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ON THE VARIATION OF THE DYNAMIC LOADING WHEN SETTING OUT UNDER LOAD OF THE ACTUATORS FOR THE MACHINE-TOOLS

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Abstract: *This paper presents the variation model of the dynamic load factor for a system under load with the static torque which is started using a constant torque produced by an electric machine without starting gear. The input data the inertia torques values of the two mechanic systems in angular displacement: the inertia torque of the J_1, rotor, the resisting inertia torque J_2 and the torsion elastic constant k of the coupling shaft. The paper is organized in 3 parts section one consists of the study of a method of mathematical modeling section 2 its application mathematical modeling of the dynamics for the I and II stage of starting of linear mechanic actuator type, section 3 on optimization procedure.*

Key words: *actuator, mechatronic, intelligent systems of production, machine-tools, virtual modeling*

1. INTRODUCTION

The large range of machine-tools, as well as to the requests imposed on the technological processes make necessary the new instruction of systems of programmable actuator with individual changing actions ever more compact to increase the quality and the flexibility of the products. The new generation of machine tools requires powers and very high speeds; the precision of regulating the position but also a rational coordination of the composing individual action. Today, the electrical regulating actions are important parts of the machine tools with quick evolution, from the actions of continuous electric power to those with alternative power are reunited as far as the high speed of regulation and precision of regulating, the couple are concerned as well as the good dynamic or other quality factors[1, 5, 7].

The electromechanic linear actuators, which are mechatronic products and they are part of the intelligent flexible systems of manufacture and they have to fulfill special requirements which impose new concepts of design (Fig. 1). An actuator' s function is to provide thrust and positioning in machines used for production or testing. One type is the electromechanical actuator, which converts the torque of an electric rotary motor into linear mechanical thrust. Establishing the loading coefficient is necessary in view of the choice of the acting engine and of the calculation of the overall efficiency of the mechanical transmission of the actuator [4].

Thus results the great importance of the correct establishment of the functioning in this functioning regime by mathematical modeling of these influences.

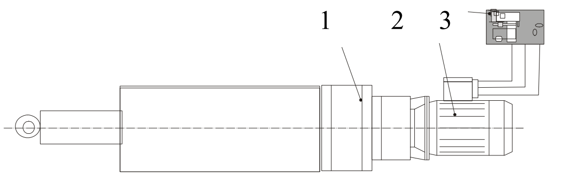

Fig.1. The linear actuators with converter.

2. MATHEMATICAL MODELING OF THE LINEAR ACTUATOR DYNAMICS

The mathematical model belonging to the dynamic behavior of the actuator can be expressed as a differential equation of the movement, of some transfer functions or some frequency characteristics. The characteristics traced on the analysis of the dynamic behavior include: index of velocity, acceleration and space, frequency characteristics etc. After the achievement of the mathematical model the analysis of the dynamic behavior follows next, along with the establishment of the major influence of the functional constructive parameters on the general characteristic parameters as well as the performances of the actuators. Digital simulation is required in order to determine the priority module where the functional - constructive parameters influence the parameters and the performances of the dynamic behavior.

The projection of those transmissions has to fulfill the stability requests, precision, transitory answer etc, resorting to a compromise between the accepted measure of the deviation, stationary and the desired degree of dynamic stability. The control of these parameters is done by “correction” using a net with appropriate configuration of parallel type introduced in the reaction loop of the servo-system. Using this method of control of the movement leads frequently to multiple to loop systems used especially for the electromechanic actuators where the input signal is of alternative power. The block scheme of a servo - system of control with the transfer functions of the composing elements for the electromechanic actuator with position reaction and the most used speed is presented in Fig. 2.

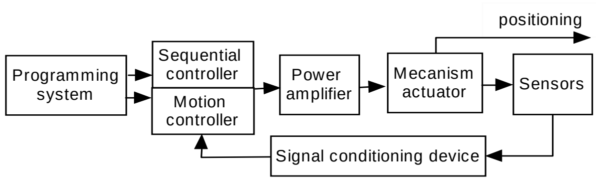

Fig. 2. The structural mathematical model for actuators.

The starting stage is defined by configuration from Fig. 3 where moment M is applied to an object having the inertion moment J, with the torsion rigidity k and the damper B of the system produce a shift θ (t) measured in the poise position and B being constant. The positioning systems with good dynamic and great possibilities of regulating the couple, which satisfy the mentioned requests, are programming servomechanism with a regulating action [5]. The tracing systems must correspond to the standards of stability, precision, transitory answer, and stationary deviation and to the desired degree of dynamic stability. The positioning systems of that type request positioning transducer of wheels without ignition. From the point of view of dynamic modeling, in the principle of transmission with wheel it is a rotational system, where its three mathematics components are the inertial moments, the elastic rigidity and the amortization

In Fig. 3 there is the definition of the configuration in which the couple M_t is applied to a rigid having the inertial moment J with the torsion rigidity and amortization B [8]. In the particular case of the electro mechanic linear actuators taking into account the concrete elements within the automat regulating systems, of the speed, obtaining the black scheme of the system, Fig. 2.

For the transitory regimes of functioning, the efficiency can be calculated deterring the two components of the moment of losses within the transmission according to the relation (1) including the dynamic moment. According to Newton' s have when the load s is coupled to the engine which leads by means of a gear mechanism, by combining the equations and the grouping results the equations which describe the system:

$$J_{echiv.}\frac{d^2\theta_i}{dt^2}+B_{echiv.}\frac{d\theta_i}{dt}+k_{echiv.}\theta_i+M_s/i_r=M \,. \quad (1)$$

The equation represent the performances of the system as a function of a single variant, the input angle is θ. A system equivalent is the one that has the inertion moment equivalent, damping and equivalent rigidity.

The servo engine and gear is chosen in a way that creates the required pair M_s and the imposed acceleration ε_s which should take the load to the required speed. The mathematic pattern reflected the parameters of the engine J_m and K_m at the output axis. The choice of the optimum transmission raises a complex problem in the case when it is imposed a minimal angular velocity to trace ω_s and ε_s or in a minimum time when the weight reaches ω_s.

The main criterion of the dynamic properties of the system is the report ε_s / ω_s

$$\frac{\varepsilon_s}{\omega_s}=\frac{M_{pm}}{(J_m+J_{red.})(1+\delta.J_s)\omega_m}(1-\frac{N_s}{N_p}), \quad (2)$$

where:

- M_{pm} is the starting moment of the engine
- N_p – the starting power,
- N_s – the power of the static load.

The condition of the maximum acceleration is the maximum of the size of $M_m / (J_m + J_{red.})$. The condition of a good dynamics of the system is that the report ε_s / ω_s determined the relation (1) should be higher than the size $(\varepsilon_s / \omega_s)_p$. For the pattern disc in Fig. 3, the equation of movement derived from the energy law is nonlinear and has the form considering the couple of variable reduced moment in report to the position and speed. Transitory processes take place either at the constant limit point or at the limit point varying linear to the speed.

Out of the points balancing equation

$$M_1=\pm M_x+i\frac{d\omega}{dt}=\pm M_x+\frac{\pi i}{30}\cdot\frac{dn}{dt}\ (\mathrm{Nm}) \quad (3)$$

(where sign + stands for the acceleration and the braking, and $M_x = M_{at}$ for operating and $M_x = M_0$ for empty running), there results:

$$\Delta t=\int_{ni}^{nj}\frac{\pi i}{30}\cdot\frac{1}{Ml\pm M_x}dn\ (\mathrm{s})\cdot \quad (4)$$

2.1. Mathematical modeling of the dynamics for the I stage of starting

The mathematical model of the linear actuator for the I stage of starting is presented in Fig. 3, when the moment engine M acts upon the rotor having the response time J_1, and the resident whole represented by J_2, it is still not working [4]. The situation corresponds to a clutch spindle with one end embedded and acted upon the other end by the moment engine. At the initial moment the disc J_1 is not working ($t = 0$, resulting $\theta_1 = 0$, $\dot{\theta} = 0$).

The differential equation of the rotor movement to the response time J_1 is expressed by:

$$J_1\ddot{\theta}+k\theta=M \,. \quad (5)$$

Stage I of starting ends when the rotation angle φ_1 is large enough to start the system o load resistant, meaning:

$$\theta_1=M_s/k\,, \quad (6)$$

where the time t at the stage I of starting results from:

$$t_1=\sqrt{\frac{J_1}{k}}\arccos\ \frac{M-M_s}{k}\,. \quad (7)$$

Introducing in the velocity relation the date of 2 we obtain the velocity of the disc J_1 (which is the same with the one corresponding to the beginning of the stage II).

$$\varphi_1(t_1)=\sqrt{\frac{M_s(2M-M_s)}{J_1k}}\,. \quad (8)$$

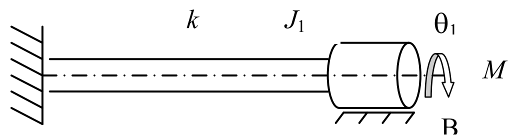

Fig. 3. The mathematical model for the I stage of starting.

2.2. Mathematical modeling of the dynamics for the stage II of starting

For the stage II of starting under loading the mathematical model is represented in Fig. 4 when on the disc J_1 acts the engine disc M while on disc J_2 acts the resistant moment M. At the initial moment the disc having the response time J_2 is not working ($t = 0$, resulting $\varphi_1 = 0$, $\dot{\varphi} = 0$), and the disc having the response moment J_2, has the following relation of the angular velocity [4]:

$$J_1\ddot{\varphi} + k(\varphi_1 - \varphi_2) = M \; ,$$
$$J_2\ddot{\varphi} - k(\varphi_1 - \varphi_2) = M \; . \qquad (9)$$

The torsion moment of the clutch spindle is expressed by the relation: $M = k \cdot \varphi$ The dynamic coefficient ψ is defined as a ratio between the maximum moment and the average dynamic moment:

$$\psi = M_{\max} / M_{aver} \; . \qquad (10)$$

From the analysis of the above relations, for a stationary functioning at a power-supply U at a frequency f, the components of power balance are determined by expressions that include the parameters of the engine and the value of the sliding that depend on the degree of loading (of the value of the loading required at the clutch by the working machine). As the experimental determination when exploiting the power at the clutch raises some difficulties, in order to determine the loading of the engine we used one of the following indicators:
- loading degree with active power defined as a ratio between the regime power and the nominal power $\lambda = I / I_n$
- loading degree with power, defined as a ratio between the absorbed active power in the considered regime and the nominal one: $\gamma = P_A / P_n$.

The scheme of a programmable servomechanism with speed and positioning reaction the most often used within the tracing systems presented in Fig. 2.

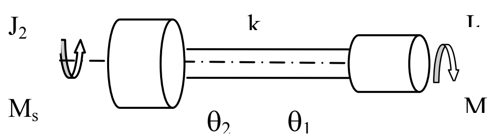

Fig. 4. The mathematical model for the II stage of starting.

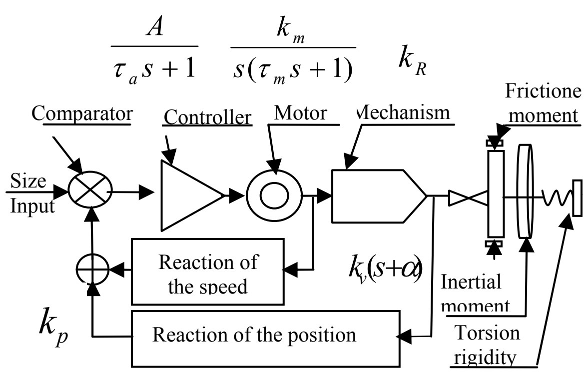

Fig. 5. The dynamic model of programmable servoactuator.

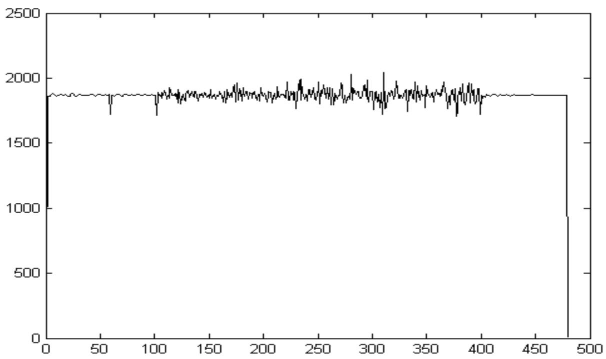

Fig. 5. The mathematical model for the I stage of starting.

The graphical visualization of the acceleration for linear actuator is presented in the Fig. 5.

3. THE OPTIMUM WORKING REGIME

The parameters which characterize the economic regime are the training electric power and the efficiency of all the structural components.

The basic problem in order to obtain a profitable regime is to correctly establish the nominal power according to the efficiency, the transmission report, the increase or decrease in the speed and the cinematic moment. In the situation of the actuators, to establish acting power is very important owing to the conditions of transitory regime of work. When calculating the overall efficiency of the actuator's transmission we approximate taking into consideration the only losses that occur while the friction within the mechanism, neglecting these depending among others on the degree of covering as well. To take into consideration all the losses we write the relation of the overall efficiency according to the total / overall moment M_t and to that clue to the constant ΔM_c and variable ΔM_a mechanical losses as it follows:

$$\eta_t = \frac{M_t}{M_t + \Delta M_c + \Delta M_a} \; . \qquad (11)$$

If we define: the loading coefficient, $K_i = M_t / M_n$ and the loss coefficient, $K_p = \Delta M_t / M_t$ using the relation (1) results:

$$\eta_t = \frac{\eta_n}{1 - \eta_n K_p \left(1 - \frac{1}{K_i}\right)} \; . \qquad (12)$$

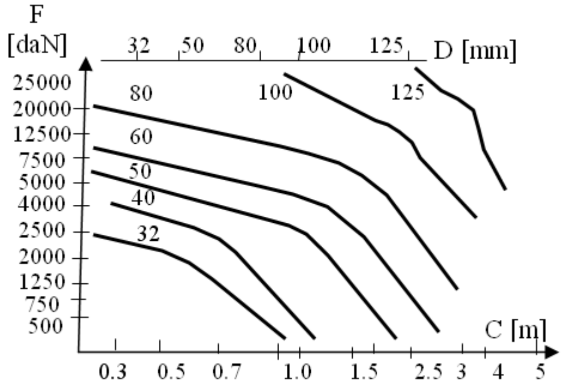

Fig. 6. The performances curves of the linear actuators.

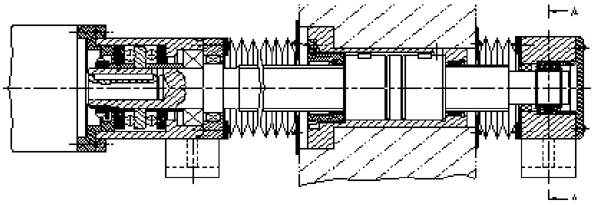

Fig. 7. Unity of translation with linear acting.

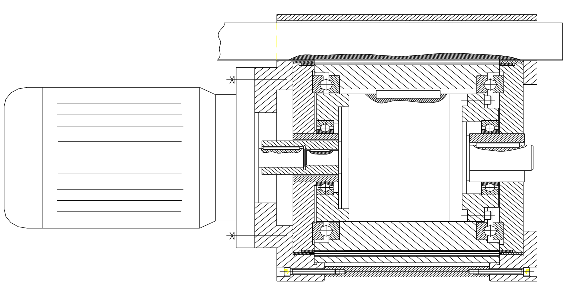

Fig. 8. Mechanism planetary wheel with rolls.

For this, we make real assessment of the value of the efficiency of the actuator's transmission considering the overall of the power losses within the actuator and for partial loading. For the transitory regimes of functioning, the efficiency can be calculated deterring the two components of the moment of losses within the transmission according to the relation (2) including the dynamic moment. The experimental determination of power losses specific to the mechanical transmission of an actuator has shown its dependence according to the degree of loading and functioning regime. The minimal value of these losses represents 2 – 6 % out of the transmission power, load nearly to the nominal one but not exceeding it.

Establishing the loading coefficient is necessary in view of the choice of the acting engine and of the calculation of the overall efficiency of the mechanical transmission of the actuator. For the new criteria of the performances called errors of trajectories of
machine tools with numeric control it is required the reconsideration of the main parameters of tracing servomechanisms which should correspond to the working transitorily and critical regimes.

The main structural constructions developed are presented in Figs. 7 and 8. This offers the best solution to linear actions owing to the large flexibility to the high efficiency to the cinematic, dynamic and high precision capacities.

4. SUMMARY AND CONCLUSION

Thus, results the great importance of the correct establishment of the functioning in this functioning regime by mathematical modeling of these influences.

The maximum value of the dynamic coefficient ψ it is obtained when the value of the corresponding resistant response moment of the system J_2 is very high as compared to the response moment of the rotor J_2. The minimum value of the dynamic coefficient ψ it is obtained when the value of the corresponding resistant response moment of the system J_2 is very low as compared to the response moment of the rotor J_2. The maximum value of the dynamic coefficient ψ it is obtained when the value of engine moment is very high as compared to the resistant moment M. The value of the engine moment M is equal to the resistant moment M_r we obtain an over unitary dynamic factor.

The kinematics and dynamic analysis on synthetic pattern of the actuator type of the analogical servo - systems of rapid control has direct implications by deducted practical recommendations to project the transmissions of mechatronic systems.

The conception and its manufacture assisted on the computer has as application field the assembly of the process of developing new products, covering the conception aspects, manufacture and the link between them. In order to optimize the functioning of a tool, actions must be able to regulate the speed continuously by converting the reduced dissipation of electric energy into mechanic energy.

The correct definition of the economic functioning regime of an electro mechanic linear actuator must take into account, on one hand, the clues that characterize the economic regime. For the actuators used on machine tools with digital control or at the manufacturing centers, the dynamic stability is of utmost importance, fact that makes the study of the loading coefficient variation in a transitory regime when starting under loading welcome and fashionable.

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