Faraday Laser with Cavity Mode Locked for Optical Pumped Rubidium Atomic Clock

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***Abstract*—We measure the light shift of the rubidium atomic clock under interaction of a 780 nm laser, which has potential application in the laser power stabilization. At the same time, in order to improve the performance of rubidium clock, we demonstrate a Faraday laser of which the cavity mode is locked to the peak of the transition spectrum, thus suppressing the otherwise existed power and frequency noise caused by the cavity mode fluctuations. This Faraday laser is suitable for the optical pumped rubidium atomic clock with the frequency being stably on resonance with the rubidium 780nm transition, and has potential applications on the cesium beam clocks and fountain clocks.**

Keywords—rubidium clock; Faraday laser; light shift

I. Introduction

The stabilities of rubidium clocks pumped by RF-discharge lamps are limited by the signal-to-noise ratio (SNR) of the detection line and the photon shot noise. At the same time, with the light intensity and spectral characteristics of the lamp varies with time, the clock frequency is affected by the light shift effect [1]. Laser-pumped rubidium clocks can in principle improve the pumping efficiency as well as avoid the noise caused by stray light, and have the potential to achieve rubidium clocks with short-term frequency stabilities better than the commercial lamp-pumped standards [2], but is limited by the vulnerability of the laser system.

The Faraday laser [3] is a device that the Faraday Anomalous Dispersion Optical Filter (FADOF) act as the frequency selector inside an external cavity diode laser, instead of the common frequency selectors such as grating, Fabry Perot cavity and interference filters. Owing to this working mechanism, the Faraday laser can stably operate at the atomic transition line with the frequency immune to fluctuations of injection current and diode temperature. Such a laser is an excellent candidate for the optical pumped atomic clock. However, for a free-running Faraday laser, its output power and frequency are still influenced by the cavity mode fluctuations, which limits the stability of the atomic clock. In this paper, we demonstrate a Faraday laser of which the cavity mode is locked to the peak of the transition spectrum, thus suppressing the otherwise existed power and frequency noise caused by the cavity mode fluctuations. With the output frequency being stably on resonance with the Rubidium 780 nm transition, this Faraday laser can be used as the pumping laser of a Rubidium atomic clock, thus improving the stability and robustness of the clock system.

II. Results

Firstly, we measure the light shift of the rubidium atomic clock under interaction of a 780 nm laser. which is determined by the laser intensity and frequency.

α represents the laser intensity of light shift coefficient, that is, when the laser frequency is unchanged, the influence of the laser intensity on the clock transition frequency [4].

$$\alpha = \frac{\Delta v_{clock}/v_{clock}}{\Delta I_L} \tag{1}$$

β represents the laser frequency of light shift coefficient, that is, when the laser intensity is unchanged, the influence of the laser frequency on the clock transition frequency [4]. Therefore, we built a 780nm laser pumped rubidium atomic microwave clock (see Fig.1) to measure the light shift coefficients.

$$\beta = \frac{\Delta v_{clock}/v_{clock}}{\Delta v_L} \tag{2}$$

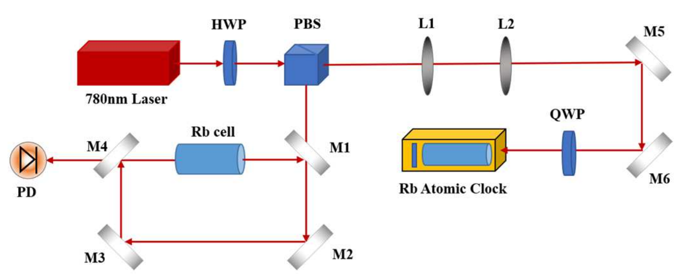

Fig.1 The experimental device is a 780nm rubidium atomic microwave clock based on modulation transfer spectrum frequency stabilization. The laser is divided into two beams. One beam is used to modulate transfer spectrum for frequency stabilization, and other beam enters the physical system of rubidium as pump light.

Keeping the laser frequency as a constant, we change the laser intensity and measure the output frequency of the rubidium clock at the same time for getting the light shift α and β coeffcients (see Fig 2).

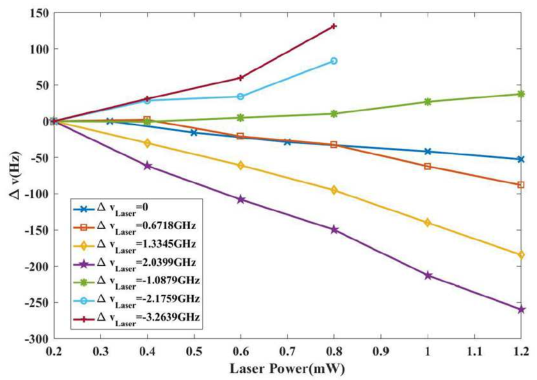

Fig.2 Frequency shift of the rubidium atomic clock depending on the 780nm pumping laser power.

When the frequency of 780nm laser is on the transition $F_g=2 \rightarrow F_e=2,3$ and laser intensity 0.8mW, the microwave transition frequency is 6.89509761GHz. Set the microwave frequency as zero point and the laser frequency as the center frequency, we bring the data measured into formula (1), then get the α result (see Table 1).

Table 1 Value of α

Laser frequency offset (GHz)	Value of α (Hz • cm^2/mw)
$\Delta v_{laser}=0$	20.7880
$\Delta v_{laser}=0.6718$	33.1747
$\Delta v_{laser}=1.3345$	66.1860
$\Delta v_{laser}=2.0399$	92.2780
$\Delta v_{laser}=-1.0879$	-14.9580
$\Delta v_{laser}=-2.1759$	-45.9648
$\Delta v_{laser}=-3.2639$	-84.6280

Then we keep the laser intensity as a constant, change the laser frequency and measure the output frequency of the rubidium clock at the same time for getting the light shift (see Fig 3).

We bring the data measured into formula (2), then get the β result. (see Table 2)

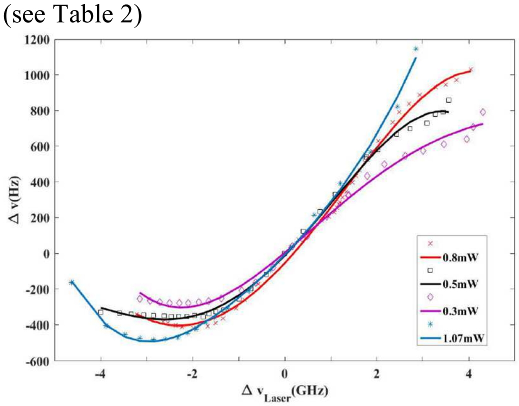

Fig.3 Frequency shift of the rubidium atomic clock depending on the 780nm pumping laser frequency.

Table 2 Value of β

Laser intensity (mW)	Value of β (/Hz)
$P_{laser}=1.07$	4.12×10^{-17}
$P_{laser}=0.8$	4.08×10^{-17}
$P_{laser}=0.5$	3.93×10^{-17}
$P_{laser}=0.3$	3.44×10^{-17}

In order to improve the performance and long-term stability of rubidium clock, we demonstrate a Faraday laser of which the cavity mode is locked to the peak of the transition spectrum, thus suppressing the otherwise existed power and frequency noise caused by the cavity mode fluctuations (See Fig.4).

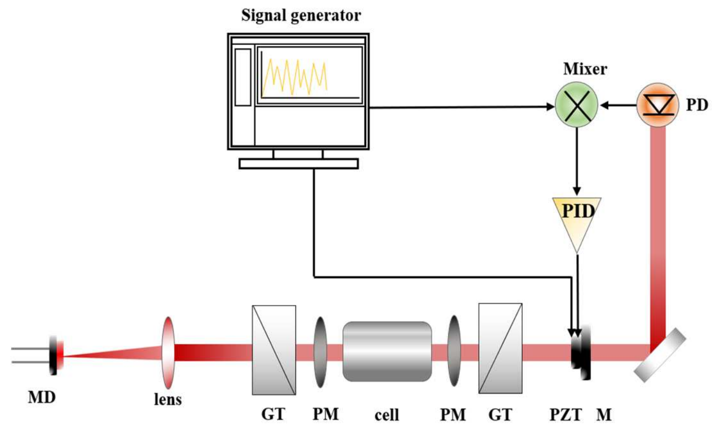

Fig.4 The experimental setup of the cavity mode locked Faraday laser. The signal generator generates a modulation signal for the piezo, as well as a demodulation signal for a mixer. The laser with modulation information is detected by a photodetector and transmitted to the mixer for getting error signal.

So far, we have obtained the transmission spectrum of Faraday laser and the error signal for locking (See Fig.5).

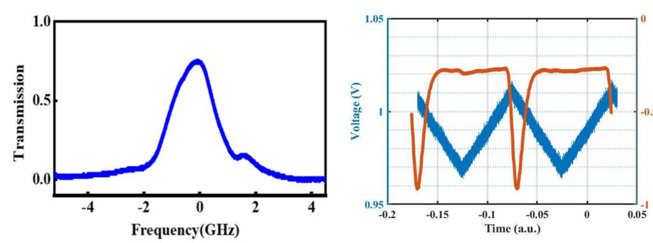

Fig.5 The transition spectrum of the rubidium cell (left) and the error signal (right)

III. DISCUSSION

The measured light shift of the rubidium atomic clock is propotional to the power and frequency of the 780 nm laser in the specific range. Taking advantage of this feature, when the laser frequency is locked, the light shift can be utilized to stabilize the laser power by keeping the output frequency of the rubidium clock constant. On the other hand, by utilizing of a cavity mode locked Faraday laser for optical pumping, the influence of the light shift on the stability of rubidium clocks can be effectively suppressed.

IV. CONCLUSIONS

In conclusion, We measure the light shift of the rubidium atomic clock under interaction of a 780 nm laser, which has potential application in the laser power stabilization. Then, to improve the performance of rubidium clock, we demonstrate a Faraday laser of which the cavity mode is locked to the peak of the transition spectrum, thus suppressing the otherwise existed power and frequency noise caused by the cavity mode fluctuations. This Faraday laser is suitable for the optical pumped rubidium atomic clock with the frequency being stably on resonance with the rubidium 780nm transition, and has potential applications on the cesium beam clocks and fountain clocks.

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