Digital Automatic Relocking Method and Implementation of Ultra-stable Laser

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***Summary*—We present a practical method of automatically relocking of ultra-stable laser. Without transmission threshold detection, digital servo automatic scans for relocking while PID remaining enabled, and the laser can be automatically relocked within 3 s when losing lock occurs.**

Keywords—Automatic relock; Digital servo; Ultra-stable laser

I. INTRODUCTION

Ultra-stable lasers owns extremely-high frequency stability and play important roles in in optical atomic clocks [1], time and frequency transfer [2], ultra-low phase noise microwave generation [3], and fundamental physics experiments [4]. These applications require ultra-stable lasers to be able to operate stably over long periods of time. However, sometimes unexpected environmental perturbations can cause the system losing lock. Human intervention to retrieve the lock is no guarantee to be in time when the system is out of lock. Analog and digital automatic relocking electronics have been demonstrated [5,6], but the structure are complex, and the transmission detection is needed. Here we show a simple method of automatic relocking digitally. Without detecting the transmission of the F-P cavity, this approach is able to complete automatic relocking within 3 s after losing lock.

II. METHODS/RESULTS

In our system shown in Fig.1, the commercial fiber laser (NKT E15) is frequency shifted by an acousto-optic modulator (AOM) and locked to the resonant frequency of the optical reference cavity using the PDH method. As indicated in Fig.2, the demodulated error signal is used as an input to the digital servo, corrected by proportional-integral-integral-derivative (PIID), which is consist of four cascaded first order infinite impulse response filter, and output to the AOM driver via output 1 for fast feedback of the laser frequency. The signal from output 1 is then fed into the laser piezoelectric converter (PZT) port via output 2 after a one-stage low-corner frequency proportional-integral (PI) correction for a wide range of slow compensation of the laser frequency.

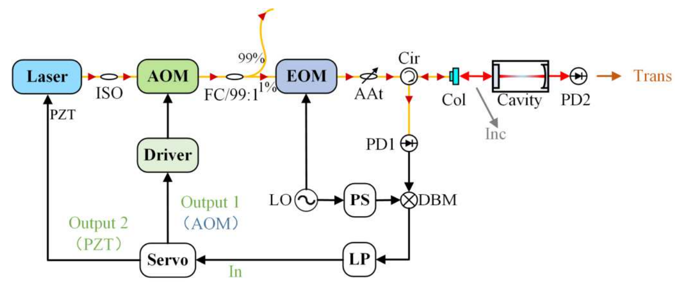

Fig.1.Schematic diagram of ultra-stable laser system with signal identification. ISO, isolator; AOM, acousto-optic modulator; FC/99:1, 99:1 fiber coupler; EOM, electro-optic modulator; AAt, adjustable attenuator; Cir, circulator; Col, focus-adjustable collimator; PD, photodetector; LO, local oscillator; PS, phase shifter; DBM, double balanced mixer; LP low-pass filter; Servo, digital servo; PZT, piezoelectric transducer.

When the PIID parameters are properly set, the laser frequency can be locked tightly to the cavity resonance frequency. In order to achieve automatic laser locking, a 2 Hz, zero bias 4-Vpp triangle wave is superimposed on output 1, which is integrated by the PI before output 2, and the PIID output and PI output are zeroed when they reach the maximum or minimum value of the limit. In this way, when the integration saturates, the output does not stay at the extreme value, but goes to the superimposed wave or offset value and reintegrates. Thus automatically scan for relocking.

The principle of its automatic locking relies on the fact that the input of PI filter is not consistently zero. This is due to the non-ideal characteristics of the circuit, which include noise and non-ideal bias. Therefore, the input signal is always integrated. When the system is in a locked state, both external disturbances and changes in the servo output are detected by the system, generating corresponding error signals. These error signals are used to correct the deviation and stabilize the output at a certain value to ensure the stability of the laser frequency.

When the system loses lock, the laser frequency deviates significantly from the cavity resonance frequency. The frequency detection function of the system fails, causing the laser frequency to vary within a considerable range. In this case, the error signal does not respond, and the output remains at zero. The servo continuously integrates, causing the output to climb or descend to its maximum or minimum value. The saturation zeroing function reverts the saturated output back to zero, and then a triangular wave disturbance signal or offset signal is added to change the scanning starting point, thus improving the scanning efficiency. Ultimately, the scanning of the lock point and relocking aare accomplished through the coordination of the two channels.

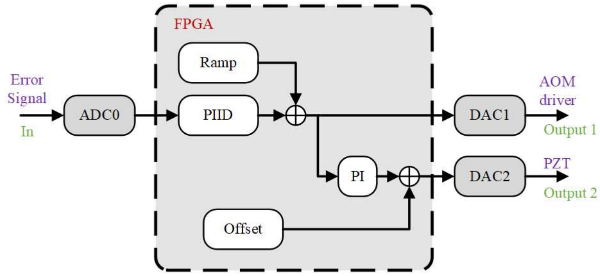

Fig.2. Schematic of digital servo. Ramp, module that generate triangle wave.

To verify the ability of the method to relock, we achieved ns-level laser on/off delays by feeding a step signal to the amplitude modulation port of the AOM driver. As shown in Fig.3, the blue line is actually a denser periodical creeping sawtooth waveform similar to the green line, with a triangular wave in the upper envelope and a straight line in the smaller envelope. Since the data is read from the oscilloscope, the blue line is slightly distorted due to the limitation of the number of read points. Due to the fact that the integral input of the green line is actually the output of the blue line, the initial value of the integral at the saturation zero moment is not exactly the same. Therefore, the scanning of the green line appears to have periodicity, but in reality, the starting direction and climbing speed of each "cycle" are different, which can make the scanning more comprehensive. After 0 s, the laser is turned on and incident into the optical reference cavity, and after 2.4 s, the system resumes locking. During the automatic relock, the output 1 and Output 2 were continuously scanned while maintaining the PID function, allowing for a quick relock after the laser is restored.

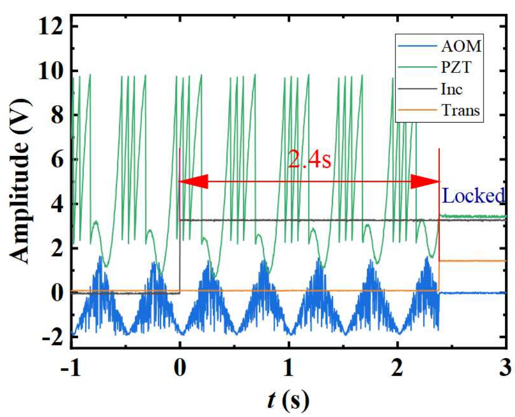

Fig.3. Signal diagram of the automatic re-locking process. AOM, output 1 signal fed into AOM driver; PZT, output 2 signal fed into PZT port; Inc, cavity incidence signal; Trans, cavity transmission signal.

III. CONCLUSIONSDIS

In conclusion, we report a simple method to achieve auto-relock, which only needs the output to be zeroed when saturated, while superimposing a low-frequency triangular wave at the fast output to achieve auto-scan and auto-relock without threshold detection, ensuring that the ultra-stable laser quickly recover the lock and achieve long-term operation after losing lock as encountering an unexpected disturbance.

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