Comparative analysis of beam and cold atom frequency standards is presented and there is a short description of the principles of laser cooling for atoms and equations for their movement. Results are provided for studies directed at creating a new generation of quantum standards for frequency, i.e., a cesium fountain. The atomic resonance for cold atoms with Q of the order of $10^{10}$ is obtained by experiment. A plan is developed and the main assemblies for a frequency primary standard vacuum system in a cold atom fountain are prepared.

Key words: cesium frequency standard, laser cooling, control of atom movement, atomic fountain.

Time and frequency are the most precisely measured physical quantities, but nonetheless an improvement in the accuracy of their measurement remains an important task. Currently in different areas of the frequency range there are frequency standards that are comparable in accuracy. The range of precision frequency measurements extends from fractions of hertz to $10^{15}$ Hz. Standards for other physical quantities are connected with a frequency standard through quantum effects and fundamental physical constants. The meter as the unit of length is the distance passed by a plane electromagnetic wave for time $1/c$, where $c$ is the speed of light. The Josephson relationship makes it possible to establish through fundamental constants a connection between the hertz and the volt ($\nu = 2 eV$).

Thus, quantum effects, fundamental physical constants and time standards are the basic system of contemporary standards. A sequence of transitions is achieved from macroscopic to quantum standards (for example from the kilogram to the quantum standard of mass). The first transition to a quantum standard is one from the platinum-iridium meter to a meter based on reproduction of the orange line of krypton. The next stage is the transition from stellar time to atomic time; from normal elements to a standard of the volt based on the Hall quantum effect, etc.

Measurements of time and time intervals are one of the fundamental bases for operation of contemporary satellite navigation systems.

Studies are being performed for the application of methods of time and frequency measurement in other fields, and also creation of frequency standards of a new type, for example, fountain.

The atomic second of the International System of Units (SI) is the duration of 9,192,631,770 periods of the radiation corresponding to the unexcited transition between the two hyperfine structures of the ground state of the cesium 133 atom (1964). The SI second has been inherited from the rotational second of the middle of the XIX century and currently it is reproduced by means of a cesium atomic spectroscope.

Classical atomic cesium spectroscope. Beams of atoms are used in a classical atomic spectroscope that are formed by a collimator placed at the outlet of a cesium furnace. The velocity of atoms in the beam is hundreds of meters per second.
The flight time of atoms through two arms determine the quality factor of the UHF-resonator, and with reasonable dimensions of a laboratory device the width of the resonator is about 100 Hz, that corresponds to a quality factor \( Q \approx 10^8 \).

Observation of resonance by means of a beam of atoms makes it possible to exclude Doppler shift \( (\delta \nu / \nu) = (v/c) \approx 10^{-6} \), but square Doppler shift \( (\delta \nu / \nu) = (v^2/c^2) \approx 10^{-12} \) remains. Theoretically, it is possible to consider Doppler shift with an accuracy to several percent. However, more precise consideration is difficult due to the impossibility of determining the distribution of atoms in a beam with respect to velocity. Consequently, the accuracy of a beam standard for frequency is determined with an error of the order of \( 10^{-14} \) [1].

**Fountain.** The basis of fountain operation is twofold passage of an atomic cloud through a UHF-resonator with ballistic flight. The cloud is thrown vertically upwards and after reaching the apogee it returns downwards over the same trajectory flying through the UHF-resonator over a path upwards and downwards. Since the same resonator is used, then this avoids the problem of a difference in phases inherent for a two-arm resonator used in the beam standard for frequency. Ultra-cold atoms are almost immobile on a laboratory coordinate system, and this makes possible all potential shifts in frequency connected with movement of atoms. Atoms fly through the resonator with a velocity of several meters per second and consequently the quadratic Doppler effect is of the order of \( 10^{-16} \). In addition, the velocity of atoms in the cloud is centimetres per second and the Doppler effect of the second order may be considered with an error up to \( 10^{-20} \). Physical fields operating on atoms may either be excluded or their effect may be considered with a high degree of accuracy. In particular, it is necessary to consider the effect on a shift in frequency of gravitational potential and “black” body radiation. Currently, the error of frequency standards for cold atoms does not exceed the level of \( 10^{-15} \) [2]. Thus the main limitation for the beam standard of frequency is not a limiting factor for a frequency standard of the fountain type.

**Laser cooling of atoms.** The basis of a frequency standard of the fountain type is the technology for laser cooling of atoms [3]. Contemporary technology for laser cooling and the control of atom movement is a powerful tool for developing and creating a new generation of very highly accurate time and frequency standards. In fact, laser cooling makes it possible