Towards the species of the auto relock schemes of the high-frequency feedback loops of the stabilization systems

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Abstract. In this paper, we discuss existing and propose new schemes of the feedback auto relock. These schemes provide a closing loop of the logic sequence: keeping stabilization point - automatic search of the stabilization ranges and lock points. The addition correctors to update old and to create new feedbacks schemes were proposed. These correctors allow extended or potentially infinite operation time, for correction signals.

1. Introduction

Optical lattice clocks and frequency standards, spectroscopes, systems of the transmission of the reference optical signal, and other industry or scientific installations with stable narrow-line light sources, contain the special feedback loops with the physical part. This physical part can determine the special parameters of the radiation (high-finesse cavities, frequency multiplier, and laser with external cavity) [1-3]. There are some ways to a couple of the physical part and radiation source systems: synchronous detection [4], Doppler noise cancellers [5], stabilization with modulated sidebands or Pound-Drever-Hall (PDH) lock [6], keeper of the cavity constant polarization or Hänsch-Couillaud lock (HC) [7-8]. This mnemonic schematic is shown in Figure 1. The sources of radiation may be lasers, which frequency of operation coincides with the frequency of the operation transition of the radio, μ-wave or optical frequency standard. The reliability of function, automatic search, repeatability of the finding of the range and reference point, elimination of the false error signal are necessary conditions for the system. These systems allow long-term measurements and experiments, provide continuous monitoring of the stabilization system, carry out the statistically more correct tuning of the equipment [1-3] and can be digital, analogue or mixed. Despite the simplicity and accessibility of digital stabilization systems, they have some disadvantages. Thus, the systems operating according to the simple algorithm for searching the signal maximum or minimum values, give a noise level of 7–10 dB more [9] than systems that implement analogue stabilization algorithms, such as PDH lock or detection with proportional-integrating parts (PI). Opposite to the general opinion that it is necessary and simple enough to align the lock point of the error signal and the middle of the control range to implement an auto-recovery sequence of the keeping the system lock point (Fig. 2), it is necessary to use special electronic devices - automatic compensators or correctors.
Figure 1. The simplest (almost ideal) system with feedback includes minimum 4 components: - initial part, which provides the "tools" to observe the regulation parameter, -physical part is medium of the resonance features, -signal processing part is, frequently, electronic or automatic part, which proceeds the data from physical part and produces the feedback regulation law (almost always negative feedback law) and environmental impact, which includes unintentional fluctuations of the temperature, pressure, electric and magnetic fields.

Figure 2. Flowchart of the logic sequence of the keeping of the system lock point and automatic search of the condition and ranges of the stabilization. There are two ways to search for the lock point: automatic with additional corrector and manual search by the operator.

Further, we consider the technical aspects of the automatic correctors were developed and used in many feedback systems (Fig. 2), based on digital and analogue operating principles.

2. Auto relock system based on leakage currents of the laser feedback
The cheapest and straightforward addition of the integrator of the feedback system is a passive auto-recovery system (auto relock) or passive compensator. Its action is zeroing of the accumulated signal of the integrator by short-circuiting of the contacts of the capacitor C (Fig. 3) [4]. This addition of the PI or part of the proportional-integral-differential (PID) regulator consists of the signal rectifier necessary to rectify the signal from the output of the buffer amplifier, comparator and relay, as a zeroing element.

As was shown on Figure 2, there is the loss of the lock point after the impact of the certain environmental factor (mechanical vibration, shutting of the optical beam, electrical interference of the
power supply circuits). The lock point position of the error signal is shifting relatively of the keeping range of the feedback circuit.

Thus, the input signal, i.e. the error signal at the input becomes equal to zero. Therefore, in the case of an ideal integrator, the output signal stops the change and remains indefinitely. The state when it is necessary to tune the error signal lock point and the keeping range. In case of the real operational amplifiers, the additional zero shifting (due to technological imperfections or added artificially) at the output allows the capacitor accumulating the charge, i.e. an output voltage may reach a value near the supply voltage. If there is a rectifier-comparator circuit, we can get a signal for the zeroing element, for example, at the level of 0.9 Usup, after reaching this value by the voltage at the output of the integrator.

After that, the zeroing element (mechanical relay, semiconductor relay or transistor) set the integrator output value to zero. Further, the algorithm for searching for the lock point error signal is closed.

![Figure 3](image)

**Figure 3.** Flowchart of the feedback integrator (PI- or part PID) with addition part of the passive automatic search by scanning of the keeping range with zeroing of the integrator charge.

The main features of this scheme are the simplicity of implementation and direct predictability of the result. At the same time, this system has one significant drawback. In the process of the stabilization over the entire scanning range or changes in the correction signal, the false error signals may occur in neighbouring modes from the main one. In this case, the search process may stop when finding the first passage through zero of the error signal. But this lock point may not correspond to the initial stabilization conditions, for example, specific mode. This system can be applied if the basic mode is unique over the entire range of the correction signal.

3. **A recovering system with the force scanning system**

Another implemented compensator of the feedback system integrator is an auto relock system using digital microcircuits. The operation algorithm of this corrector includes the ability of the circuit to reset the charge of the integrator C (see Fig. 4a and Fig. 4b), and scanning of the entire range of the correction signal. In this case, analysis and selection of the necessary stabilization shape according to its parameters of width and absolute amplitude is performed. The difference between this corrector and as corrector was described above, is the additional photodetector, microcontroller, analogue-to-digital converter (ADC), digital-to-analogue converter (DAC). This photodetector allows observing the stabilization shape by decreasing the signal, which is passed through the cavity. The decreasing of the signal indicates the reflection of the modulated signal from the cavity in the PDH lock [6] and the finding of the system lock point.

According to with the flowchart on Figure 4a and Figure 4b, when the lock point is lost the microcontroller turns on the integrator zeroing device and starts scanning, for example, with a
triangular or sawtooth signal, by adding a signal from the DAC to the input of the integrator buffer operation amplifier. ADC, the constant noise component digitize the signal coming from the cavity to the photodetector, the peak width of the feedback shape and its amplitude is found. After that, the decision is made whether the shape peak is correct, the scan stops, and the zeroing device is turned off.

**Figure 4.** Flowchart of the feedback integrator (PI- or part PID) with active digital addition part of the automatic search by scanning of the entire regulation range with zeroing of the integrator charge for a - PDH lock, b - HC lock.

In contrast to the algorithms and circuits given in [9-10], the digital parts of the circuits Figures 4 a, b are used as a digital corrector for the operation of analogue circuits. Since, as was mentioned above, completely digital feedback circuits and operating algorithms create an increased noise level, especially at frequencies close to the range of mechanical vibrations, a narrowed passband and frequently not able to effectively stabilize the radiation source over a high-quality physical part, for example, a high-finesse cavity. The presented automatic corrector circuits made the possibility to close the logic auto relock sequence of the feedback of 813 nm optical lattice lasers is based on the PDH and HC locks, 698 nm clock laser and 689 nm trap laser [1-3], using automatic microcontroller-based correctors. This process made it possible to significantly increase the duration of the time for obtaining the measurement data to reduce the error of measurement data [1].

**4. A system with error signal analysis**

In the described above, stabilization systems with correctors, an additional photodetector is required to analyze the signal and make a decision about the right lock point position. This circumstance is not always feasible, for example, in systems such as stabilization of the beat notes of femtosecond lasers with reference radiation. One of the main parts, where the beat notes are obtaining, is a phase-frequency detector (PFD). In case of feedback as PDH lock the mixer and optical high-finesse filter (for example, high-finesse cavity) are used (Fig.6b). PFD compares the phases of the reference source and the output signal of the controlled system (beat signal received from the photodetector) (Figure 6a). Further, the signal is filtered by low-pass filters (LPF) to eliminate high-frequency components. The output signal after the passage of the low-pass filter is converted (amplified, summed). The output voltage allows the voltage-controlled oscillator (VCO) or another voltage-controlled element adjusts its output frequency until a detecting signal is obtained at the output (for example, by a beat note of the optical signals of the reference laser and output laser of the stabilized system). The frequency/phase coinciding with the frequency/phase of the reference source and is applied to the PFD/mixer. With the modulation of the VCO control signal, the output of the PFD/mixer is shown in Figure 5a. The stabilization of the system occurs around the point of intersection of the signal with the horizontal axis. The presence of a parasitic offset in the error signal for reasons beyond the control of the developers, such as leakage currents due to
imperfect manufacturing technology of operational amplifiers, leads to an offset of the error signal and, accordingly, to an asymmetry in the regulation of the working point of the feedback system. The shape of the error signal offset at the output of the mixer/PFD of the feedback is shown in Figure 5b. It is clear to see the offset of the control point in frequency $\Delta F$, when there is offset of the control signal, for example, the voltage $\Delta U$. With additional automatic feedback corrector, the effect is to detect and eliminate the error signal shift of feedback circuits and other systems that operate using carrier frequency modulation, as well as the ability to search for a stabilization point. The expanding the capabilities of the stabilization system by using a completely automatic compensator that simultaneously works with the main feedback system [12], which generates a correction signal to shift the error signal, allowed increasing the time of correct operation of the fem to second laser device used for measurements.

![Figure 5](image1.png)

**Figure 5.** Error signal shapes: a - at the output of the mixer or phase detector of the feedback, b - at the output of the mixer or phase detector of the feedback with a shift by physical or technological reasons.

![Figure 6](image2.png)

**Figure 6.** Flowchart of the feedback with automatic searching of the lock point and correction of the error signal shift: a - for phase-locked loop, b - for PDH lock.
5. Conclusions
In this paper, some aspects of stabilization, differences between the automatic search for a lock point and search by the operator were considered. The principles of the operation of the developed and applied additional correctors for standard feedbacks such as PDH and HC locks were described. These correctors allowed increasing the duration of measurements, and reducing the daily service on the maintenance of these systems. The simplest correctors are based on technological imperfections of the operational amplifier microcircuits or on the artificial introduction of zero unbalance, for example, such a part of the PID controller as an integrator. The complete correctors/auto relock based on the circuits of the widely available ADCs, DACs, and microcontrollers.

Acknowledgements
Authors gratefully acknowledge for the invaluable help and collaboration with the department of the development of the fibre lines system of the FSUE «Russian metrological Institute of Technical Physics and Radio engineering». Also, authors acknowledge for funding of the direction of the Novosibirsk State Technical University.

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