Compact optical frequency standard based on ^{87}Rb D1 line

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***Abstract*—In this paper, we investigate the modulation transfer spectroscopy (MTS) of ^{87}Rb D1 line under noncycling transitions. The line shape of the MTS signal was determined, and the system's long-term stability was measured. Results showed that the system consistently performed at a short-term and long-term stability of E-14 level estimated from the residual error signal, indicating high performance of the compact optical frequency standard.**

I. Introduction

Modulation transfer spectroscopy (MTS) is a heterodyne spectroscopy technique featuring external modulation frequency stabilization [1]–[3]. Compared to other spectral frequency stabilization methods, the MTS signal has a high signal-to-noise ratio and sensitivity because heterodyne detection can effectively eliminate noise fluctuation independent of laser frequency [4]. Consequently, MTS can be used to build compact optical frequency standard [5]. Laser stabilized to ^{87}Rb D1 line has widely use in cold atom experiments [6], [7], and its stability can be improved by use of MTS. However, experiments based on noncycling transition lines are rarely reported because the MTS signal is significantly suppressed for the presence of the optical pumping [8], [9]. To the best of our knowledge, stability of MTS stabilized laser to ^{87}Rb D1 line has not been reported.

In this paper, we investigate a compact optical frequency standard based on ^{87}Rb D1 line by utilizing of the MTS for the first time. The system has an outstanding instability of E-14 level for both short and long-term.

II. Experimental Procedure

The experimental setup is shown in Fig.1, where the red lines represent the optical path and the black lines represent the electrical circuit. We can see that the beam emitted by the 795 nm laser passes through an isolator to prevent optical feedback. A half-wave plate ($\lambda/2$) and a polarizing beam splitter (PBS) divide the laser, where one of the beams transmits as the output beam and the other beam enters the MTS system for frequency

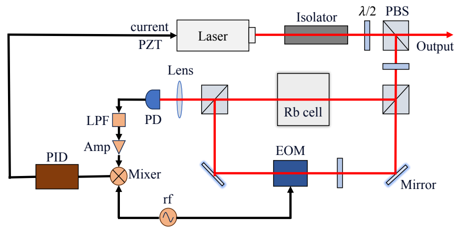

Fig. 1. Schematic diagram of the MTS experiment setup. The beam path is represented by the red line, and the circuit is shown with the black line.

stabilization. The laser for MTS is then split into two beams, where the pump beam exhibits higher power than the probe beam. The pump-to-probe power ratio is approximately 12:1.

The pump beam is modulated by an electro-optical modulator (EOM, Thorlabs EO-PM-R6-C1) driven by an oscillator. And it is aligned collinearly with the counter-propagating and unmodulated probe beam through a rubidium vapor cell. In order to optimize the signal-to-noise ratio of the spectrum, a half-wave plate is positioned in front of the EOM to align the polarization direction of the pump beam with the electro-optic crystal axis. The modulation transfer process occurs in the atomic vapor cell, and then the sidebands of the probe beam are generated. Finally, the beat signal between the sidebands and carrier of the probe beam is detected by a photodiode (PD).

When receiving the beat signal, the PD converts the optical signal into an electrical signal which then enters the servo feedback system. The electrical signal is is filtered by a low-pass filter (LPF) to attenuate background noise, amplified by an amplifier (amp), and finally mixed with the demodulation signal using a frequency mixer. At the output of frequency mixer, the error signal is derived from the demodulated dispersive signal and passes through the proportional-integral-derivative controller (PID) to stablize frequency by changing the driving current and the piezoelectric actuator (PZT) of the

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laser.

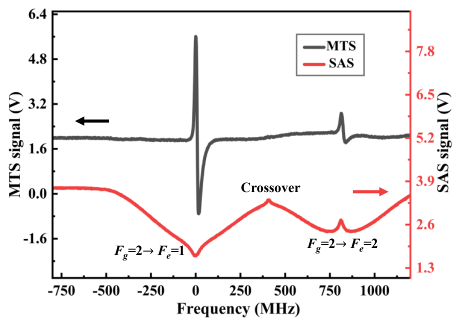

Fig. 2. Spectra signals of (top) MTS and (bottom) SAS

III. Experimental Results

The signals of MTS and saturated absorption spectroscopy (SAS) obtained by experiments are displayed in the top and bottom of Fig.2, respectively. The three peaks from left to right are $F_g = 2 \rightarrow F_e = 1$, crossover peak and $F_g = 2 \rightarrow F_e = 2$. Among these peaks, the slope and amplitude of the MTS signal of $F_g = 2 \rightarrow F_e = 1$ are the largest, and the corresponding signal-to-noise ratio is the highest. We use this signal as error signal and lock the laser frequency to this hyperfine energy level transitions.

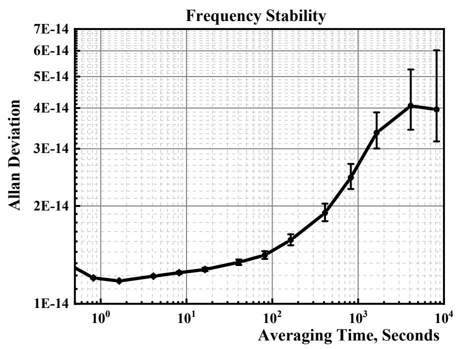

Fig. 3. The self-evaluated Allan variance after stabilizing frequency of the laser using MTS, The frequency stability of the 795 nm laser reaches 4×10^{-14} for measurement times τ between 1 s and 10000 s

The system stability curve obtained by the self-evaluation method is shown in Fig.3. The frequency stability of 1 s integration time is better than E-14, and the long-term stability of the laser reaches 4E-14, indicating good performance of closed-loop locking of the system. Further assessment of the out-loop stability will be carried out in the future.

IV. Conclusion

In summary, we have studied MTS for the D1 line of ^{87}Rb and build the compact optical frequency standard. The self-evaluated frequency stability of 1 s integration time is better than 1.2E-14, and the long-term stability of the laser reaches 4E-14, indicating good performance of closed-loop locking of the system. The highly stable 795 nm laser can play an important role in the field of atomic physics such as cold atom physics. The obtained results provide an alternative method for the high frequency stability of 795 nm laser.

Acknowledgment

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