Design of High-power Diode Laser Driver under High-temperature Environment

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***Abstract*—Diode laser driver’ s performance directly affects the output stability and life of laser device. A design method of 100W high power fiber coupled diode laser module driver is described under 40℃ high-temperature environment in this paper, and its main contents include: constant-current source design, TEC double direction temperature controller, corresponding MCU controller and protection circuit design . The diode laser driver achieves the following functions: output current can be continuously adjusted from 0-45A; Current control accuracy is better than 2%; Range of temperature control is +15℃-+35℃; and temperature control precision is 0.5℃.**

Keywords- High-power diode laser; constant-current source; TEC temperature controller; MCU controller

I. INTRODUCTION

The diode laser is also known as laser diode（LD）.In recent years along with the continuous development of diode laser technology, the application range of diode laser has become more and more widely. As diode laser has the advantage of small volume, light weight, high electro-optical conversion efficiency and long life, it is widely used both in civil areas, such as material processing, laser marking, laser printing, laser scanning, laser ranging, laser storage, laser display, laser lighting and laser medical applications; and in military fields, such as laser targeting, laser guidance, laser night vision, laser weapons and other military fields. In addition to the direct usage, it can also be as the pumping source of Diode Pump Solid State Laser（DPSSL）and Fiber laser.

Studies show that about 50% diode laser failures are caused by the driver, and about 25% by itself, and 25% by improper usage. So diode laser driver is an important part of system. Its performance directly affects electro-optical conversion efficiency, laser output stability and laser life. Design of high power diode laser driver is described in this paper under high temperature environment, and its main content includes constant-current source, double direction temperature controller, MCU controller and protection circuits etc.

II. SYSTEM CONFIGURATION

High power diode laser driver system adopts modular design, and its advantage includes that a module has a problem does not affect other modules, and at same time it is helpful for system maintenance and debugging. The driver system is mainly composed of a constant-current source module, a TEC double direction temperature controller, a MCU controller. The system is particularly suitable for driving DILAS 100W high power fiber coupled module（M1F4S22-795.3-90C-IS9.2MP）。The driver’ s system block diagram is shown in Figure 1.

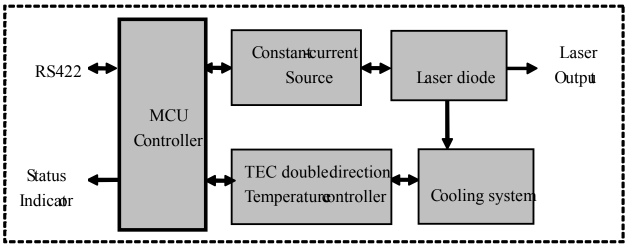


Figure 1. Driver system block diagram

Constant-current source: Driving LD module, it controls the output laser power by adjusting the drive current.

TEC double direction temperature controller: it makes LD to work at a given temperature.

MCU controller: it controls LD how to work, outputs the given current and the given temperature, detects the actual drive current and the actual LD temperature, and itself is controlled by host computer through RS422 serial communication.

Cooling system: it mainly includes TEC, a heat sink and fans, which removes the heat by LD and TEC, and makes LD to work at a given constant temperature.

RS422 serial communication interface: it communicates with the host computer, receiving the commands of the host computer, and returning the current state of the driver system.

The connections among the constant current source drive circuit board, the TEC double temperature controller circuit board and the MCU controller circuit board are shown in Figure 2.

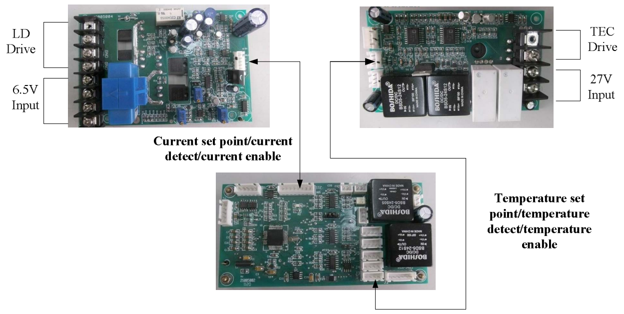


Figure 2. Connections of the constant current source, the temperature controller and the MC controller.

III. CONSTANT CURRENT SOURCE

The DILAS 100W high power fiber coupled laser diode module is chosen as LD, and its main specifications include:

P: 94.6W/43A; Threshold: 6.2A; Slope: 2.84W/A; Overall efficiency: 42.4%; UF: 5.18V; Temperature: 24.5 ℃ ; Wavelength (cent.): 793.7nm.

The optical output power-drive current-forward voltage (PIV) characteristic of the LD module is shown in Figure 3. The Functional block diagram of the constant current source is shown in Figure 4..

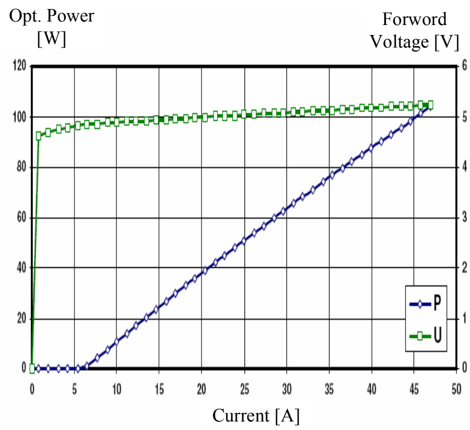
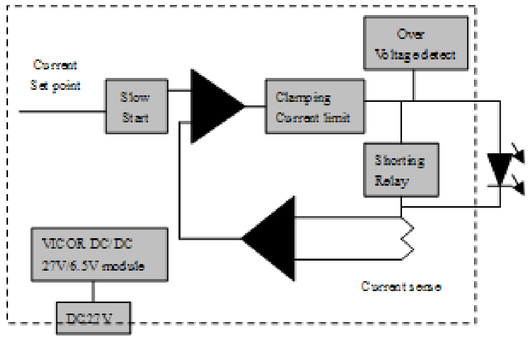


Figure 3. Optical output power and voltage vs.drive current characteristic.

The constant current source should be designed not only to drive the LD, but also to protect the LD. This section introduces how to drive the laser diode, and the protection of the laser diode is introduced in Section 6.

Since a laser diode is inherently a current device, a current source is needed to drive laser diodes. The maximum output current of the constant current source is limited to 45A. High power MOTFETs are used as the current adjusting device. The constant current source stabilizes output current by the current closed loop negative feedback, and its main composition includes DC/DC voltage converter, input circuits for a given current, error amplifier circuits, current sense , current adjusting output circuits and protection circuits.



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The VICOR DC/DC voltage conversion module is chosen for 27V total input power supply. The module outputs 6.5V regulatory voltage and its maximum power output is up to 300W with small voltage, high efficiency and long life.

The adjusting current devices use high power MOSFETs, and four high power MOSFETs are connected in parallel to extend the output current become the output current is high. The output current is adjusted by the VGS drive voltage. The deep closed loop negative feedback is realized with a high-speed and high-stability operational amplifier to complete adjusting the output current. To protect against the turning on transients, the soft start circuit is designed with start-up time longer than 100ms.

Since the sampling is high, if the traditional way of resistance is used to detect current, the heat dissipation problem will have to be considered, and this certainly increases the complexity of circuit. If Hall current sensor is used to detect current, the heat dissipation problem is by-passed for its small heating. Furthermore its output signal is isolated from the circuit of detecting current. Therefore Hall current sensor is much more suitable for the driver system to detect the high current.

IV. DOUBLE DIRECTION TEMPERATURE CONTROLLER

The laser output wavelength of the LD is related to its temperature, and the laser wavelength changes with temperature. So the LD must work at the steady temperature in order to output steady laser wavelength.

The design of the TEC thermoelectric temperature control system mainly includes thermal load analysis, TEC selection, temperature sensor selection, temperature controller design, heat sink design, fan selection, air duct design and proper mounting.

The operating environment temperature of system is at -20 ℃-+40℃, and the normal operating temperature of the LD is +24.5℃. So the temperature should both heat and cool the LD.

The photoelectric conversion efficiency of the LD module is 42%, that is to say the 58% of electric energy changes to heat. When 100W maximum laser needs to be output, the heat of the LD PMAX can be calculated as:

$$P_{MAX} = 100W / (42\%) * 58\% = 138W$$

TEC pumping heat includes not only the LD itself generating heat PACTIVE, but also the absorbing heat PPASSIVE from the environment. PPASSIVE includes conduction heat PCOND, radiation heat PRAD and convection heat PCONV. By the heat shielding box to the LD, it can effectively reduce the LD module absorbing heat with convection and radiation from the working environment. In most applications, the conduction heat loss from sensor connections and cooling plate mounting is negligible, and the heat pumped from the TEC's cold surface can be calculated as:

$$P_{PUMP} = P_{ACTIVE} + P_{PASSIVE} = P_{ACTIVE} + P_{COND} + P_{CONV} + P_{RAD}$$

The main heat dissipation of the LD module is that the module transfers heat to the cooling plate by conduction. Based on the Peltier effect, the TECs pump the heat from the cooling plate to the cold surface of the TEC, that is to say to the heat sink. The heat sink absorbs the heat pumped from the TEC cold surface and the3heat generated by the TEC itself, and then the heat sink dissipates the heat to the ambient environment. The TEC thermoelectric temperature control principle diagram is shown in figure5.

When the maximum ambient temperature is 40℃, the temperature of the LD module is 24.5℃, and the maximum temperature rise of the heat sink is 15℃, then the temperature difference between the hot and cold surface can be calculated as:

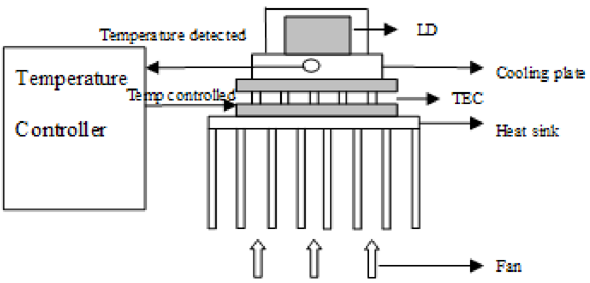

Figure 5. TEC thermoelectric temperature control principle diagram

$$T_{\Delta} = T_H - T_C = (40+15) - 24.5 = 30.5°C$$

Considering the high power needed to drive the TECs, the temperature controller drives the TECs by PWM. In order to decrease the heat generated by the high power MOSFET itself, the temperature controller operates with 100Hz. The negative temperature coefficient (NTC) 10k thermistor is chosen as the temperature sensor for its high sensitivity, small volume and low cost.

V. MCU CONTROLLER

The MCU controller is the core of driver system, and its principle diagram is shown in Figure 6. MCU IC chooses the ADUC842 of the USA AD company. ADUC842 is an 8052 core, which offers 8 ADCs, 2 DACs, a serial port and a I2C. MCU communicates serially with the host computer by RS422 interface. The DAC7574 is a low power, quad-channel, 12 bit buffered voltage output DAC, communicating with MCU controller by a I2C interface, and extending the MCU controller's number of the DA channel. The 5V reference voltage source is used as on-chip reference. MCU controller detects the LD internal temperature by the 200μA constant current source.

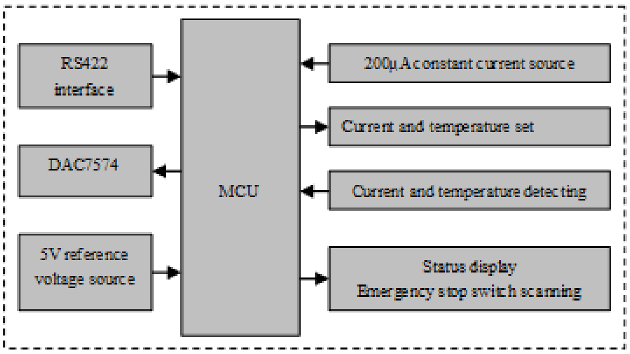

Figure 6. Principle diagram of MCU controller.

The controller software uses modular design by C51 language, and mainly includes the main program and serial port interrupt subroutines。 The function of the main program includes initialization, soft starting, soft close, scanning the emergency stop switch, detecting actual LD current, detecting actual LD temperature, receiving commands of host computer and feeding back system state. The whole program executes each function by scanning and interrupt mode, and forms an organic whole. The work flow chart of main program is shown in Figure 7.

VI. PROTECTION OF LD

The LD module is one of the system core devices, and its price is very high. In order to avoid time-consuming and pecuniary loss, the LD needs to be adopted to be equipped with the perfect protection measures. Main reasons of causing LD failures include surge current, over current, reverse voltage, over heat and electrostatic discharge (ESD).

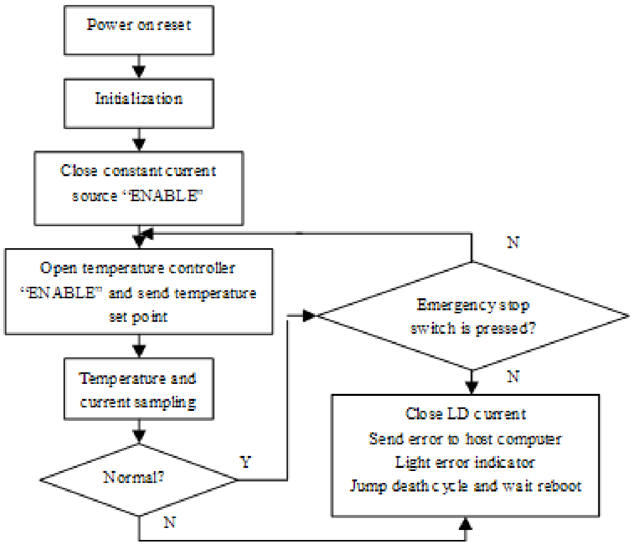

Figure 7. The main work flow chart of main program

Since LD is a kind of junction device, surge brings to it instantaneously over voltage and destroys PN junction. The laser power caused by forward over current under instantaneous over voltage can destroy the cleavage plane, and this current above maximum allowable current also destroys the cleavage plane even in a few nanoseconds time. Main protection measures include soft start or soft close, the RC integral circuit in the LD current set-point outputs the current set point signal by slow rising or descending way; at the same the MCU controller program also includes soft start and soft close, for example the LD current is dropped gradually to 0 in a small step, when the laser output is closed.

Operation at temperatures above specification will increase threshold and lower slope efficiency of the LD, and at the same time will accelerate device aging and can destroy the device. So over temperature protection measures must be taken. The LD working temperature is 15℃-35℃.If MCU controller detects the LD temperature reaching the upper temperature limit 35℃, then it will stop the laser output and simultaneously give the temperature alarms. Reverse voltage and ESD protection circuit diagram is shown in Figure 8.

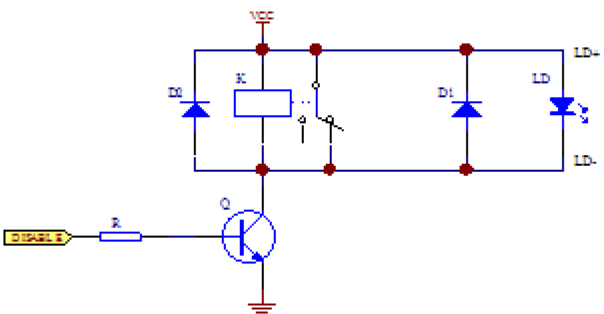

Figure 8. Reverse voltage and ESD protection circuit principle diagram

Negative current transients greater than 25μA and/or reverse voltages >2V can destroy the LD. So adequate protection measures must be provided for reverse-biasing the LD. For this, a protection transient voltage suppressor diode (TVS) D1 is added in parallel to the LD. The TVS D1 immediately conducts when reverse-biasing the LD. Therefore the voltage of the LD is clamped at a very low level, and this is done to avoid the destruction of the LD by reverse-biasing.

LD, like most semiconductor devices, is sensitive against electrostatic discharge. As ESD can cause PN junction to be damaged or destroyed, precautions are taken when LD is used or stored. Main ESD precaution depends on a group of normally closed contact of the relay K in parallel to the two ends of the LD in Fig.8. The relay K will open first when the LD starts to work, and given driving current it can output to the LD; the relay K will keep to close , when in a short-circuit state causing the LD will not work.

VII. EXPERIMENTAL RESULTS AND CONCLUSION

The experimental test results prove that the driver system can work normally under 40℃ high-temperature environment. The temperature controller can control LD temperature to 24.5 ℃ while LD outputs 100W maximum laser power, and can achieve temperature control accuracy of 0.5℃ as well as temperature control time of less than 3min. Drive current can be adjusted in the range of 0-45A continually, and its accuracy is better than 2%.

As the driver system adopts modular design, it brings up make the system's simple layout simple, convenient installation and debugging. The constant-current source drive circuit uses VICOR DC/DC power module and high power MOSFET. This simplifies the drive circuit, effectively suppresses the input power surge, and also protects LD from interfering with external input power supply. By the bidirectional temperature driver of TEC by PWM, driving efficiency is improved and the heat of high power MOSFET is reduced. The system has been applied to pumping the source of DPSSL, and works well through nearly six months of usage. This shows that the system design is reasonable, stable and reliable.

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