Study of A Compact Atomic Magnetometer with Dynamically Regulated Double Feedbacks

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Abstract

Atomic magnetometers are among the most sensitive technologies for detecting and characterizing magnetic fields. A compact atomic magnetometer utilizes a built-in laser diode to generate light at the specified frequency. The stability of the diode significantly affects the sensor's performance. This paper proposes a novel method of stabilizing the laser diode output by a regulated double feedbacks control setting. The control coefficients are regulated dynamically according to the operating state of the atomic magnetometer. The method does not need any additional component and performs better than the conventional approach in a long-time operation. A compact atomic magnetometer with sensitivity 14 fT/Hz$^{1/2}$ @10 Hz is developed and tested, which demonstrates the feasibility of the proposed method.

1 Introduction

Atomic magnetometer can detect ultra-weak magnetic field making it a sensor with a wide range of application scenarios. For an atomic magnetometer, it is critical to main the wavelength and power of the laser light constant. The technologies that require complicated system and an addition external reference to provide feedback are not suitable for a compact atomic magnetometer [1] [2]. To meet the needs of sensor miniaturization, the designs of atomic magnetometers with a single laser beam generated by a built-in laser diode for both pumping and probing were studied [3]. Previously, the diode is monitored by a temperature sensor to maintain its output laser frequency constant. The response of the temperature sensor is slow that cannot track the variation timely. Consequently, a more reliable method should be developed.

2 Compact Atomic Magnetometer Design and Control Method

This paper proposes a method of stabilizing the state of a compact atomic magnetometer based on a dynamically regulated control with two feedbacks. The laser diode is controlled by two feedbacks proportional–integral close-loop control scheme, as written in (1).

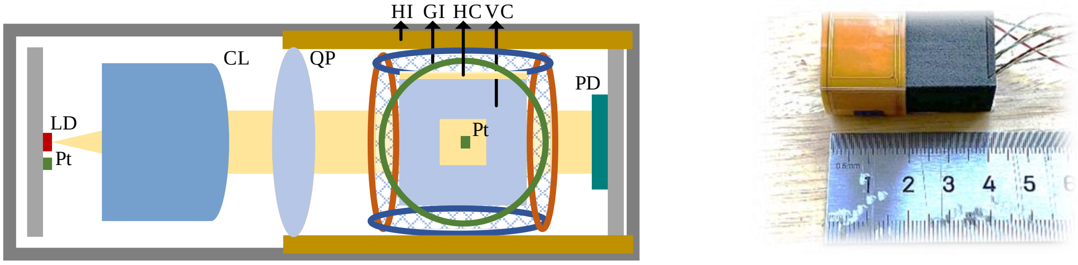
$$V_c = \chi^\alpha (K_p^\alpha e_{(t)}^\alpha + K_i^\alpha \int e_{(t)}^\alpha dt) + \chi^\beta (K_p^\beta e_{(t)}^\beta + K_i^\beta \int e_{(t)}^\beta dt) \tag{1}$$

where V_c is the control signal, K_p^α, K_i^α, K_p^β and K_i^β are constant coefficients, $e_{(t)}^\alpha$ and $e_{(t)}^\beta$ are the errors of the temperature and PD voltage, respectively. χ^α and χ^β are the dynamically regulated coeficients, which are functions of the laser operating temperature T_m written as (2) and (3), where ξ, $T_o$and ΔT are constant parameters.

$$\chi^\alpha(T_m) = \frac{e^{-\xi(T_m - T_o + \Delta T)}}{e^{\xi(T_m - T_o + \Delta T)} + e^{-\xi(T_m - T_o + \Delta T)}} + \frac{e^{\xi(T_m - T_o - \Delta T)}}{e^{\xi(T_m - T_o - \Delta T)} + e^{-\xi(T_m - T_o - \Delta T)}} \tag{2}$$

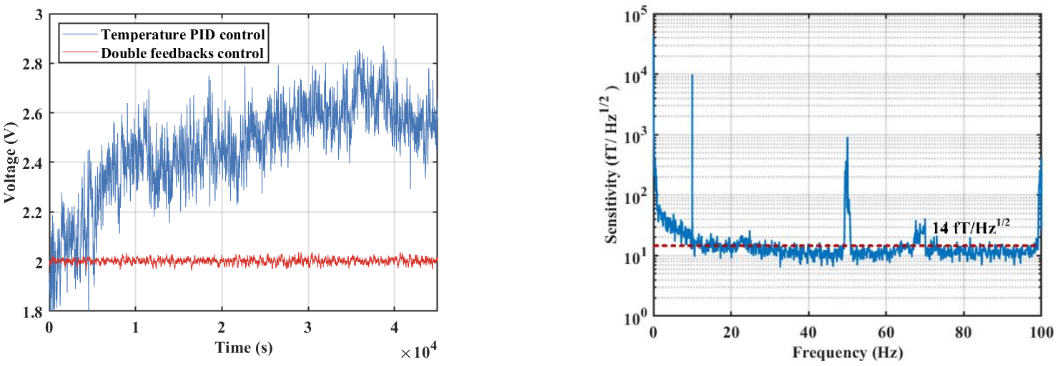
$$\chi^\beta(T_m) = 1 - \chi_{(T_m)}^\alpha \tag{3}$$

To verify the feasibility of this method, a compact magnetometer was developed and tested.The schematic diagram and a phtograph of the magnetometer is shown in Fig. 1. A laser diode that can radiate 795 nm near infrared light is utilized as the light source. The proposed method is compared with a conventional feedback control system based on the measurement of the signal stability. The result is presented in Fig.2(a), which indicates that the proposed method can better maintain the PD output voltage signal constant. The noise spectrum of the atomic magnetometer is presented in Fig. 2(b). Experiments show that the sensitivity of the sensor is about 14 fT/Hz$^{1/2}$@10 Hz and it can operate stably for a long time.



(a) (b)

Fig. 1. (a) Schematic diagram of the atomic magnetometer, where Pt presents Pt1000 temperature sensor; LD is the laser diode; QP is the quarter wave plate; HC is the cell heater; GI is the insulated glass cell; PD is the photodiode. (b) A photograph of the compact magnetometer.



(a) (b)

Fig. 2. (a) Comparison of the proposed method and a conventional PID control. (b) Noise spectral density of the atomic magnetometer.

3 Conclusion

The method proposed in this paper utilizes both the temperature and PD signal as the feedbacks, which combines the advantages of the two signals. The control parameters are regulated dynamically according to the operating state of the laser diode to improve the stabilization of the compact atomic magnetometer. The experimental results demonstrate the feasibility of the method.

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References

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