Status Report to the 16th meeting of the CCTF on Time and Frequency Activities at KRISS

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1. Atomic Frequency Standards

1.1 The KRISS-1 frequency standard

Improvement of laser system

The master laser is changed to ECDL (extended-cavity diode laser) from DBR (Distributed Bragg reflector) diode laser [1]. The frequency of ECDL is locked to the crossover resonance between F=4 to F'=4 and F=4 to F'=5 transitions using the FM spectroscopy. In order to generate an optical pump (F=4 to F'=4) and a probe light (F=4 to F'=5), two acousto-optic modulators are used. The laser beams are delivered to the KRISS-1 by polarization maintained optical fibers. These changes make the laser beam profile and the stability of alignment greatly improved.

Accuracy evaluation

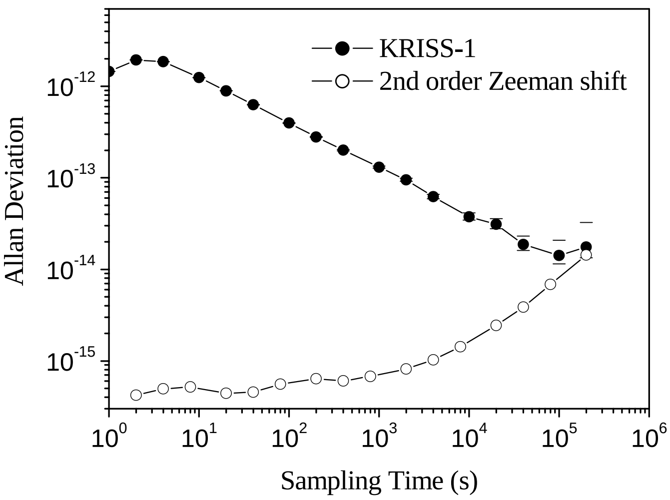

Fig. 1. Allan deviation of KRISS-1 (closed circles) and 2nd order Zeeman shift (open circles).

Table 1. Uncertainty budget

Physical Effect	Shift ($\times 10^{-14}$)	Uncertainty ($\times 10^{-14}$)
Quadratic Zeeman	31900	0.1
Second-Order Doppler	-30	0.04
Cavity Pulling	28.1	0.15
Rabi Pulling	-0.4	< 0.1
Magneic Field Inhomogeneity	-8.0	0.02
End-to-end Cavity Phase Shift	406.5	6.8
Black Body Radiation	-1.6	0
Gravitational Shift	0.9	0.1
Electronics	0	0.6
Combined Type B Uncertainty		6.8

The frequency stability of KRISS-1 is $4\times10^{-12}\tau^{-1/2}$ as shown in Fig. 1. The limit of long term stability is 1.4×10^{-14} at the sampling time of 10^5 s. Recently we measured the stability of 2nd order Zeeman shift which get worse as time goes by, as shown in Fig. 1. We predict that the drift of 2nd order Zeeman shift is one of the major reasons that limit the long term stability of KRISS-1. We may improve this problem by compensation of 2nd order Zeeman shift.

Table 1 shows the uncertainty budget of KRISS-1. The end-to-end phase shift measured by the beam reversal experiment is 4.1×10^{-12}, and the uncertainty is measured to be 6.8×10^{-14}. The frequency shift caused by magnetic field inhomogeneity has been determined by Shirley's Rabi pedestal method [2]. The frequency shift and uncertainty is measured to be 8×10^{-14} and 2×10^{-16}, respectively. The overall uncertainty was estimated as 6.8×10^{-14}, most of which was caused by the measurement error of the end-to-end cavity phase shift.

1.2 Cesium atomic fountain standard

We have constructed a cesium atomic fountain frequency standard at KRISS. In our fountain, cesium atoms were launched upwards by using an optical moving molasses method after they were cooled in a magneto-optical trap. The temperature of launched atoms was about 2.5 K. We were able to observe Ramsey fringes of 1 Hz linewidth on the 9.2 GHz clock transition of cesium atoms [3-5].

We are presently building a second fountain. The new apparatus will include an improved fluorescence collector and the signal will be normalized to the total number of atoms. In the second fountain, we are going to install a second microwave cavity for magnetic state selection of atoms [6].

The fabricated microwave cavity system installed in the second fountain consists of two separated, identical, TE_{011} mode cylindrical cavities. One is used for microwave interrogation and the other for magnetic state selection. The measured loaded Q is about 10 000. Both cylindrical cavities are fed by two resonant rectangular cavities with a hole of 5 mm diameter.

The fluorescence collector system consists of two identical fluorescence collectors. Both fluorescence collectors are composed of two semi-spheres with different diameters. The collection efficient of the fluorescence collector is estimated to be around 50 %.

We are currently assembling the second fountain system and testing performance of each component of the second fountain. The second fountain system of KRISS will be completely assembled soon.

1.3 Slow atomic beam frequency standard

At present, we are improving the first developed slow atomic beam frequency standard [7,8]. A 35-cm long H-plane microwave cavity is designed and fabricated. The microwave cavity tuning has been finished. We predict the linewidth of Ramsey fringe to be approximately 20 Hz with the new microwave cavity. And the beam tube is changed to the aluminum chamber and wounded by solenoid coil to generate the longitudinal magnetic field. This system will be operated as a thermal beam frequency standard until new slow atomic beam generator based on the MOT [9] is developed.

2. Optical Frequency Standard Under Development

At the optical frequency domain, we have recently started a long-term research project toward the realization of an Yb optical lattice clock. The idea of the optical lattice clock is originally proposed by Katori with ^{87}Sr fermions. Among the group-II atoms, however, we have recently pointed out that ^{171}Yb fermions (natural abundance 14.4%, nuclear spin = 1/2) are also have unique features for the ultimate operation of the optical lattice clock with the natural line width of 10 mHz. Especially, we have demonstrated a compact violet Yb MOT with recently developed InGaN violet laser diodes, in which we could trap more than 1.4 x 10^6 ^{171}Yb fermions, with $6s^2\,{}^1S_0$ - $6s6p\,{}^1P_1$ dipole-allowed transitions at 398.9 nm. In addition, we have completed the development of an optical frequency synthesizer with a phase-locked femtosecond mode-locked Ti:Sapphire that can be used not only for the absolute optical frequency measurement, but also for the optical lattice clock work.

In order to load the cold Yb atoms into the optical lattice formed by an intense single-mode electric field at the magic wavelength of 752 nm, we need to make the temperature of Yb atom cloud below 10 μK. The technical difficulties of Yb optical lattice clock are to make stable lasers at 555.8 nm for second-stage trapping with $6s^2\ ^1S_0$ - $6s6p\ ^3P_1$ intercombination transition and at 578.4 nm for the optical clock excitation with $6s^2\ ^1S_0$ - $6s6p\ ^3P_0$ doubly spin-forbidden transition. Both wavelengths can be accessed by using dye lasers, but we are now trying to use the second-harmonic outputs of two solid-state DFB fiber lasers emitting tunable single-mode outputs (> 1 W output power) at the fundamental wavelengths of 1111.6 nm and 1156.8 nm, respectively. We are now also constructing a modified vacuum chamber for optical lattice configuration with Zeeman slower and stable laser sources with high frequency stability at 555.6 nm and 578.4 nm employing an Yb atomic beam machine. We expect at the end of year 2004 we can try to detect the first signal from the Yb optical lattice.

3. Time and Frequency Comparisons

We have four cesium frequency standards (HP5071A) and two Hydrogen masers (Sigma-Tau, KVARZ), which are used to generate UTC(KRIS). Newly developed algorithm is used to generate UTC(KRIS) as an ensemble time scale from Oct. 2003 and is still under development. We are improving the system for time keeping by introducing more cesium frequency standards operating in other laboratory and a multi-clock phase measurement system using 5 MHz rather than 1 PPS output from the clocks.

For the routine international time comparison of UTC(KRIS), we operate two single-channel GPS receivers (TTR-6) and one multi-channel GPS receiver (Topcon Euro-80) for the GPS common-view time transfer using the BIPM tracking schedule. From Oct. 2003, the data from the multi-channel receiver is reported to BIPM. The research to use the GPS data to keep UTC(KRIS) close to UTC is also under way.

Two-way satellite time transfer via JCSAT-1B using CRL multi-channel modem has been evaluating among several stations in Asia. Preliminary result of comparison between KRISS and CRL shows measurement accuracy down to 1 ns level. One more TWSTFT facility via PAS-8 has been established for Oceania and North America link. In addition, another system will be equipped for Europe link in this year.

System for short baseline precise time comparison using carrier phase is under development and the precision is expected to be less than several hundreds ps.

4. Dissemination of Time and Frequency

We are operating Time Server with three workstations to allow users to synchronize computer clocks via the Internet using Simple Network Protocol (SNTP). UNIX, LINUX based time synchronization software was also developed and the error was measured to be less than 0.1 ns after automatic compensation of time delay on the network. The number of connections to the server is around 6 million per day. A 5-MHz broadcasting station (call sign: HLA) is maintained for dissemination of Korea Standard Time (KST) and Korea Standard Frequency (KSF). More than 100 organizations are using the signal for the reference. Preliminary research on the possibility of establishing new broadcasting station with carrier frequency around 50 kHz is under way.

References

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