Study on Following of Parmeter α of 2-DOF PID Controller Using Fuzzy Algorithm

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Abstract

2-mass system is generally used as controller of the variable-speed to transfer electromotion power to mechanical load such as industrial robot, driving parts of electric vehicle, rolling machine system of steel plant and driving parts of elevator. In this case, PI controller is often used as a velocity controller because of simplicity of system. But PI control algorithm is not enough for obtaining the control characteristics required for this system. To solve this problem, 2-mass system based on the PID controller derives the optimum PID parameters by pole assignment and estimation of the ITAE performance index. In this case, the system have tenacious properties about disturbance, but it causes extreme overshoot and vibration because of rapidly output of controller in early transient response about desired value. And if speed control system is applied by 2-DOF parameter α, a temporary value, we must induce most suitable parameter by complicate pole assignment and estimation of the ITAE performance index whenever α changes. In this paper, to solve this problem we suggest control algorithm to followed exactly value of α as 2-DOF parameter by using fuzzy algorithm. So, intelligence algorithm modeled by human knowledge, experience, teachability and judgment follow exact α value and it can compose the efficient 2-DOF PID controller to improve following performance, overshoot decrease.

Key Words : 2-mass system, 2-DOF PID control, Fuzzy Algorithm

Ⅰ. Introduction

2-Mass resonant system using controller of the variable-speed to transfer electromotion power to mechanical load such as industrial robot, driving parts of electric vehicle, rolling machine system of steel plant and driving parts of elevator happens on thraw vibration by electric motor and inertia of load. Particularly such as longed shaft and electric motor driving system using rolling large of load-side mass or robot arm maintaining softness union, mass of two pieces or than, case of system is connected out of shaft of low stiffness, because of mechanical resonance frequency of itself system is much lower by degree a few Hz ~ several of Hz, happens on thraw vibration by control way such as PI controller uncontrollable, serious case problem that shaft is damaged. Therefore, for elementary method, control signal slowly is increased or controller gain is dropped, stiffness improve to enlarge diameter of shaft and so on, but not only these method can not gain fast speed response but also side of economic performance become problem. To solve these problem, method and so on that use state observer and H^{∞} theory and μ -Synthesis is studied. However most these method, control performance and tuning method are very superior and yet there is limitation in aspect that unintelligible and complicated control theory is practical being required mathematically. On the other hand control theory of PID controller is simple extremely and user's convenience and general purpose lie in trend more increase. As well much more researches are achieved in advanced country. Specially when PID controller controls speed of 2 inertias system can decide damping characteristics and also can design practical speed controller if induce optimum PID parameter by pole assignment techniques and estimation of the ITAE performance index. However, In this case the system is superior damping characteristics about disturbance, but it causes extreme overshoot and vibration in early transient response. Also IF 2-DOF apply parameter α to 2 inertias speed control system by voluntary fixed value, it must induce most suitable parameter by complicate pole assignment and estimation of the ITAE performance index whenever α changes.

In this paper, to solve this problem we suggest control algorithm to followed exactly value of α as 2-DOF parameter by using fuzzy algorithm. Through established control way and simulation to prove effectiveness of proposed control method comparison and confirm.

Ⅱ. 2 Inertias speed control system structure

1. Control Algorithm

2 inertias speed control system that have general 2-DOF PID controller has appeared to figure 1. Here, parameter is same as following.

J_m : electromotor inertia　　J_L : load inertia

ω_r : reference speed of electromotor　　ω_m : speed of electromotor

ω_L : load speed　　K_s : thraw constant of driving shaft

T_L : disturbance torque　　α : 2-DOF parameter

In figure 1, transfer function between reference speed of electromotor ω_r and load speed ω_L, transfer function between disturbance torque T_L and load speed ω_L is given by each equation (1), (2)

$$\frac{\omega_L(s)}{\omega_r(s)} = \frac{(\alpha K_p s + K_i)\omega_a^2}{J_m s^2(s^2+\omega_o^2)+(K_d s^2+K_p s+K_i)(s^2+\omega_a^2)} \tag{1}$$

$$\frac{\omega_L(s)}{T_L(s)} = \frac{1}{J_L}\frac{s\,[(J_m+K_d)s^2+K_p\,s+\;K_i\;+\;K_s]}{J_m s^2(s^2+\omega_o^2)+(K_d s^2+K_p s+K_i)(s^2+\omega_a^2)} \tag{2}$$

Here, If do ω_o : resonance frequency, ω_a : antiresonance frequency, R : inertia ratio is defined as each following.

$$\omega_o = \sqrt{\frac{K_s}{J_m}+\frac{K_s}{J_L}}, \quad \omega_a = \sqrt{\frac{K_s}{J_L}}, \quad R = \sqrt{\frac{J_L}{J_m}} \tag{3}$$

In equation (2), (3), parameter α shows that is influencing only in a set point without relation to disturbance. Therefore, after decide PID parameter to be tenacious to disturbance, if follow α value exactly taking advantage of fuzzy algorithm, satisfied control is available all in a set point and disturbance.

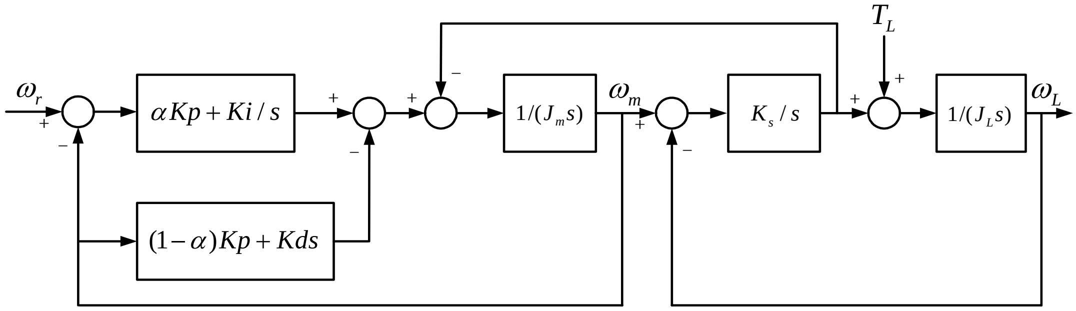


Fig. 1. A 2-mass speed control system with 2-DOF PID controller

2. Controller gain and inertia ratio

In equation (2) $\frac{1}{J_L}$ be concerned only size of response and do not influence substantially on pole and zero point. Therefore if arrange except this part when express equation (2) in form that have being complex conjugate roots of two pair, to design tenacious controller to disturbance, numerator polynomial $N(s)$ and denominator polynomial $D(s)$ are gained as each equation (4), (5).

$$N(s)=$$

$$s\left\{s^2+2(\zeta_1\omega_1+\zeta_2\omega_2)s+\frac{\zeta_1\omega_1^3+\zeta_2\omega_2^3}{\zeta_1\omega_1+\zeta_2\omega_2+4\zeta_1\omega_1\zeta_2\omega_2}\right\} \quad (4)$$

$$D(s)=(s^2+2\zeta_1\omega_1 s+\omega_1^2)(s^2+2\zeta_2\omega_2 s+\omega_2^2) \quad (5)$$

Here, ω_1 , ω_2 are eigen angular frequency, ζ_1 , ζ_2 are damping ratio.

Controller gains K_p, K_i, K_d are derived as each following in equation (2), (5).

$$K_p=2(\zeta_1\omega_1+\zeta_2\omega_2)(J_m+K_d) \quad (6)$$

$$K_i=\frac{\omega_1^2\omega_2^2}{\omega_a^2}(J_m+K_d) \quad (7)$$

$$K_d=\frac{\omega_a^4\ R\ J_m}{\omega_a^2(\omega_1^2+\omega_2^2+4\zeta_1\zeta_2\omega_1\omega_2)-\omega_1^2\omega_2^2-\omega_a^4}-J_m \quad (8)$$

$$\omega_1\zeta_1(\omega_2^2-\omega_a^2)=\omega_2\zeta_2(\omega_a^2-\omega_1^2) \quad (9)$$

3. Pole assignment and ITAE performance index estimation, decision of suitable parameter

It is $-\omega_1\zeta_1\pm\zeta\omega_1\sqrt{1-\zeta_1^2}$, $-\omega_2\zeta_2\pm\zeta\omega_2\sqrt{1-\zeta_2^2}$ if seek being complex conjugate number in equation (5). Real part of this pole points is important element that influence on settling time of transient response. In this study, Real part of pole points arrange as following to compare under condition such as results presented in reference [1].

$$-\omega_1\ \zeta_1\ =\ -\omega_2\ \zeta_2 \quad (10)$$

It is same as following if seek ω_2 in equation(9), (12).

$$\omega_2=\sqrt{2\omega_a^2-\omega_1^2} \quad (11)$$

Therefore, can arrange pole point of 2 inertias speed control system simply if set up ζ_1 and ω_1.

ITAE performance index value changes according to ω_1/ω_2, and index value amounts to smallest when it is $\zeta_1=0.77$, $\omega_1=0.66\omega_a$. Here, antiresonance frequency is 1[rad/sec], and it is sought by $\zeta_2=0.406$, $\omega_2=1.251\omega_a$ by equation (10) and (11).

Therefore, if substitute this result in equation (6)-(8), most suitable parameter by pole assignment and ITAE performance index estimation method is derived as following.

$$K_p=1.504\ \omega_a\ J_L$$
$$K_i=0.504\ \omega_a^2\ J_L \quad (12)$$
$$K_d=0.74\ J_L\ -\ J_m$$

Ⅲ. α value following of proposed 2-DOF PID controller

In this paper, To follow 2-DOF parameter α with figure 2 use fuzzy algorithm by controller design methodology. Fuzzy algorithm is that define suitable fuzzy rule and inference in parameter α value. α of proposed 2-DOF PID controller is decided on the basis of current error signal $e(k)$ and rate of error change $\triangle e(k)$. Fuzzy rule of parameter α is same with table 1

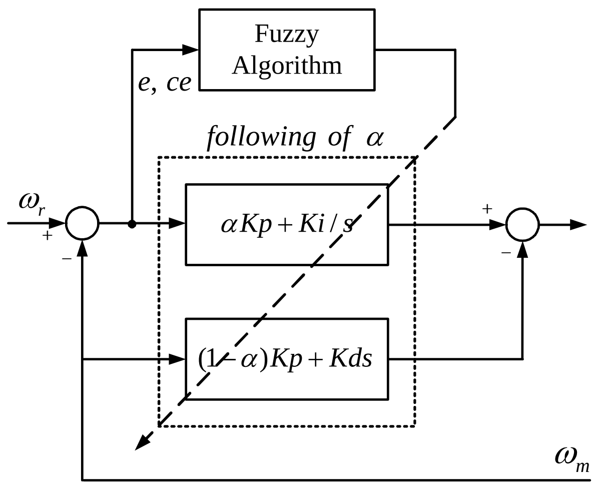


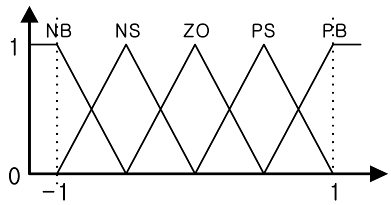
Fig. 2. Following of Parmeter α using Fuzzy Algorithm

Table 1. Table of fuzzy rule

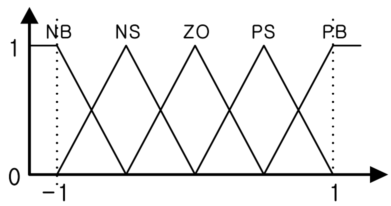
ce \ e	NB	NS	ZO	PS	PB
NB	NB	NB	NB	NS	ZO
NS	NB	NS	NS	ZO	PS
ZO	NB	NS	ZO	PS	PB
PS	NS	ZO	PS	PS	PB
PB	ZO	PS	PB	PB	PB

Here, reasoning methods uses Mamdani's Max-Min rule.

Each fuzzy membership funtions and rule table that follow α value of 2-DOF PID controller are same with figure 3.



(a) Membership Functions of e, ce



(b) Membership Functions of u

Fig. 3. Membership Functions

Figure 4 showed look-up table about fuzzy rule.

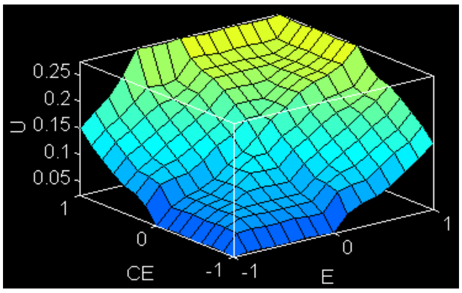


Fig. 4. Look-up table

Ⅳ. Simulation

Electromotor and inertia of load that use in simulation of this paper are 0.01[kgm^2] and 0.02[kgm^2]. Antiresonance frequency to verify validity of proposed control method applied 1[rad/sec] used in this paper and reference [1], and step disturbance torque impressed on -0.3 K_s[Nm] per 20[sec]. Also 2-DOF parameter α establish by 0.29, Though value by following parameter α that use fuzzy controller and simulation analyzed each comparison.

Method that select general α value, using fuzzy algorithm, result that compare control method that follow α value of proposed 2-DOF PID controller show each to figure 5 and figure 6.

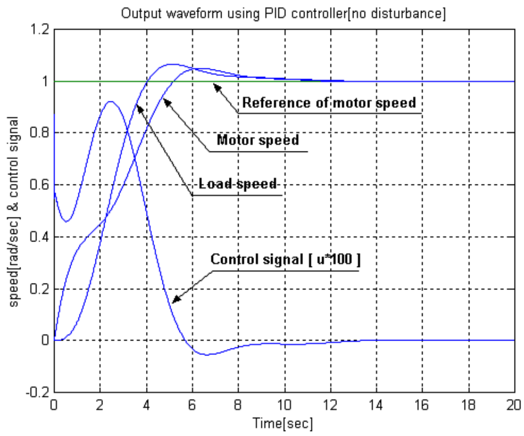


Fig. 5. Output 2-DOF PID Controller[No Disturbance]

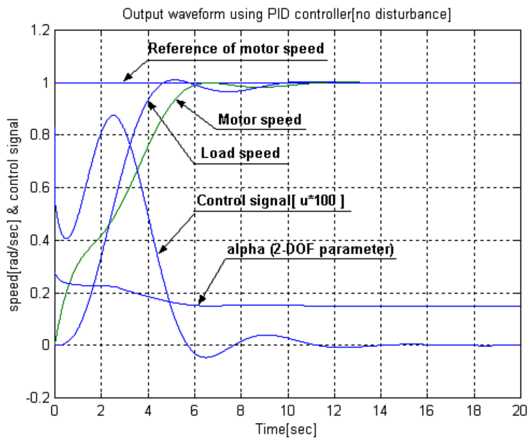


Fig. 6. Output 2-DOF PID Controller using Fuzzy Algorithm[No Disturbance]

In figure 5 and 6, when followed α value of 2-DOF PID controller that use proposed fuzzy algorithm, we can know that show overshoot that is less comparatively and fast desire value following performance.

In 2 inertia speed control system, figure 7 and 8 analyzed each method comparison in occurrence disturbance.

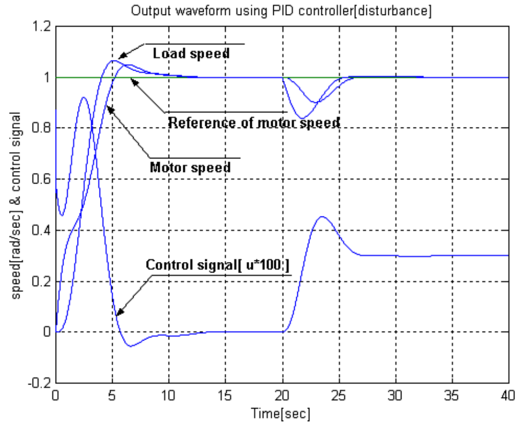


Fig. 7. Output 2-DOF PID Controller[Disturbance]

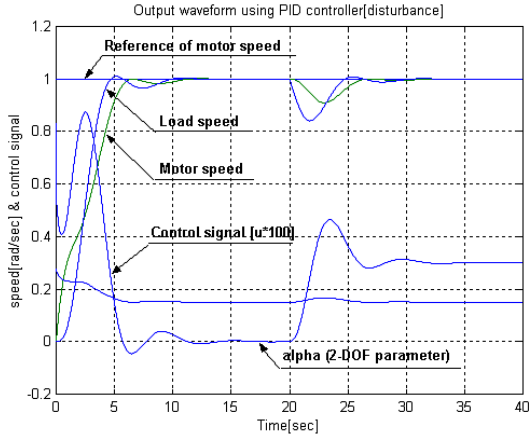


Fig. 8. Output 2-DOF PID Controller using Fuzzy Algorithm[Disturbance]

Proposed 2 inertia speed control system can know that show still small overshoot and fast desired value following performance.

V. Conclusion

In this paper applied PID controller to 2 inertia speed control system. Follow α value that take advantage of fuzzy algorithm in this paper composed 2-DOF PID controller. 2 inertia PID controller that α value is fixed, it causes extreme overshoot and vibration because of rapidly output of controller in early transient response about desired value. Following α value of most suitable that using this problem by fuzzy algorithm, we could confirm that is reaching fast steady state and desired value following performance, overshoot decrease when impress disturbance. Also, by 2-DOF PID controller follows parameter α value that using of proposed fuzzy algorithm, we could gain efficient output character and restrain thraw vibration occurrence of shaft by electromotor and inertia of load. Hereafter subject apply to plant and multi degree of freedom system.

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