)}e^{p_kt}-\sum_{k=1}^{4}\frac{F_3(p_k)}{F_4'(p_k)}e^{p_kt}. \quad (30)$$

$p^2+2\delta_мp+\omega_м^2=0$ depending on the values of the parameters of the mechanical chains p_2 and p_3 MD, which are the roots of the equation, are known [11, 254-257 pp.], can be real and different, real and identical and complex joint roots. We find the functions A (t) for these roots.

1) $\delta_{м1}>\omega_{м1}$ and $\delta_{м2}>\omega_{м2}$ the roots of the equation are real and different, that is $F_2(p)=0$ for $p_{2,3}=-\delta_{м1}\pm\sqrt{\delta_{м1}^2-\omega_{м1}^2}$. And $F_4(p)=0$ for $p_{2,3}=-\delta_{м2}\pm\sqrt{\delta_{м2}^2-\omega_{м2}^2}$. For this case, Equation (30) looks like this:

$$A_1(t)=A_{10}+A_{11}e^{-\frac{1}{T_\mu}t}+A_{12}[M_1ch(\omega_{м1}'t)-N_1sh(\omega_{м1}'t)]e^{-\delta_{м1}t}$$
$$-A_{13}[M_2ch(\omega_{м2}'t)-N_2sh(\omega_{м2}'t)]e^{-\delta_{м2}t} \quad (31)$$

Where is $A_{10}=\left(\frac{K_1U_{м10}}{\omega_{м1}^2}-\frac{K_2U_{м20}}{\omega_{м2}^2}\right)T_\mu$, $[\Omega\cdot s]$;

$A_{11}=\left(\frac{K_1U_{м10}}{(2\delta_{м1}T_{эк}-T_{эк}^2\omega_{м1}^2-1)}-\frac{K_2U_{м20}}{(2\delta_{м2}T_{эк}-T_{эк}^2\omega_{м2}^2-1)}\right)T_\mu^3$, $[\Omega\cdot s]$;

$A_{12}=\frac{4K_1U_{м10}T_\mu}{M_1^2-N_1^2}$, $[\Omega\cdot s^3]$; $A_{13}=\frac{4K_2U_{м20}T_\mu}{M_2^2-N_2^2}$, $[\Omega\cdot s^3]$;

$\omega_{м1}'=\sqrt{\delta_{м1}^2-\omega_{м1}^2}$, $[1/s]$; $\omega_{м2}'=\sqrt{\delta_{м2}^2-\omega_{м2}^2}$, $[1/s]$;

$M_1=14T_\mu\delta_{м1}^3+5\delta_{м1}^2-\omega_{м1}^2-8T_\mu\omega_{м1}^2\delta_{м1}$, $[1/s^2]$;

$N_1=2T_\mu\omega_{м1}'^3+5\omega_{м1}'\delta_{м1}+T_\mu\omega_{м1}^2\omega_{м1}'+12T_\mu\delta_{м1}^2\omega_{м1}'$, $[1/s^2]$;

$M_2=14T_\mu\delta_{м2}^3+5\delta_{м2}^2-\omega_{м2}^2-8T_\mu\omega_{м2}^2\delta_{м2}$, $[1/s^2]$;

$N_2=2T_\mu\omega_{м2}'^3+5\omega_{м2}'\delta_{м2}+T_\mu\omega_{м2}^2\omega_{м2}'+12T_\mu\delta_{м2}^2\omega_{м2}'$, $[1/s^2]$.

2) $\delta_{м1}=\omega_{м1}$ ва $\delta_{м2}=\omega_{м2}$ in the case of

$$A_2(t)=A_{20}+A_{21}e^{-\frac{1}{T_\mu}t}+A_{22}e^{-\delta_{м1}t}-A_{23}e^{-\delta_{м2}t}, \quad (32)$$

Where is $A_{20}=A_{10}$, $[\Omega\cdot s]$; $A_{21}=A_{11}$, $[\Omega\cdot s]$;

$A_{22} = \frac{K_1 U_{м10} T_\mu}{2T_\mu \omega_{м1}^2 \delta_{м1} + 10T_\mu \delta_{м1}^3 + 7\delta_{м1}^2 + \omega_{м1}^2}$, $[\Omega \cdot s]$;

$A_{23} = \frac{K_2 U_{м20} T_\mu}{2T_\mu \omega_{м2}^2 \delta_{м2} + 10T_\mu \delta_{м2}^3 + 7\delta_{м2}^2 + \omega_{м2}^2}$, $[\Omega \cdot s]$;

3) $\delta_{м1} < \omega_{м1}$ and $\delta_{м2} < \omega_{м2}$ when the roots of the equation are abstract

$$A_3(t) = A_{30} + A_{31} e^{-\frac{1}{T_\mu}t} + A_{32} e^{-\delta_{м1}t} \cos(\omega'_{м1}t - \varphi_1) - -A_{33} e^{-\delta_{м2}t} \cos(\omega'_{м2}t - \varphi_2), \tag{33}$$

Where is $A_{30} = A_{10}$, $[\Omega \cdot s]$; $A_{31} = A_{11}$, $[\Omega \cdot s]$; $A_{32} = \frac{2K_1 U_{м10} T_\mu}{\sqrt{B_1^2 + S_1^2}}$, $[\Omega \cdot s]$; $A_{33} = \frac{2K_2 U_{м20} T_\mu}{\sqrt{B_2^2 + S_2^2}}$, $[\Omega \cdot s]$; $B_1 = 28\delta_{м1}^3 T_\mu + 10\delta_{м1}^2 - 2\omega_{м1}^2 - 16T_\mu \omega_{м1}^2 \delta_{м1}$, $[s^{-2}]$;

$S_1 = 24T_\mu \delta_{м1}^2 \omega'_{м1} - 4T_\mu \omega'^3_{м1} + 10\omega'_{м1}\delta_{м1} + 2\omega_{м1}^2 \omega'_{м1} T_\mu$, $[s^{-2}]$;

$\varphi_1 = arctg\left(\frac{S_1}{B_1}\right), [degri]$; $\varphi_2 = arctg\left(\frac{S_2}{B_2}\right), , [degri]$.

$B_2 = 28\delta_{м2}^3 T_\mu + 10\delta_{м2}^2 - 2\omega_{м2}^2 - 16T_\mu \omega_{м2}^2 \delta_{м2}$, $[s^{-2}]$;

$S_2 = 24T_\mu \delta_{м2}^2 \omega'_{м2} - 4T_\mu \omega'^3_{м2} + 10\omega'_{м2}\delta_{м2} + 2\omega_{м2}^2 \omega'_{м2} T_\mu$, $[s^{-2}]$.

Based on Equation (27), we find the original voltage at the MD output as follows:

$$u_{э.чик.}(t) = A(t) \cdot \frac{d}{dt}\left[i_{эк}(t)\right] = A(t)\omega_э I_{экm} sin\omega_э t. \tag{34}$$

MD mechanical chains considering expressions (31), (32) and (33) $p^2 + 2\delta_м p + \omega_м^2 = 0$ The roots of the characteristic equation are real and different, for real and the same and complex joint roots, equation (34) is as follows:

$$u_{э.чик.1}(t) = U_{1m0} sin\omega_э t + U_{1m1} e^{-\frac{1}{T_\mu}t} sin\omega_э t + +[U'_{1m2} ch(\omega'_{м1}t) - U''_{1m2} sh(\omega'_{м1}t)]e^{-\delta_{м1}t} sin\omega_э t - -[U'_{1m3} ch(\omega'_{м2}t) - U''_{1m3} sh(\omega'_{м2}t)]e^{-\delta_{м2}t} sin\omega_э t, \tag{35}$$

Where is $U_{1m0} = A_{10}\omega_э I_{экm}$; $U_{1m1} = A_{11}\omega_э I_{экm}$; $U'_{1m2} = A_{12}\omega_э I_{экm} M_1$; $U''_{1m2} = A_{12}\omega_э I_{экm} N_1$; $U'_{1m3} = A_{13}\omega_э I_{экm} M_2$; $U''_{1m3} = A_{13}\omega_э I_{экm} N_2$, $[V]$.

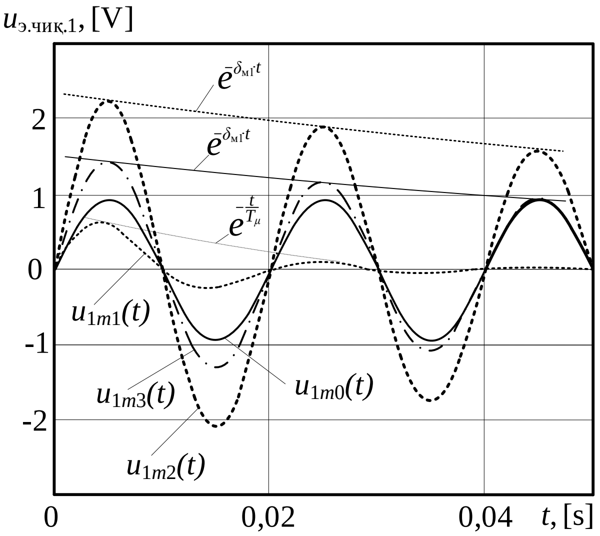
$$u_{э.чик.2}(t) = U_{2m0} sin\omega_э t + U_{2m1} e^{-\frac{1}{T_\mu}t} sin\omega_э t + +U_{2m2} e^{-\delta_{м1}t} sin\omega_э t - U_{2m3} e^{-\delta_{м2}t} sin\omega_э t\ , \tag{36}$$

Where is $U_{2m0} = A_{20}\omega_э I_{экm}$; $U_{2m1} = A_{21}\omega_э I_{экm}$; $U_{2m2} = A_{22}\omega_э I_{экm}$; $U_{2m3} = A_{23}\omega_э I_{экm}$, $[V]$.

$$u_{э.чик.3}(t) = U_{3m0} sin\omega_э t + U_{3m1} e^{-\frac{1}{T_\mu}t} sin\omega_э t + U_{3m2} e^{-\delta_{м1}t}\{sin[(\omega_э - \omega'_{м1})t + \varphi_1] + sin[(\omega_э + \omega'_{м1})t - \varphi_1]\} - -U_{3m3} e^{-\delta_{м2}t}\{sin[(\omega_э - \omega'_{м2})t + \varphi_2] + sin[(\omega_э + \omega'_{м2})t - \varphi_2]\}, \tag{37}$$

Where is $U_{3m0} = A_{30}\omega_э I_{экm}$; $U_{3m1} = A_{31}\omega_э I_{экm}$; $U_{3m2} = \frac{1}{2} A_{32}\omega_э I_{экm}$; $U_{3m3} = \frac{1}{2} A_{33}\omega_э I_{экm}$, $[V]$.

Graphs of functions (35), (36) and (37) are shown in Figures 4÷5, respectively.



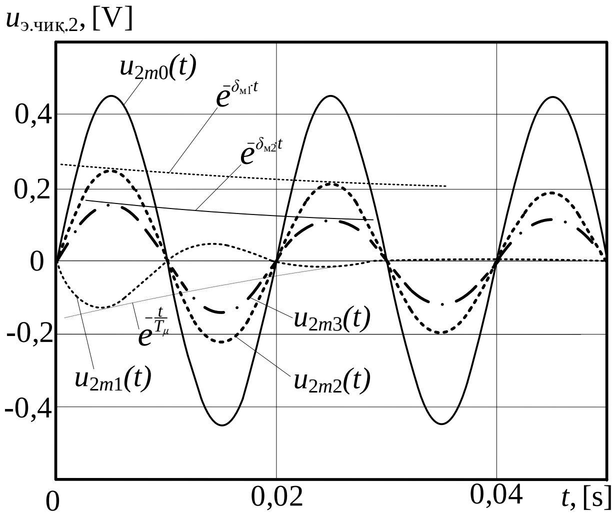


Figure 4 Transient voltage time diagrams when the input of MD is given the difference of jumping moments and when $\delta_{м1} > \omega_{м1}$ ва $\delta_{м2} > \omega_{м2}$

Figure 5. Transient voltage time diagrams when the input of MD is given the difference of the moments of the jump and when $\delta_{м1} = \omega_{м1}$ and $\delta_{м2} = \omega_{м2}$

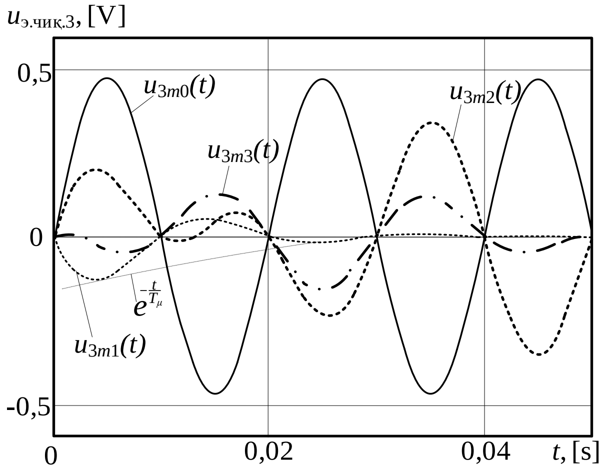


Figure 6. Transient voltage time diagrams when the input of the MD input is given the difference of the alternating moments and when $\delta_{м1} < \omega_{м1}$ ва $\delta_{м2} < \omega_{м2}$

2. *2. A condition in which sinusoidal variable mechanical moments are given to the MD inputs, that is* $U_{м1}(t) = U_{мm1} sin\Omega_{м1} t$ *and* $U_{м2}(t) = U_{мm2} sin\Omega_{м2} t$. Their operator images $U_{м1}(p) = \frac{\Omega_{м1} U_{мm1}}{p^2+\Omega_{м1}^2}$ and $U_{м2}(p) = \frac{\Omega_{м2} U_{мm2}}{p^2+\Omega_{м2}^2}$ Substituting (27) into, we obtain the following operator equation:

$$A(p) = \frac{K_1 U_{мm1}}{(p^2+\Omega_{м1}^2)(p^2+2\delta_{м1}p+\omega_{м1}^2)\left(p+\frac{1}{T_\mu}\right)} -$$

$$- \frac{K_2 U_{мm2}}{(p^2+\Omega_{м2}^2)(p^2+2\delta_{м2}p+\omega_{м2}^2)\left(p+\frac{1}{T_\mu}\right)} = \frac{F_1(p)}{F_2(p)} - \frac{F_3(p)}{F_4(p)}. \quad (38)$$

$F_2(p) = 0$ and $F_4(p) = 0$ we find the following roots of the characteristic equations:

$$p_1 = \pm j\Omega; \quad p_{2,3} = -\delta_м \pm \sqrt{\delta_м^2 - \omega_м^2}; \quad p_4 = -\frac{1}{T_\mu}. \quad (39)$$

1) $\delta_{м1} > \omega_{м1}$ and $\delta_{м2} > \omega_{м2}$ for the present case (38) the original of equation (38) is in the following form according to the propagation theorem:

$$A_1(t) = A_{11} e^{-\frac{1}{T_\mu}t} + A_{12}\cos(\Omega_{м1}t - \varphi_1) - A_{13}\cos(\Omega_{м2}t - \varphi_2) +$$
$$+ A_{14} e^{-\delta_{м1}t}(B_1 ch\omega'_{м1}t - S_1 sh\omega'_{м1}t) -$$
$$- A_{15} e^{-\delta_{м2}t}(B_2 ch\omega'_{м2}t - S_2 sh\omega'_{м2}t), \quad (40)$$

Where is $A_{11} = \left(\frac{\Omega_{м1} K_1 U_{мm1} T_\mu^4}{2(T_\mu^2\Omega_{м1}^2+1)(T_\mu^2\omega_{м1}^2-2\delta_{м1}T_\mu+1)} - \frac{\Omega_{м2} K_2 U_{мm2} T_\mu^4}{2(T_\mu^2\Omega_{м2}^2+1)(T_\mu^2\omega_{м2}^2-2\delta_{м2}T_\mu+1)}\right)$, $[\Omega \cdot s]$;
$A_{12} = \frac{T_\mu K_1 U_{мm1}}{2\sqrt{M_1^2+N_1^2}}$, $[\Omega \cdot s]$; $A_{13} = \frac{T_\mu K_2 U_{мm2}}{2\sqrt{M_2^2+N_2^2}}$, $[\Omega \cdot s]$; $A_{14} = \frac{2\Omega_{м1} K_1 U_{мm1} T_\mu}{B_1^2 - S_1^2}$, $[\Omega \cdot s^4]$;
$A_{15} = \frac{2\Omega_{м2} K_2 U_{мm2} T_\mu}{B_2^2 - S_2^2}$, $[\Omega \cdot s^4]$; $\varphi_1 = arctg\left(\frac{N_1}{M_1}\right)$, $[degri]$; $\varphi_2 = arctg\left(\frac{N_2}{M_2}\right)$, $[degri]$; $M_1 = T_\mu \Omega_{м1}^3 - 2\Omega_{м1}\delta_{м1} - T_\mu \Omega_{м1}\omega_{м1}^2$, $[s^{-2}]$; $N_1 = \omega_{м1}^2 - \Omega_{м1}^2 - 2T_\mu\delta_{м1}\Omega_{м1}^2$, $[s^{-2}]$; $M_2 = T_\mu\Omega_{м2}^3 - 2\Omega_{м2}\delta_{м2} - T_\mu\Omega_{м2}\omega_{м2}^2$, $[s^{-2}]$; $N_2 = \omega_{м2}^2 - \Omega_{м2}^2 - 2T_\mu\delta_{м2}\Omega_{м2}^2$, $[s^{-2}]$; $\omega'_{м1} = \sqrt{\delta_{м1}^2 - \omega_{м1}^2}$, , $[s^{-1}]$; $\omega'_{м2} = \sqrt{\delta_{м2}^2 - \omega_{м2}^2}$, $[s^{-1}]$; $B_1 = 2T_\mu\omega_{м1}^4 + 8T_\mu\delta_{м1}^4 + 4\omega_{м1}^2\delta_{м1} - 4\delta_{м1}^3 - 2T_\mu\Omega_{м1}^2\omega_{м1}^2 + 2T_\mu\Omega_{м1}^2\delta_{м1}^2 - 10T_\mu\omega_{м1}^2\delta_{м1}^2$,$[s^{-3}]$; $S_1 = 4\omega'^3_{м1} + 2\Omega_{м1}^2\omega'_{м1} + 2\omega_{м1}^2\omega'_{м1} + 4T_\mu\delta_{м1}^3\omega'_{м1} - 12T_\mu\delta_{м1}\omega'^3_{м1} - 2T_\mu\Omega_{м1}^2\delta_{м1}\omega'_{м1} - 6T_\mu\omega_{м1}^2\delta_{м1}\omega'_{м1}$, $[s^{-3}]$; $B_2 = 2T_\mu\omega_{м2}^4 + 8T_\mu\delta_{м2}^4 + 4\omega_{м2}^2\delta_{м2} - 4\delta_{м2}^3 - 2T_\mu\Omega_{м2}^2\omega_{м2}^2 + 2T_\mu\Omega_{м2}^2\delta_{м2}^2 - 10T_\mu\omega_{м2}^2\delta_{м2}^2$, $[s^{-3}]$; $S_1 = 4\omega'^3_{м2} + 2\Omega_{м2}^2\omega'_{м2} + 2\omega_{м2}^2\omega'_{м2} + 4T_\mu\delta_{м2}^3\omega'_{м2} - 12T_\mu\delta_{м2}\omega'^3_{м2} - 2T_\mu\Omega_{м2}^2\delta_{м2}\omega'_{м2} - 6T_\mu\omega_{м2}^2\delta_{м2}\omega'_{м2}$, $[s^{-3}]$;

2) $\delta_{м1} = \omega_{м1}$ ва $\delta_{м2} = \omega_{м2}$ in the case of:

$$A_2(t) = A_{21} e^{-\frac{1}{T_\mu}t} + A_{22}\cos(\Omega_{м1}t - \varphi_1) - A_{23}\cos(\Omega_{м2}t - \varphi_2) +$$
$$+ A_{24} e^{-\delta_{м1}t} - A_{25} e^{-\delta_{м2}t}, \quad (41)$$

Where is $A_{21} = A_{11}$, $[\Omega \cdot s]$; $A_{22} = A_{12}$, $[\Omega \cdot s]$; $A_{23} = A_{13}$, $[\Omega \cdot s]$; $A_{24} = \frac{\Omega_{м1} T_\mu K_1 U_{мm1}}{(\omega_{м1}^2-\delta_{м1}^2)(T_\mu\Omega_{м1}^2+3T_\mu\delta_{м1}^2-2\delta_{м1})}$, $[\Omega \cdot s]$;
$A_{25} = \frac{\Omega_{м2} T_\mu K_2 U_{мm2}}{(\omega_{м2}^2-\delta_{м2}^2)(T_\mu\Omega_{м2}^2+3T_\mu\delta_{м2}^2-2\delta_{м2})}$, $[\Omega \cdot s]$.

3) $\delta_{м1} < \omega_{м1}$ and $\delta_{м2} < \omega_{м2}$ in the case where (38) the original of equation is as follows:

$$A_3(t) = A_{31}e^{-\frac{1}{T_\mu}t} + A_{32}\cos(\Omega_{м1}t - \varphi_1) - A_{33}\cos(\Omega_{м2}t - \varphi_2) + \\ +A_{34}e^{-\delta_{м1}t}\cos(\Omega_{м1}t - \varphi_3) - A_{35}e^{-\delta_{м2}t}\cos(\Omega_{м2}t - \varphi_4), \quad (42)$$

Where is $A_{31} = A_{11}$, $[\Omega \cdot s]$; $A_{32} = A_{12}$, $[\Omega \cdot s]$; $A_{33} = A_{13}$, $[\Omega \cdot s]$;
$A_{34} = \frac{2\Omega_{м1}K_1U_{мм1}T_\mu}{\sqrt{B_3^2+S_3^2}}$, $[\Omega \cdot s]$; $A_{35} = \frac{2\Omega_{м2}K_2U_{мм2}T_\mu}{\sqrt{B_4^2+S_4^2}}$, $[\Omega \cdot s]$;
$B_3 = 8T_\mu\omega_{м1}^4 - 4T_\mu\delta_{м1}^4 - 8\omega_{м1}^2\delta_{м1} + 8\delta_{м1}^3 + 4T_\mu\Omega_{м1}^2\omega_{м1}^2 - 4T_\mu\omega_{м1}^2\delta_{м1}^2 - 4T_\mu\Omega_{м1}^2\delta_{м1}^2$, $[s^{-3}]$; $S_3 = 4T_\mu\delta_{м1}^3\omega'_{м1} - 6T_\mu\omega_{м1}^2\delta_{м1}\omega'_{м1} - 2T_\mu\Omega_{м1}^2\delta_{м1}\omega'_{м1} - 4\omega'^3_{м1} + 2\Omega_{м1}^2\omega'_{м1} + 2\omega_{м1}^2\omega'_{м1} - 12T_\mu\delta_{м1}\omega'^3_{м1}$, $[s^{-3}]$; $B_4 = 8T_\mu\omega_{м2}^4 - 4T_\mu\delta_{м2}^4 - 8\omega_{м2}^2\delta_{м2} + 8\delta_{м2}^3 + 4T_\mu\Omega_{м2}^2\omega_{м2}^2 - 4T_\mu\omega_{м2}^2\delta_{м2}^2 - 4T_\mu\Omega_{м2}^2\delta_{м2}^2$, $[s^{-3}]$;
$S_4 = 4T_\mu\delta_{м2}^3\omega'_{м2} - 6T_\mu\omega_{м2}^2\delta_{м2}\omega'_{м2} - 2T_\mu\Omega_{м2}^2\delta_{м2}\omega'_{м2} - 4\omega'^3_{м2} + 2\Omega_{м2}^2\omega'_{м2} + 2\omega_{м2}^2\omega'_{м2} - 12T_\mu\delta_{м2}\omega'^3_{м2}$, $[s^{-3}]$; $\varphi_3 = arctg\left(\frac{S_3}{B_3}\right)$, $[degri]$; $\varphi_4 = arctg\left(\frac{S_4}{B_4}\right)$, $[degri]$.

For a case where sinusoidal variable mechanical moments are applied to the MD inputs (40), (41) and, given (42), Equation (34) is in the following form:

$$u_{э.чик.1}(t) = U_{1m1}e^{-\frac{1}{T_\mu}t}sin\omega_э t + \\ +U_{1m2}\{sin[(\omega_э - \Omega_{м1})t + \varphi_1] + sin[(\omega_э + \Omega_{м1})t - \varphi_1]\} - \\ -U_{1m3}\{sin[(\omega_э - \Omega_{м2})t + \varphi_2] + sin[(\omega_э + \Omega_{м2})t - \varphi_2]\} + \\ +e^{-\delta_{м1}t}(U'_{1m4}ch\omega'_{м1}t - U''_{1m4}sh\omega'_{м1}t)sin\omega_э t - \\ -e^{-\delta_{м2}t}(U'_{1m5}ch\omega'_{м2}t - U''_{1m5}sh\omega'_{м2}t)sin\omega_э t, \quad (43)$$

Where is $U_{1m1} = A_{11}\omega_э I_{экm}$; $U_{1m2} = \frac{1}{2}A_{12}\omega_э I_{экm}$; $U_{1m3} = \frac{1}{2}A_{13}\omega_э I_{экm}$; $U'_{1m4} = A_{14}B_1\omega_э I_{экm}$; $U''_{1m4} = A_{14}S_1\omega_э I_{экm}$; $U'_{1m5} = A_{15}B_2\omega_э I_{экm}$;
$U''_{1m5} = A_{15}S_2\omega_э I_{экm}$; $[V]$.

$$u_{э.чик.2}(t) = U_{2m1}e^{-\frac{1}{T_\mu}t}sin\omega_э t + \\ +U_{2m2}\{sin[(\omega_э - \Omega_{м1})t + \varphi_1] + sin[(\omega_э + \Omega_{м1})t - \varphi_1]\} - \\ -U_{2m3}\{sin[(\omega_э - \Omega_{м2})t + \varphi_2] + sin[(\omega_э + \Omega_{м2})t - \varphi_2]\} + \\ +U_{2m4}e^{-\delta_{м1}t}sin\omega_э t - U_{2m5}e^{-\delta_{м2}t}sin\omega_э t, \quad (44)$$

Where is $U_{2m1} = A_{21}\omega_э I_{экm}$; $U_{2m2} = \frac{1}{2}A_{22}\omega_э I_{экm}$; $U_{2m3} = \frac{1}{2}A_{23}\omega_э I_{экm}$;
$U_{2m4} = A_{24}\omega_э I_{экm}$; $U_{2m5} = A_{25}\omega_э I_{экm}$, $[V]$.

$$u_{э.чик.3}(t) = U_{3m1}e^{-\frac{1}{T_\mu}t}sin\omega_э t + \\ +U_{3m2}\{sin[(\omega_э - \Omega_{м1})t + \varphi_1] + sin[(\omega_э + \Omega_{м1})t - \varphi_1]\} - \\ -U_{3m3}\{sin[(\omega_э - \Omega_{м2})t + \varphi_2] + sin[(\omega_э + \Omega_{м2})t - \varphi_2]\} + \\ +U_{3m4}e^{-\delta_{м1}t}\{sin[(\omega_э - \Omega_{м1})t + \varphi_3] + sin[(\omega_э + \Omega_{м1})t - \varphi_3]\} - \\ -U_{3m5}e^{-\delta_{м2}t}\{sin[(\omega_э - \Omega_{м2})t + \varphi_4] + sin[(\omega_э + \Omega_{м2})t - \varphi_4]\}, \quad (45)$$

Where is $U_{3m1} = A_{31}\omega_э I_{экm}$; $U_{3m2} = \frac{1}{2}A_{32}\omega_э I_{экm}$; $U_{3m3} = \frac{1}{2}A_{33}\omega_э I_{экm}$;
$U_{3m4} = \frac{1}{2}A_{34}\omega_э I_{экm}$; $U_{3m5} = \frac{1}{2}A_{35}\omega_э I_{экm}$, $[V]$.

Graphs of functions (43), (44) and (45) are shown in Figures 7 ÷ 9, respectively.

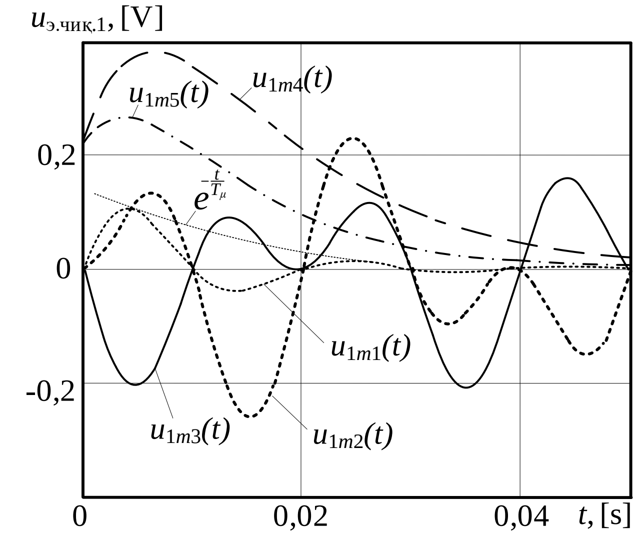


Figure 7 Transient voltage time diagrams when the input of MD is given the difference of harmonically varying moments and when $\delta_{м1} > \omega_{м1}$ and $\delta_{м2} > \omega_{м2}$

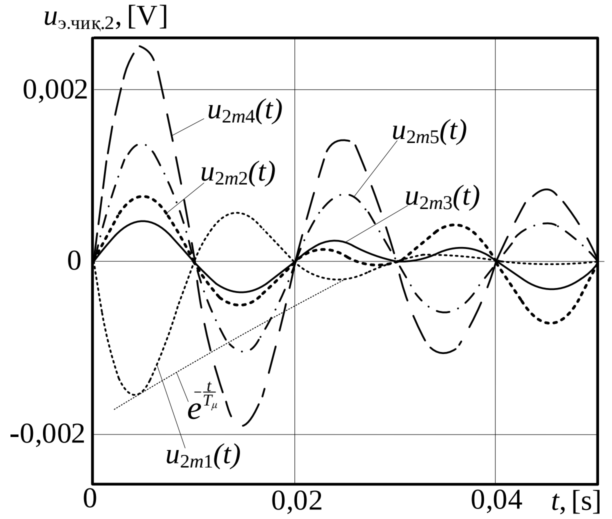


Figure 8 Transient voltage time diagrams when the input of MD is given the difference of harmonically varying moments and when $\delta_{м1} = \omega_{м1}$ and $\delta_{м2} = \omega_{м2}$

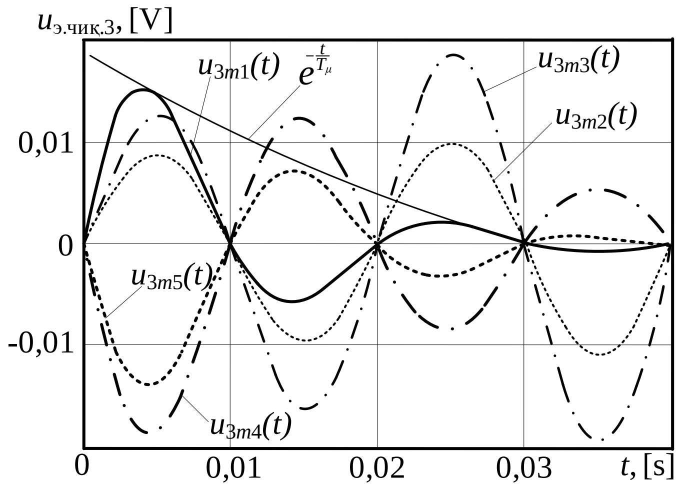


Figure 9 Transient voltage time diagrams when the input of MD is given the difference of harmonically varying moments and when $\delta_{м1} < \omega_{м1}$ and $\delta_{м2} < \omega_{м2}$

CONCLUSION

1. A new transformer measuring the difference in angular displacement supplied by the current source can be described in the form of a real differentiating link, given the difference in the output magnitudes of the two oscillating links at the input to the block diagram of the applied automatic control system.
2. A new transformer supplied by a current source consists of an algebraic sum of three free components, one of which is constant, the magnets of which are magnetic, and the two mechanical chains, depending on the time constants, respectively.
3. Transient voltage frequencies at the output of a new transformer converter supplied from the current source at two inputs with two torques of harmonic variable of different amplitude and frequency at the two inputs source current frequency ($\omega_э$) and input size frequency ($\Omega_м$) two constants consisting of a sum of signals equal to the difference and the sum, amplitude values will consist of an algebraic sum of three free constituents that are extinct depending on the time constants of the magnetic and two mechanical chains, respectively.

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