Report to the 16th Session of CCTF

Research Activities on Time and Frequency National Metrology Institute of Japan (NMIJ) / AIST

The NMIJ Time and Frequency Division is involved in the following research activities: (1) Operation of an optically pumped Cs frequency standard, NRLM-4, as a primary frequency standard. (2) Development of an atomic fountain Cs frequency standard. (3) Development of cryogenic sapphire-loaded cavity oscillators (SLCO) as ultra-low phase-noise microwave oscillators for the advanced frequency standards such as the Cs atomic fountain. (4) Cavity auto-tuning experiment of a hydrogen maser for improved long-term stability. (5) Experiment of a two way satellite time and frequency transfer (TWSTFT) and the T&F comparison using GPS P3 code. (6) Development of the frequency stabilized lasers including Iodine stabilized Nd:YAG laser, Rb two photon stabilized laser diode, and C_2H_2 stabilized laser diode. (7) the optical frequency measurement system connecting a Cs microwave frequency standards and optical frequencies, using a mode-locked fs comb generator. (8) Development and implementation of an accredited quality management system which is compriant with ISO/IEC 17025. (9) Development of the local and remote frequency calibration system for traceability.

1. Optically Pumped Cs Frequency Standard, NRLM-4

The optically pumped cesium frequency standard, NRLM-4, has been operating as a primary frequency standard since February 1998 [1]. The NRLM-4 has the following characteristics, (1) adjustable position and direction of a Cs oven with translation and rotation stages, (2) high fluorescent light collection efficiency using the combination of spherical and ellipsoidal mirrors, (3) adoption of a graphite shield pipe surrounding Cs atomic beam to minimize the influence of microwave leakage. The current uncertainty is 2.9×10^{-14}, which is limited by the distributed cavity phase shifts. The operation have been stopped from November, 2000, and the modification and reevaluation of the uncertainty is under way now to improve the uncertainty level.

2. Cs Atomic Fountain Frequency Standard, JF-1

A cesium atomic fountain frequency standard, named JF-1, is developed. The uncertainty evaluation is in progress. The detail of the structure of the JF-1 is described in [2].

The JF-1 is operated using a MOT, because it provides large signal, which is advantageous for the frequency stability. In order to reduce the collisional frequency shift, we employed state selection. In addition, we developed two techniques to lower the initial density of the atomic cloud so that the collisional frequency shift is reduced without reducing the number of atoms. The first one is to use an atom trap that produces lower density atomic cloud than a normal MOT. The second one is to expand the atomic cloud quickly. These techniques allowed us to observe a linear relationship between the atom number and the collisional frequency shift with an uncertainty below 10^{-15} by extrapolation method.

The Ramsey fringes with the narrowest linewidth (FWHM) of 0.8 Hz were observed. The microwave frequency was stabilized to the central Ramsey fringe and the frequency stability was measured against a hydrogen maser with the observed stability of $\sigma_y(\tau)=5\times10^{-13}\tau^{-1/2}$.

The uncertainties of the second order Zeeman shift, the blackbody radiation shift, the cold collision shift, and the shift due to the distributed cavity phase shift, were estimated to be 3×10^{-16}, 4×10^{-16}, 6×10^{-16}, and 5×10^{-16}, respectively [3,4]. The uncertainty of the JF-1 is currently expected to be 1.4×10^{-15}.

3. Ultra-Low Phase-Noise Microwave Oscillator

We have been developing a cryogenic sapphire oscillator (CSO) for a local oscillator of a Cs atomic fountain. The CSO is a loop oscillator incorporating the sapphire-loaded cavity (SLC), which operates on a Whispering Gallery mode, $E_{15,1,1}$ (quasi-transverse magnetic polarization) of 10.812 GHz. The SLC was cooled in a cryostat with liquid helium. The turnover temperature for the SLC was measured at 6.14 K. At this temperature an unloaded Q-factor of 1×10^9 and a fractional frequency curvature ($1/f\ d^2f/dT^2$) of -1.7×10^{-9} K^{-2} were also measured. A temperature control of about 1 mK at the turnover temperature was provided by the temperature controller using the thermometer and the heater. The frequency stability of the CSO was measured from a 20 kHz beat between the CSO and the reference signal from a hydrogen maser. The Allan standard deviation was calculated to be 6×10^{-13} at integration times of 1 s, which is limited by a hydrogen maser reference [5]. This oscillator is also expected to supply low noise frequency to the femtosecond mode-locked laser for optical frequency measurement.

4. Cavity auto-tuned Hydrogen Maser

In order to evaluate the frequency stability and uncertainty of the atomic fountain frequency standard, and to calibrate the TAI with small uncertainty, we need a local oscillator which has small enough short-term stability and whose frequency is well known relative to the TAI. For this purpose, we have been developing a hydrogen maser with simple cavity auto-tuning mechanism, under the collaboration with Anritsu Cooporation (Japan). We obtained the medium-term stability of $\sigma_y(\tau)=2\times10^{-15}$ at $\tau=10^3$ s~10^4 s without auto-tuning. By using the cavity auto-tuning, we could improve the frequency stability by an order of magnitute at $\tau=10^5$ s with the $\sigma_y(\tau)$ smaller than 2×10^{-15} at $\tau=2\times10^3$ s to 10^6 s.

5. Time and Frequency Comparison

We have been participating in the two-way satellite time transfer experiment to link Asia-Pacific region. Also, we recently introduced a geodetic-type GPS receiver, Ashtech Z12-T (Metronome). We participated in the international campaign initiated by the BIPM to calibrate geodetic-type GPS receivers. We were involved in the calibration trip of the BIPM receiver in Asia, starting on November 2001. In addition, we have started the regular report of the Z12-T data to BIPM.

6. Optical Frequency Measurement

We have been developing an optical frequency measurement system using a femtosecond mode-locked laser and a photonic crystal fiber (PC fiber) connecting a cesium microwave frequency standard and optical frequencies.

Our source of an optical frequency comb was a chirped-mirror- dispersion-controlled mode-locked Ti:sapphire laser, of which repetition rate f_{rep} and pulse duration were 150 MHz and 11 fs, respectively. By using a PC fiber, made at University of Bath and Mitsubishi cable corporation the comb was broadened over one octave, i.e., from 480 nm to 1070 nm at -20 dB. We stabilize f_{rep} by using PZT and carrier-envelope-offset frequency f_{CEO} by using AOM to control the pump power. We use a Hydrogen maser as a microwave reference.

To realize the continuous-wave optical frequency synthesizer, we try to combine an optical comb and a continuous-wave optical parametric oscillator (cw-OPO). We succeed to phase-lock a cw-OPO to an optical frequency comb in the 830 nm region. The optical frequency of the optical parametric oscillator was controlled by changing the cavity length of the pump laser. Its control bandwidth was about 20 kHz. We consider it will be available for optical frequency measurement of the low power lasers [6].

Evaluation and improvement of the uncertainty and the noise characteristics of the comb system involving microwave processing are now undergoing [7] to determine the absolute frequencies of the frequency-stabilized lasers. Also, we plan to begin the calibration service for optical frequencies of stabilized lasers in 2004.

The absolute frequency of an iodine-stabilized Nd:YAG laser is measured to be 563 260 223 507 897 (58) Hz using a femtosecond optical comb, when the laser was stabilized on the a_{10} component of the R(56)32-0 transition of $^{127}I_2$ for a cold-finger temperature of $-10\,^{\circ}C$ [8].

Frequency stability and reproducibility of the acetylene-stabilized diode laser are evaluated by the femtosecond comb using a H-maser as a frequency reference. The absolute frequency of the laser stabilized on the P(16) transition of $^{13}C_2H_2$ is determined to be 194 369 569 383.6 (1.3) kHz [9]. The acetylene-stabilized laser serves as an important optical frequency standard for telecommunication applications.

7. Development of the frequency calibration system

As a national laboratory responsible for time and frequency, we routinely perform the calibration of the frequency standards. We have maintained and improved the calibration procedure and the uncertainty evaluation method under the quality system implemented in March 2001. In addition, the remote calibration method using GPS is under development. The details of this remote calbration system are described in [10].

References

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