Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2014, 6(10):826-832

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Study on the Fuzzy-PID control with incomplete derivation of S-ECR

Zhang Kai, Li De Sheng, Wang Wei Jie and Zhang Ze Nan

College of Mechanical Engineering and Applied Electronic Technology, Beijing University of Technology, Beijing, China

---

ABSTRACT

In order to overcome highly nonlinearity, multi-interference and coupled system of the S-ECR, the Fuzzy PID with Incomplete Derivation (F-PID) control scheme is being proposed. The control algorithm is different ways with different speeds during the vehicle is constant downhill speeds. The intelligent hierarchical control and Cruise control system was established. The system achieves adjust the braking torque for when the vehicle speed is changed, and it has fast response and stable control. The test results show that the control system has good dynamic characteristics. The control algorithm improves the anti-interference ability of the control system and control accuracy. The proposed control system has a greater degree of fine performance to enhance vehicle stability and safety.

Key words: F-PID, Electromagnetic, Retarder, Control

INTRODUCTION

The self-excitation retarder [1-3], as an auxiliary brake tools, is commonly used in heavy vehicles. In order to overcome highly nonlinearity, multi-interference, multivariable function and coupled system of the S-ECR, the coherence between the braking torque and the temperature of the stator is complexity, it is difficult to adopt PID control through real-time adjustment of the braking torque to the stator temperature is controlled in the range of safety running. Conventional proportional-integral-derivative (PID) controllers have been well applied for industrial automation, industrial motor drives and process control. But the controllers may not perform delay system, complex and nonlinear system, vague system without precise mathematical models and uncertainties. The conventional PID controller fails to provide an effective control to the S-ECR due to nonlinear and coupled field system.

The fuzzy controllers can realize nonlinear control due to their nonlinear linguistic mapping between inputs and outputs. The utility and capability of PID controller has increased to a good extent due to its hybridization with fuzzy controller [4-7]. K. S. Tang [8] introduces an optimal fuzzy proportional-integral-derivative (PID) controller by using the multiobjective generic algorithm. The results demonstrate that the controller is suitable for the control for the control of nonlinear plants in industrial applications. Ahmed Rubaai [9, 10] presents an integrated environment for the rapid prototyping of a robust fuzzy PID controller that allows rapid realization of novel designs. Xiao-Gang Duan[11] presents a saturation-based tuning method for fuzzy PID controller, to have a nominal tuning for achieving the equivalent control and a robust tuning for achieving the switching control.

The control system of the S-ECR [12] belongs to nonlinear system, higher order and time-delayed linear system. In this paper, we designed a fuzzy PID with Incomplete Derivation (F-PID) controller to improve the dynamic performance and the static stability. Fuzzy logic is employed execute and fuzzy rule base. The PID with Incomplete Derivation is analyzed. The braking torque are analyzed and tested.

MATHEMATICAL MODEL

The F-PID controller is a digital controller, which contains a fuzzy controller and a PID with Incomplete Derivation.

The fuzzy controller consists of fuzzification, control rule establishment and defuzzification. According to the principle of fuzzy control to on-line modification of three parameters, it satisfy different E and EC to the control parameters of different requirements, make the controlled object has a good dynamic and static performance. The block diagram of Fuzzy-PID control system is shown in Fig. 1. The flow chart for the F-PID is shown in Fig. 2.

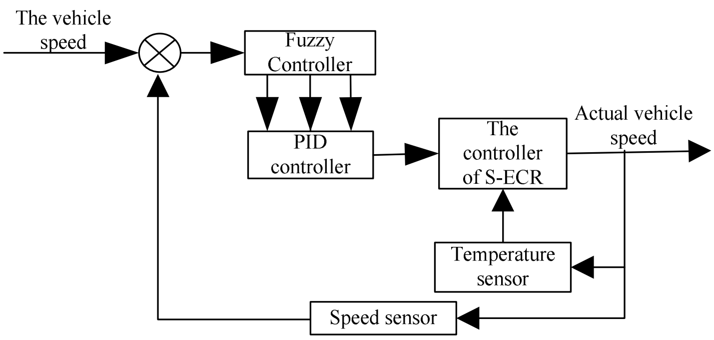


Fig. 1: Block diagram of Fuzzy-PID control system

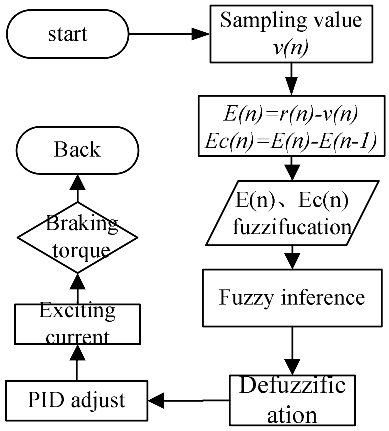


Fig.2: The flow chat of control system

A PID WITH INCOMPLETE DERIVATION ALGORITHM

The introduction of the differential signal can improve dynamic performance of the conventional PID control system. It can also introduce the high frequency interference. Therefore, the low-pass filter is joined in the control algorithm. The PID with incomplete differential algorithm is effective to overcome the retarder the negative effects of interference signals on the control system. The high frequency interference is suppressed. The Block diagram of PID with Incomplete Derivation control algorithm is shown in figure 3.

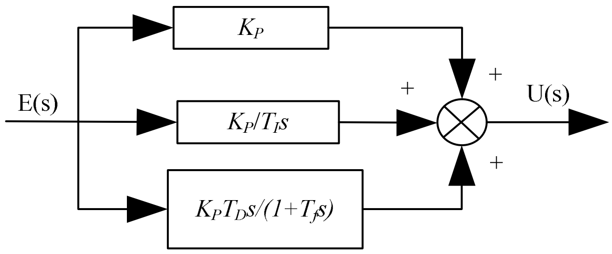


Fig. 3: The Block diagram of PID with Incomplete Derivation control algorithm

The transfer function of PID with incomplete differential algorithm is given by

$$U(s)=K_c[1+\frac{1}{T_i s}]E(s)+K_c\frac{T_d s}{1+\frac{T_d}{K_d}s}E(s) \quad (1)$$

Discretization is given by

$$U(n)=K_c[e(n)+\frac{Ts}{T_i s}\sum_{i=0}^{n}e(i)] \quad (2)$$

The differential part into differential equation is given by

$$\frac{T_d}{K_d}\frac{d_{P_d}(t)}{dt}+U_d(t)=K_c T_d\frac{de(t)}{dt} \quad (3)$$

The differential item into difference is given by

$$\frac{T_d}{K_d}\frac{P_d(n)-U_d(n-1)}{T_s}+U_d(n)=K_cT_d\frac{e(n)-e(n-1)}{T_s} \quad (4)$$

$$U_d(n)=\frac{\frac{T_d}{K_d}}{\frac{T_d}{K_d}+T_s}U_d(n-1)+\frac{K_cT_d}{\frac{T_d}{K_d}+T_s}[e(n)-e(n-1)] \quad (5)$$

Where $A=\frac{T_d}{K_d}+T$, $B=\frac{\frac{T_d}{K_d}}{\frac{T_d}{K_d}+T_s}$, so

$$U_d(n)=BU_d(n-1)+\frac{K_cT_d}{A}[e(n)-e(n-1)] \quad (6)$$

The incremental algorithm of PID with incomplete differential algorithm is given by

$$\Delta U_d(n)=K_c[e(n)-e(n-1)]+K_c\frac{T_d}{T_i}e(n)+\frac{K_cT_d}{A}[e(n)-2e(n-1)+e(n-2)]+B[U_d(n-1)-U_d(n-2)] \quad (7)$$

The average method is used to eliminate random interference, which is the sampling value of "*m + 1*" sampling time instead of the *"n+1"* sampling values.

$$\bar{e}(n)=\frac{e(n)+e(n\text{-}1)+\cdots+e(n\text{-}m)}{m+1} \quad (8)$$

Then $\bar{e}(n)$ is acquired via operate program. The used control law of PID can make the controlled quantity to control quantity of set value quickly. The PID control parameters and time domain performance index of the relationship is shown in table 1.

Table 1 The PID parameters and time domain performance index of the relationship

parameters	Rise time	overshoot	Accommodation time	Static error
K_P	↓	↑	—	↓
K_I	↓	↑	↑	×
K_D	—	↓	↓	—

where：“↑”——increased; “↓”——decreased; “—”——small change; “×”——eliminate;

FUZZY CONTROL ALGORITHM

The fuzzy control algorithm was used to control the braking torque of the S-ECR and to realize the grading control. The controller consists of the handle position, the error (E_V) and the error change rate (EC_V) between the theoretical value and the actual value of the speed, the error (E_T) and the error change rate (EC_V) between the theoretical value and the actual value of temperature. The handle position, the error (E_V) and the error change rate (EC_V) are used as the inputs to the controller.

According to the speed of rotation and the current at the actual work of the S-ECR and the coil temperature, the errors described above by the basic domain is mapped to the corresponding fuzzy set theory domain. The basic domain of E_V and E_I :

E_I =EC_I= {-6，-5，-4，-3，-2，-1，0，1，2，3，4，5，6}
E_V = EC_V={-6，-5，-4，-3，-2，-1，0，1，2，3，4，5，6}

The linguistic fuzzy variable "E_V" and "EC_V" has seven sets: negative big (NB), negative large (NL), negative small (NS), zero (Z), positive large (PL), positive big (PB), and positive small (PS), with each set having its own membership function.

The ΔK_P, ΔK_I and ΔK_D are used as the inputs to the fuzzy controller.
The basic domain of ΔK_P:
{-0.6，-0.4，-0.2，0，0.2，0.4，0.6}

The basic domain of ΔK_I:
{-0.3，-0.2，-0.1，0，0.1，0.2，0.3}

The basic domain of ΔK_d:
{-6，-4，-2，0，2，4，6}

The linguistic fuzzy variable "ΔK_P", and "ΔK_I" and "ΔK_D" has seven sets: NB, NL, NS, Z, PL, PB, and PS, with each set having its own membership function.

Fig. 4, Fig. 5 and Fig. 6 show the membership functions for the fuzzy inputs.

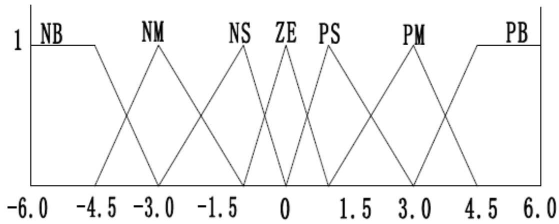


Fig. 4: E_V,EC_Vs fuzzy member function

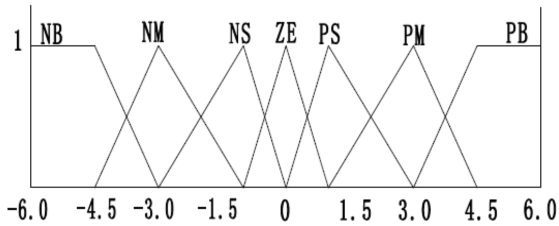


Fig. 5: E_T、EC_T's fuzzy member function

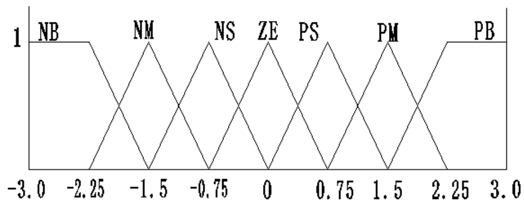


Fig. 6: I's fuzzy member function

The output of the fuzzy controller is shown in Table 2.

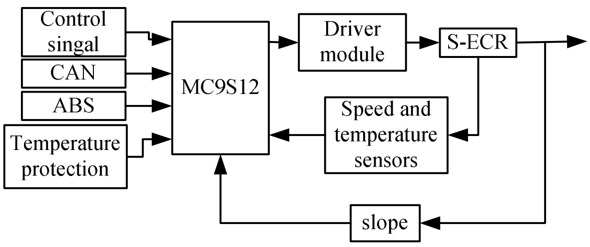
Table 2 Block diagram of Fuzzy controller

$\Delta K_P/\Delta K_I/\Delta K_d$		EC_V						
		NB	NM	NS	Z	PS	PM	PB
E_V	NB	PB/NB/PS	PB/NB/NS	PM/NM/NB	PM/NM/NB	PS/NS/NB	Z/Z/NM	Z/Z/Z
	NM	PB/NB/PS	PB/NB/NS	PM/NM/NB	PS/NS/NM	PS/NS/NM	Z/Z/NS	NS/Z/Z
	NS	PM/NB/Z	PM/NM/NS	PM/NS/NM	PS/NS/NM	Z/Z/NS	NS/PS/NS	NS/PS/Z
	Z	PM/NM/Z	PM/NM/NS	PS/NS/NS	Z/Z/NS	NS/PS/NS	NM/PM/NS	NM/PM/Z
	PS	PS/NM/Z	PS/NS/Z	Z/Z/Z	NS/PS/Z	NS/PS/Z	NM/PM/Z	NM/PB/Z
	PM	PS/Z/PB	Z/Z/PS	NS/PS/PS	NM/PS/PS	NM/PM/Z	NM/PB/PS	NB/PB/PB
	PB	Z/Z/PB	Z/Z/PM	NM/PS/PM	NM/PM/PM	NM/PM/PS	NB/PB/PS	NB/PB/PB

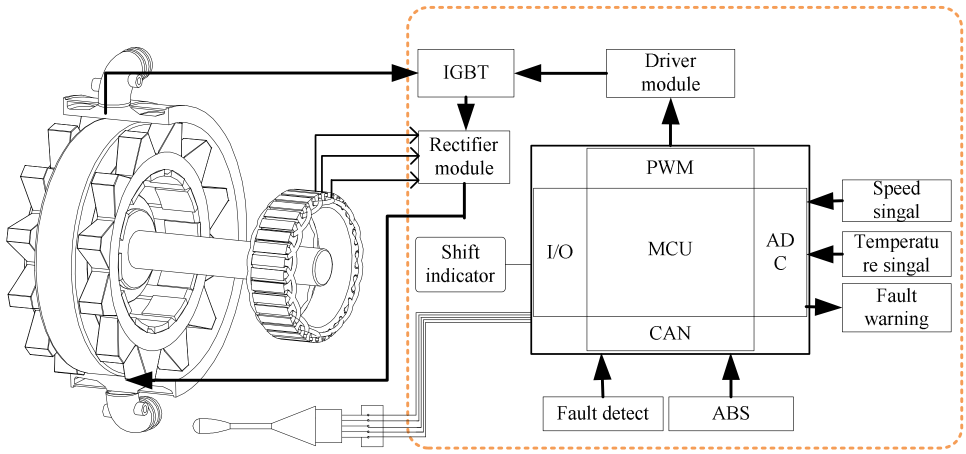
Acquired fuzzy subset of fuzzy inference is converted to a precision digital to get the fuzzy control output. The Maximum Degree of Membership method is used the control system. The ΔK_P, ΔK_I and ΔK_D are acquired by the F-PID.

EXPERIMENT

The proposed F-PID method is applied to control the braking torque of the S-ECR. The Freescale forms the core of the closed-loop system. It used PWM (Pulse Width Modulation) to adjust the excitation current and IGBT (Insulated Gate Bipolar Transistor) as driver chip. It constitutes loop control system via acquired the signals of temperature sensor and velocity sensor, the slope as the feedback signal. It computes an error signal, delivers the error signal to the control algorithm, and executes the control algorithm to determine a control signal. The hardware block diagram of Fuzzy-PID control system is shown in Fig. 7. The test bench of the S-ECR is shown in Fig. 8.



(a)



(b)

Fig. 7: Block diagram of F-PID control system

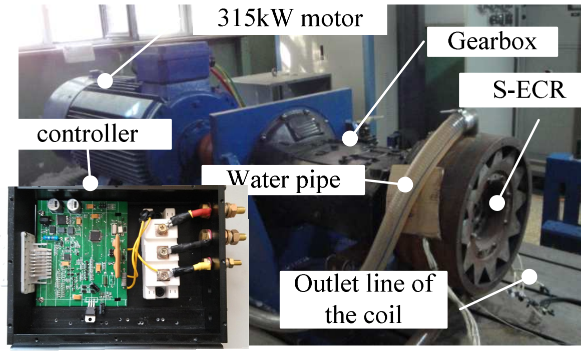


Fig. 8: Test bench for the S-ECR

Analyzed speed characteristics and braking characteristics were utilized to measure the braking ability of the retarder and to facilitate F-PID control when the vehicle constant downhill. The dynamics equation of the vehicle is given by

$$F_j = G\sin\theta - F_f - F_w - F_R \quad (9)$$

where F_j is the inertia force, G is total mass, F_f is the rolling resistance, F_w is the air resistance, F_R is the braking force of the S-ECR, θ is slope.

Fig. 9 shows the experimental curve of the braking torque at various speeds. The braking torque increased as the current increased. The braking torque reached a stable value at 750 rpm. Fig. 10 shows the experimental curve of the braking torque at various current. This experiment was utilized to tune the braking torque for cruise control system (CCS) by adjusting the value of the excitation current. As the braking time increased, the braking torque decreased.

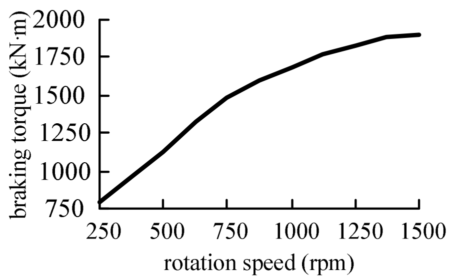


Fig. 9: The comparison of braking torque obtained by measurement and calculation

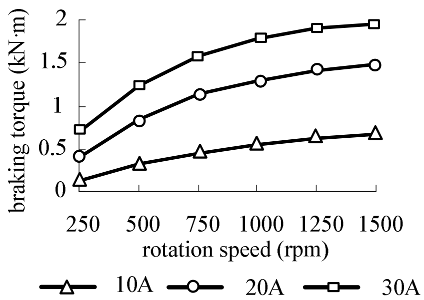


Fig. 10: The braking torque at various current

Fig. 11 shows the vehicle continuous downhill when the slope is 6°. When the value of speed was set 30km/h and the braking only used S-ECR, the test results demonstrated that the error was 3 km/h between actual speed and target speed. The results indicated that the control system improves the anti-interference ability of the control system and control accuracy. It met the vehicle cruise control requirements.

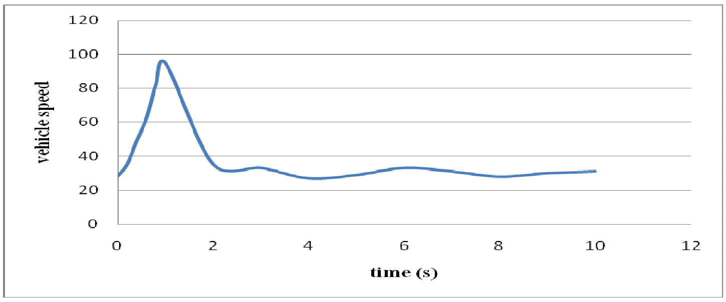


Fig. 11: The comparison of braking torque obtained by measurement and calculation

CONCLUSION

This paper proposed a F-PID with Incomplete Derivation to overcome highly nonlinearity and multi-interference and coupled system of the S-ECR. The ΔK_P, ΔK_I and ΔK_D are adjusted on-line according to the fuzzy control principle. It meets the different error and error change rate of the control parameters. The test results showed that the system has good dynamic characteristics, reduces the braking torque decreased when the temperature of coil rises. The control system improves the anti-interference ability of the control system and control accuracy. The results indicated that the proposed F-PID has a greater degree of fine performance and is more suitable for S-ECR.

Acknowledgments
The authors thank Su Yanqiang and Zhang Longxi for help in the control system and the braking torque analysis. This work is supported by the National Natural Science Foundation of China under Project 51277005.

REFERENCES

[1] HE Ren, ZHANG Ju, ZHAO Wangzhong. *Academic J. Light Vehicle.*, **2005**, (07), 12-15.
[2] ZHAO Wang-zhong, WENG Mao-rong. *Academic J. Journal of Zhengjiang Industry and Trade Polytechnic.* **2005**, 5 (04), 36-40.
[3] SHI Zhu-li. Analysis and research of auto self-motivated eddy current retarder [D]. Changchun University of Science and Technology, **2011**.
[4] H. Baogang, G. K. I. Mann and R. G. Gosine. *Academic J. IEEE Transactions on Fuzzy Systems.* **1999**, 7(5), 521-539.
[5] YUE Wen-jie, XIE Shou-yong, CHEN Chong, et al. *Academic J. Journal of Agricultural Mechanization Research.* **2014**, (04), 194-197.
[6] H. Bao-Gang, G. K. I. Mann and R. G. Gosine. *Academic J. Fuzzy Systems, IEEE Transactions on.* **2001**, 9(5), 699-712.
[7] T. S. Li, C. Shih-Jie and C. Yi-Xiang. *Academic J. Industrial Electronics, IEEE Transactions on.* **2003**, 50(5), 867-880.
[8] K. S. TANG, F. M. KIM, CHEN Guan-rong, et al. *Academic J. IEEE Transactions on Industrial Electronics.* **2001**, 48(4), 757-765.
[9] AHMED RUBAAI, MARCEL J. CASTRO-SITIRICHE, ABDUL R. OFOLI. *Academic J. IEEE Transactions on Industry Applications.* **2008**, 44(6), 1977-1986.
[10] AHMED RUBAAI, MARCEL J. CASTRO-SITIRICHE, ABDUL R. OFOLI. *Academic J. IEEE Transactions on Industry Applications.* **2008**, 44(4), 1090-1098.
[11] DUAN Xiao-gang, DENG Hua and Li Han-xiong. *Academic J. IEEE Transactions on Industrial Electronics.* **2013**, 60(11), 5177-5185.
[12] ZHANG Kai, LI De-sheng, DU Xiao, et al. *Academic J. IEEE Transactions on Energy Conversion.* **2014**, 29(1), 196-203.