Self-tuning fuzzy temperature control system for the DPSS blue laser at 473 nm

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This paper introduces a self-tuning fuzzy temperature control system for the diode-pumped solid-state (DPSS) blue laser at 473 nm. This temperature control system includes circuit of temperature sampling, power circuit of temperature adjusting, and fuzzy proportional-integral derivative (PID) controller. Circuit of temperature sampling adopts the precision temperature sensor for exact temperature sampling. The input signal of fuzzy PID controlling is digital signal from A/D transform chip, then the input analog signal of A/D transform chip is the differential signal of temperature sampling signal and setting temperature signal. The traditional PID control method cannot self-tune parameters of $K_{\rm p}$, $K_{\rm i}$, $K_{\rm d}$ in operating, this paper applies the method of combining fuzzy illation with traditional PID controlling to realize self-tuning parameter of PID. This system designs the power circuit to respond to control signal of fuzzy PID controller, that power circuit is made up of high power metal-oxide-semiconductor (MOS) field effect transistors semiconductor and Peter component. This self-tuning fuzzy temperature control system has good dynamic characteristic and static characteristic, and the system has lower over-adjusting and shorter response time. The temperature control precision of system is up to $\pm 0.05°$, the change range of the pump laser diode wavelength is below 0.02 nm, and the power stability of the laser at 473 nm is below $\pm 1\%$.

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In the few years, the blue lasers are applied to many fields such as spectrum analysis, medicine, biology, lasing fluorescence, aeronautics and space etc.. Especially, diode-pumped solid-state blue lasers at 473 nm are paid attention widely. Blue lasers at 473 nm are the intracavity second harmonic generation (SHG) from diode laser pumped Nd:YAG laser at 946 nm. The Nd:YAG laser at 946 nm is quasi-three-level system transitions and has higher pumping threshold[1−4]. In order to get efficiency and stability output, the match between pumping spectrum band and absorbing spectrum band at 808−809 nm is very important[1−4]. Because the wavelength of pumped laser diode and thermal effects of Nd:YAG and SHG crystals change with temperature[1−5], the temperatures of pumped laser diode, Nd:YAG and SHG crystals must be controlled in laser at 473 nm operating. In addition, it is necessary that the laser is controlled in balance operating temperature, in order to obtain higher power stability and lower exceed tuning of system. In a word, the good static characteristic and good self-tuning dynamic characteristic are required in the temperature control system of the DPSS blue laser at 473 nm.

This paper developes a self-tuning fuzzy temperature control system for the DPSS blue laser at 473 nm. This temperature control system includes circuit of temperature sampling, power circuit of temperature adjusting, and fuzzy proportional-integral-derivative (PID) controlling. The circuit of temperature sampling adopts the precision temperature sensor for exact temperature sampling. The input signal of fuzzy PID controlling is digital signal from A/D transform chip, and then the input analog signal of A/D transform chip is the differential signal of temperature sampling signal and setting signal. The traditional PID control method can not self-tune parameters of $K_{\rm p}$, $K_{\rm i}$, and $K_{\rm d}$ in operating, this paper applies the method of combining fuzzy illation with traditional PID controlling to realize self-tuning parameter of PID. This system designs the power circuit to respond to control signal of part of fuzzy PID controller, the power circuit is made up of high power metal-oxide-semiconductor (MOS) field effect transistors semiconductor and semiconductor cooling chip. This self-tuning fuzzy temperature control system has good dynamic characteristic and static characteristic, and the system has shorter adjusting time and faster response velocity.

The structure of self-tuning fuzzy PID temperature control system of the DPSS blue laser at 473 nm is shown in Fig. 1. The system includes circuit of temperature sampling, power circuit of temperature adjusting, and fuzzy PID controlling. The precision temperature sensor integrate chip AD590J is adopted in temperature sampling and feedback circuit for measuring the change of laser temperature. The integrate chip AD590J can be regarded as current supply whose current changes with the temperature. The output current of AD590 sensor is 298 μA at the room temperature 25 °C, and its output current changes 1 μA when the temperature changes 1 °C. The temperature precision of AD590 chip is up to 0.001 °C (per 1 nA). The spur circuit is made up of AD590 chip and resistance R2 for transforming current to voltage, and the reference supply $V_{\rm ref}$ provides voltage for this spur circuit. The current changing of resistance R2 equals the current changing of chip AD590 when the temperature of laser changes. The current changing of resistance R2 brings to voltage changing of resistance R2. This process transforms the laser temperature to a voltage signal, which is the input voltage signal of the comparing amplifier U1 positive pole. The spur circuit is made

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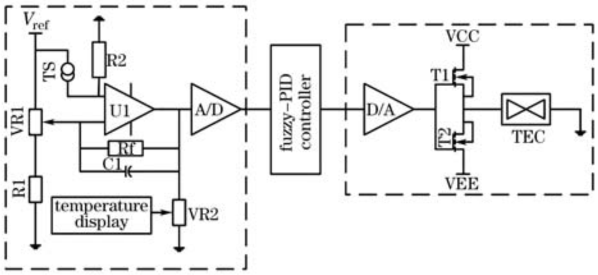

Fig. 1. Temperature control system structure of laser.

up of rheostat VR1 and resistance R1 for setting the temperature of laser operating, and the spur circuit also is provided age by the reference supply V_{ref}. The sampling voltage of rheostat VR1 is the setting voltage signal, which is input voltage of the comparing amplifier U1 negative pole. The difference circuit damps the common mode noise availably, which is made up of the spur circuit of VR1, R1, and the spur circuit of AD590, R2. The output signal of comparing amplifier U1 is the error signal of the laser operating temperature and the setting temperature. This error signal is input to the temperature display system by rheostat VR2 to display the changing of laser operating temperature. Simultaneous, this error signal is transformed a digital signal to become one of the input signals of self-tuning fuzzy PID controller by the precision A/D chip. The other input signal of self-tuning fuzzy PID controller is the differential signal of the temperature error signal. In order to improve the temperature sampling precision, the error precisions of the rheostats VR1, VR2 and the resistances R1, R2 are below 0.1% in the temperature control system.

The digital controlling signal is output from self-tuning fuzzy PID controller, which transforms analog controlling signal by the precision D/A chip. The controlling signal controls the temperature tuning circuit to tune the operating temperature of laser, and this temperature tuning circuit is made up of push-pull power circuit and Peter components. The push-pull power circuit is made up of high power MOS field effect transistors semiconductors T1 and T2. The push-pull power circuit can fleetly respond to the controlling signal to tune the output power of Peter components, then the operating temperature of laser can be controlled in setting temperature fleetly.

After the arithmetic is designed in the traditional PID controlling, the parameters K_{d}, K_{i}, K_{p} of system cannot be changed in operating, and the dynamic characteristic, the static characteristic, and the respond time of system cannot also be changed when the condition changes. In order to improve the power stability of the blue laser at 473 nm, the system should have lower over-adjusting and shorter response time when the operating temperature is between 15 and 30 °C. This system applies the method of combining fuzzy illation with traditional PID controlling to realize self-tuning parameters K_{d}, K_{i}, K_{p} of PID. This self-tuning fuzzy PID control system is made up of fuzzy illation and self-tuning parameter PID. The structure of temperature controlling is shown in Fig. 2.

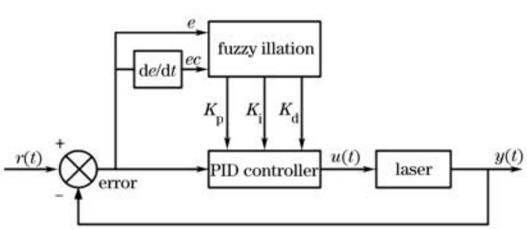

Fig. 2. Structure of self-tuning fuzzy PID controller.

The increment PID controlling is used in the self-tuning parameter PID in order to reduce system error and gain better controlling effect. The arithmetic of the increment PID controlling is shown as[6]

$$\Delta u(k) = K_{\text{p}}\left[e(k) - e(k-1)\right] + K_{\text{i}}e(k) + K_{\text{d}}\left[e(k) - 2e(k-1) + e(k-2)\right]. \quad (1)$$

The temperature error and differential error are the input of the fuzzy illation, and the output of the fuzzy illation is self-tuning parameters K_{d}, K_{i}, K_{p}. Figure 3 shows the input versus output of the fuzzy illation.

When the error e and differential error ec change, the self-tuning rule of parameters K_{d}, K_{i}, K_{p} is put forward. The fields of input varieties and output varieties are decided in the self-tuning fuzzy illation, on the basis of the system operating condition and the self-tuning rule of parameter. The fields of input varieties and output varieties are as follows.

The field of e and ec: $\{-3, -2, -1, 0, 1, 2, 3\}$, the field of K_{d}: $\{-0.3, -0.2, -0.1, 0, 0.1, 0.2, 0.3\}$, the field of K_{i}: $\{-0.06, -0.04, -0.02, 0, 0.02, 0.04, 0.06\}$, the field of K_{p}: $\{-3, -2, -1, 0, 1, 2, 3\}$. The fuzzy subset of the input varieties and output varieties is $\{\text{NB}, \text{NM}, \text{NS}, \text{Z}, \text{PS}, \text{PM}, \text{PB}\}$, where NB is negative large, NM is negative middle, NS is negative small, Z is zero, PS is positive small, PM is positive middle, and PB is positive large.

The membership degree function curves of the input varieties and output varieties are shown as Fig. 4.

The rule tables of the parameter fuzzy control are set up on the basis of the PID parameter self-tuning rule and the membership degree function. The tables of the K_{d}, K_{i}, K_{p} parameters fuzzy control rules are shown in Tables 1–3.

The arithmetic of the self-tuning fuzzy PID control dependent on digital signal processes the DSP chip TMS320C50 to carry out the self-tuning fuzzy PID control program. The flow chart of program is shown in Fig. 5.

When operating temperature of the DPSS blue laser

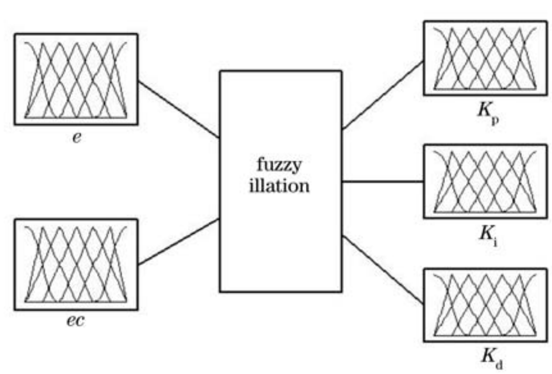

Fig. 3. Progress of fuzzy illation.

at 473 nm is controlled by the self-tuning fuzzy PID temperature controlling system, the curve of the laser operating temperature is shown as Fig. 6.

In Fig. 6, the laser operating temperature is up to equilibrium after 10 minutes. In beginning 10 minutes,

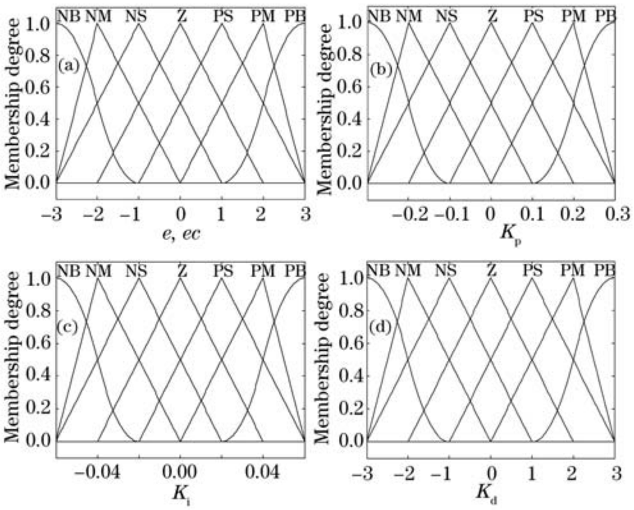

Fig. 4. Degree function of membership versus (a) e and ec, (b) K_p, (c) K_i, and (d) K_d.

Table 1. Fuzzy Rule of K_p

	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PM	PM	PS	Z	Z
NM	PB	PB	PM	PS	PS	Z	NS
NS	PM	PM	PM	PS	Z	NS	NS
Z	PM	PM	PS	Z	NS	NM	NM
PS	PS	PS	Z	NS	NS	NM	NM
PM	PS	Z	NS	NM	NM	NM	NB
PB	Z	Z	NM	NM	NM	NB	NB

Table 2. Fuzzy Rule of K_i

	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NM	NM	NS	Z	Z
NM	NB	NB	NM	NS	NS	Z	Z
NS	NB	NM	NS	NS	Z	PS	PS
Z	NM	NM	NS	Z	PS	PM	PM
PS	NM	NS	Z	PS	PS	PM	PB
PM	Z	Z	PS	PS	PM	PB	PB
PB	Z	Z	PS	PM	PM	PB	PB

Table 3. Fuzzy Rule of K_d

	NB	NM	NS	Z	PS	PM	PB
NB	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NB	NM	NM	NS	Z
NS	Z	NS	NM	NM	NS	NS	Z
Z	Z	NS	NS	NS	NS	NS	Z
PS	Z	Z	Z	Z	Z	Z	Z
PM	PB	NS	PS	PS	PS	PS	PB
PB	PB	PM	PM	PM	PS	PS	PB

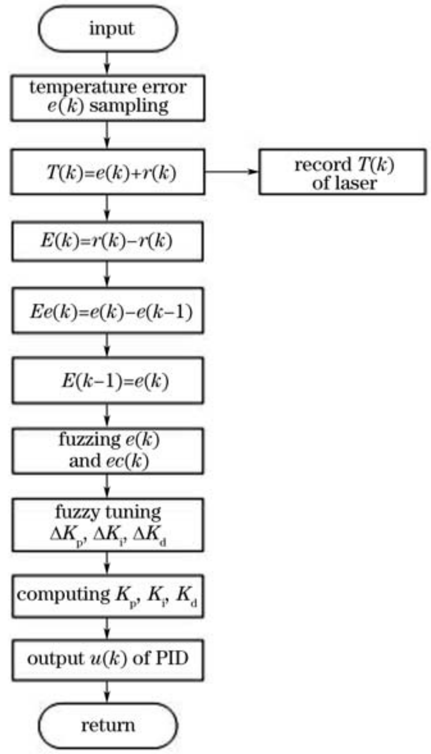

Fig. 5. Flow chart of self-tuning fuzzy PID.

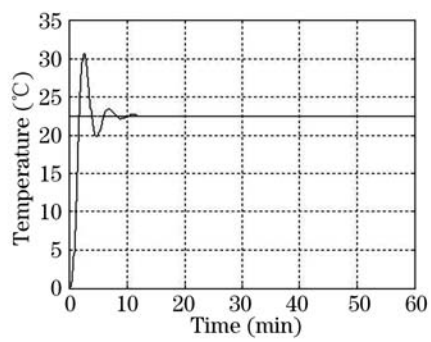

Fig. 6. Temperature of Laser.

the temperature controlling system tunes the PID parameter K_p, K_i, K_d by itself, and then the laser operating temperature is up to the setting temperature fast. After the temperature is up to equilibrium, the tuning of PID parameters is little to keep the laser operating balance temperature. The temperature control precision of system is below ±0.05 °C.

The wavelength stability and changing range of pumped laser diode are below 0.02 nm as shown in Fig. 7, when the laser operating temperature is controlled by the self-tuning fuzzy PID temperature controlling system and the current ripple of the laser supply is below 0.5%.

The power stability curve of the blue laser at 473 nm is shown as Fig. 8, when the current ripple of the laser supply is below 0.5%.

From Fig. 8, we can see that the power stability of the blue laser at 473 nm is better by the self-tuning fuzzy PID temperature controlling system than that by the

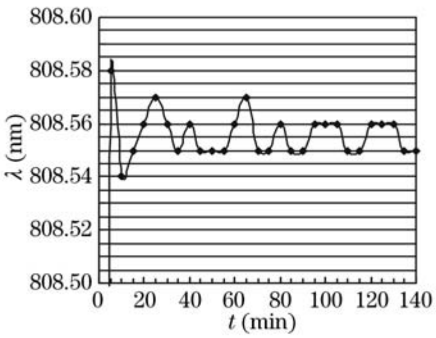

Fig. 7. Stability of pump laser diode wavelength.

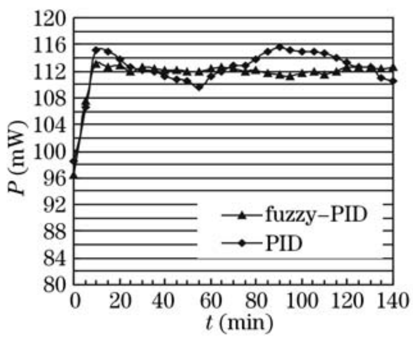

Fig. 8. Stability of laser power at 473 nm.

traditional PID temperature controlling system. The power stability is

$$\delta = \pm \frac{P_{\max} - P_{\min}}{P_{\max} + P_{\min}} \times 100\%. \quad (2)$$

The calculated result indicates that the power stability of laser at 473 nm is ±0.85% to be below ±1% by adopting self-tuning fuzzy PID temperature controlling system, but the power stability of laser at 473 nm is ±2.62% by adopting tradition PID temperature controlling system.

This paper proposed a self-tuning fuzzy temperature control system for the DPSS blue laser at 473 nm. This self-tuning fuzzy temperature control system has good dynamic characteristic and static characteristic, and the system has shorter adjusting time and faster response. The test result indicates that the temperature control precision of system is up to ±0.05 °C, the change range of the pump laser diode wavelength is below 0.02 nm, and the power stability of the laser at 473 nm is below ±1%.

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