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Theoretical Analysis and Experimental Research on Constant Current Source of High Stability Semiconductor Laser

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To carry out theoretical analysis of the constant current source of the high stability semiconductor laser, and to perform in-depth experiments and research on this basis. It used certain technical means, and the stability and safety of the laser's power supply were tested and studied based on theoretical analysis of the constant current source of the high-stability conductor laser. According to the experimental results, it was proved that the development of high stability laser power supply was of great significance to the stability and safety of the laser power supply. In improving the stability and safety of semiconductor laser constant current sources, the application of high stability driving power that meets international standards has significantly improved the stability of output power and extended the use time. Therefore, it has certain value of application and promotion.

1. Introduction

Driven by social economy, the application range of semiconductor lasers is continuously expanding, and more and more people begin to pay attention to the research and development of semiconductor laser voltages. Under this background, the traditional semiconductor laser has a single function, which fails to fully meet the current social and economic development requirements of China, and its stability is also a key content of current scientific research. At this stage, the semiconductor lasers developed by our country are still not mature enough. Most of the semiconductor lasers rely on imported power supplies during their working process, and due to the high cost of imported power supplies, their operating costs are correspondingly increased, which is very unfavorable for the development of semiconductor lasers in China. To effectively control the cost and improve the applicability of LD in portable applications, designing a LD drive power suitable for small and medium power levels has become the core content of the entire industry. With the deepening of research, the function of the laser voltage can not only improve the stability of the driving semiconductor laser, but also provide important protection technology for its safe operation. In addition, the information shared with the control system can also be realized, and the instructions of the feedback control system can be executed in time. Therefore, in the actual application, the intelligent level of the laser power supply has been greatly improved. Therefore, to further promote the development of semiconductor lasers in China, we must not only increase research efforts on its key technologies, but also focus on a number of related theories for comprehensive analysis, thus providing important reference for improving its stability and safety.

2. Literature review

With the increasingly mature power electronics technology, many new power electronic devices and technologies have been applied to the research and development of high stability constant current sources. At present, constant current sources are widely used in laser equipment, electrochemistry, semiconductor measurement, and sensor technology and other industrial applications. The semiconductor laser power supply load, that is, the semiconductor laser, has a smaller size, a lighter weight, a higher conversion efficiency, and can be directly modulated. However, the LD's ability to resist power surges is very poor. Subtle fluctuating currents may cause extreme changes in the output power of the LDs, and may even cause permanent

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damage to the pump source, leading to stringent requirements on the drive performance of the power supply. The development trend of high stability constant current source is high stability, high power density, good reliability, small size, high operating frequency, high efficiency, and large current level. In addition, there are more stringent specifications for the constant current source's external dimensions and layout, in order to increase the overall standard of the constant current source and meet the larger market demand. Due to the limitations of various conditions, there has been a considerable gap between domestic and overseas research on high reliability, high stability pump laser drive power (Rösch et al., 2015).

For the research and development of laser power, foreign countries have already obtained a lot of outstanding research results. In some developed countries such as Germany, Italy, the United Kingdom, Japan, the semiconductor laser technology research is obviously higher than the domestic research level. The research and development of semiconductor laser drive power abroad has mastered more mature theoretical technologies, such as Japan's authoritative magazine "Optical Review". With the publication of a large number of high-level papers on semiconductor lasers, it has become the vane of semiconductor laser cutting-edge technology (Redding et al., 2015).

Compared with foreign countries, the research on LD started late in China, and the research and development of the laser constant current source also greatly inherited the mature research theory of the developed countries. Nevertheless, remarkable achievements have been made in the research of laser power supply by domestic researchers. Through data review, the current domestic research on semiconductor laser power mainly focuses on output current stability and reliability (Li et al., 2015). On the one hand, stability is the basis for ensuring the normal operation of the laser power supply; on the other hand, the reliability of the laser power supply is very important. For example, the control of the laser temperature is indispensable for the stable operation of the laser (Li et al., 2014). By combining these two major research directions, China has also developed a number of laser constant current sources that can be used in a wide range of applications. At present, the research and design of semiconductor laser drive power are mainly from the following two aspects.

The first is to build a pure analog circuit for the semiconductor laser power supply. The analog circuit is used to realize the closed-loop control of the constant current source current. The design idea is mainly to use the detection circuit and soft switch to achieve the adjustment of the output current size. If the detection current is less than the pre-set reference current value, the switch is turned on so that the output current increases. When the current value is greater than the pre-set reference current value, the switch turns off and the output current decreases. Therefore, the output current remains in a dynamic balance during this process, and the output current is controlled within the allowable range (Wang et al., 2017).

The second is to abandon the analog modulation technology load circuit. Digital modulation technology is used to achieve digital adjustment of the laser drive power output current. Xue pointed out that its main control ideas are as follows. The sampling circuit is used to sample the output current and voltage, and the data is A/D converted. The digital data is transmitted to the controller and a series of logic processing and calculations are performed in the controller to achieve programmatic control of the output current (Xue et al., 2018). The digital control circuit can not only simplify the previous complex analog circuit structure, increase the integration degree and overall efficiency of the driving power supply, but also can increase the control flexibility, facilitate debugging, and save debugging costs. It provides powerful conditions for the expansion of the function of semiconductor lasers. With the maturation of microcontrollers, FPGAs, DSPs and other control chips, more and more laser power supplies are designed using digital modulation technology. However, most of them are limited to partial theoretical research or the realization of simple control. There are no practical studies on the core parameters such as low ripple coefficient, perfect protection function, and anti-jamming required by semiconductor lasers. The use of software algorithms to implement digital methods such as suppression of output current harmonics and other anti-jamming methods is not mature. It is difficult to make a high-precision semiconductor laser power source in a good semiconductor laser. As a result, the highly stable laser power supply market is still largely occupied by similar foreign products (Fan et al., 2014).

Domestically, a series of in-depth studies have also been conducted on the control of the semiconductor laser pumping temperature. The temperature has a direct influence on the stability of the output light of the semiconductor laser. By controlling the operating temperature of the semiconductor laser, its output power is controlled. This method has also been studied by more and more researchers. Xiang, a research unit of the Chinese Academy of Sciences' affiliated Shanghai Institute of Optics and Mechanics, has developed a method that can realize the photothermal modulation of a semiconductor laser. By controlling the modulation of the junction temperature of the semiconductor, this method can also achieve precise control of its output optical power and output laser frequency (Xiang et al., 2014).

In summary, the modulation theory and technology of semiconductor laser optical signals abroad have been quite mature. There are many systematic studies. Although China's research in this area has achieved certain results, the technical theory is not too mature. Therefore, it has long way to go to develop a highly stable

semiconductor driving power supply. In connection with this situation, a design method for a dual-channel constant current source of a semiconductor laser is given for driving a fiber laser with a power level of 10W and 30W. Due to the high price of similar foreign products, a laser constant current source with dual output, stable performance, complete protection measures and low cost has certain practical significance and research value. Therefore, technologies such as digital signal processors, constant current sources, LED displays, and rotary encoder switching are applied. A method for switching constant current sources of small and medium power semiconductor lasers is proposed.

3. Methods

This project aims to design a constant current source driving power supply and a digital signal processing system for two fiber-pumped lasers that can meet their normal operations. For the development of laser power supplies, most traditionally used analog modulation technology, such a circuit structure is relatively simple, high precision. However, the adjustment mode of the laser power supply of the analog control mode can only be manually adjusted, and can not be used for digital control or remote control by a computer, hence the laser power supply designed by this method has a low level of automation in industrial applications, which greatly limits the the application scope of semiconductor laser power supplies. This project uses the two semiconductor lasers K98S02F-10.00WR and KA3F-30.00WR as target loads, and designs a dual-output laser driving power source that can manually adjust the output current value of the upper computer software. The current stability is high and the output optical power of the semiconductor laser can be modulated. By consulting relevant data on semiconductor lasers and grasping their work requirements for laser power supplies, in this paper, it considers the limitation of the power supply size in the practical application field of semiconductor laser power supply, and designs a dual-circuit semiconductor laser driving power source with small size, high integration and low ripple coefficient. It designs the main control circuit of constant current source, auxiliary power supply circuit, protection circuit, signal processing module based on DSP, display and regulation circuit, etc. The method of suppressing the EMC of the entire integrated circuit board is analyzed, and finally the driving power is measured in a practical application environment, and a large amount of data and waveforms are obtained. Commonly used circuit topologies are shown in Figure. 1 and Figure. 2, and their principles use a fully-controlled power switch tube to adjust the output current through current feedback in its amplification region.

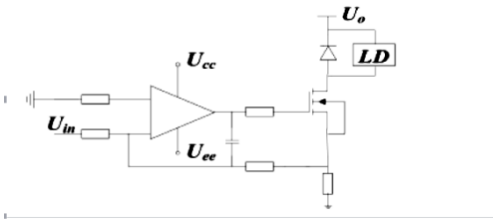

Figure 1: Linear constant current source topology.

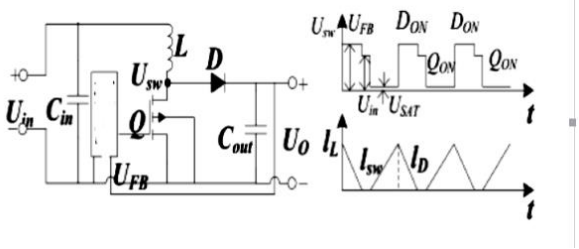

Figure 2: Boost the Boost circuit.

4. Result and discussion

4.1 Characteristic analysis of semiconductor lasers

The PN junction of a small semiconductor laser is composed of a direct bandgap semiconductor material. The PN junction is mainly activated by three types of excitation modes: an electrical injection type, a high-energy

electron beam excitation type, and an optical pump type. Among them, the electro-injection excitation method is one of the most widely used LDs. The principle is to apply a forward voltage to the two ends of the semiconductor laser PN junction, which is equivalent to a forward biased diode being excited by a positive voltage, making stimulated emission occur in the PN junction plane region. To make the semiconductor laser as a coherent radiation source emit laser light, the following three conditions are required: (1) The carrier distribution in the reversed active region is established. (2) It is necessary to obtain a coherent stimulated radiation, so that the stimulated radiation must receive multiple feedbacks to form a laser oscillation inside the optical resonator. (3) The gain of the laser medium should be large enough to facilitate the formation of stable oscillation. Under this premise, the loss of light and the output loss from the cavity surface can be compensated, and the cavity light field can be gradually increased. Injecting a sufficiently large current into the laser is a necessary condition to achieve the above process, because a large injection current can cause a large number of particles to reverse, and the inversion particle number is proportional to the gain, when the injection current reaches a certain threshold, the output laser with a certain wavelength will resonate within the cavity and be amplified to obtain a continuous output laser.

4.2 LD volt-ampere characteristic analysis

This subject is mainly for research and design of low-ripple, high-reliability semiconductor laser power supplies. To design a more applicable laser power supply, it is necessary to focus on the volt-ampere characteristics of the semiconductor laser. Semiconductor lasers have a variety of structures, but they all consist of a resonant cavity and a PN junction diode. Therefore, when the semiconductor laser is unstimulated, its volt-ampere characteristic is similar to that of the conventional diode. The equivalent circuit of the semiconductor laser is shown in Figure. 3, where D1 is an ideal diode and ZV1 is an ideal Zener diode.

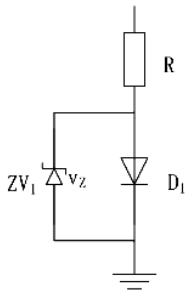

Figure 3: Semiconductor laser equivalent circuit.

4.3 Analysis and comparison of design schemes of traditional laser power supply

The design of the traditional laser power supply topology differs depending on the power level and the output current, but most of them are improved through the existing circuit topology and reasonable peripheral circuits. The topological structure of the common power supply circuit is mainly the two circuit types of linear power supply and switching power supply. Among them, the linear power supply is mainly used in semiconductor lasers with low power, low output current, and low requirement for power supply efficiency. Although this type of power supply can guarantee the stability of the output current, it has low efficiency, large heat loss, and requires a large amount of heat dissipation equipment. Generally, the work efficiency is about 50%. The topology of the switching power supply is divided into the Boost circuit, the BUCK circuit, the Buck-Boost circuit, the fly back circuit, and the single-transistor fly back circuit according to different circuit functions and circuit devices.

Through the above analysis of the traditional laser power supply topology, it can be seen that the linear power supply has been widely and maturely applied, but the traditional linear constant current source will generate more heat and lower efficiency, generally only up to 35%-60%. For components such as semiconductor lasers that are sensitive to temperature, in order to reduce the temperature and avoid overheating damage of the semiconductor laser, bulky heat sinks are required, so the linear power supply is usually bulky. Therefore, the linear power supply is mainly used in low-power semiconductor lasers. Its output power generally does not exceed 3W, and its operating voltage is less than 2V. It requires high stability of the drive current, and the operating current is generally continuously adjustable from 0A to 3A. Therefore, the application of linear laser power supply is very limited.

In contrast, since the power switching device of the switching power supply operates in a switching state, the switching power supply has a high efficiency and can reach 70% to 95%. The high efficiency of the switching power supply stems from the small power consumption of the switch tube and the low heat generation, which greatly reduces the volume of the heat dissipation device, so that the internal temperature rise of the circuit components is relatively low, thus improving the stability and reliability of the entire switching circuit. In addition, most of the switching circuits work in the high-frequency switching state of the super audio, and the circuit operates at a low noise level. In general, there needs to be more linear power supply in terms of protection measures of the switching power supply. When the circuit fails, it can cut off the power failure in time to ensure reliable power supply operation.

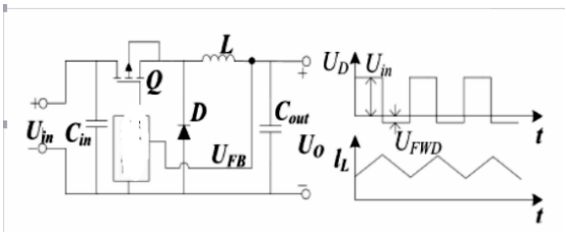

Figure 4: BUCK the BUCK circuit.

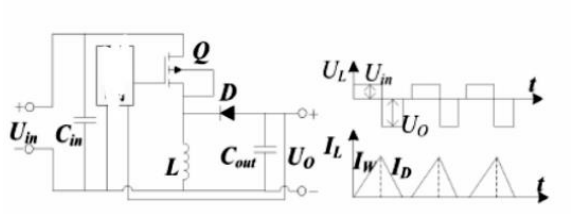

Figure 5: The Boost - Buck circuit

4.4 System test equipment

Laser power test equipment mainly include: laser; power laser BMU25A-915 seed-source laser K915F02RN; DC power supply: DH1718E-6 dual DC power supply Beijing Dahua DC 0-40V; wave device: DSO-X 2024A; Wave device: DSO-X 2024A; Optical Power Meter: 1918R; Load: 9 series diodes IXYS DSEI30-06A; DC power supply: PWR1600L DC0-80V100A1600W; Oscilloscope: TEKTRONIX MSO4034; Current probe: TEKtronix TCP312 30ADC; Current converter: TEKtronix TCPA300.

4.5 System test analysis

After repeated testing and debugging, the current can be 0-12A smooth and continuously adjustable, and the current ripple is small. When the current reaches 12A, the peak value of the AC ripple is about 20mA, and the ripple coefficient is only about 0.083%, which is much less than the required 2% current ripple coefficient. The dual-channel constant current source of the laser power supply has a short time from 0A to 12A at the time of the power source start-up, and no spike is turned on, which satisfies the requirement for the laser power to rise to the specified power in a short time. The above tests on laser constant current source drive are mainly test of output characteristics; In addition, a series of tests are conducted on the current stability of the two constant current sources, the power supply efficiency, the soft start time of the constant current source, and the response of the constant current source to the set value of the host computer. Output current stability analysis: Constant current source I The model KA3F-30.00WR semiconductor laser is used as the load, and the constant current source I is set to continue working for 2 hours when the output current is 8A. During this period of time, the output current value is measured every 5 minutes to obtain the output current line graph, as shown in Figure. 6. We can see the average deviation of 8A from Figure.6.

To further verify the stability of the laser power supply, in the same experimental manner, the output current is measured over a wide range of 0A-12A. Through the analysis and calculation of the measured data, the maximum average output current deviation ΔIO is about 8mA; The greater the output current is, the higher the current stability will be; The above condition is determined by the duty ratio of the driving signal of the switch tube. If the duty ratio is too small, the current harmonics will increase, but the overall variation range meets the design requirements. Soft-start time: The output current rises from 0A to 1.5A for 3.8ms, which is of great

significance for semiconductor lasers used for industrial marking; Because if the current rise time is too long, if it exceeds the s level, it will cause the semiconductor laser to emit light too slowly, causing the mark to lose step; Therefore, the current rise time should be made as short as possible while avoiding the spike of the current start-up. Experiments show that the current source rise time of the constant current source is about 10ms at 12A, which is in line with the industrial application of the laser.

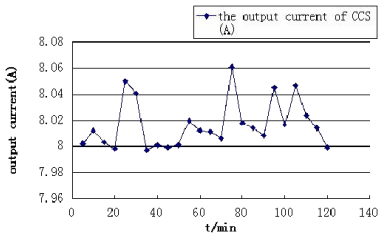

Figure 6: Output current stability polyline chart.

5. Conclusion

Based on the current development of semiconductor lasers in our country, in this paper, it deeply studies the stability of the constant current source of semiconductor lasers, and uses its research results as the theoretical basis for designing constant current source systems. In the actual design of the constant current source, by adding a PWM controller, the difficulty of debugging is increased, and the filter circuit is designed based on the stability of the output current and the suppression of higher harmonics, and the rationality of this method is still in need of further research and analysis. The application of the above method in the semiconductor laser power supply not only limits the application of control theory, but also affects the sustainable development of laser power supply from another perspective. Therefore, to improve its stability, the main research direction should be to fully use the digital signal processor's computing function. For some harmonics that are relatively easy to generate and have a relatively large proportion, cash algorithms can be used to suppress them in advance, thereby simplifying the post filter design, reducing the scope of harmonic pollution, and greatly improving the digital control the of laser power and stability.

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