A SHORT-SCALE QUANTUM FREQUENCY STANDARD BASED ON TWO QUANTUM MAGNETOMETERS FOR ON-BOARD APPLICATIONS

Sagitov E.A., Ermak S.V., Semenov V.V.
Peter the Great St. Petersburg Polytechnic University, Saint Petersburg, Russia
E-mail: e-sagitov@mail.ru

Abstract: The paper is devoted to the possibility of construction of the quantum frequency standard based on two quantum magnetometers system. One of the magnetometers is based on self-oscillation spin generator, another is M_z-type magnetometer based on end microwave resonance. The laser pumping of ^{87}Rb atoms placed into anti-relaxation coated cell is provided. The experimental results on the magnetometers frequency difference fluctuations measurements and Allan deviation are presented. The role of the radio-optical resonance frequency light shift different components is noted for the choosing the quantum magnetometers optimal operation mode. The effect of the light shift compensation is demonstrated.

Keywords: quantum frequency standard, quantum magnetometer, optical pumping, frequency stability, alkali atoms, hyperfine structure, frequency shifts.

Introduction

Quantum frequency standards implement the synchronization of telecommunication and precise time systems. They provide correct operations of stationary and mobile systems, ensuring their reliability and accuracy. The basis for such frequency standards is the optical pumping method, which have been developed since the beginning of 1950s. The optical pumping leads to the redistribution of populations in the atom energy structure ground state, that creates the conditions to observe the magneto-dipole transitions in the hyperfine structure, providing a possibility for precise measurement of the resonance frequency, that determines the stability of standard [1]. The main measurement error source is the light frequency shift associated with the influence of non-resonant light components.

Theoretical and experimental studies have shown the ability to reduce the influence of the light frequency shift component compensation in the case of end magneto-dependent hyperfine structure transitions, which is not possible in the case of magneto-independent 0-0 transition [2]. In the case of the atomic clock on end resonance, Zeeman transitions in spin generator can be selected to compensate the magnetic fluctuations in an external magnetic field. Hereby, the compensation of the magneto-dependent end resonance magnetic dependence and the additional frequency destabilizing factors of the atomic clock are provided.

Obviously, this compensation is achieved by simultaneous registration of end resonance signal using the synchronous detection technique and self-oscillating quantum magnetometer signal. The mathematical processing of the received signals is provided.

The system of two quantum magnetometers

The basis of experimental research is the magnetic induction meter scheme based on the system of two quantum magnetometers with optical pumping, one of which is spin generator (low frequency magnetometer), and another is passive M_z-magnetometer based on microwave radio-optical resonance, resonance frequency of which corresponds to magneto-dependent transitions between hyperfine structure sublevels with extreme values of a magnetic quantum number. The simplified functional scheme of such device is presented in Fig.1.

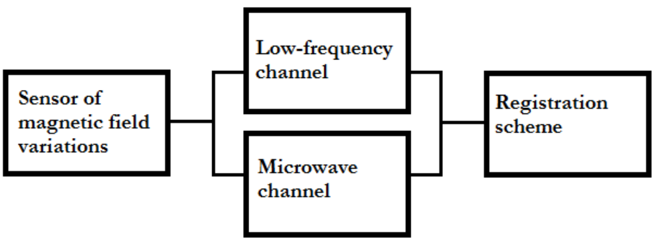

Fig.1. Functional scheme of two-channel quantum magnetometer system with optical pumping.

The functional schemes of low frequency spin generator and microwave Z-type magnetometers are presented in Fig.2 and Fig.3. The original result of this research is the using of one cell with anti-relaxation coating, containing alkali atoms for two magnetometers, which provides additional possibilities in the light shift reduction.

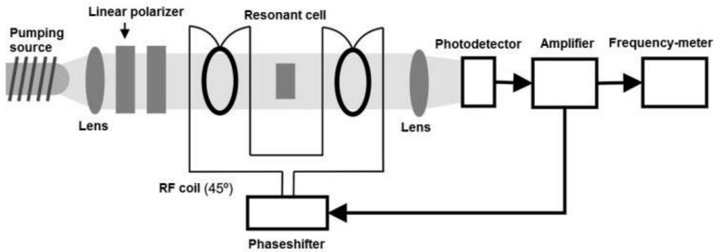

Fig.2. Spin generator, low frequency channel.

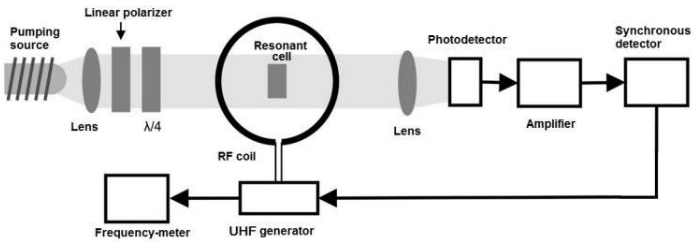

Fig.3. M_Z – magnetometer, microwave channel.

The experimental verification of the light shift compensation effect was carried out within the ^{87}Rb atoms with laser optical pumping of ground state F=2 by light component $S_{1/2} - P_{3/2}$ of D_2 line in system of quantum magnetometers. The functional scheme of it contains well known elements used in gas-cell atomic clock. The scheme is operated on the microwave radio-optical resonance signals and on the weighted average resonance frequency of the Zeeman structure. It provides simultaneous measurement of magnetic field fluctuations by registration of the microwave measuring channel error signal and by measurement of the low-frequency measuring channel, which react to changes of an external magnetic field and laser pumping parameters.

Then, the signals from two channels are detected by the registration scheme where they are relatively subtracted (see Fig.4). This method provides a compensation of the magnetic fluctuations and joint light shift components compensation [2, 3]. Further, Allan variance for the differential signal of two quantum magnetometers is calculated.

Allan variance for two directions of the pumping light circular polarization (σ+ and σ–) is presented in Fig.5. The light power is about 100 μW, that corresponds to the quality factor mode of low-frequency and microwave radio optical resonance signals. The represented experiments have also been carried out under other similar conditions. Thus, there is a principal possibility of scalar and vector light shift mutual compensation by choosing a suitable sign of the pumping light circular polarization, that allows realizing the reduced resonance frequency light shift of the atomic clock based on the two quantum magnetometers system.

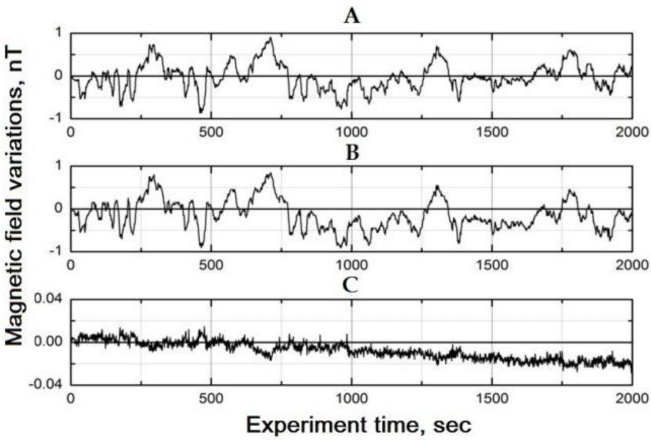

Fig.4. The magnetic variations compensation system of two quantum magnetometers. A – low-frequency channel, B – microwave channel, C — difference of the magnetic variations registered by low-frequency and microwave channels.

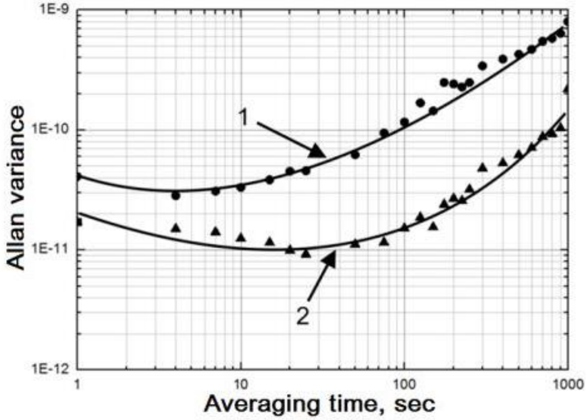

Fig.5. Allan variance for system of two quantum magnetometers. Graphs 1 and 2 correspond to the σ– and σ+ types pumping light polarization respectively.

The greatest interest in applications represents the area of averaging time 10^2-10^3s. It was the cause to providing experiments for the quantum magnetometers operating mode optimization in time of averaging exceeding a time barrier of hundreds of seconds [4]. The correct choice of the laser pumping light polarization allows of the light shift various component mutual compensation of the atomic clock resonant frequency and therefore, increases its long-term stability.

Conclusion

It was experimentally shown that the effect of the light shift components compensation allows the reducing of the atomic clock based on the system of two quantum magnetometers frequency Allan variance in comparison with the atomic clock on 0-0 transition.

References

1. 1. F. Riehle. Frequency Standards: Basics and Applications // Weinheim: WILEY-VCH Verlag GmbH & Co. KGaA. – 2004.
2. 2. A. A. Baranov, S. V. Ermak, E. A. Sagitov, R. V. Smolin, V. V. Semenov. Double resonance frequency light shift compensation in

optically oriented laser-pumped alkali atoms // Journal of Experimental and Theoretical Physics. – 2015. – V.121, № 3. – P. 393-403.

3. 3. 4. A. A. Baranov, S. V. Ermak, E. A. Sagitov, R. V. Smolin, V. V. Semenov. Signal correlation in the tandem of a spin oscillator and microwave frequency discriminator with laser-pumped alkali atoms // Technical Physics Letters. - 2016, V.42, №4, - P.38-45.
4. 4. E. B. Aleksandrov, A. K. Vershovskii // Phys. Uspekhi. – 2009. – V.52. – P.573.

A REVIEW ON THE DEVELOPMENT OF MICRO-NANO SATELLITE CONSTELLATION AND FORMATION FLYING TECHNOLOGIES

Sun Shu-jian, Meng Tao, Jin Zhong-he
School of Aeronautics & Astronautics, Zhejiang University, Hangzhou, China
E-mail: mengtao@zju.edu.cn

Abstract: Constellation and formation flying have been becoming the most promising development trends for further micro-nano satellite applications. A review of the development of micro-nano satellite constellation and formation flying technologies is proposed in this paper. The classification, characteristics, and applications of micro-nano satellite constellation and formation flying are illustrated, and the differences between them are argued in details. This paper also provides a brief overview of the advanced technologies and the future development trends of these two kinds of distributed micro-nano satellite system. This work has guiding significance for the research of micro-nano satellite and related fields.

Keywords: micro-nano satellite; constellation; formation flying; networking; distributed satellite system.

Introduction

Micro-nano satellites have taken an increasingly important part in kinds of space missions during recent years. Particularly, distributed micro-nano satellite system has been becoming the most