

Mathematical modeling of drive transitive process with linear change in control input

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Abstract

The paper researches into dynamic parameters of transitive processes in electrical drive of technological equipment in acceleration mode given changes in control input under law of linearity. Analysis of two-mass dynamic model allows for solutions of differential equations describing three stages in the drive acceleration mode. Dynamic and static components of drive errors are discussed in relation to its velocity as being conditioned on the moment of load, the total moment of the drive inertia, stiffness ratio of static parameter and pre-defined programmed acceleration.

Keywords

Technological equipment, transitive process, drive acceleration, motor angular velocity

1. Introduction

Conditions under which manufacturing and industrial equipment operates require setting a process of transition either to produce a pre-defined principle of changes in actuator angular velocity, or as a requirement for pre-determined speed of equipment operation, or to produce limited and controlled dynamic loads. The required parameters determining transitive process can be achieved by setting the law for changes in control input –voltage $U_c(t)$, which is transferred to the armature. This law is made operational by a specialized transducer.

2. Mathematical Modeling

The control input that is changed linearly can be described by the following equation:

$$\frac{U_c}{kF}(t) = \omega_0(t) = \varepsilon_p t \quad (1)$$

where F is magnetic flux, k is designed parameter of motor, ε_p is the pre-determined value of programmed acceleration provided by transducer operation.

The moment of motor can be given as:

$$M_m = \beta_m \varepsilon_p t - \beta_m \omega_m \quad (2)$$

The dynamic model is given in Figure 1:

Differential equations for drive motion are done as:

$$\begin{aligned} J_m \dot{\omega}_m &= M_m + M_{12}, \\ J_i \dot{\omega}_i &= M_{21} - M_i^0, \\ M_m &= \beta_m \varepsilon_p t - \beta_m \omega_m \end{aligned}$$

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Analysis and description of the drive in acceleration mode requires determining the static mechanical parameter of the motor [1,2,7], with the moment of load considered a constant. The above system can be reduced to one equation in relation to ω_m .

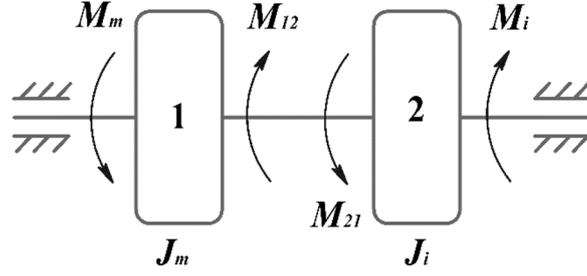


Figure 1: Dynamic model of technological drive

$$(J_m + J_i)\dot{\omega}_m + \beta_m \omega_m = \beta_m \varepsilon_p t - M_i^0 \quad (3)$$

At the initial point in acceleration given $t=0$ $\omega_m=0$, the control input given (1) equals zero $\omega_0(0) = 0$ and consequently given (2) the moment of motor also equals zero. Hence, (3) conditions the drive motion to be possible only if the moment of motor M_m has values higher than the moment of load M_i^0 . The mode of acceleration is characterized by a stage when the moment of motor is continuously increasing with time while mechanical system remains static. This stage can be described by the following equation:

$$\beta_m \varepsilon_p t - M_i^0 = 0$$

This first stage finishes with $t=t_1$, for which the condition of $M_m(t_1) = \beta_m \varepsilon_p t_1 = M_i^0$ holds. It produces

$$t_1 = \frac{M_i^0}{\beta_m \varepsilon_p}.$$

At the second stage in acceleration mode, given $t > t_1$, the mechanical system is set in motion and the moment of motor is described as:

$$M_m(t) = \beta_m \varepsilon_p (t - t_1) + M_i^0 - \beta_m \omega_m.$$

The equation describing the system motion in the second stage can be done as:

$$T_m \dot{\omega}_m + \omega_m = \varepsilon_p (t - t_1),$$

where $T_m = (J_m + J_i)\beta_m^{-1}$.

Solution to equation (3) produces equation which determines changes in angular velocity at the second stage of acceleration mode:

$$\omega_m(t) = \varepsilon_p (t - t_1) - T_m \varepsilon_p \left[1 - e^{-\frac{t-t_1}{T_m}} \right] \quad (4)$$

Given dependence (1), relation of $\varepsilon_p t_1 = \frac{M_i^0}{\beta_m}$, produces:

$$\omega_m(t) = \omega_0(t) - \frac{M_i^0}{\beta_m} - \frac{(J_m + J_i)\varepsilon_p}{\beta_m} \left[1 - e^{-\frac{t-t_1}{T_m}} \right] \quad (5)$$

The value of $\Delta\omega_m^0 = \frac{M_i^0}{\beta_m}$ determines reductions in the angular velocity value in relation to the pre-set value $\omega_0(t)$, determined at the drive input and conditioned on the moment of load M_i^0 - this produces drive velocity static error. The value of $M_m^d = (J_m + J_i)\varepsilon_p$ determines the dynamic component of moment M_m generated by the motor and providing conditions for the drive acceleration with the pre-

determined acceleration rate ε_p . The third addend in (5) is given as reduction in the angular velocity in relation to pre-determined value $\omega_0(t)$, conditioned on the dynamic load and considered drive velocity dynamic error. The value of $\Delta\omega_m^d = \frac{(J_m + J_i)\varepsilon_p}{\beta_m} = T_m\varepsilon_p$ is regarded the pre-determined value of dynamic error. The resulting function (5) can be given as:

$$\omega_m(t) = \omega_0(t) - \Delta\omega_m^0 - \Delta\omega_m^d \left(1 - e^{-\frac{t-t_1}{T_m}} \right) \quad (6)$$

Given $t=t_2=3T_m+t_1$ the function $e^{-\frac{t-t_1}{T_m}} = 0,05$ and then given $t>t_2$ the angular velocity $\omega_m(t)$ can be described as:

$$\omega_m(t) = \omega_0(t) - \Delta\omega_m^0 - \Delta\omega_m^d \quad (7)$$

The second stage of the drive acceleration mode is completed in time $t=t_3$, in which the angular velocity in idle running ω_0 reaches a certain pre-determined value ω_0^* . Time moment t_3 is determined in the following manner: $t_3 = \frac{\omega_0^*}{\varepsilon_p}$.

The third stage of the drive acceleration mode, when $t>t_3$, can be described with differential equation (3) done as:

$$(J_m + J_i)\dot{\omega}_m + \beta_m\omega_m = \beta_m\omega_0^* - M_i^0$$

Dividing all components of equation by β_m produces the following equation:

$$T_m\dot{\omega}_m + \omega_m = \omega_0^* - M_i^0\beta_m^{-1}.$$

The difference $\omega_0^* - M_i^0\beta_m^{-1}$ determines the values of angular velocity ω_m^0 under the steady-state mode of drive motion. Differential equation describing the third stage of the drive acceleration mode can be done as:

$$T_m\dot{\omega}_m + \omega_m = \omega_m^0.$$

Solution to the last equation produces condition according to which the value of angular velocity at this stage is determined by the function:

$$\omega_m(t) = \omega_m^0 - \Delta\omega_m^d e^{-\frac{t-t_3}{T_m}} = \omega_m^0 - T_m\varepsilon_p e^{-\frac{t-t_3}{T_m}} \quad (8)$$

Figure 2: demonstrates the diagrams for dependencies $\omega_0(t) = \varepsilon_p t$, $\omega_0(t) = \varepsilon_p(t - t_1)$, $\omega_0(t) = \omega_m(t)$. The curve abc is plotted based on (4). When the point of the curve in which $t=t_1$ reached, the drive mechanical system is set in motion, transiting from static to dynamic mode. Given this condition, velocity time error t equals ω_m^0 . It is determined by the value of the moment of load M_i^0 and stiffness ratio of static parameter β_m . Given changes in time value t in the range of $t_1 < t < t_2$ acceleration of the drive mechanical system is determined by region ab of the curve in which the total error in velocity is increased by the dynamic components rising in the range of 0 to the steady-state value of $\Delta\omega_m^d$. Within this time range the angular velocity value is determined by dependencies (4) - (6). Given $t>t_2$ the drive acceleration mode is determined by region bc of the curve, in which the value of angular velocity is described by function (7). The steady-state value of dynamic error in velocity $\Delta\omega_m^d$ is the higher the higher the total moment of the drive inertia J_m+J_i and the pre-determined programmed acceleration ε_p , and is the lower the higher β_m .

The diagram of dependence of equation (8) is shown with the curve cd . The value of angular velocity $\omega_m(t)$ asymptotically approaches the value of ω_m^0 , which determines the drive angular velocity in steady-state mode of drive motion. Given $t>t_4=3T_m+t_3$ angular velocity $\omega_m(t)$ is different from the value ω_m^0 by less than 5%, and transitive process is considered completed. Under the steady-state mode of the drive operation drive velocity static error $\Delta\omega_m^0$ preserves.

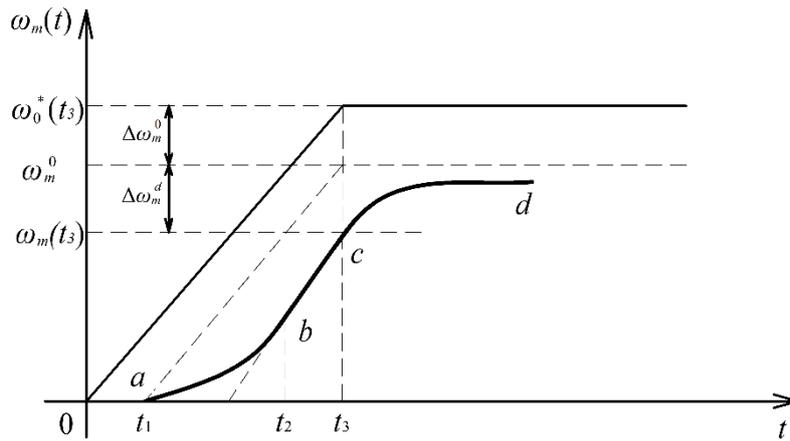


Figure 2: Diagram of the motor angular velocity dependence

The t_4 time range of transitive process of the third stage in drive acceleration is then calculated as:

$$t_4 = 3T_m + t_3 = 3T_m + \frac{\omega_0^*}{\varepsilon_p} \quad (9)$$

3. Conclusion

It follows from expression (9) that reductions in time intervals required for transitive process or increases in performance speeds of the drive can be gained by lower values of mechanical constant T_m and higher values of programmed acceleration ε_p . Observance of the first condition requires either reduced values of total moment of inertia or increased values of stiffness ratio of static parameter β_m . Observance of the second condition requires increases in values of the motor starting torque which is subjected to a number of limitations conditioned on the parameters of the motor operation [3-6, 8-15].

4. References

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