Frequency stabilization of a single-frequency all-solid-state laser for Doppler wind lidar

Xutao Sun (孙旭涛), Jiqiao Liu (刘继桥), Jun Zhou (周 军), and Weibiao Chen (陈卫标)

Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800

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The master laser of an injection-seeded laser for Doppler wind lidar is frequency stabilized to a Fabry-Perot (FP) cavity using Pound-Drever-Hall technique. The FP cavity is specially designed to gain high temperature stability with Zerodur cavity and spacer. A computer based controller is used to sample and process the error signal. After the master laser is locked, the relative frequency drift is ±25 kHz in 1 s, and ±55 kHz in 1 h, which can satisfy the need of Doppler wind lidar.

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The light source of laser Doppler wind lidar[1,2] requires single mode laser with high frequency stability. It is realized by means of injection-locking technique with a monolithic laser diode (LD)-pumped master Nd:YAG laser[3,4]. The frequency drift of laser used in Doppler wind lidar should be no more than 1 MHz[5], corresponding to the velocity accuracy of better than 0.5 m/s. The master laser has a frequency drift with time, which causes the frequency drift of slave laser according to the theory of injection seeding[6,7]. Therefore, the frequency of the master laser should be stabilized to satisfy the requirement of Doppler wind lidar. In this letter, the frequency of the master laser is locked to a homemade confocal Fabry-Perot (FP) cavity using Pound-Drever-Hall technique[8].

The master laser is a commercial 200-mW LD-pumped Nd:YAG continuous-wave (CW) laser with nonplanar ring oscillator[9] at 1064 nm. Frequency of the laser can be changed by both slow temperature tuning and fast piezoelectric transducer tuning. The frequency drift is about 45 MHz in three hours. A confocal FP cavity is used as frequency standard. The frequency standard in frequency stabilization system should have high stability to keep the length of cavity constant and then keep the central frequency unchanged approximately. The cavity length is affected by temperature changing, vibration, and sound. The most serious affection is temperature fluctuation, therefore the design, the material of cavity and spacer, and the temperature controller are optimized. The spacer and cavity mirrors of the confocal FP cavity are made of Zerodur (Schott, Germany) with the expansion coefficient of less than 0.05×10^{-6} K^{-1}. Two highly reflective mirrors are optical-contacted to the ends of spacer. The spacer is cylindrical, 193 mm long and 40 mm in diameter, with an 8-mm hole running longitudinally along its axis. The mirrors are concave, with a radius of curvature of 200 mm. The finesse of the FP cavity is measured to be 220, and the linewidth is 1.7 MHz. The FP cavity is sealed in a temperature-controlled box, and the temperature stability is better than 0.01 K. A laser stabilized to the FP does not have good frequency reproducibility, but it is not important for Doppler wind lidar, in which the accuracy is affected by frequency drift rather than frequency reproducibility.

Figure 1 shows the schematic of the frequency stabilization system. The beam from the master laser passes through a Faraday isolator (FI) and is phase modulated at 30 MHz by an electro-optic modulator (EOM) driven by radio frequency (RF) local oscillator to make frequency-modulated (FM) sidebands. The incident laser beams are closely mode matched to the TEM_{00} mode of the reference cavity with lenses L1 and L2. The light reflected from the reference cavity is separated from the incident beam with a polarization beam splitter (PBS) and a quarter-wave plate ($\lambda/4$). The reflected laser is detected by a photo detector (PD), the output of which is mixed with the local oscillator's signal. The phase shifter is used to compensate for the unequal delays between the two paths. After being filtered by a low-pass filter and amplified, the error signal is obtained. Figure 2(a) shows the FP transmission spectrum with FM sidebands, and Fig. 2(b) shows the error signal. The slope of the discriminator is measured to be 0.9 V/MHz.

In order to record and analyze the error signal, the error signal is digitized by a data acquisition card (NI 6259), rather than analog servo system[10−12]. The program with a virtual proportional controller and a virtual integrator is written by Labview language, and the feedback signal is controlled by 16-bit digital-to-analog (D/A) converter. Due to the 16-bit sampling resolution of NI 6259, the error signal is acquired with high accuracy. In addition, it is easy to optimize the parameters of the virtual controller. After the frequency is locked to the FP,

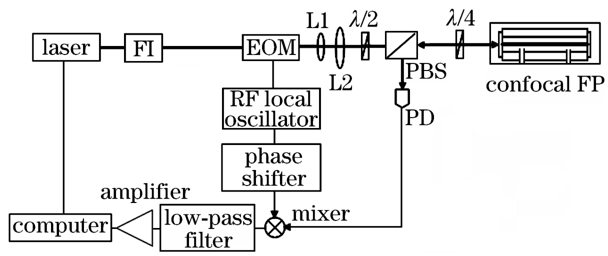

Fig. 1. Schematic of the frequency stabilization system.

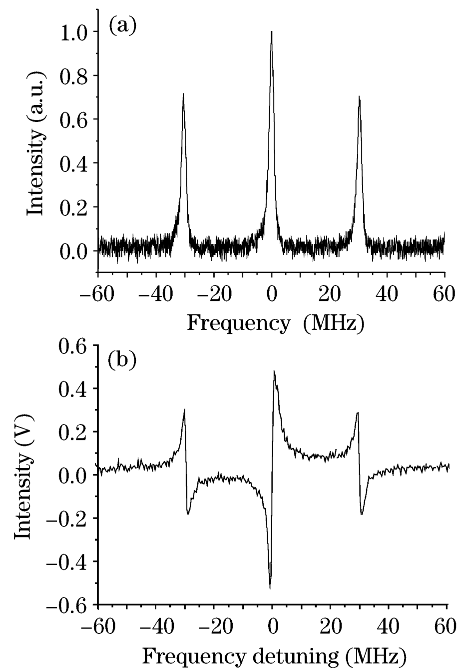

Fig. 2. (a) FP transmission spectrum with two 30-MHz sidebands; (b) error signal.

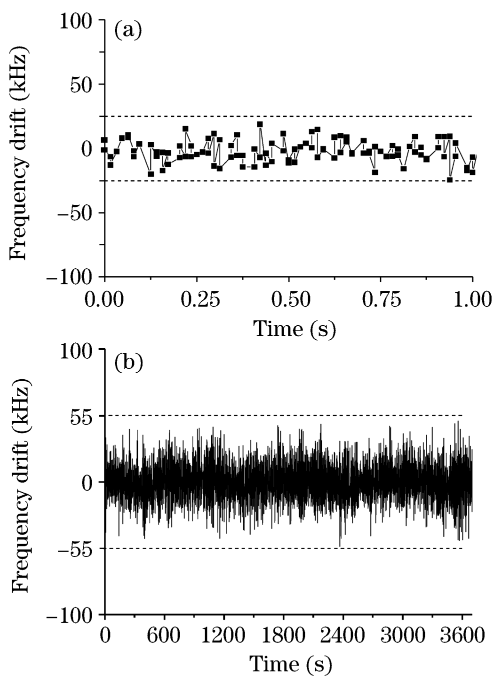

Fig. 3. (a) Frequency drift in 1 s; (b) frequency drift in 1 h.

the error signal is recorded. The frequency drift in 1 s is shown in Fig. 3(a), and the frequency drift is between −25 and +25 kHz. When the laser has continually run for one hour, the frequency is still quite stable (within −55 to 55 kHz), the corresponding error signal is shown in Fig. 3(b).

If the temperature stability and fineness of the FP cavity is higher, the laser frequency will be more stable. In this experiment, the result was affected by the residual amplitude modulation (RAM)[13] in EOM, which induced the variation of the incident laser power, and this variation is regarded as the frequency drift introduced by the system. It can be solved by adding a differential detector.

The frequency drift calculated from the error signal is a relative result[14], because the central frequency of FP fluctuates with temperature change. In this system, because of the high temperature stability of the cavity, the theoretical frequency drift of FP is about 140 kHz. Therefore, the absolute frequency drift is less than 0.2 MHz, which well satisfies the need of Doppler wind lidar.

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