Stabilization of Laser Power Using a Rubidium Clock

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***Abstract*—Stable laser power is indispensable in current research. Traditional methods for power stabilization often limits the long-term stability of laser power. To address this issue, a novel method is proposed in this paper. Based on the principle of light shift, this method utilizes Rubidium atomic clocks to measure and stabilize the power of a 795 nm laser. By tracing laser power fluctuations back to variations in the output frequency of atomic clocks, significant improvements in laser power stability were achieved. Experimental results demonstrate a significant improvement in laser power stability, decreasing from 6E-3@10000s to 1.8E-5@10000s. This research holds promise for wide application in fields such as atomic interferometers and atomic clocks.**

***Index Terms*—laser power, light shift, Rubidium clock**

I. Introduction

Stable laser power is crucial for the proper functioning of technologies such as atomic interferometers [1], atomic clocks [2], and gravitational wave detection [3]. In atomic interferometers, laser power stability significantly affects experimental results. Atomic interferometers used in gravity measurements require long-term measurement capabilities, which necessitate a stable laser system. In integrated sphere cold atomic clocks, long-term drift in detection light power can cause frequency drift in the clock [4].In rubidium atomic clocks using pulsed laser pumping, laser power fluctuations are the primary factor affecting long-term stability. Optical frequency standards, which use lasers to manipulate atoms and lock the laser frequency to atomic level transitions, offer stability that is 2-3 orders of magnitude higher than traditional microwave clocks. In optical clock systems, multiple lasers of different wavelengths are used, and the fluctuations in laser power impact the frequency stability of these optical frequency standards.

Laser power fluctuations are primarily caused by noise from the pump current, thermal variations within the gain medium, and disturbances from external optical components. Current research efforts aimed at stabilizing these fluctuations typically employ detectors to measure laser power and implement power stabilization techniques [5]–[9]. Conventional approaches to measuring laser power, especially at weak laser power, are more susceptible to environmental noise and intrinsic drift. Consequently, these methods limit the accurate measurement of weak laser power and present challenges in achieving long-term stabilization.

To address these challenges, this paper proposes a novel method to improve the long-term stability of laser power. The method utilizes rubidium atomic clocks to measure and stabilize the power of a 795 nm laser. By utilizing the atomic light frequency shift effect, the fluctuations of laser power are traced to the atomic clock's output frequency, thereby enhancing the stability of the laser power.

II. Experiment setup

The diagram of the power stabilization experimental system is shown in Figure 1. This system includes a laser power measurement section, a power feedback control section, and a laser frequency stabilization section. A 795 nm external-cavity semiconductor laser is used as as the laser source.The laser first passes through an isolator, which prevents reflected light in the optical path from affecting the laser's normal operation. The laser exiting the isolator then passes through a half-wave plate and a polarizing beam splitter (PBS), which splits the laser into two beams.

The reflected beam is used for laser frequency locking. A wavelength meter reads the laser frequency value and compares it with the reference frequency set in the program. The error signal serves as the input for the PID algorithm. The PID output control signal is processed through a data acquisition card, which performs digital-to-analog conversion. This control signal is applied to the laser's piezoelectric transducer(PZT) to stabilize the laser frequency.

The transmitted beam from the PBS is utilized for laser power stabilization. It passes through the acousto-optic modulator(AOM), driven by a signal generator. The first-order diffracted light from the AOM is coupled into the fiber. This laser light is then directed into the atomic clock, where it interacts with the atoms in the atomic cell, producing a light shift effect [10]. The laser power directly affects the output frequency of the atomic clock. A frequency counter reads the changes in the atomic clock's output frequency. The PID feedback mechanism then adjusts the diffraction efficiency of the AOM to control the laser power.

In the experiment, the relationship between the output frequency of the atomic clock and the incident laser was measured based on the principle of light shift effect. Using linear fitting, the changes in the atomic clock's output frequency collected by the frequency counter were converted into power changes. The laser frequency was locked at 794.96810 nm,

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and the laser power incident on the atomic clock through the optical fiber is 28 µW.

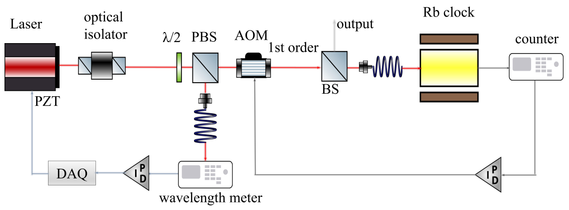

Fig. 1. Schematic diagram of the experimental setup. HWP: half wave plate, PBS: polarization splitter, BS: beam splitter. AOM:acousto-optic modulator

III. RESULTS

In the experiment, to prevent laser frequency fluctuations from affecting the experimental results, the laser frequency was first locked using a wavelength meter. the laser power was initially measured under free-running conditions by directing the laser into the atomic clock and using a frequency counter to collect the output frequency of the atomic clock. Using the fitting coefficient, the power value was inferred from the frequency value. The stability of the laser power measured in this setup is shown in Figure 2. Subsequently, the system was tested in a closed-loop condition where the laser power was stabilized. The stability of the laser power under these conditions is shown in Figure 3.

The comparison reveals that the laser power stability was 6E-3@10000s under free-running conditions. After implementing laser power feedback control, the stability improved to 1.8E-5@10000s, enhancing long-term power stability by two orders of magnitude. These results demonstrate the significant improvement in laser power stability achieved through the feedback control mechanism. Due to influenced by temperature variations in the laboratory, the Allan deviation over 1000 seconds degrades after power stabilization.

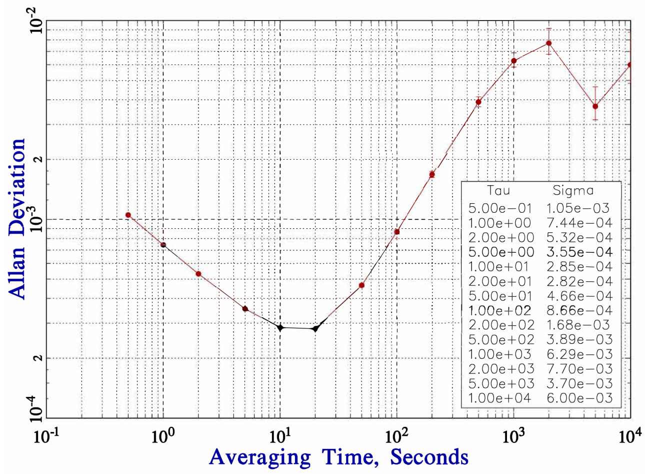

Fig. 2. The stability of laser power at free running condition.

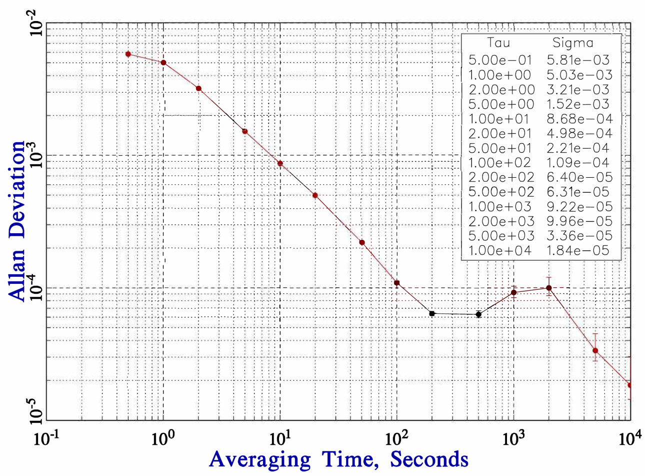

Fig. 3. The stability of laser power at locked condition.

IV. CONCLUSION

In this paper, a novel method for measuring and stabilizing laser power based on the atomic light frequency shift effect is proposed. A rubidium atomic clock was used to measure changes in laser power. The variation in laser power were traced to the output frequency of the atomic clock, achieving further stabilization of the laser power. The experimental results show a significant improvement in laser power stability. The stability improved from 6E-3@10000s to 1.8E-5@10000s, representing a two orders of magnitude enhancement in long-term stability. Further improvement in power stability could be achieved with enhanced control of laboratory temperature. The proposed method provides a robust and innovative solution for maintaining laser power stability, which is essential for precision measurement applications . By achieving higher laser power stability, the accuracy and reliability of these precision instruments can be significantly improved. Future research will focus on optimizing the control mechanisms and exploring advanced techniques to mitigate the influences of laboratory temperature influences. These efforts aim to enhance the stability of laser power. In summary, this study demonstrates the feasibility and effectiveness of using a rubidium atomic clock to stabilize laser power through the atomic light frequency shift effect. The results indicate a promising direction for improving the stability and performance of various high-precision measurement systems.

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