Stabilization of a fiber femtosecond frequency comb to an optical frequency standard based on a single ytterbium ion

N.A. Koliada[1,*], V.S. Pivtsov[1,2], A.S. Dychkov[1], S.A. Farnosov[1], S.A. Kuznetsov[1], A.A. Filonov[1], D.Yu. Primakov[1]

[1]*Institute of Laser Physics SB RAS*
[2]*Novosibirsk State Technical University*
[*]*E-mail:* n.koliada@mail.ru

A femtosecond frequency comb is one of the main parts of a femtosecond optical clock (FOC) [1 - 2]. FOCs allow studying fundamental physical processes and measuring the frequency of transitions of atoms and molecules. Systems based on FOCs are being developed to increase the accuracy of satellite navigation. Modern FOC includes three main parts – an optical frequency standard, a femtosecond frequency comb (whose frequencies are stabilized to the reference standard) and an electronic stabilization system. The femtosecond comb generates equidistant frequencies. Each frequency of this comb is expressed by the sum $f_n = f_o + n{\cdot}f_{rep}$, where f_o is the offset frequency of the comb, f_{rep} is the pulse repetition rate (intermode frequency), n is an integer [3]. If stabilize two of these three frequencies, one can obtain a comb of stabilized optical and radio frequency. Each component will have a relative stability of the reference optical standard.

In this work, we experimentally investigated the possibility of precision stabilization of the femtosecond optical frequency comb (generated by a femtosecond erbium fiber laser) to an optical frequency standard based on a single ytterbium ion [4]. The comb offset frequency f_o was detected using a two-arm f-2f interferometer [5] and stabilized using an extracavity fiber coupled acousto-optic frequency modulator (AOFM). Using an optical mixer, the beat frequency f_b was obtained between the frequency of the output optical radiation of the Yb + standard (at a wavelength of 871 nm) and the nearest frequency-doubled component of the femtosecond comb (at a wavelength of 1742 nm). The obtained beat signal was stabilized using an intracavity electro-optical modulator based on a KTP crystal [6]. In this way, all components of the femtosecond frequency comb were stabilized. An advantage of the proposed method is that the stabilization of high-frequency disturbances of two signals using an intracavity EOM and an extracavity AOFM practically does not affect each other. With this approach, the modulation frequency of ~ 200 kHz for f_b with the EOM and the modulation frequency of ~ 30 kHz for f_o with the AOFM have become possible. The stabilization frequency of the AOFM is limited by the AOFM configuration and the PLL system and can be increased.

Instability of the output radio frequency of a fiber comb was investigated. To implement the measurement, a Ti: Sa-based femtosecond frequency comb (developed earlier at the Institute of Laser Physics of the SB RAS) was additionally used. Each frequency comb was stabilized to the frequencies of two different laser systems that are part of the optical standards (based on a single ytterbium ion). The intermode beat signal at a frequency of ~ 3 GHz was detected at the outputs of both frequency combs. Using a radio frequency mixer, a difference signal was obtained at a frequency of ~ 10 MHz. The resulting difference signal was recorded using a Microsemi TSC-5120A phase noise test set. This device compares phases of the reference signal and the signal under test. A signal from a passive hydrogen standard («Vremya-CH» JS COMPANY) with a frequency of 10 MHz was used as a reference signal. The Allan deviation was calculated for the obtained data, which characterizes the total relative instability of the signals at the output of two femtosecond combs. The obtained values are close to the instability of the laser systems of the optical standards.

The work was carried out using the equipment of the Center for Collective Use "Femtosecond Laser Complex" at the ILPh SB RAS. The research was carried out with the financial support of the program of fundamental scientific research of the SB RAS No. II.11.1.

References

[1] S.N. Bagayev, V.I. Denisov et al, *Laser Phys.* **14**, 1367 -1374 (2004)
[2] S.A. Diddams, Th. Udem et al, *Science* **293**, 825 - 828 (2001)
[3] H.R. Telle, G. Steinmeyer et al, *Appl. Phys. B* **69**, 327-332 (1999)
[4] S.V. Chepurov, A.A. Lugovoy et al, *Quantum Electronics* **49**, 412-417 (2019)
[5] M.C. Stumpf, S. Pekarek et al, *Appl. Phys. B* **99,** 401-408 (2010)
[6] N.A. Koliada, B.N. Nyushkov et al, *Quantum Electronics* **46**, 1110-1112 (2016)