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OPTIMAL SPEED REGULATOR OF THE METAL-CUTTING MACHINE TOOL MAIN DRIVE

Introduction. The stability and the transient performance of the closed control system loop is bonded with the pole and zero location of its transfer function on the s-plane. For the control system tuning with the difficult regulator, that contains some variable parameters, the root-locus method can be used, that allows to research independently the effect of the each parameter on the control system transient performance.

Analysis of studies and publications. On the base of the obtained control devices that belong to the area of the regulators with predetermined difficulty and carried out researches for their transient performance the conclusion was made, that the control devise structure consisting of the second order polynomial in the numerator and the second order polynomial without free term in the denominator is chosen for the further synthesis of the optimal control device for the metal-cutting machine tool main drive speed loop.

Purpose of the paper is to study the effect of the speed regulator coefficients on the transient performance ratings by the step loading condition such as the motor speed decrease and the return time to the reference speed

Study materials. Assume that the control object is a squirrel cage induction motor. From the classic representation of the induction motor mathematical model with the control by varying the stator supply voltage it can be seen that it contains the cross coupling by the stator current vector components. In case of the compensation or minimization of the cross coupling influence the stator voltage vector component variation can independently set the value of the rotor flux linkage and the motor speed. Then the flux linkage and speed control channels will be divided similar to a DC motor with separate excitation. Assume that the cross coupling by the stator current vector components is compensated and the inner current loop is optimized for the technical criterion, then the control object of the electromechanical system can be described as follows [8]

$$o(s) = \frac{1.5 \cdot p_{pp} \cdot k_2}{J \cdot k_c \cdot (T \cdot s + 1) \cdot s'}$$

where s – Laplace operator; p_{pp} – induction motor pole pairs; $k_2 = L_m/L_2$ – dimensionless coefficient; L_m – magnetizing inductance, H; L_2 – rotor inductance, H; J – motor inertia moment, $kg \cdot m/s^2$; k_c – stator current sensor coefficient, V/A; T – time constant of the stator loop, s.

The control object transfer function can be written

$$o(s) = \frac{K}{s(s + p)}$$

where

$$K = \frac{1.5 \cdot p_{pp} \cdot k_2}{J \cdot k_c \cdot T},$$

$$p = \frac{1}{T}.$$

Consider the robust system synthesis with the second order regulator, which transfer function is

$$p(s) = \frac{k_3 s^2 + k_1 s + k_2}{s(cs + 1)},$$

then the closed loop transfer function can be determined as

$$cl(s) = \frac{K(k_3 s^2 + k_1 s + k_2)}{cs^4 + (cp + 1)s^3 + (p + Kk_3)s^2 + Kk_1 s + Kk_2} \quad (1).$$

The closed loop transfer function of the fourth order control system that confirms the integral weighted modular criterion:

$$cl(s) = \frac{\omega_n^4}{s^4 + 2,1\omega_n s^3 + 3,4\omega_n^2 s^2 + 2,7\omega_n^3 s + \omega_n^4} \quad (2).$$

The damped natural frequency of the system ω_n can be determined provided that the speed overshoot $\sigma = 2\%$, the damping coefficient $\zeta = 0,8$ and the desired settling time $T_s = 0,004$ s:

$$\omega_n = \frac{4}{\zeta \cdot T_s} = \frac{4}{0,8 \cdot 0,004} = 1250 \frac{1}{s}.$$

Providing that the coefficients of the expressions (1) and (2) are equal, the control device parameters can be obtained and the control system root locus can be built (fig. 1)

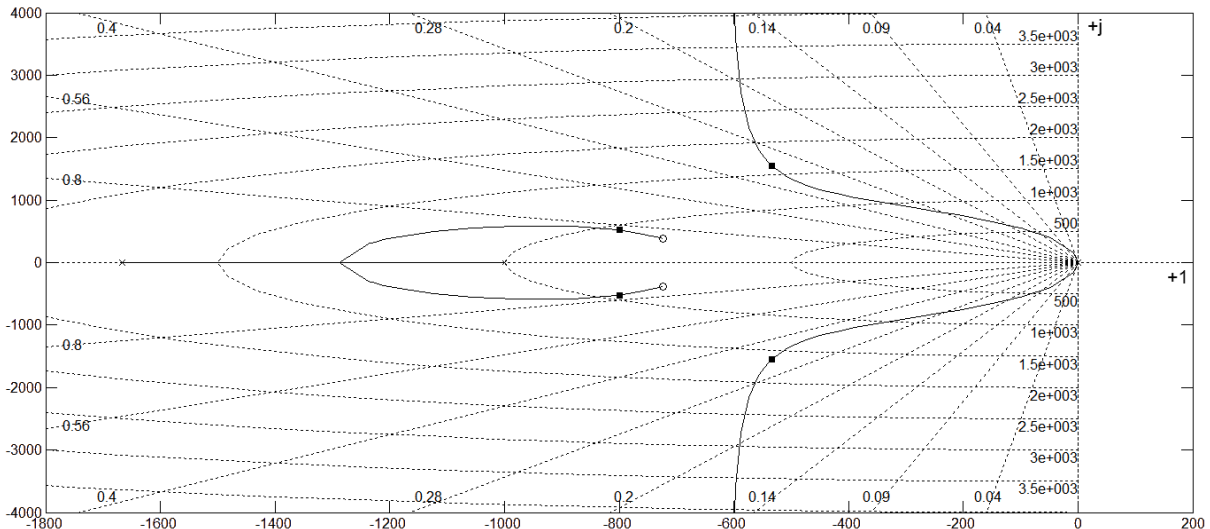


Figure 1 – The root locus of the robust speed control system

$$c = \frac{1}{2,1\omega_n - p} = \frac{1}{2,1 \cdot 1250 - 1000} = 0,0006$$

$$k_3 = \frac{3,4\omega_n^2 c - p}{K} = \frac{3,4 \cdot 1250^2 \cdot 0,0006 - 1000}{2600} = 0,84;$$

$$k_1 = \frac{2,7\omega_n^3 c}{K} = \frac{2,7 \cdot 1250^3 \cdot 0,0006}{2600} = 1216;$$

$$k_2 = \frac{\omega_n^4 c}{K} = \frac{1250^4 \cdot 0,0006}{2600} = 563401.$$

To ensure the desired transient performance ratings the filter at the system input that compensates the unwanted influence of the closed control system loop zeroes is used:

$$W_f(s) = \frac{\frac{\omega_n^4}{Kk_3}}{s^2 + \frac{k_1}{k_3}s + \frac{k_2}{k_3}} = \frac{670870}{s^2 + 1447s + 670870}.$$

By the tuning of the control system to the integral weighted modular criterion the step loading condition system transient performance ratings can be nonoptimal. To define the optimal speed regulator coefficients which provide minimal induction motor speed decrease and minimal return time to the reference speed, the each coefficient influence on the mentioned transient performance ratings by the root-locus method is studied.

The characteristic equation of the dynamic system in general view can be written as follows

$$a_n s^n + a_{n-1} s^{n-1} + \dots + a_1 s + a_0 = 0.$$

To study the coefficient a_1 influence and to build the root locus the equation must be rewritten as

$$1 + \frac{a_1 s}{a_n s^n + a_{n-1} s^{n-1} + \dots + a_2 s^2 + a_0} = 0.$$

If the system has two or more variable parameters, then it is necessary after the extraction of one of them, e.g. a_1 to write by analogy the characteristic equation taking into account that $a_1 = 0$ relative to another parameter, e.g. a_2 :

$$1 + \frac{a_2 s^2}{a_n s^n + a_{n-1} s^{n-1} + \dots + a_3 s^3 + a_0} = 0.$$

The study of the each parameter influence is carried out inversely by the substitution of the computed value of the observable parameter to the characteristic equation with the higher order. According to the eq. (1) the characteristic equation of the closed speed control system loop

$$2JT_\mu cs^4 + (2JT_\mu + Jc)s^3 + (J + KJk_{s\omega}k_3)s^2 + KJk_{s\omega}k_1s + KJk_{s\omega}k_2 = 0,$$

and the equation for the study of the each parameter influence on the step loading condition transient performance ratings can be written for it

$$1 + \frac{(2JT_\mu s^4 + Js^3)c}{2JT_\mu s^3 + (J + KJk_{s\omega}k_3)s^2 + KJk_{s\omega}k_1s + KJk_{s\omega}k_2} = 0;$$

$$1 + \frac{KJk_{s\omega}k_2}{2JT_\mu s^3 + (J + KJk_{s\omega}k_3)s^2 + KJk_{s\omega}k_1s} = 0;$$

$$1 + \frac{KJk_{s\omega}k_1s}{2JT_\mu s^3 + (J + KJk_{s\omega}k_3)s^2} = 0;$$

$$1 + \frac{KJk_{s\omega}k_3s^2}{2JT_\mu s^3 + Js^2} = 0.$$

By the study of the influence of the speed regulator coefficients on the speed decrease value and the return time to the reference speed by the step loading condition the extremal character of the curves is obtained (fig. 2)

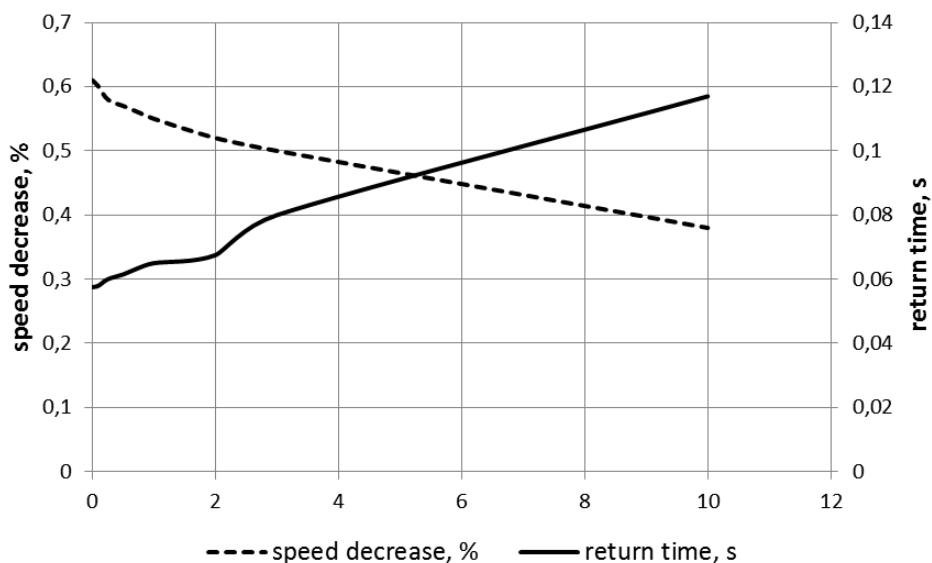


Figure 2a – The curves of the speed decrease and return time via coefficient k_3

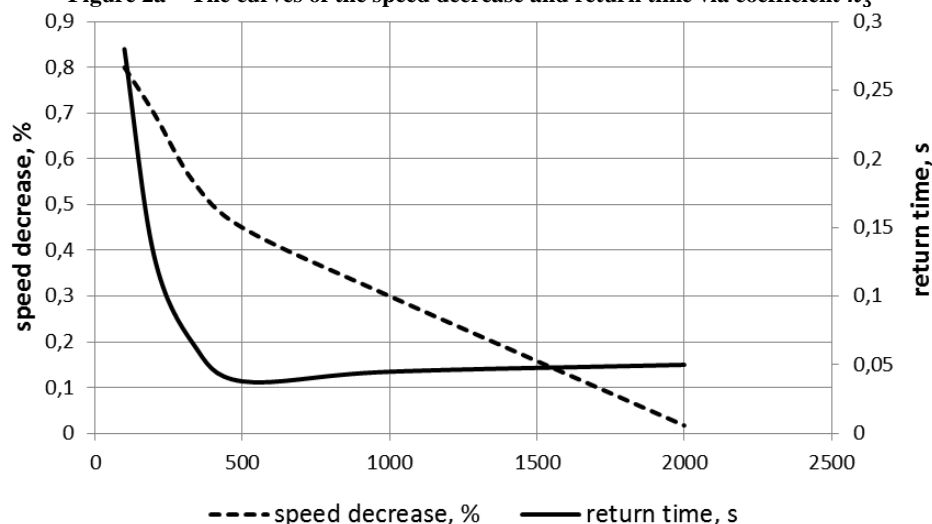


Figure 2b – The curves of the speed decrease and return time via coefficient k_1

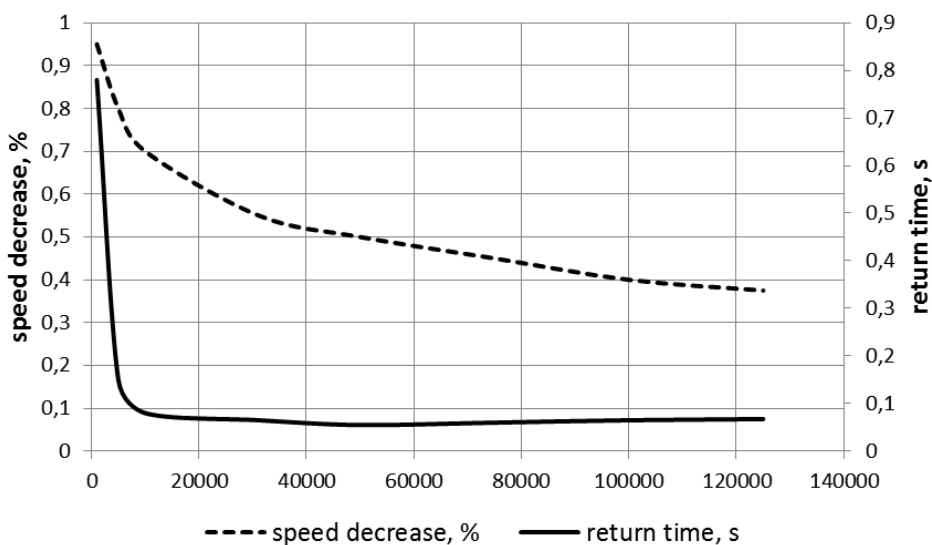


Figure 2c – The curves of the speed decrease and return time via coefficient k_2

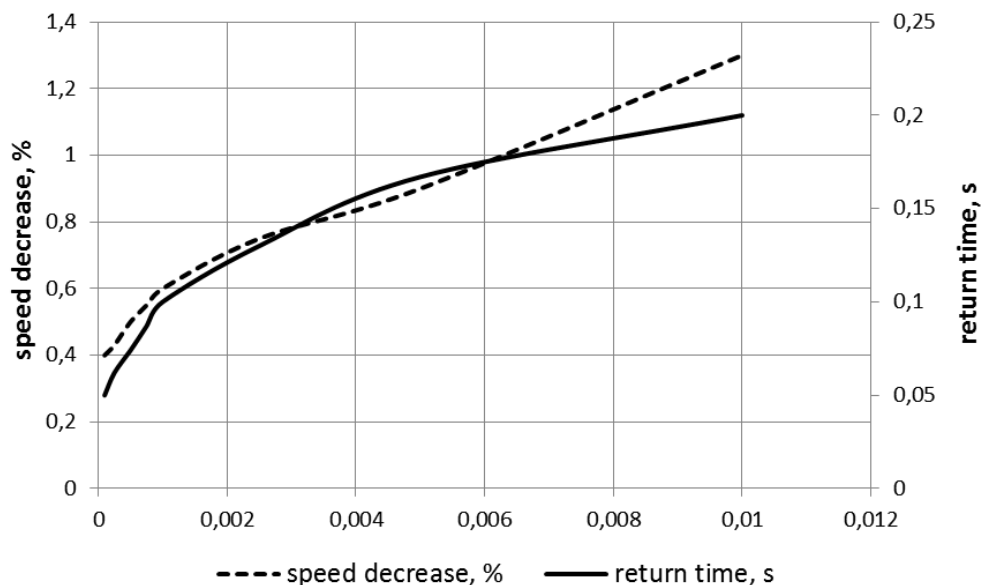


Figure 2d – The curves of the speed decrease and return time via coefficient c

Assume the coefficients k_2 and k_1 corresponding to extremal values by the return time to the reference speed and the coefficients k_3 and c to provide the minimal return time, then the speed regulator transfer function takes a form

$$W_r(s) = \frac{0,25s^2 + 500s + 100000}{s(0,0001s + 1)}$$

The simulation of the transient by the start and the step loading condition results that obtained optimal second order regulator as compared with PI-regulator provides decrease of the speed overshoot to 0.2 % by the start and reduce of the speed decrease by the step loading condition to 0.08 % (fig. 3)

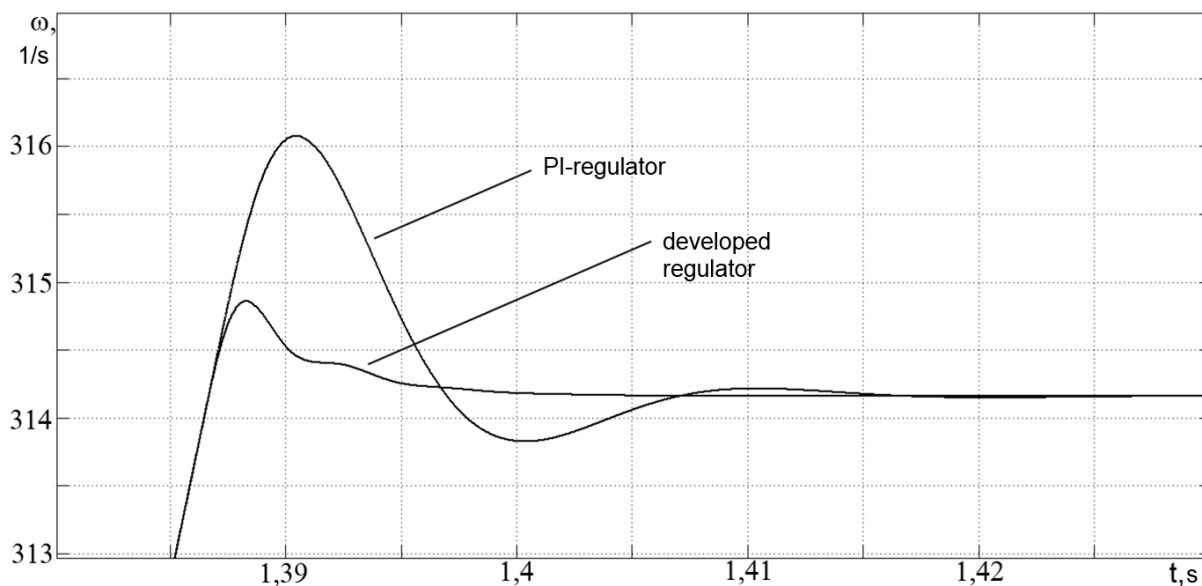


Figure 3a – The transient graph of the motor speed by the start

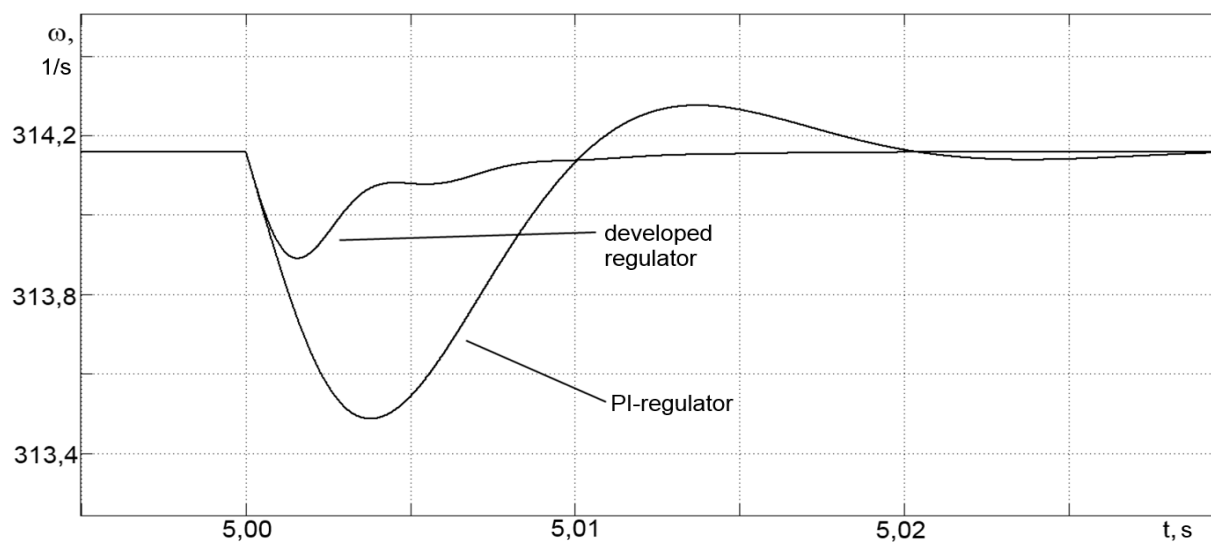


Figure 3b – The transient graph of the motor speed by the step loading condition

Conclusions. Using the root-locus method the curves of the speed decrease and return time via coefficients by the step loading conditions were obtained. The optimal parameters of the second order speed regulator of the metal-cutting machine tool main drive are defined.

References

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