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Transfer functions of the automatic electrohydraulic drive

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Summary. The linear mathematical model is presented and transfer functions of the automatic electrohydraulic drive with throttle regulation are defined. The mathematical model is adapted on drives of the special technological equipment for machining materials, constructed on the basis of standard modules.

Key words: automatic electrohydraulic drive, linear mathematical model, throttle regulation, transfer functions.

INTRODUCTION

The modern technological equipment for mechanical processing of materials demands much of characteristics of drives on accuracy of realization of the set laws of movement of a target link that is reached by use of eply electrohydraulic watching drive (AEHD) [12].

The important stage in AEHD designing is the estimation of stability, quality of regulation and correction of dynamic properties of a drive. Performance of the given stage is connected with working out of mathematical model of the non-stationary working processes proceeding in a drive. The mathematical models of dynamic processes presented in the literature [2, 15, 21], cannot be generalized on all class considered AEHD. A number from them is focused on certain designs of devices of a drive (Fig. 1), in particular electrohydraulic amplifier (EHA). In the majority of model definition of parameters which cannot be estimated from nameplate data of standard devices demand or are revealed at a stage of preliminary designing.

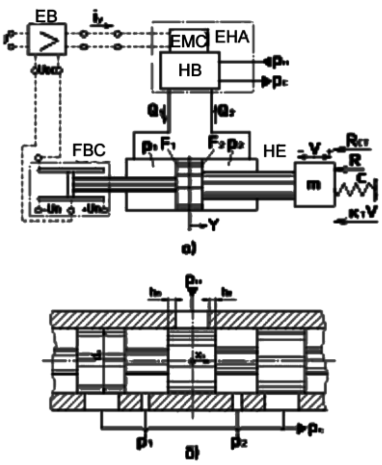

Fig. 1. Settlement scheme AEHD (a) and target cascade EHA (b)

At small deviations of parameters of system from static values use of linear models for the mathematical description of non-stationary processes is admissible. It allows to receive the analytical decisions, giving the chance to find out and present prominent features of studied process for any combination of parameters of system. Besides, analytical decisions are "standards" for an estimation of accuracy of analytical decisions.

The work purpose is working out of linear mathematical model and definition of transfer functions of an electrohydraulic watching drive with the throttle regulation, adapted on drives of the equipment for processing by the pressure, constructed on the basis of standard modules, with use for an estimation of dynamic characteristics of nameplate data of devices of a drive.

OBJECTS AND PROBLEMS

Let's allocate basic elements of the AEHD: a hydraulic engine (HE), the electrohydraulic amplifier (EHA), the including electromechanical converter (EMC) and the hydraulic booster (HB), the feedback gauge (FBG), the electronic block (EB). Further it is considered the settlement scheme of a drive presented on fig. 1.

In works [1, 6] typical nonlinear mathematical model of the AEHD with throttle regulation which includes following equations and dependences is considered:

$$U_{OC}=k_{OC}Y,\; U_{YC}=k_{YC}(U-U_{OC}),\; L_y\frac{di_y}{dt}+R_Ei_y=U_{YC},$$

$$T_{2y}^{\,2}\frac{d^2x_3}{dt^2}+T_{1y}\frac{dx_3}{dt}+x_3=k_{xi}i_y,$$

$$Q_1=\begin{cases}\mu_{\text{Ç}}\pi d_{\text{Ç}}k_{\text{ï}}\left(\text{õ}_{\text{Ç}}-h_{\text{ï}}\right)\sqrt{\frac{2}{\rho}\left|\text{ð}_{\text{í}}-\text{ð}_1\right|}\times\\ sign\left(p_{\text{í}}-\text{ð}_1\right),\text{õ}_{\text{Ç}}>h_{\text{ï}},\\ \qquad 0,\left|\text{õ}_{\text{Ç}}\right|\le h_{\text{ï}},\\ \mu_{\text{Ç}}\pi d_{\text{Ç}}k_{\text{ï}}\left(\text{õ}_{\text{Ç}}+h_{\text{ï}}\right)\sqrt{\frac{2}{\rho}\left|\text{ð}_1-\text{ð}_{\text{Ñ}}\right|}\times\\ sign\left(p_1-\text{ð}_{\text{Ñ}}\right),\text{õ}_{\text{Ç}}<-h_{\text{ï}},\end{cases}$$

$$Q_2=\begin{cases}\mu_{\text{Ç}}\pi d_{\text{Ç}}k_{\text{ï}}\left(\text{õ}_{\text{Ç}}-h_{\text{ï}}\right)\sqrt{\frac{2}{\rho}\left|\text{ð}_2-\text{ð}_C\right|}\times\\ sign\left(p_2-\text{ð}_C\right),\text{õ}_{\text{Ç}}>h_{\text{ï}},\\ \qquad 0,\left|\text{õ}_{\text{Ç}}\right|\le h_{\text{ï}},\\ \mu_{\text{Ç}}\pi d_{\text{Ç}}k_{\text{ï}}\left(\text{õ}_{\text{Ç}}+h_{\text{ï}}\right)\sqrt{\frac{2}{\rho}\left|\text{ð}_{\text{Í}}-\text{ð}_2\right|}\times\\ sign\left(p_{\text{Í}}-\text{ð}_2\right),\text{õ}_{\text{Ç}}<-h_{\text{ï}},\end{cases}$$

$$m\frac{dV}{dt} = p_1F_1 - p_2F_2 - cY - k_TV - \\ -R_{CT}\,signV - R,$$

$$\frac{dY}{dt} = V, -H/2 \le Y \le H/2,$$

$$\frac{W_{HO} + F_1(H/2+Y)}{E_{el}}\frac{dp_1}{dp_1} = Q_1 - F_1V,$$

$$\frac{W_{HO} + F_2(H/2-Y)}{E_{el}}\frac{dp_2}{dp_1} = -Q_2 + F_2V,$$

where: Y, V - moving and speed of the piston; p_1, p_2 - pressure in hydrocylinder cavities; m - the resulted weight of mobile parts; F_1, F_2 - the effective areas; c - rigidity of item loading; κ_T - factor of force of a viscous friction; R_{CT} - force of a dry friction; R - loading; H - a piston course; E_{el} - the module of elasticity of a working liquid; W_{HO}, W_{CO} - "dead" volumes of pressure head and drain highways; k_{OC} - factor of FBG transfer; k_{xi} - factor of EHA transfer; constants of time T_{2Y}, T_{1Y} which are defined on shift frequencies ν_1, ν_2 on a phase on 45 and 90 hailstones:

$$T_{2y} = \frac{1}{2\pi\nu_2}; T_{1y} = \frac{1}{2\pi\nu_1} - \frac{2\pi\nu_1}{(2\pi\nu_2)^2},$$

where: p_H, p_C - pressure of pump station and on plum; h_n - size of positive overlapping; μ_3 - factor of the expense of a crack of a valve; d_3 - diameter of a valve; k_n - factor of completeness of use of perimeter of a valve; ρ - density of a working liquid; U - entrance (operating) pressure; U_{YC} - pressure on EB exit; k_{YC} - factor of EB strengthening; L_Y - inductance of a winding of management; R_E - active resistance of the electric chain.

Let's make the linearization of the received nonlinear mathematical model, preliminary having excluded as a first approximation force of a dry friction and item loading. Usually at drawing up of linear mathematical models of hydrodrives [19, 20, 22] the assumption of equality of "dead" volumes of pressure head and drain highways is accepted:

$$W_{HO} = W_{CO} = W_o. \quad (1)$$

And the indissolubility equations register for average position of the piston, and also equality of the effective areas of the hydrocylinder:

$$F_1 = F_2 = F. \quad (2)$$

Last assumption is the most essential, however allows to simplify considerably model for the account of following possibility to admit equality of expenses in EHA lines:

$$Q_1 = Q_2 = Q. \quad (3)$$

With the account of the above-stated, the equation of movement and balance of expenses become:

$$\frac{dy}{dt} = V, \quad (4)$$

$$\frac{Wo + F\,H/2}{E_{el}}\frac{dp_1}{dt} = Q - FV, \quad (5)$$

$$\frac{Wo + F\,H/2}{E_{el}}\frac{dp_2}{dt} = Q + FV. \quad (6)$$

By linear links are described FBG, EB and operating winding EHA:

$$U_{oc} = k_{oc}y, \quad (7)$$

$$U_{yc} = k_{yc}(U - U_{oc}). \quad (8)$$

The linear accepts communication of displacement of HB valve with a current in a management winding:

$$T_{2y}^2\frac{d^2x_3}{dt2} + T_{1y}\frac{dx_3}{dt} + x_3 = k_{xi}i_y. \quad (9)$$

We use the traditional approach [6, 8] to linearization of the flow-transfer EHA characteristics:

$$Q = k_{Qx}x_3 - k_{Qp}(p_1 - p_2), \quad (10)$$

where: factors of transfers k_{Qx}, k_{Qp} in a general view are defined on expressions:

$$k_{Q_x} = \frac{\partial Q}{\partial x}\bigg|_{\substack{x_3=x_{30}\\ p_1=p_{10}\\ p_2=p_{20}}} \quad k_{Q_x} = \frac{\partial Q}{\partial x}\bigg|_{\substack{x_3=x_{30}\\ p_1=p_{10}\\ p_2=p_{20}}} \quad (11)$$

$$k_{Q_x} = \frac{\partial Q}{\partial(p_1 - p_2)}\bigg|_{\substack{x_3=x_{30}\\ p_1=p_{10}\\ p_2=p_{20}}}$$

$$k_{Q_p} = \frac{\partial Q}{\partial(p_1 - p_2)}\bigg|_{\substack{x_3=x_{30}\\ p_1=p_{10}\\ p_2=p_{20}}} \quad (12)$$

$x_{зо}, p_{10}, p_{20}$ – static values of variables.

As a first approximation in calculations it is possible to put values k_{Qx} and k_{Qp}, defined at $x_{зо} = 0, p_{10} = 0, p_{20} = 0$ for valve HB with zero:

$$k_{Qx} = \mu_3\pi d_ç k_n\sqrt{\frac{p_n}{p}}, \quad (13)$$

$$k_{Qx} = 0, \quad (14)$$

where: $p_n = p_n - p_c$ – brought to EHA pressure.

For deviations of variables from static values it is had the following system of the linear equations:

$$\begin{cases} \Delta U_{oc} = k_{oc}\Delta y, & (15) \\ \Delta U_{yc} = k_{yc}\left(\Delta U - \Delta U_{oc}\right), & (16) \\ L_y \dfrac{d\Delta i_y}{dt} + R_E \Delta i_y = \Delta U_{yc}, & (17) \\ T_{2y}^2 \dfrac{d^2\left(\Delta x_3\right)}{dt^2} + T_{1y}\dfrac{d\left(\Delta x_3\right)}{dt} + x_3 - \\ -k_{xi}\Delta i_y, & (18) \\ \Delta Q = k_{Qx}\Delta x_3 - k_{Qp}\left(\Delta p_1 - \Delta p_2\right), & (19) \\ \dfrac{W_0 + FH/2}{E_{el}}\dfrac{d\left(\Delta p_1\right)}{dt} = \Delta Q - \\ -F\Delta V, & (20) \\ \dfrac{W_0 + FH/2}{E_{el}}\dfrac{d\left(\Delta p_2\right)}{dt} = -\Delta Q + \\ +F\Delta V, & (21) \\ m\dfrac{d\left(\Delta V\right)}{dt} = \left(\Delta p_1 - \Delta p_2\right)F - k_T\Delta V - \\ -\Delta R; & (22) \\ \dfrac{d\left(\Delta y\right)}{dt} = \Delta V. & (23) \end{cases}$$

We subtract (Eq. 21) of (Eq. 20), we substitute result in (Eq. 19) then system it is transformed on Laplas [3, 4, 7] and it is led to a kind:

$$\begin{cases} \Delta U_{oc}(s) = k_{oc}\Delta y(s), \\ \Delta U_{yc}(s) = k_{yc}(\Delta U(s) - \Delta U_{oc}(s)), \\ \Delta i_y(s) = L_y \dfrac{1/R_{\acute{y}}}{T_{oy}s + 1}\Delta U_{yc}(s), \\ \Delta x_3(s) = \dfrac{k_{xi}}{T_{2y}^2 s^2 + T_{1y}s + 1}\Delta i_y, \\ (\Delta p_1(s) - \Delta p_2(s)) = \dfrac{1}{\dfrac{FH}{4E_{eh}}s + k_{Qp}} \times \\ \left[k_{Qx}\Delta x_3(s) - F\Delta V(s)\right], \\ \Delta V(s) = \dfrac{1}{ms + k_T}\left[\begin{matrix} F(\Delta p_1(s) - \\ -\Delta p_2(s)) - \Delta R \end{matrix}\right], \\ \Delta y(s) = \dfrac{1}{s}\Delta V(s), \end{cases} \quad (24)$$

where: s – Laplas variable, T_{oy} – a constant of time of a winding of management:

$$T_{oy} = L_y / R_{э}, \quad (25)$$

E_{eh} – the resulted module of elasticity of the hydrocylinder:

$$E_{eh} = \frac{E_{el}}{1 + \dfrac{2W_o}{FH}}. \quad (26)$$

To system (Eq. 24) there corresponds the block diagram presented on Fig. 2.

Let's transform the block diagram for what we will enter factor of transfer EB [5, 9]:

$$K_{eb} = K_{yc} / K_e. \quad (27)$$

And factor of strengthening EHA under the expense:

$$K_{Qi} = K_{xi} / K_{Qx}. \quad (28)$$

Value K_{Qi} it is possible to establish on nameplate data EHA: [6, 10, 11]:

$$K_{Qi} = Q_n / i_n, \quad (29)$$

where: Q_n, i_n - the nominal expense and rated current management EHA.

The transformed block diagram is shown on fig. 3.

Let's receive transfer function of a drive on an operating signal, for what we will transform the block diagram (fig. 4) see, having excluded from consideration ΔR.

Let's define a hydromechanical constant of time of the hydrocylinder:

$$T_{eh} = \sqrt{\frac{mH}{4E_{eh}F}}. \quad (30)$$

And factor relative damping of the hydrocylinder:

$$\zeta_{eh} = \frac{1}{T_{ц}}\left[\frac{K_{Qp}m}{F^2} + \frac{HK_T}{2E_{eh}F}\right]. \quad (31)$$

In real drives [6]:

$$K_{Qp}K_T / F^2 \langle\langle 1. \quad (32)$$

Therefore it is definitively possible [13, 14] to offer the block diagram of transfer of the operating signal, resulted on fig. 5.

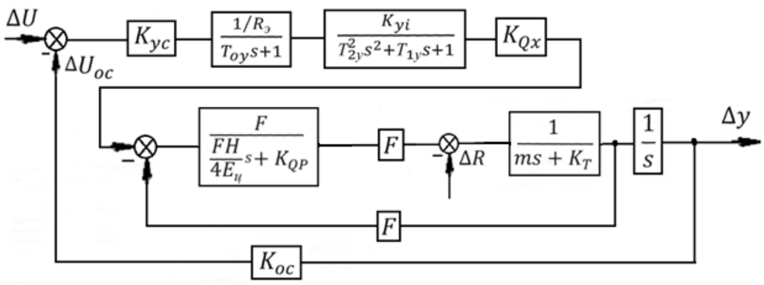

Fig. 2. The Block diagram

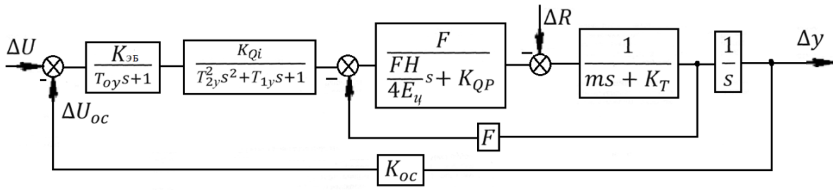

Fig. 3. The Block diagram

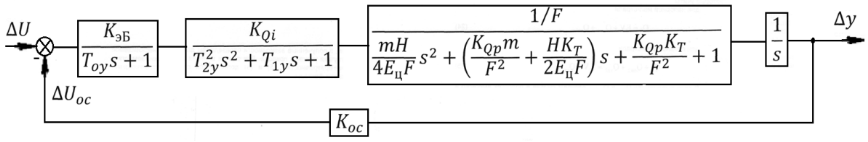

Fig. 4. To definition of transfer function AEHD on an operating signal

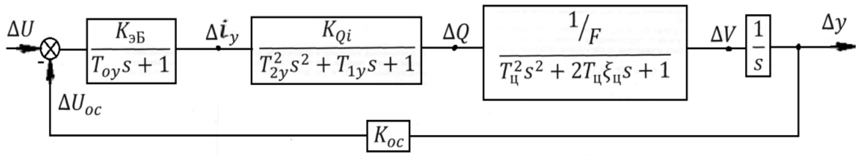

Fig. 5. The Block diagram of transfer of an operating signal

According to the block diagram it is established transfer function AEHD on an operating signal:

$$W_{yu}(s)=\frac{K_{yu}}{\frac{s}{D_{EHWD}}(T_{oy}s+1)(T_{2y}^2s^2+T_{1y}s+1)\times(T_{ц}^2s^2+2T_{eh}\zeta_{eh}s+1)+1}, \quad (33)$$

where: K_{yu} – factor of transfer AEHD on an operating signal:

$$K_{yu}=1/K_{oc}, \quad (34)$$

D_{EHWD} – good quality AEHD (factor of strengthening of the opened system),

$$D_{EHWD}=K_{EB}K_{Qi}K_{oc}/F. \quad (35)$$

For reception of transfer function AEHD on loading [18] we will exclude from the block diagram presented on fig. 3, *ΔU* and we will transform the scheme, as is shown in Fig. 6.

Let's designate a constant of time of a link of forestalling:

$$T_R=\frac{FH}{4E_{eh}K_{Qp}}. \quad (36)$$

With the account (Eq. 30 - Eq. 32) we transform the block diagram to a kind it agree Fig. 7.

Under the block diagram it is found transfer function AEHD on loading influence:

$$W_{yR}(s)=\frac{K_{yR}(T_{oR}s+1)(T_{2y}^2s^2+T_{1y}s+1)(T_{oy}s+1)}{\frac{s}{D_{EHWD}}(T_{oy}s+1)(T_{2y}^2s^2+T_{1y}s+1)(T_{eh}^2s^2+2T_{eh}\zeta_{eh}s+1)+1}, \quad (37)$$

where: K_{yR} - factor of transfer AEHD on loading influence:

$$K_{yR}=\frac{K_{Qp}}{F^2D_{EHWD}}. \quad (38)$$

The target size is defined generally by result of operating and loading influence [16, 17] according to a superposition principle:

$$\Delta y(s)=W_{yu}(s)\Delta U(s)-W_{yR}(s)\Delta R(s). \quad (39)$$

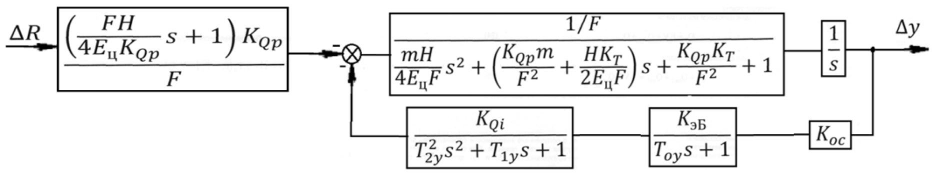

Fig. 6. To definition of transfer function AEHD on loading

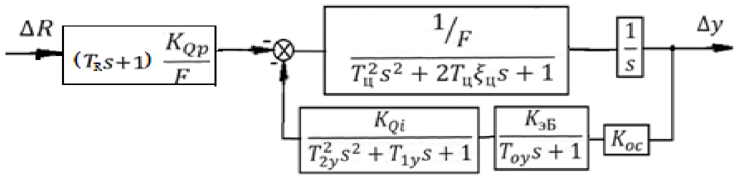

Fig. 7. The Block diagram of transfer of loading influence

CONCLUSIONS

1. The mathematical model of the dynamic features automatic electrohydraulic drive of the special technological equipment is designed.
2. Transmission functions are received for moving output link on controlling signal and loading influence.
3. Mathematical model and transmission functions which are received in this article prescribed in base for designing of system the auto control equipment.

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ПЕРЕДАТОЧНЫЕ ФУНКЦИИ АВТОМАТИЧЕСКОГО ЭЛЕКТРОГИДРАВЛИЧЕСКОГО ПРИВОДА

Я. Соколова, О. Кроль, Т. Таванюк, В. Соколов

Аннотация. Представлена линейная математическая модель и определены передаточные функции автоматического электрогидравлического привода с дроссельным регулированием. Математическая модель адаптирована на приводы специального технологического оборудования для механической обработки материалов, построенные на основе стандартных модулей.

Ключевые слова: автоматический электрогидравлический привод, линейная математическая модель, дроссельное регулирование, передаточные функции.