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THE ELECTRIC DRIVE WITH THE NONLINEARITY POSITION CONTROLLER WITH THE JERK LIMITATION

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Relevance of research. There is a need to limit the maximum velocity, acceleration, and jerk in positional electric drives (ED) of various types of mechanisms. If these limitations are not present in the position set signal, then limiting only the voltage and currents or torque in the control system loops is insufficient because, during large displacements it will lead to relatively large position oscillations due to the presence of the braking path and saturation of the controllers.[1…3]

The purpose of research is to obtain a nonlinear position controller (NPC) that limits acceleration and jerk during relatively large displacements with current controller (CC) or torque controller (TC) and velocity controller (VC) saturation while transitioning to linear control for small displacements without saturations in CC or TC and VC.

Basic research materials. The proposed structure of the NPC as part of the ED control system is shown in Fig.1. The set angular velocity ω_s is calculated by a linear position controller W_{PC} as the velocity set, with subsequent nonlinear constraints in case of exceeding ω_{min}. These constraints depend on the inertialess coefficients in the transfer functions W_{VC} of VC, W_{CC} of CC or TC of W_{TC}, and W_{PVC} of the power voltage converter (PVC), as well as saturation limits in them. The limitation of angular jerk ζ_{max}, in addition to acceleration ε_{max}, increases the braking path. Additionally, the time delay t_c between the signal set and its execution due to inertia in the control system increases the braking path. For braking from the initial speed ω_{in} to 0, this position shift is:

$$\Delta\varphi_{sh} = t_{out} \cdot \omega_{in} = \left(t_c + \frac{\varepsilon_{max}}{2\zeta_{max}} \right) \cdot \omega_{in} . \quad (1)$$

Therefore, the braking should start earlier by outrunning time of tout due to subtracting $\Delta\varphi_{sh}$ from the position control error $\Delta\varphi$. The recalculated $\Delta\varphi'$ allows for the calculation of static velocity constraints ω_φ using the same relationship as in the case of limiting only ε_{max} and ω_{max}.

The mentioned nonlinear static relationship does not allow for limiting jerk and acceleration during acceleration. Therefore, the constraint on the velocity set ω_{lim} is calculated by integrating acceleration, which is the integral of jerk. With this double integration, the acceleration set is initially calculated, taking into account the sign, through the static relationship based on the deviation from the previous ω_φ, denoted as $\Delta\omega_\varphi$:

$$\varepsilon_s = \mathrm{sgn}\left(\Delta\omega_\varphi\right)\sqrt{\left|2\zeta_{max}\Delta\omega_\varphi\right|} . \quad (2)$$

Then, the error in the acceleration set determines the presence and sign of the maximum permissible jerk.

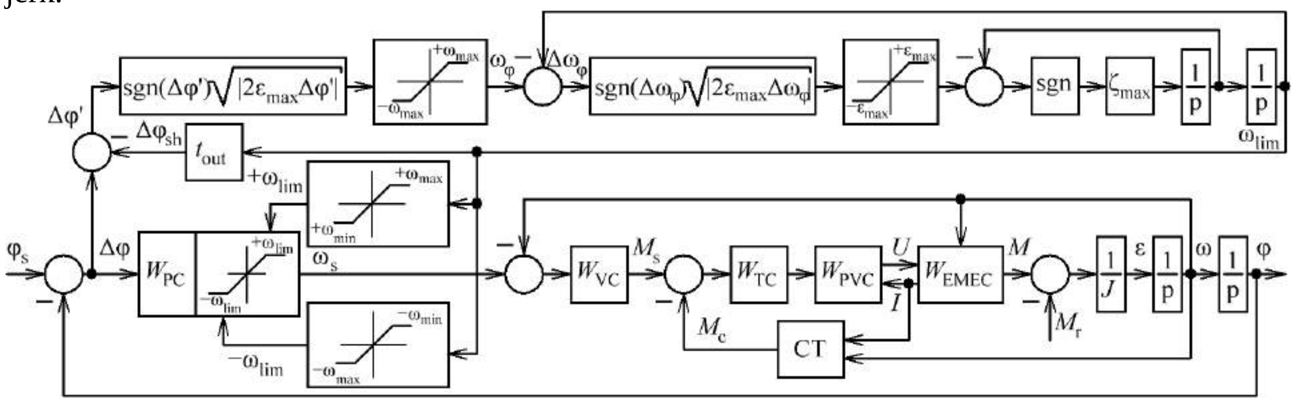

Fig.1 – The structure of the electric drive with the nonlinearity position controller

In Fig.1 additional notations include control loops of torque M and angular velocity ω with unity feedback as part of the subordinate control system, the transfer functions of the power voltage converter W_{PVC} and the electromechanical energy conversion in the electric motor (EM) W_{EMEC}, the calculation of torque (CT) and the resistive torque M_r, which loads the first inertia shaft with a moment of inertia J, incorporating the EM rotor.

The operation of the positional electromechanical system with the previously mentioned controller is simulated using a direct current machine as an example. The values of armature current $I_a^* = I_a / I_{a.max.}$, acceleration $U_a^* = U_{a.max.} / U_{a.max.}$, and jerk $\zeta^* = \zeta / \zeta_{max}$ are depicted in Fig.2 relative to their allowable maximum values. The values of angular velocity $\omega^* = \omega / \omega_{max}$, and acceleration $\varepsilon^* = \varepsilon / \varepsilon_{max}$, are shown in Fig.3 relative to their allowable maximum values. The position $\varphi^* = \varphi / \varphi_s$ is displayed in Fig.3 relative to displacement, which is set by a step change at φ_s. Time is represented relative to the constant time T_μ, which is an approximate characteristic of the nonlinear PVC and is not compensated for in this control system.

From the beginning until 10 T_μ, there is no jerk and acceleration because the torque increases to the resistance value, as seen in the current graph. After that, motion commences. As a result, jerk is primarily limited by the rate of change of currents due to the inductance in the motor armature windings until 100 T_μ. This confirms the expected operation of the NPC without saturation in VC, CC, TC, and the power converter. The same pattern repeats on three intervals during both acceleration and deceleration. Two intervals, 105…200 T_μ and 505…595 T_μ, have acceleration constraints at the set values. This also demonstrates the anticipated absence of saturation in VC. After 690 T_μ, the set velocity becomes lower than ω_{min}, and the control system transitions to the linear zone with position tracking. This transition takes longer in time compared to continuing braking with constant jerk due to the t_c calculation error when determining t_{out}.

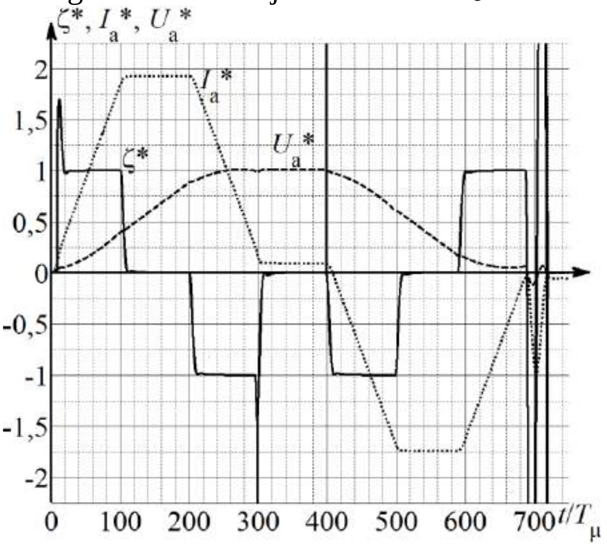

Fig.2 – Jerk, armature current and voltage

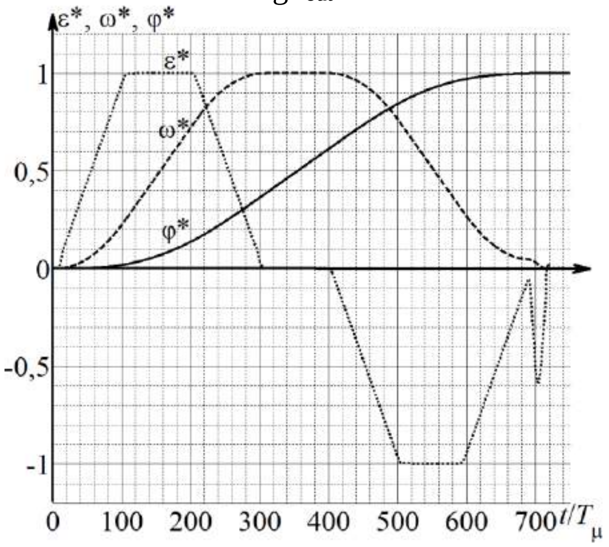

Fig.3 – Displacement, velocity and acceleration

Conclusion. Computer simulation has shown that the proposed NPC provides acceleration and jerk limitations during relatively large displacements without saturations of CC or TC and VC, while transitioning to linear control during relatively small displacements. Further refinement of the NPC structure is needed to limit jerk during relatively small displacements, reduce the influence of the control time determination error t_c on braking path calculation accuracy to enhance efficiency, and minimize the influence of the load characteristics.

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