Design of PI Controller with Lowpass Filter for Resonant Mechanical System

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Key words: Extended Parameter Plane Method, PI Control, Lowpass Filter, Resonant Mechanical System.

1. Introduction

Motor drive systems driving a load through a shaft or a transmission system are widely found in industrial applications. Suppression of mechanical resonance is one of important topics in control of two-inertia system. It is shown that PI control is not able to provide a sufficient damping when the inertia ratio of load to motor becomes small⁽¹⁾. One compensation method is to change the inertia ratio via the derivative feedback of motor speed⁽¹⁾⁽²⁾. In general, the derivative computing brings noise easily. In order to avoid the noise problem, PI controller combined with a lowpass filter is considered⁽³⁾⁽⁴⁾⁽⁵⁾.

In practice, a simple and easy understanding design is desired. The extended parameter plane method proposed by authors⁽⁶⁾, provides an analytical design for control systems with three adjustable parameters. This paper presents how to use the method to analysis of speed control system with PI control plus a lowpass filter.

2. Speed Control System

Fig. 1. Speed control system with PI controller plus a lowpass filter

A speed control system of two-inertia system, which employs PI control plus a one-order lowpass filter, is shown in Fig.1. K_p and K_i are proportional and integral feedback coefficients, respectively. T_d is the time constant of the filter. In this figure,

J_m : Motor inertia, J_L : Load inertia

ω_m : Motor speed, ω_L : Load speed

K_s : Torsional stiffness of drive shaft

ω_r : Reference input of motor speed

The transfer function from the reference input to the load speed is given by

$$\frac{\omega_L(s)}{\omega_r(s)} = \frac{K_i \omega_a^2}{a_5 s^5 + a_4 s^4 + a_3 s^3 + a_2 s^2 + a_1 s + a_0} \quad (1)$$

where

$$a_5 = T_d$$

$$a_4 = 1$$

$$a_3 = \omega_0^2 T_d + K_p/J_m$$

$$a_2 = \omega_0^2 + K_i/J_m$$

$$a_1 = \omega_a^2 K_p/J_m$$

$$a_0 = \omega_a^2 K_i/J_m$$

ω_a is antiresonant frequency, ω_0 is resonant frequency, and R is inertia ratio. They are defined as follows :

$$\omega_a = \sqrt{\frac{K_s}{J_L}}, \quad \omega_0 = \omega_a \sqrt{1+R}, \quad R = \frac{J_L}{J_m} \quad (2)$$

The system in Eq.(1) is a fifth-order one, but there are only three adjustable coefficients (K_p, K_i, T_d). It is not easy to design the system due to the less adjustable parameters.

3. System Analysis

The coefficients a_k ($k = 0, 1, \dots, 5$) in Eq.(1) are the linear functions of three parameters K_p, K_i and T_d . Furthermore, $K_p/J_m, K_i/J_m$ and T_d are considered as three designed parameters in analysis since J_m is a constant. The extended parameter plane technique determines three adjustable parameter by assigning three poles in the complex plane⁽⁶⁾.

The pair of complex poles (●) and the negative real pole (+) are simply arranged to have an identical radius, and the poles (●) are fixed with the damping coefficient = 0.8. For three different inertia ratios $R = 0.75, 0.5$ or 0.25 , the pole locations are shown in Fig.2 where the radius is varied from $0.5\omega_a$ to $1.0\omega_a$. It is seen that the locations of the designed poles obviously effect the pair of vibratory poles (×). That is, as the three designed poles (● and +) move away from the imaginary axis, the damping of the vibratory poles (×) gets weak. It is also noted that the system shows a slight vibratory behavior as the inertia ratio is lowered.

Fig. 2. Pole locations for $R = 0.75, 0.5, 0.25$

The step responses are given in Fig.3, where the radius of the designed poles is selected as $0.7\omega_a, 0.8\omega_a$ or $0.9\omega_a$, and ω_a is normalized as 1 rad/s . The system shows good response for $R = 0.75$ or 0.5 , compared with the one for $R = 0.25$.

4. Conclusions

Based on the extended parameter plane method, the speed control system with PI controller plus a lowpass filter was analyzed. The lowpass filter clearly improves the response of the system when the inertia ratio is greater than 0.5 , however its effect gradually decreases as the inertia ratio gets small.

(Manuscript received April 23, 1999)

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(a) The case of $R = 0.75$

(b) The case of $R = 0.5$

(c) The case of $R = 0.25$

Fig. 3. Step responses for $R = 0.75, 0.5, 0.25$

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