Towards the providing of the noises cancellation in the optical systems of the distribution and detection of the optical signals

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Abstract. In this paper, the scheme of the transmission system of the optical signal with the active phase compensation is suggested. This system is used for transmission of the frequency standards optical signals, distribution and detection of the laser radiation. The principles and algorithms of such systems are shown. The feedback corrector is presented. This corrector allows realizing the long continuous operation time of the suggested transmission system with active phase compensation.

1. Introduction

The optical lattice clocks (OLC) and another frequency standards with different types of optical parts (double-wavelength cavity, ECDL, narrow spectra lasers) [1-2], on the current stage of the development, consist of many optical communication lines and separated optical and laser systems. These lasers systems are connected between themselves and with other standards by the fiber lines.

The fiber lines are exposed to environment acoustic, thermal noise and mechanical disturbance due to operation and, consequently, transform these vibrations to the noise of the output signal. The cancellation of the impact of these mechanical perturbations is impossible to imagine without special, reducing noise distributors and detectors architectures. Here we describe more frequently used example of such systems, which allows the distribution of the laser radiation to different parts of the system without mechanical noise perturbations and the detection of the useful signal from the active zone of OLC or other frequency standards by the specific way with less noise [3-4]. It is known that almost all OLC in the world allow the measurement of the parameters only in capture mode when the time intervals separate the pumping, scanning, and cleaning procedures. It imposes more certain restrictions on functionality and ability of the operation. Further, the technical aspects and the way to cancel the mechanical perturbations and technical limitation of the detection during the operation of the frequency standards are shown.

2. The system with mechanical disturbances of the fiber line

The relatively large sizes of stationary modern atomic clocks require the use of optical communication cables between the components of the system. For example, a typical clock laser design requires a separate optical table in special boxes. Transport of the radiation from this scheme is carried out by an optical fiber line (maintain, single-mode fiber) [1-3]. However, the use of this line introduces the
parasitic modulation in the spectrum of the radiation because of environment acoustic, thermal noise and mechanical disturbances. For the creation of the Doppler noise canceller (DNC), every visible part and electronic parts of the DNC should satisfy some requirements:

- the electronic parts are fast enough to compensate induced phase shift;
- the total length of the fiber line is not long enough to make almost equivalent disturbances for straight and reflected backlight;
- the special recovery system should be used for restoring the control beyond the range of the control of electrical or optical perturbations.

The design of the DNC is shown in Figure 1. The initial coherent, monochromatic light (introduced by \( \cos(\Omega_L t) \)) is split by a non-polarizing beam splitter (NPBS). It is important to note that here and further. We will not consider the amplitude of the radiation power, but only phase and frequency. The first part of the beam is reflected from the optical shoulder with mirror, and it is one part of the homodyne detection for a photodetector (PD). Another part is passed through the AOM1 and acquired the frequency and phase shift \( \cos(\Omega_L t + \omega_{AOM} t + \varphi_{reg}) \). The left connector of the fiber (Fig.1) is injected by +1 order of the diffraction of the AOM1. During the passing of the fiber line, the light is influenced by some mechanical or acoustic noises. After the right output fiber connector, the signal has additional phase noise \( \varphi_{noise} \) component \( \cos(\Omega_L t + \omega_{AOM} t + \varphi_{reg} + \varphi_{noise}) \). The light goes through the AOM2: \( 0^\text{th} \) and \( 1^\text{st} \) useful orders. The \( 1^\text{st} \) order beam represents a recovered signal. If the electronic feedback is working well the phase shift \( \varphi_{reg} \) compensates the noise-induced phase shift \( \varphi_{noise} \), and at the output of the DNC, we have "clean" coherent and monochromatic light, which was at the input of DNC. A mirror reflects the \( 0^\text{th} \) order through the fiber line. Where it is influenced by the same mechanical or acoustic noises again. It is important to note, that in that configuration we assumed that the fiber line is not so long to feel the difference between forwarding and back passage noises. The light in fiber line experiences the same phase shift as in forwarding passage \( \varphi_{noise} \) and summarizes with it: \( \cos(\Omega_L t + \omega_{AOM} t + \varphi_{reg} + 2\varphi_{noise}) \). After AOM1, the light has additional frequency and phase shift from error signal through VSO of the regulation system, and it has the form \( \cos(\Omega_L t + 2\omega_{AOM} t + 2\varphi_{reg} + 2\varphi_{noise}) \). The mixture of the initial beam \( \cos(\Omega_L t) \) and beam after back passage \( \cos(\Omega_L t + 2\omega_{AOM} t + 2\varphi_{reg} + 2\varphi_{noise}) \) gives the radio-frequency signal convenient to mix with double \( 2\Omega_{AOM} \). Error signal of the system contains information about the necessary correction of the VCO at the moment \( U_{\text{vcg}} \). The low-pass filter is allocated this correction, which is in case of the fast enough electronic, must compensate for the noise influence of the noisy ambient, i.e., make \( \varphi_{reg} = -\varphi_{noise} \). The electronic part of the feedback was equipped by "autorelock" schematic, which allows recovering the system the system in default condition of the operation. In general, at this step, the loop of the DNC feedback is closed.

The multichannel DNC is shown in Figure 2. Radiation can be distributed through the mainline of the half-lambda plates and beam splitters to other optical parts such as:

- optical lattice clocks;
- Ti:S, Er-fiber or another femto-comb;
- fiber connection of the clock laser high-finesse cavity.
Figure 1. The scheme of the doppler canceller. The green arrows and expressions above indicate the directions of the signal (light, radiofrequency signal) and appropriate argument conditions of it.

Figure 2. The sketch of the optical radiation distributor, for example, radiation of the clock laser radiation.

3. Increasing of the operation period of the systems with DNC
One of the main problems of OLC and included systems is long-time measurements. Feedback systems (synchronous detection, phase compensator, Pound-Drever-Hall, Hänsch-Couillaud as a particular case of ellipsometry) are an integral part of modern OLC. If these systems are correctly configured, it can provide continuous synchronization during the tens of minutes. However, these systems can not provide recovering the synchronization after any incidents in the environment (strong mechanical vibrations, short-term optical barriers). At this point, the recovery system ("autorelock" system) or corrector can help to recover the resonant state of the feedback. As a typical example, we can introduce the electronic part of the phase compensator is shown in Figure 3. The recovery system was introduced into the active filter after the mixer. This simple scheme represents an analogue-to-digital corrector system. The main task of this system is to find the right point of the stabilization. As can be seen from Figure 3, this system consists of rectifiers, filters, level limiters, analogue-to-digital converters, a microcontroller and digital-to-analogue converters.
The systems help to ensure the fastest preparation of installations for the experiment. This redistributes human efforts to other parts of the installation, and, as a result, reduces the loss of time and increase the efficiency.

From a physical standpoint, the extension of the measurement process leads to reducing the error of the systematic measurements. The block diagram of the microcontroller system electronic part with insensitivity for the imbalance of the analogue part is shown. As usual, in such systems, the first step is the digitization of the input signals, the second step is the processing of the data by a special algorithm, and the third step is the digital-to-analogue conversion of the output data to correct the behaviour of the DNC feedback system. The decision-making algorithm on the fidelity of the found stabilization or synchronism condition is embedded in the microcontroller program [5]. Moreover, based on the search for the sharpest transition of the error signal through zero.

Figure 3. Feedback corrector. The capabilities of the stabilization system are expanded through the use of an auto-recovery scheme that simultaneously works with the main feedback system.

4. Conclusions
In this paper, we describe an active optical signal transmission system with feedback corrector, the implementation of which will reduce the effects of mechanical vibrations and noise on the distribution of laser radiation and detection of signals in the core of the OLC or other laser standards. For example, they are applicable in strontium lattice clock. It was also proposed to introduce the feedback corrector that helps to find the conditions for stabilization or synchronism of the feedback loop of the DNC as an effective way to reduce the share of the human factor by introducing systems.

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References
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