Research on water cooling technique for frequency stabilized He-Ne laser

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Abstract. An enhanced stabilized He-Ne laser with water cooling structure is proposed in this paper. The water cooling structure establishes a constant temperature working environment for the laser tube, so it can decrease the effect of temperature variation and increase the frequency stabilities of the laser. The structure can also decrease the thermal pollution released to working environment. In addition, the structure provides a lower working temperature for the laser, so the laser’s preheating time will be decreased and service life will be increased. In order to select a more appropriate water cooling structure model, double helix structure model are analyzed in this paper. To get the best effect of heat dissipation, the radiating effect and uniformity of temperature field of double helix water cooling structure are investigated under different flow velocity. The experimental result shows that the frequency stability of the water cooling stabilized He-Ne laser is less than 5.3 × 10⁻¹⁰.

1. Introduction

Nowadays, the majority of commercially stabilized He-Ne laser are traditional thermal stabilized He-Ne laser, which adjust the temperature of laser tube through heater in order to actively control the length of the laser tube. The laser can only be cooled through the air and has large thermal resistance. The variation of the environment temperature brings unfavorable influence on the laser. These two reasons decrease the relative frequency stabilities of the laser. Meanwhile the laser causes the thermal pollution released to the working environment, which will affect the accuracy and stability of other instruments. In addition, the laser’s higher working temperature can’t only change the original physical property but also decrease the service life of the laser tube.

Water cooling technology is widely used in many industry field [1,2]. It can increase the system’s heat dissipation rate effectively. Manske and Jager applied the water cooling technology in the stabilized He-Ne laser successfully [3]. Zygo Corporation has developed the water cooling laser head Zygo 7714 and 7722/7724 [4].

In this paper, a water cooling stabilized He-Ne laser is presented. The water cooling structure establishes a constant temperature working environment for the laser tube, so it can decrease the effect of temperature variation and provide a lower working temperature for the laser.

2. The power balance method and the water cooling principle

The two longitudinal modes with different frequencies are located over the He-Ne laser’s gain profile. The two modes are both linearly polarized and orthogonal to each other as a result of mode-competition. The magnitude of each mode is eventually confined by the gain profile. The two modes’ frequency $f_1$, $f_2$, and power change with the length of the laser tube, and the length is linear with the temperature. The laser is stabilized by using the power balance technique. Once the laser is
stabilized, the power difference of the two modes is zero and the two modes are located symmetrically over the center frequency $f_0$, as shown in Fig. 1.

![Frequency Spacing vs Gain Curve](image)

Fig. 1 Two longitudinal modes within the laser gain curve

The schematic diagram of the control system used in this research is shown in Fig. 2. A commercial internal mirror He-Ne laser with two longitudinal modes is used in this system. The cavity length of the laser tube is about 155 mm, which corresponds to a mode spacing of about 1 GHz. A thin-film heater is wrapped around the laser tube to thermally adjust the laser cavity length. A temperature sensor is mounted on the laser tube to measure the initial temperature for the frequency stabilization. The laser beam from the laser tube is divided into two orthogonal polarized beams by a polarization beam splitter (PBS). The beams are detected by two photodiodes (PD1, PD2) and converted to current signals respectively. The current signals from the photodiodes are amplified and converted to digital signals by a 16 bit analog-to-digital converter (A/D). The two digital signals are compared in the microprocessor (MCU) to obtain the power difference of the two modes. The power difference is amplified, accumulated and differentiated (PID) to provide a control signal. The control signal is converted to analog signal by a digital to analog converter (D/A) and amplified by a power amplifier (P-AMP). The P-AMP output is applied to the thin-film heater to thermally control the cavity length for the laser frequency stabilization.

![Schematic Diagram of Frequency Stabilization](image)

Fig. 2 The schematic diagram of frequency stabilization

The schematic diagram of the water cooling system used in this research is shown in Fig. 3. Thermostatic water bath can keep the temperature of the water constant by its own

![Schematic Diagram of Water-Cooling System](image)

Fig. 3 The schematic diagram of water-cooling system
independent temperature control system. Two temperature sensors are installed in the inlet and outlet of the water cooling stabilized laser, in order to measure the temperature of the water flow and calculate the instantaneous temperature difference. The water pump can control the flux of the water. The water flow into the inlet and out of the outlet, then pass through flow meter, water pump, throttle and get back to the water bath. All these components form a water circulatory system.

3. The design and simulation of the water cooling structure

Several research have proposed a water cooling structure that twines metal pipelines around a metal tube. Inspired by it, this article proposed a new water cooling structure that machines a metal tube with milled helix grooves. The new structure can make the contact area of the two parts larger and guarantee the uniform contact between the water and the tube, so the radiating effect will be increased. But the one helix groove will lead to non-uniformity of axial temperature field because the water temperature is different between the inlet and outlet. The improvement structure replaces the one helix groove with the double helix groove. In the double helix groove, the two helix grooves have inverse flow directions, so the uniformity of axial temperature field will be increased by the average effect of the water temperature in the two grooves.

After the double helix groove is gotten, the cross section of the groove and the length of the double helix should be confirmed. The form of the cross section has two options: rectangle or half round. The half round form simulates the structure that twines metal pipelines around a metal tube. The rectangle form can increase the contact area and radiating effect, but the water resistance will larger than the half round. The longer the length of the helix is, the contact area and radiating effect is bigger, but the weight of the tube is lower, so the temperature of the tube will be increased. The four designed structure are shown in Fig. 4, Fig. 5, Fig. 6 and Fig. 7.

![Fig. 4 Rectangle 31mm helix](image1)
![Fig. 5 Rectangle 25mm helix](image2)
![Fig. 6 Half round 31mm helix](image3)
![Fig. 7 Half round 25mm helix](image4)

In order to guarantee the radiating effect and the uniformity of axial temperature field of the water cooling structure, the most appropriate form of the cross section and length of the helix are confirmed through the thermodynamics simulation.

Based on the previous studies, to simplify the simulation environment, some fundamental assumptions are presented:

1. The fluid steady flow;
2. The fluid flow without wall slip;
3. Ignoring the radiation heat transfer, only the conductive and convective heat transfer are taken into account.
4. The flow velocity distribution is uniformity in the inlet of the water cooling laser.

The laser’s heat dissipated power is basically rated, so the simulation adopts the steady analysis method. The other simulation parameters are settled as follows: the water temperature in the Thermostatic water bath is 20°C; the quantity of flow is 0.3L/min. The laser tube and the thin-film heater are located in the structure, and between the laser tube and the structure inner wall is the heat-conducting medium, so the laser’s heat dissipated power, 10W, is assumed to be equal to the structure inner wall’s heat dissipated power.

Fig. 8 Simulation of Rectangle 31mm helix
Fig. 9 Simulation of Rectangle 25mm helix
Fig. 10 Simulation of Half round 31mm helix
Fig. 11 Simulation of Half round 25mm helix

In this article, the water cooling structure is designed to build an invariable temperature environment for the laser tube, so the radiating effect and uniformity of temperature field are the key indexes to evaluate the simulation result. The structure inner wall’s temperature data are shown in the temperature distribution cloud picture, as shown in the Fig. 8, Fig. 9, Fig. 10 and Fig. 11.

From the result, the structure with the rectangle form has better radiating effect, and the structure with the longer helix has better radiating effect and uniformity of temperature field. So the design with rectangle form and longer helix is adopted.
After the structure is confirmed, the relationships between the quantity of flow and the radiating effect should be tested. The radiating effect is simulated at different quantity of flow, and the result is shown in Fig. 12 and Fig. 13.

From the result, when the quantity of flow is less than 0.15L/min, the highest temperature and temperature difference of the structure inner wall increases with the quantity acutely. When the quantity is more than 0.15L/min, it’s increase has very little influence on the highest temperature and temperature difference of the structure inner wall. So it is easy to see that higher quantity can’t help increase the radiating effect when the quantity is more than 0.3L/min. Meanwhile, the higher quantity will increase the mechanical vibration to the structure and increase the power of the pump, so new thermal pollution will be introduced. In conclusion, 0.3L/min is set as the working quantity of flow.

Fig. 12 Relationship of Flow quantity and highest temperature
Fig. 13 Relationship of Flow quantity and temperature difference

The tube of the structure is designed, but it needs a sealing device to avoid leakage. This paper presents a sealing sleeve which have inlet and outlet connected to the groove on the tube. The sleeve and tube is interference fit and cemented on both ends. The design drawing and picture of real product are shown in the Fig. 14 and Fig. 15. In the Fig. 15, there is a temperature sensor above the structure to measure the ambient temperature of the laser.

![Fig. 14 The design drawing](image1.png) ![Fig. 15 The picture of real product](image2.png)

4. The test of the water cooling stabilized laser

The water cooling structure decreases the interaction between the environment temperature and the laser. The laser release less thermal pollution to the environment. The traditional thermal stabilized He-Ne laser and the water cooling stabilized He-Ne laser are tested to compare their influence on the environment temperature. The result of the test is shown in the
From the result, during the same working time, the ambient temperature of the water cooling laser and traditional laser increase 0.4 °C and 1 °C respectively. The result shows that the water cooling stabilized He-Ne laser can decrease the thermal pollution released to the environment and the preheat time effectively.

As a reference, an iodine-stabilized laser with frequency uncertainty of $2 \times 10^{-11}$ is used. The frequency of a longitudinal mode is measured by frequency beating it with the reference laser. The beating frequency is measured with a sampling time of 0.5s over a period of 50min, and the frequency variation is less than 250 kHz. The laser frequency stability is shown in Fig. 18. It indicates that the laser frequency stability of the water cooling laser is better than $5.3 \times 10^{-10}$. 

![Fig. 16 water cooling laser’s thermal pollution](image1)

![Fig. 17 traditional laser’s thermal pollution](image2)
5. Conclusion

In summary, a new water cooling structure is designed. Many key index of the structure are confirmed by the thermodynamics simulation. The new cooling structure can decrease the working temperature of the laser tube and increase its service life. Meanwhile, the structure can decrease the laser’s heat dissipated power and thermal pollution released to the environment. Above all, the structure can decrease the influence of environment temperature variation and increase the relative frequency stability of the laser. The experimental results show that the laser frequency stability of the water cooling stabilized He-Ne laser is better than $5.3 \times 10^{-10}$.

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