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Control of Two Mass Electromechanical System

BIYA MOTTO Frederic[1], TCHUIDJAN Roger[2], NDZANA Benoît[3]

[1]Faculty of Science, University of Yaounde I, PO.Box 812 Yaoundé, Cameroun
[2,3]National Advanced School of Engineering of Yaounde

Abstract: In two-mass electromechanical system, the electromagnetic torque focuses on one (the first) mass. In that case, the second mass related with the first elastic link, can move through oscillating trajectory. The issue of two-mass control system consists of designing the speed regulator that can ensure etalon dynamic processes of second mass movement. A solution to that problem is proposed in this paper.

Keywords:- *control, two-mass system*

1. INTRODUCTION

The multi-mass systems are widely represented in processing machines. The typical representatives are machine-tools, robots, turntables, etc. The first mass is formed by the electric coupling stator-rotor and by rotor inertia. The elasticity of mechanical parts of the kinematical chain, together with their moment of inertia, forms the second and typically the rest of the masses. It is possible to characterize them by their natural frequency and dumping constant. In other words such a mechanism can be expressed by the second or higher order system with complex poles. During the excitation of a multi-mass system in addition to the required motion there are also evoked torsional vibrations at the end of the mechanism which refers to their natural frequencies. This torsional vibration may seriously affect the servomechanism positioning accuracy, especially if the mechanism moves through the long elastic shaft with the masses of large inertia. Depending on the excitation function each mass may produce various amplitude of torsional vibration frequency. This mechanism end-link vibration can be hardly suppressed by the conventional cascade control structure. Usually, another control strategy must be used. There are lots of articles that are devoted to this topic. Various control strategies have been proposed [1], [2], [3], [4]. The typical way to apply those strategies is in programing the control structure into the signal processor. From the whole control structure of the servo controller there is typically used only the power section starting from the current control loop. But the producers are increasingly putting the pressure on substitution of those special solutions by structure that is easily applicable into the standard servo control unit.

In some industrial applications, the mechanical part of the system has very low resonant frequency, because of a long shaft between the motor and the load machine. So, especially in the drive systems with high performances speed and torque regulation, the motor speed is different from the load speed during transients. This speed difference means that the shaft is undertaking large torsional torque which influences it in a negative way. Additionally, speed oscillations cause decrease in the quality of the rolling material and can influence the stability of the control system. Except for rolling mill drives [12], [13] a similar problem appears in servo drives [5], [7], [8], [10], [14], [16], [18], space network antennas [9], robot arm [19] or cage host drive.

Several control structures have been developed for suppression of torsional vibrations. Most popular are structures with PI speed controller and different additional feedbacks [7], [8], [10], [12], [13], [15]. However there is a lack of analytical formulas for controller parameters adjustment as well as a comparative analysis with other control structures seems to be interesting.

Moreover, in the last few years fuzzy logic control (FL) has appeared a great field of interest in many technical applications, also in electrical drives [11], [14], [17]. FL controllers are specially designated in control problems of nonlinear, non-stationary, ill-defined systems. But recently the fuzzy logic techniques are also used for linear or quasi-linear systems.

2. CURRENT LOOP OF ELECTRIC DRIVE WITH TWO-MASS MECHANICAL SYSTEM

When designing the control algorithm of electric drive with two-mass mechanical system, we shall assume that the dynamic behavior of electromagnetic moment (armature current) is given through creation of current loop.

The regulator of current loop is designed by the method of series correction.

The transfer function of current loop is designed by the expression

$$W_C = \frac{i_2^*}{x_1^*} = \frac{{}^{1}/_{K_C^*}}{2T_\mu^2 P^2 + 2T_\mu P + 1}$$

For the design of following control loop, we use the approximation by the aperiodical element of first order

$$W_C = \frac{M^*}{x_1^*} = \frac{1/K_C^*}{2T_\mu^2 P^2 + 2T_\mu P + 1} \approx \frac{1/K_C^*}{2T_\mu P + 1}$$

At the entrance of current loop, we consider the installation of the current limitation element to avoid possible overloads of electric drive. (figure 1)

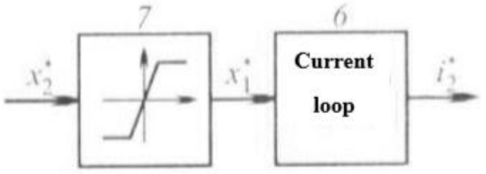

Figure 1 – Current loop 6 and current limitation element 7

Thus, for the design of speed mass movement the control loop is represented by an aperiodical element of first order. The speed mass movement control is done by the torque M^* whose expression is given by the signal x_2^*. Obviously, the control can only be done on linear part of current limitation element with $x_1^* = x_2^*$.

3. DYNAMIC MODEL OF TWO-MASS ELECTROMECHANICAL SYSTEM

We assume that in the system during the transmission of moment from the electromotor to the executive organ of working machine, there is no dissipative component. The movement equations of conservative mechanical system with two-mass look as follows:

$$\begin{cases} J_1 . P^2\alpha_1 = M - C_{1,2}.(\alpha_1 - \alpha_2); \\ J_2 . P^2\alpha_2 = C_{1,2}(\alpha_1 - \alpha_2) - M_r; \end{cases}$$

Where

J_1, J_2 – moments of inertia of first and second mass respectively applied to the shaft of electromotor

$C_{1,2}$ – coefficient of rigidity

M – Electromagnetic torque of electromotor

M_r- Resistance torque

α_1, α_2– generalized mass coordinates

By representing the movement equations of mechanical system in per-units, and assuming that $\alpha_1 = \omega_1/p$ and $\alpha_2 = \omega_2/p$:

$$\begin{cases} T_1 p\omega_1^* = M^* - C^*(\omega_1^* - \omega_2^*)/p; \\ T_2 p\omega_2^* = C^*.(\omega_1^* - \omega_2^*)/p - M_C^*. \end{cases} \quad (1)$$

Where $_1 = J_1\omega_B/M_B$, $T_2 = J_2\omega_B/M_B$ - Mechanical time constants

$C^* = C_{1,2}\omega_B/M_B$

Assuming M_r=0, from (1) we find Laplace representation of movement speeds of the mass:

$$\omega_1^* = W_1 . M^*;\ \omega_2^* = W_2 . M^* \quad (2)$$

Where $W_1 = (P^2.T_2 + C^*)/(p)$; $W_2 = C^*/Y(p)$ The characteristic polynom:

$Y(p) = p.\ [T_1.\ T_2.\ p^2 + C^*.\ (T_1 + T_2)]$ of the mechanical system will have imaginary roots:

$P_0 = 0$; $P_{1,2} = \pm j\sqrt{C^*.(1/T_1 + 1/T_2)}$

Consequently, the mechanical system is at stability limit.

In that case, the construction of dynamic processes of movement mass speed by the series correction method is not necessary. That is why for the dynamic process design, we use the parallel correction method.

4. DESIGN OF SPEED REGULATOR FOR TWO-MASS ELECTROMECHANICAL SYSTEM

The feedback can be introduced either on speed □$_1$ or in □$_2$. Usually it is simple to install the speed captor directly on the shaft of electromotor and control the speed ω_1. The structural control circuit with feedback of speed ω_1 is shown on figure 2

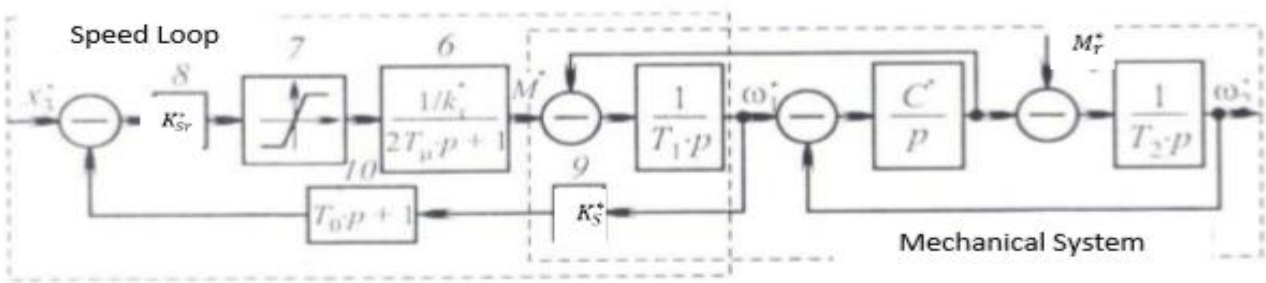

Figure 2 Structural circuit of speed control loop ω_1:

6- current loop; 7- current limitator; 8- speed regulator; 9- speed captor ; 10- element of speed feedback

The transfer function of feedback connection T_0 P+1 is chosen so as to design the transfer function of speed loop with characteristic polynom that has standard aspect.

The proportional regulator with transfer coefficient K_{sr}^{*} does not change the transfer function order, but enlarges the design possibilities. The constant time $2T_u$ characterizes the fast action of current loop is in general less than T_1 and T_2.

We shall therefore assume that the current control loop is a proportional element with transfer coefficient $^1/_{K_C^*}$

From Figure 1,

$$M^* = K_{sr}^*/\,K_C^*.\,[x_3^* - (T_0P+1).\,K_S^*.\,\omega_1^*]$$

Considering (2) and resolving relatively to ω_1^*, ω_2^*,

We have

$$\omega_1^* = W_{11}.\,x_3^* = \frac{(d_2.T^2.P^2+1)/K_S^*}{T^3P^3+d_2T^2P^2+d_1TP+1}.\,x_3^*$$

,

$$\omega_2^* = W_{22}x_3^* = \frac{^1/_{K_S^*}}{T^3P^3+d_2T^2P^2+d_1TP+1}.\,x_3^*$$

,

Where

$$T^3 = \frac{(K_S^*.K_{Sr}T_0+K_C^*T_1)T_2}{K_S^*.K_{sr}^*.C^*}$$

;

$$d_2 = \frac{T_2}{T^2.C^*}$$

$$d_1 = \frac{T^2.\,C^*}{T_2} + \frac{K_C^*.\,T_2}{K_S^*.\,K_{sr}.\,T}$$

The values of d_1 and d_2 characterize the form of transient process. Thus aperiodical process corresponds to the values d_1=d_2=3, while the process optimal from fast action point of view corresponds to d_1=d_2≈ 2,14. The given values of d_1 and d_2 should correspond to regular parameters:

$$K_{sr}^* = \frac{K_C^*\,d_2\,\sqrt{d_2C^*T_2}}{K_S^*(d_1.d_2-1)}$$

;

$$T_0 = \frac{T_1.(1-d_1d_2)+T_2}{d_2.\sqrt{d_2C^*T_2}}$$

The plots of transient functions created by transfer functions W_{11} and W_{22}, are represented on figure 3.

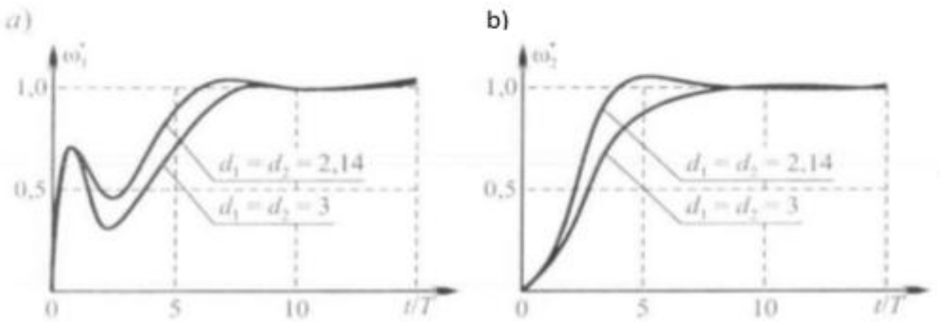

Figure 3: Transients function plots created by transient function of speed loop a) W_{11} b) W_{22} .

The designed dynamic processes have etalon character meanwhile, it should be reminded that when designing the speed loop, we considered that the time constant of torque control loop is very small. That is why in real processes there will be a different situation on the behavior created by transfer functions W_{11} and W_{22}.

It should also be observed that the parameters of control object for twomass mechanical system can change during operation.

5. CONCLUSION

To ensure etalon dynamic processes for the speed control of second mass movement in two-mass mechanical system, we need to construct speed control loop. The installation of speed captor in second mass movement is technically a difficult task. That is why the speed stabilization is often done on speed movement of first mass.

Since the two-mass system is on stability limit, thus in control loop we add parallel and series regulators. The parameters of regulators depend on the second mass value.

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