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Incremental Regulation of Automatic Machine-Tools Working Parts

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ABSTRACT

This paper aims to establish some criteria to choose the elements of incremental positioning systems including electromagnetic clutches and brakes, in order to obtain, starting from designing phase, an optimization of their performances: minimal times of load acceleration, working frequencies as high as possible, maximum precision.
***Keywords**: electromagnetic clutches / brakes, incremental positioning, coupling / decoupling frequency.*

1. Regulation Systems Structure

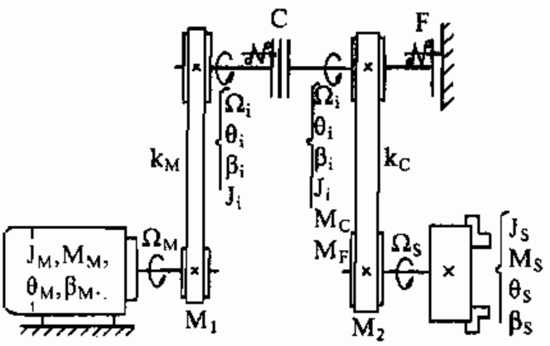

Fig.1 – Structure of a Position Incremental Regulation System, including Electromagnetic Clutch and Brake

Position incremental regulation system, including electromagnetic clutches and brakes, no matter of its constructive or functioning principle, has a structure as shown in Fig. 1.

The equations of such a system are:

$$M_M = J_M \frac{d\Omega_M}{dt} + \beta_M \Omega_M + k_M\left(\theta_M - \theta_i \frac{\Omega_M}{\Omega_i}\right) + M_1; \tag{1}$$

$$k_M\left(\theta_M - \theta_i \frac{\Omega_M}{\Omega_i}\right) = \left(J_i \frac{d\Omega}{dt} + \beta_i \Omega_i + M_e\right)\frac{\Omega_i}{\Omega_M}; \tag{2}$$

$$M_C - M_F = J_C \frac{d\Omega_C}{dt} + \beta_C \Omega_C + k_C\left(\theta_C - \theta_S \frac{\Omega_C}{\Omega_S}\right); \tag{3}$$

$$k_C\left(\theta_C - \theta_S \frac{\Omega_C}{\Omega_S}\right) = \left(J_S \frac{d\Omega_S}{dt} + \beta_S \Omega_S + M_2\right)\frac{\Omega_S}{\Omega_C}; \tag{4}$$

$$\frac{d\theta_M}{dt} = \Omega_M; \quad \frac{d\theta_i}{dt} = \Omega_i; \quad \frac{d\theta_C}{dt} = \Omega_C; \quad \frac{d\theta_S}{dt} = \Omega_S, \tag{5}$$

where: M_M means driving motor torque;
M_1, M_2 – resistant torque;
M_C – torque transmitted by C clutch;
M_F – torque applied by F brake;
J – inertial moment;
Ω, θ – angular speed / displacement;
β – friction ratio;
k_M, k_C – rigidity coefficients.

2. Load Adaptation

Load adaptation is analyzed referring to the part from the system functioning cycle that is corresponding to clutch action (so, $M_F = 0$). As it follows from relations (1) ... (5):

$$M_C = J_C \frac{d\Omega_C}{dt} + \left(J_S \frac{d\Omega_S}{dt} + M_2\right)\frac{\Omega_S}{\Omega_C}. \tag{6}$$

It can be observed that a fraction from transmitted torque is used to accelerate the clutch driven (outgoing) part, while the rest is necessary to accelerate the load and to beat the resistant torque.

Maximum load acceleration can be obtained by making a speeds ratio, Ω_C/Ω_S, appropriate choice.

By denominating $\alpha_S = \frac{d\Omega_S}{dt}$ and $\alpha_C = \frac{d\Omega_C}{dt}$, from relation (6) results

$$\alpha_S = \frac{M_C - \frac{M_2}{q}}{q \cdot J_C + \frac{J_S}{q}} \quad (7)$$

Extreme values for $\alpha_S(q)$ can be obtained by solving the equation $d\alpha_S / dt = 0$; it results

$$q_0 = X + \sqrt{X^2 + Y}, \quad (8)$$

where

$$X = \frac{M_2}{M_C} \text{ and } Y = \frac{J_S}{J_C}. \quad (9)$$

In the case of an ideal system, $M_2 = 0$, it follows:

$$q = \sqrt{\frac{J_S}{J_C}} \text{ and } \alpha_S = \frac{M_C}{q \cdot J_C + \frac{J_S}{q}}. \quad (10), (11)$$

By drawing the variation curve of the function $q_0 = f\left(\frac{J_S}{J_C}\right)$, see Fig.2, results that in the case of load high inertia, relative to the clutch one, load acceleration doesn't change significantly, for a large range of q ratio values.

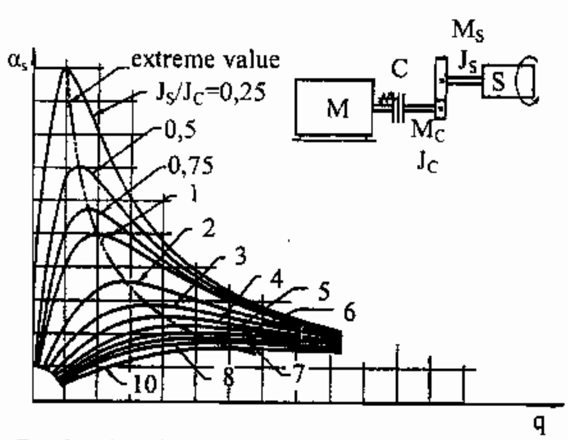

Fig.2 – Load Acceleration Dependence on the Angular Speeds Ratio

When real systems, characterized through resistance torques presence, are considered, initial inclination of drawn curves from Fig.2 is smaller and the extreme value also suffers a reduction. Another way, load acceleration $\alpha_S = \frac{d\Omega_S}{dt}$ decreases more intensively when speeds ratio $q = \frac{\Omega_C}{\Omega_S}$ increases.

3. Coupling / Decoupling Frequency

The steps of a functioning cycle, specific to incremental positioning regulation system, including electromagnetic clutches and brakes are shown in Fig.3.

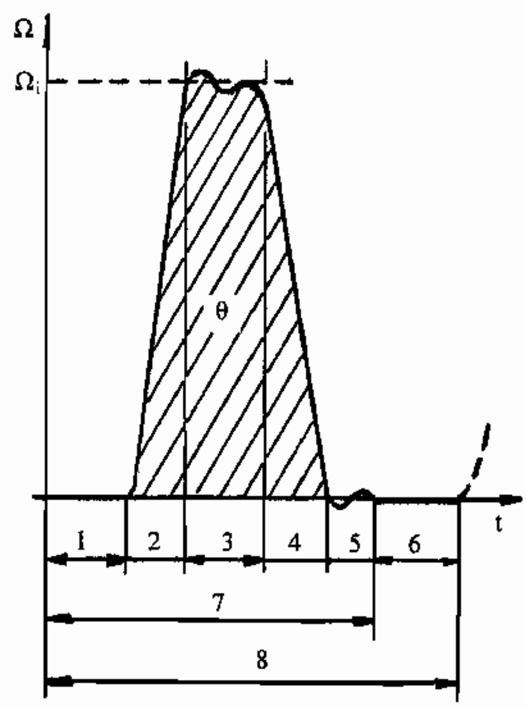

Fig.3 – The Steps of an Incremental Positioning Cycle by using Electromagnetic Clutches and Brakes

Due to this purpose, the following denominations were made:

1 – Electrical delay time, t_e;
2 – Acceleration time, t_a;
3 – Constant speed displacement time, t_m;
4 – Deceleration time, t_d;
5 – Time necessary to damp the oscillations when stoping, t_D;
6 – Stop time;
7 – Motion time;
θ – Displacement domain;
Ω_i – Driving shaft angular speed.

By admitting that t_0, stoping time, is required by the system, results that in order to increase work frequency it is necessary to reduce acceleration - deceleration times (t_a and t_d), the time necessary to damp the oscillations when stoping (t_D), the electrical answer times (specific to the clutch and to the brake, t_{eC} and t_{eF}) and also the time of system constant speed functioning (t_m).

Smaller clutches and brakes have reduced inertia moments and time electric characteristics. This is why these categories of components allow better heat dissipation, a longer lifetime and assure higher work frequencies.

To evaluate the electric responding time, t_e, the following relation can be used [2]:

$$t = 0.6 \cdot t_e + t_a \,, \qquad (12)$$

where t_e is specified in the technical documentation of the clutch / brake, and t_a can be found by solving the equation

$$(M_S)_{med} = J_S \cdot \alpha_S = J_S \frac{\Delta\Omega_S}{\Delta t}. \qquad (13)$$

In equation (13), $(M_S)_{med}$ is the dynamic medium torque applied to the load. This factor used because in the cases of most clutches and brakes, when working at high frequencies, transmitted torque linearly increases, starting from the moment of the electrical connection of the windings.

Working with $(M_S)_{med}$ imposes the use of medium values of the acceleration

$$(\alpha_S)_{med} = \frac{\Omega_S}{t_a}. \qquad (14)$$

It follows

$$t_a = J_S \frac{\Omega_S}{(M_S)_{med}}. \qquad (15)$$

4. Positioning Precision

If both torque and speed would be constant, the clutch and the brake would be commanded by a simple frequency generator. The clutch should be coupled during a certain interval of time then the brake should be used.

In fact, the temperature rises during functioning and particles detached from friction discs interpose between them; thus, dynamic and friction torques aren't constant and this leads to load speed modifications and further, effective displacement modification.

When talking about an open circuit, like the analyzed one, displacement errors are cumulating themselves. Because in the cases of numerous practical applications errors cumulating is not essential, open command circuits are able to realize their purposes at lower costs.

If higher precision systems are considered, without accepting errors cumulating, closed command circuits, based on displacement measurement by using detecting elements, are necessary.

Thus, reaction signals will indicate the moment when working cycle is over and initiate the new working cycle.

Close command circuits are very precise because they are not depending on the dynamic way on which the load reaches desired position. This is the reason why clutch commutable torque and driving speed variations are eliminated from the analysis regarding system precision.

Positioning errors, caused by friction medium dynamic torque variations, $(M_S)_{med} \pm (M_S)_{var}$, remain to be found together to load angular speed variation $\Omega_S \pm (\Omega_S)_{var}$.

Starting from the situation exposed in Fig.3, the equation giving displacement domain can be expressed:

$$\theta_S = \frac{\Omega_S \cdot t}{2}. \qquad (16)$$

From relations (13) and (16) further results:

$$t = \frac{J_S \cdot \Omega_S}{(M_S)_{med}} \qquad (17)$$

and

$$\theta_S = \frac{J_S\left[\Omega_S \pm (\Omega_S)_{var}\right]^2}{2\left[(M_S)_{med} \pm (M_S)_{var}\right]}. \qquad (18)$$

Relation (18) reveals the fact that angular displacement is more sensitive to Ω_S variations than to $(M_S)_{med}$ variations.

In the case of rapid systems, where displacement time interval is an essential criteria, high speeds leading to concessions made to positioning precision are necessary to be imposed.

A system characterized by small values of absorption coefficients has smaller increasing time and faster reaches desired position.

To maintain an acceptable precision at high working frequencies, heat dissipation has a positive influence because it decreases clutches and brakes dynamic torques.

5. Conclusions

Because torques transmitted by friction change depending on both angular speed and friction ratio, there is not a speeds ratio unique optimal value; that's why a medium optimal value should be found. Generally speaking,

$$(q_o)_{med} > q_o . \quad (16)$$

Working frequency can be substantially increased by using adequate electronic command circuits; thus, electric answering times reduced by 50 ... 70% relative to the case of direct coupling at a DC (direct current) source can be obtained; same effect results by increasing the medium dynamic torque that leads to reducing the acceleration times.

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Reglarea incrementală a poziţiei organelor de lucru ale maşinilor-unelte

Rezumat

În lucrare se urmăreşte stabilirea unor criterii pentru alegerea elementele sistemelor de poziţionare incrementale cu cuplaje şi frâne electrice, astfel încât să se realizeze, prin proiectare, o optimizare a performanţelor acestora: timpi minimi de accelerare a sarcinii, frecvenţe de lucru cât mai mari, precizii cât mai bune.

La régulation incrémentale de la position des éléments actifs des machines-outils automatiques

Résumé

Le but de ce papier est d'établir des critères pour choisir les éléments des systèmes pour le positionnement incrémental avec couplages et freins électriques, de manière qu'on réalise, dés de la phase du projet, une optimisation pour leurs performances : minimum temps d'accélération du charge, fréquences du travaux plus élevés, maximum précision.