A Study on Temperature Control of Semiconductor Lasers using Fuzzy-Smith Control

Lili GAO*[1], Zhaoxue LUAN[2]

[1.] College of Mechanical and Electronic Engineering , Shandong University of Science and Technology, Qingdao, Shandong,266590, China

[2.] Tai'an branch , Shandong Qilu transportation development group ,Taian,Shandong, 271000, China

***Abstract* — The wavelength of semiconductor lasers drifts with temperature, therefore their output accuracy will be reduced. The temperature must be controlled very precisely so that semiconductor lasers can work properly. A new temperature control algorithm is presented in this paper based on fuzzy-Smith control which combines fuzzy PID control with the Smith predictor. The simulation results show that the method can improve the control performance and enhance the robustness and stability for temperature control systems of semiconductor lasers.**

Keywords-semiconductor laser; temperature control; fuzzy-Smith control; Smith predictor

I. INTRODUCTION

Semiconductor laser is widely used with the advantages of small volume, high efficiency, long life, low cost, tunable wavelength and so on. For example, it is used as the light source of optical pump, the sensitivity can be improved more than an order of magnitude[1].Semiconductor laser is sensitive to temperature and its characteristic parameters are affected by temperature such as output wavelength, output optical power, threshold current, service life and so forth[2,3,4].For a general semiconductor laser, the temperature increases by 1□, and the laser wavelength increases by about 0.06nm in the case of a constant current [5].Obviously, it is vitally important to control the temperature of semiconductor laser.

In this paper, a new intelligent temperature control method for semiconductor laser is proposed which based on fuzzy-Smith control. Fuzzy PID control and Smith predictor control are united. The stability of output for semiconductor laser is improved. The whole system has good robustness and anti-interference ability.

II. DESIGN OF FUZZY-SMITH TEMPERATURE CONTROLLER

A. Mathematical Model of the Temperature Control System

The temperature control system of semiconductor laser mainly consists of temperature sensor, high precision amplifier, thermoelectric cooler(TEC) and its drive circuit. The temperature sensor and TEC all have thermal inertia and therefore the temperature variation of semiconductor laser is a slow drift process. From the view in control theory, the temperature control system is a typical first order hysteretic link. So its transfer function can be expressed by $1/(Ts+1)$ .The transfer function of temperature sensor in feedback channel is $e^{-\tau s}$ because signal transmission has a certain lag when temperature sensor is used. In addition, The other parts of the system can be regarded as the proportional link. From above analysis, mathematical model of the system can be expressed as follows:

$$G_D(s) = \frac{Ke^{-\tau s}}{T_1 s + 1} = G(s) \cdot e^{-\tau s} . \tag{1}$$

Where

$$G(S) = \frac{K}{T_1 + 1} \tag{2}$$

T_1 is the time constant of the TEC, unit is second. τ is the constant of the lag time, unit is also second. K is the proportional coefficient.

B. Control Algorithm of the Temperature Control System

Fuzzy PID control has strong robustness and strong anti-interference ability and it does not depend on the accurate mathematical model of the system. Fuzzy control has good control performance for the controlled object with uncertainty and nonlinearity, but it is difficult for it to describe time variant and time delay. Because the temperature control system of semiconductor laser has the characteristics of time varying and delay, the traditional fuzzy PID control can not get good control effect. n order to overcome the disadvantage of the traditional fuzzy PID control, a new control algorithm is adopted which is Smith predictive control.

The basic control strategy of Smith predictive control is: through constructing a process reference model, take the delay link out of the closed loop, so the feedback signal of the system is not affected by the delay and the regulating quality of the system is improved, such as the stability and response speed and so on.

Fuzzy PID control and Smith predictor are combined to form fuzzy-Smith control. This new control algorithm can not only solve the problem of time delay for the system, but also make up the defect for Smith predictor which calls for a higher accuracy of the model parameters.

1) Design of Fuzzy PID Controller: Fuzzy PID control is based on the traditional PID control which uses fuzzy logic theory to establish the function relationship between the parameters: K_P, K_i, K_d and E (error),and E_C (error change).The principle diagram is shown in Fig.1.Real time temperature deviation E and deviation change rate E_C are input signals of the fuzzy controller and its basic discourse domain is determined by the range of temperature. The output signals of the fuzzy controller are the tuning parameters-ΔK_p, ΔK_i, ΔK_d, and then are used to tune the parameters of the PID controller. Its basic discourse domain is determined by the PID parameters which have been set. Each language variable is assigned correspondingly as {NB, NM, NS , ZO, PS, PM, PB} and the fuzzy domain is [-6, 6]. Usually, the membership functions of E, E_C, ΔK_p, ΔK_i and ΔK_d are established by trigonometric function because the calculation is relatively simple and the control performance is good[6].

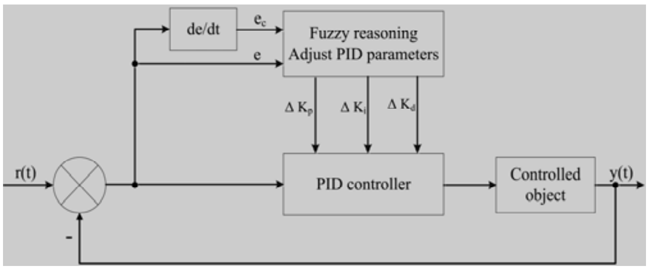

Figure 1. Principle Diagram of Fuzzy PID

From Fig.1,assuming the fuzzy PID transfer function is Gc(s) and the transfer function of the controlled object is showed in (1),so the closed-loop transfer function of the system can be expressed as follows:

$$\phi(s) = \frac{G_C(s)G(s)e^{-\tau s}}{1+G_C(s)G(s)e^{-\tau s}} \quad (3)$$

From (2),the characteristic equation of the system can be derived as:

$$1+G_C(s)G(s)e^{-\tau s} = 0 \quad (4)$$

In the characteristic equation, $e^{-\tau s}$ is contained. With the increase of frequency(ω),the phase angle for $e^{-\tau s}$ decreases infinitely and the stability of the system is greatly reduced. To ensure the stability, the gain can only be reduced and the role of regulation and control weakened, so that the response speed of the system is slowed and system adaptability got poor .That is to say, the time delay link directly affects the stability and rapidity of the system. In order to overcome the delay effectively, a Smith predictor is brought into the system.

2) Design of Smith Predictor: Smith predictive control algorithm can compensate for the pure delay of the model and it can reduce the overshoot of the system and enhance system stability. The basic principle of the Smith predictor is to build the estimated model and uses it to compensate by estimating the dynamic characteristics of the controlled object. In fact, it is to construct a Smith compensation function, so that the feedback signal of the system is not affected by $e^{-\tau s}$.

Assuming the Smith compensation function is Gm(s).In order to compensate for the delay of the controlled object, the following relationships must be satisfied:

$$G(s)e^{-\tau s} + G_m(s) = G(s) \quad (5)$$

So the Smith estimate function of the system can be got, as shown below:

$$G_m(s) = G(s)(1-e^{-\tau s}) \quad (6)$$

3) Fuzzy-Smith Intelligent Control: Fuzzy-Smith intelligent control is the combination of fuzzy PID control and Smith predictive control. The mathematical model of fuzzy-Smith intelligent control is shown in Fig.2.

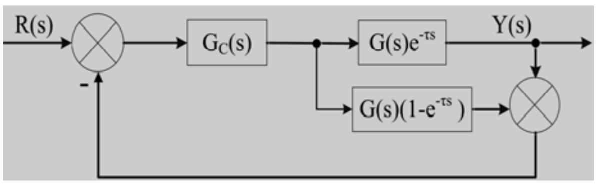

Figure 2. Mathematical Model of Fuzzy-Smith Intelligent Control

From Fig.2,the closed-loop transfer function of the system can be expressed as follows:

$$\phi(s) = \frac{G_C(s)G(s)}{1+G_C(s)G(s)}e^{-\tau s} \quad (7)$$

From (7),the characteristic equation of the system is derived as follows:

$$1+G_C(s)G(s) = 0 \quad (8)$$

In (8),the delay part ($e^{-\tau s}$)of the controlled object has been eliminated in the characteristic equation after the Smith predictor control is introduced to the delay system. It is demonstrated that the Smith predictor control method can effectively eliminate the adverse effect of time delay.

III. SIMULATION of CONTROL ALGORITHM AND RESULT ANALYSIS

In order to illustrate the effect of fuzzy-Smith PID control algorithm, three kinds of control algorithms, which are the traditional PID, fuzzy PID and fuzzy-

DOI 10.5013/IJSSST.a.17.49.02 ISSN: 1473-804x online, 1473-8031 print

Smith PID, are simulated in this paper. To complete the simulation work, Simulink simulation tool of MATLAB is used. The controlled object used in the simulation is:[7,8]

$$G_D(s) = \frac{e^{-\tau s}}{25s+1} \tag{9}$$

In (9),take $\tau = 5$,the simulation result is shown in Fig.3.We can see, in the three control algorithms, fuzzy-Smith PID algorithm performs better than the other two algorithms. Its response speed is relatively fast, adjustment time is short and the overshoot is effectively controlled.

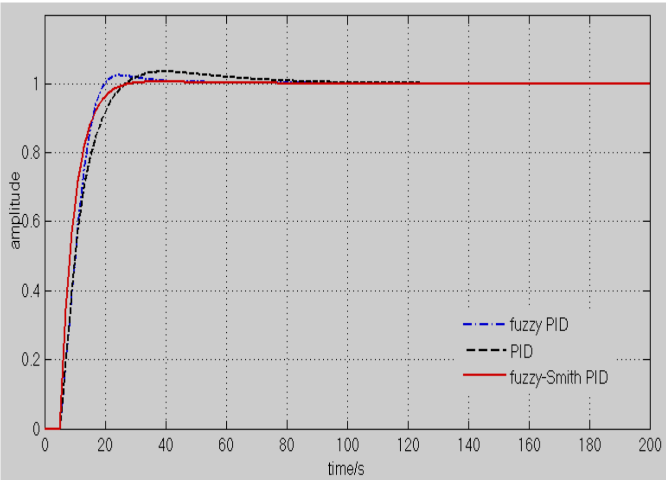

Figure 3. Simulation Result of Three Algorithms

The step response simulation result of the system after the addition of Gauss noise perturbation is shown in Fig.4.By comparing, fluctuation in the response of fuzzy-Smith PID controller is minimum and it can rapidly tend to keep stable .

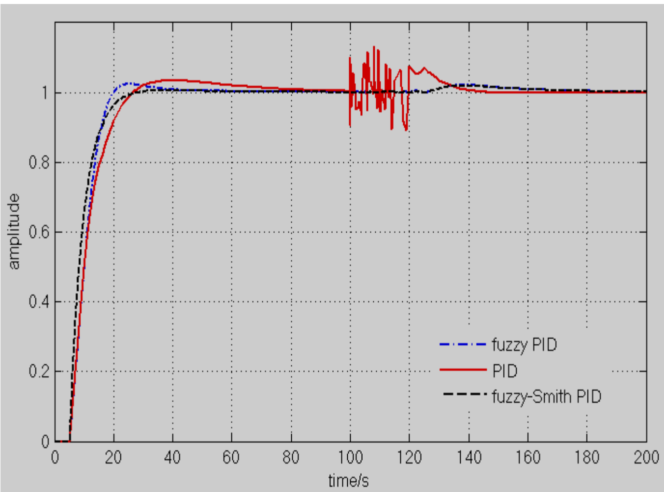

Figure 4. Simulation Result After Adding Disturbance

Through the simulation results, it can be seen that the effect of fuzzy-Smith PID control algorithm is the best.

IV. CONCLUSIOS

The fuzzy-Smith control algorithm proposed in this paper not only has high control accuracy but also has strong adaptive capability. he result of the simulation demonstrates that it can solve the problem of time varying, time delay and noise interference for the temperature control of semiconductor laser. The dynamic and static response quality of the system is improved.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

ACKNOWLEDGMENT

The authors thank Professor Xu Kebao for critical reviews.

REFERENCES

[1] H. Gilles, J. Hamel and B. Cheron., Laser pumped4 He magnetometer[J].American Institute of Physics, vol.72(5):.2253-2260,2001.

[2] G. Park ,D. L. Huffaker and Z.Zou.Temperature dependence of lasing characteristics for long-wavelength (1.3-um) GaAs-based quantum-dot lasers[J].Photonics Technology Letters,IEEE,vol.11, No.3:301-303,1999.

[3] Schetzen Martin.Analysis of the single-mode laser-diode linear model[J].Optics Communications,vol.282(14):2901-2905,2009.

[4] S. M.Mitani , M. S.Alias and M.R.Yahya.Temperature effect on gain and threshold current of GalnNAS-based 1.3 um semiconductor laser[C].In ISIE 2009,International Symposium on Industrial Electronic,Seoul,2009,.2208-2211.

[5] J. Zhao.Study on the control system of VCSEL laser on chip scale atomic optical device.M.S. Thesis[D].North University of China,Taiyuan, on China,2009.

[6] S.Majhi , D. P.Atherton.Obtaining controller parameters for a new smith predictor using autotuning[J].Automatica,vol.36: 1651-1658,2000.

[7] N.Zhang,Y.L.Yu and X.J.Tian.Principle and application of constant temperature control of semiconductor laser[J].Journal of Jilin University,vol.40:284-287,2013.

[8] Z.K.Wang,Y.Zhang,H.D.Zhao and L.Y.Li.Simulation Research on temperature control of semiconductor laser based on fuzzy PID control[J].Journal of Liaoning University of Technology,vol.34:79-81,2011.