A Starter Testing System Based on Fuzzy-PID Control *

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Abstract: A fuzzy self-tuning PID controller for a starter testing system (STS) is designed in this paper, which is composed of a standard PID controller and a fuzzy self-tuning mechanism. The fuzzy self-tuning mechanism tunes a single parameter α to adjust PID parameters on line in such a way that the controller has features of rapid response and good robustness. The practical application shows that the STS is with the characteristics of high precision, quickness and reliability.

Key words: fuzzy self-tuning; PID control; performance test

Fuzzy-PID 控制起动机性能测试系统的研究

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摘要: 针对起动机性能测试系统, 设计由标准 PID 控制器和模糊自整定机构组成的模糊自整定 PID 控制器. 其模糊自整定机构通过调整参数 α 来在线整定 PID 参数以求控制的快速性和鲁棒性. 实际运行结果表明起动机性能测试系统检测精度高, 快速性好, 可靠性高, 已稳定运行于复杂环境的电机生产线上.

关键词: fuzzy 自整定; PID 控制; 性能测试

1 Introduction

Starters and generators used in automobile belong to small motors. Their testing systems are indispensable for quality detecting of products in automobile industry. Imported testing systems are with the features of high reliability, accuracy and stability, but their operation is not very straightforward and convenient. Furthermore, their price is very high and maintenance is difficult. Domestic testing systems of high precision are usually used in institutions of research or appraisal, whose reliability and stability are not satisfying when they work in complicated environments of motor production.

The STS is applied to check the quality of motors used as both starters and generators in American racing cars. Test items include loading experiment and braking experiment in which voltage, current, rotational speed and torque are measured. Because of large working current in test process, the experiments must be finished in very short time. In addition, the tested motors are starting-generating motors in racing car, the requirements of testing accuracy and period are more strict than that of ordinary starters. Moreover, good robustness and suitableness for performance test of various kinds of motors are needed.

Conventional PID controller has been widely applied in the field of control engineering because of its simplicity and stability. But the contradiction between static performance and dynamic performance and the contradictions among alternation of the objective parameters have not been well resolved. It is difficult to keep good control effect once the control parameters are set[1~3]. Therefore a novel controller which is composed of a standard PID controller and a fuzzy self-tuning mechanism is designed according to the requirements of STS. The fuzzy self-tuning mechanism realizes tuning of PID parameters in different states. So it has better control effect and stronger robustness than conventional PID controllers. The practical results demonstrates its effectiveness.

2 Composition of the STS

STS is composed of machine components, a set of pneumatic installation, a direct-current regulated power supply (DCRPS, DC/15V/500A) and an electrical control system which consists of an excitation power supply, a magnetism power brake, sensors, data acquisition and control cards and so on.

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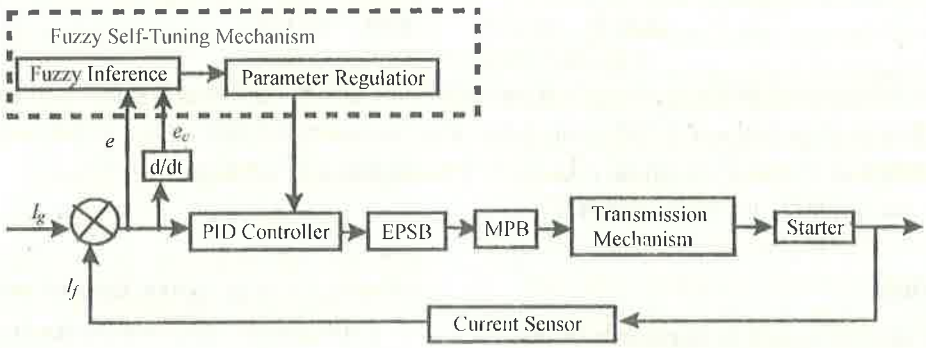
There are four functions: parameter setting, parameter collation, data management and performance test in STS, which are realized by an industrial computer. Under the parameter setting, the experiment conditions of different kinds of starters can be inputed, modified and reserved. In the function of the parameter collation, the measure value of torque, voltage, current and rotational speed can be collated adaptively. The data management can process testing parameters comprehensively on line. The parameters test does loading experiment and braking experiment automatically.

3 Design of the controller

Once the loading experiment begins the starter is supplied with input voltage by DCRPS. The excitation current of the magnetism power brake which is the starter's load, is regulated by fuzzy self-tuning PID controller quickly. So the starter's loading current I_f can reach the given value I_g very soon.

3.1 Structure of the controller

Fuzzy self-tuning PID controller is composed of a standard PID controller and a fuzzy self-tuning mechanism. According to the error and error rate, corresponding strategies are designed through fuzzy inferences. PID parameters K_p, T_i, T_d are regulated continuously. The controller's structure is shown is Fig.1.



EPSB——Excitation Power Supply of Brake; MPB——Magnetism Power Brake

Fig. 1 The structure of fuzzy self-tuning PID controller

3.2 Fuzzy self-tuning of PID parameters

PID control algorithm is as follows:

$$u(t) = K_p\left[e(t) + \frac{1}{T_i}\int_0^t e(t)\mathrm{d}t + T_d \frac{\mathrm{d}e(t)}{\mathrm{d}t} \right], \tag{1}$$

where K_p, T_i, T_d are respectively, proportional gain, the integral time and the derivative time of the controller which are to be adjusted on line. In order to keep high quickness, self-tuning algorithm should be realized easily and its calculation time must be very short. So Single Parameterization Formula[4] which is inspired by the Ziegler-Nichols formula shown in equation (2) is applied to adjust PID parameters adaptively.

$$K_p(k) = 2\alpha(k)K_{p0}, \quad T_i(k) = \frac{1.5}{1+\alpha(k)}T_{i0},$$

$$T_d(k) = \frac{1.5}{1+\alpha(k)}T_{d0}. \tag{2}$$

Where K_{p0}, T_{i0}, T_{d0} are initial value of PID controller. $\alpha(k)$ is parameters' self-tuning factor. It is adjusted on line by fuzzy self-tuning machanism.

Regulation of $\alpha(k)$: Error $e = I_g - I_f$ and error rate $e_c = [e(k) - e(k-1)]/T$ are input variables, and $h(t)$ which is collating factor of $\alpha(k)$ is output. Both of them form fuzzy sets through fuzzification. T is the sampling interval. The input linguistic variables E, E_c and output linguistic variable H are all defined as {PB, PM, PS, ZE, NS, NM, NB} whose membership functions are triangular shape. The universe of discourse for E, E_c and H are all defined as {-3, -2, -1, 0, 1, 2, 3}. According to the fuzzy control states, max-min fuzzy inference rules are adopted to calculate $h(k)$ by use of defuzzification with the method of gravity center. The inference process is indicated by equation(3).

$$h(k) = k_3\left\langle \frac{\langle k_1 e(k)\rangle + \langle k_2 e_c(k)\rangle}{2} \right\rangle, \tag{3}$$

where $\langle x \rangle = \mathrm{sgn}(x) * \mathrm{int}(|x| + 0.5)$, k_1, k_2, k_3 are quantification factors of input E, E_c and output H respectively. According to the experiment's results, the universe of discourse for error e is defined to be [-10A, 10A], the universe of discourse for the error rate e_c is [− 10A/s, 10A/s]. The universe of discourse for output H is [− 1, 1]. So the parameters are calculated as $k_1 = 3/10$, $k_2 = 3/10$, $k_3 = 1/3$. After obtaining $h(k)$, $\alpha(k)$ is rectified through recurrence formula (4)

$$\alpha(k)=\begin{cases}\alpha(k-1)+rh(k)[1-\alpha(k-1)], & \alpha(k-1)>0.5,\\ \alpha(k-1)+rh(k)\alpha(k-1), & \alpha(k-1)\leqslant 0.5,\end{cases} \quad (4)$$

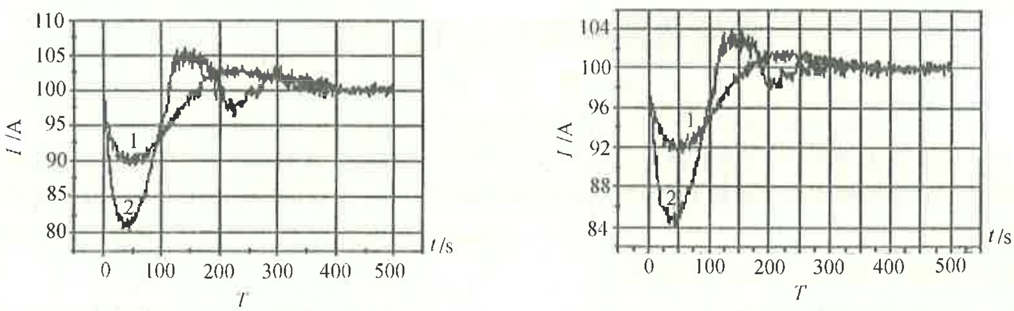
where r is a constant, which is often chosen within [0.2, 0.6]. It is used to rectify convergence speed. $r = 0.4$ is adopted in this paper, and $\alpha(0)$ is set to be 0.5.

$\alpha(k)$ obtained every time is substituted into equation (2), $K_p(k)$, $T_d(k)$, $T_i(k)$ are obtained, then PID parameters are adjusted on line adaptively.

3.3 Analysis of control effect

Conventional PID control algorithm and Fuzzy-PID control algorithm are adopted respectively to realized load current controlling. Two sets of corresponding current curves for type GSB107-04A and GSB107-06E shown in Fig.2 are gotten when adjusting period T is 4 ms.

In the figure Curves 1 corresponding to GSB107-04A



(a) Conventional PID control (b) Fuzzy-PID control

Fig. 2 Practical running results

indicate that the current under PID control reaches stable within 1.6s, its maximum of overshoot is 103A, and the current under Fuzzy-PID control reaches stable within 1.1s, its maximum of overshoot is 102A. Curves 2 corresponding to GSB107-06E indicate that the current reaches stable within 1.5s and 1.0s, its maximum of overshoot is 106A and 104A respectively. Experiments for different kinds of starters have been done for many times. All experiments have proved that Fuzzy-PID control has such features as rapid response, small overshoot and good robust performance in various cases compared with conventional PID control.

4 Conclusion

Fuzzy self-tuning PID controller has been proposed in this paper, in which PID controller is maintained and fuzzy-inferences are adopted to tune standard PID controller's parameter self-tuning. Simplicity, flexibility and robustness of PID control and fuzzy control are integrated. The merits of conventional control and fuzzy control are developed respectively.

The starter testing system has been running on the line of motor production in Hitachi Automobile Products LTD since June 1 in 1997. Errors of all parameters have not exceeded 0.5%. Response time is below 2 seconds. The conclusion of one starter's repeating experiments is unanimous. The running results show that it has possessed characteristics of reasonable design, operating convenience, hign accuracy, quick response and good stability. It is an ideal testing system of product quality.

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