An Novel Atomic Scalar Magnetometer Using Laser

Chao Wang, Zhijian Zhou, and Defu Cheng

***Abstract*—**The measurement precision of commercial atom scalar magnetometer is relatively backward compared with that of quantum magnetometer. However, the application of quantum magnetometers such as SERF requires more stringent environmental background requirements, which is not suitable for magnetic field measurement in the geomagnetic environment. The purpose of this paper is to design a ^{4}He atom scalar magnetometer using ECDL laser. Compared with the conventional atomic scalar magnetometer, this magnetometer has higher measuring precision and can work normally in the geomagnetic environment. In order to achieve the above goals, the sensitivity formula of the atomic scalar magnetometer is first deduced and calculated, and the key physical factors that directly affect the sensitivity are the optical pumping rate, transverse relaxation rate, and longitudinal relaxation rate. Then, the light source and ^{4}He cell are determined as key components which affect sensitivity. On this basis, the optical path of the ^{4}He atomic scalar magnetometer using laser is designed in this paper. The light path ensures the stability of the laser wavelength of 1083.207nm by the saturation absorption spectrum method, and it ensures the circularly polarized light enters the ^{4}He cell through the combination of various optical components. This paper also studies the electric excitation technology of the ^{4}He cell. And, combined with simulation experiments, the High-Frequency discharge excitation circuit with high energy transfer efficiency and corresponding matching network are determined. Through the optical wavelength meter, it can be determined that the optical path designed in this paper can guarantee the wavelength stability of 1083.207nm for a long time. By analyzing the detection signals of PD, the circularly polarized light enters the ^{4}He cell in the light circuit designed in this paper has a higher degree of polarization. The High-Frequency discharge excitation circuit designed in this paper can light up the cell smoothly, and the input power when the circuit works stably is about 6W. Finally, the static sensitivity of the magnetometer is 5pT/Hz$^{1/2}$. The ^{4}He atom scalar magnetometer using ECDL laser designed in this paper has high static sensitivity, which basically meets the design requirements, and the instrument can be used normally in the geomagnetic environment. However, the instrument still has a lot of room for improvement, including optical path and cell performance optimization, and we will continue to study in this direction.

***Keywords*—**Scalar magnetometer, laser, resonance signal, excitation circuit.

This work was supported by the Special Projects for Monitoring, Warning and Prevention of Major Natural Disasters, the National Key Research and Development Program of China 2018 (Grant No. 2018YFC1503803 and 2018YFC1503903).

C. Wang is with the College of Instrumentation and Electrical Engineering, Jilin University, Changchun, China (e-mail: chaow15@mails.jlu.edu.cn)

Z. Zhou is with the College of Instrumentation and Electrical Engineering, Jilin University, Changchun, China (e-mail: zhouzhijian@jlu.edu.cn)

D. Cheng is with the College of Instrumentation and Electrical Engineering, Jilin University, Changchun, China (e-mail: chengdefu@jlu.edu.cn)

I. INTRODUCTION

SINCE the nuclear magnetic resonance (NMR) findings in 1946 and the first atomic magnetometer developed in 1961 [1], the research of atomic magnetometers has made rapid progress in recent years [2]. This class of sensors has extensively applied in fields including space exploration, geophysical exploration and military anti-submarine [3]. In the last two or three decades, we found him able to play an important role in predict earthquakes, even in biomagnetism and latent disease diagnosis [4].

In the field of disease diagnosis, Magnetocardiogram (MCG) and magnetoencephalogram (MEG) can be generated by detecting magnetic information in human tissues such as the heart and brain, in turn, the latent lesion of human tissue is detected in time. The strength of the magnetic field in the body's main organs is shown in Table.I [5]. Magnetoencephalography (MEG) was studied with optically pumped magnetometer by the researchers of Okayama University [6].

Spin Exchange Relaxation Free (SERF) magnetometers have a sensitivity of 1–10 fT/Hz$^{1/2}$, it is the most sensitive atomic scalar magnetometers at presented, nevertheless, the work environment in near-zero magnetic field it needs is particularly harsh [7]. It is not suitable for the measurement of the earth's magnetic field [8].

This paper introduces a kind of optically pumped method ensures the stability of laser wavelength. With reasonable optical path construction and efficient design of HF discharge excitation circuit, we have a magnetometer reaches a sensitivity of 5pT/Hz$^{1/2}$ in a static measurement.

TABLE I. The strength of the magnetic field in the body's main organs.

Organ name	Magnetic field intensity(pT)
heart (MCG)	50
brain (MEG)	1
muscle (MMG)	10
lung (MPG)	5000
eye(MOG)	10
retina(MPG)	0.1

II. ^{4}HE ATOMIC MAGNETOMETER SENSITIVITY

Briefly, the ^{4}He atomic magnetometer we introduced, is a magnetic measuring instrument on the basis of Zeeman effect in the magnetic field, optical pumping, and NMR.