HYDROGEN FREQUENCY AND TIME STANDARDS OF IEM "KVARZ"

N.A. Demidov, S.A. Kozlov, V.A. Logatchev, A.A. Uljanov
Institute of Electronic Measurements (IEM) "Kvarz"
Russia, 603009, Nizhny Novgorod, Gagarin avenue, 176
Fax: (8312) 66–55–62, E-mail: kvarz@nnov.sitek.net

The latest achievements of the Institute of Electronic Measurements "Kvarz" in the field of hydrogen frequency and time standards development are reported.

Keywords: hydrogen maser, frequency and time standard.

1. INTRODUCTION

IEM "Kvarz" deals with development and production frequency and time standards based on hydrogen masers over 30 years. Tree generations of hydrogen masers have been developed and over 350 units have been manufactured for this period of time. The State Frequency and Time Service of Russia, Glonass system ground stations, very long base interferometers of the Russian Academy of Sciences are supplied with IEM "Kvarz" hydrogen masers. They are also used in National Time and Frequency Services or VLBI in a number of countries.
The masers of the 3[d] generation – CH1-75 active and CH1-76 passive hydrogen masers produced by IEM "Kvarz" over 10 years and their characteristics have been reported before [Ref. 1]. Nowadays the Institute has developed new masers models: CH1-75A Active Hydrogen Maser and CH1-89 Passive Hydrogen Maser differed by improved performances, which are going to be manufactured from 2003.

2. CH1-75A ACTIVE HYDROGEN MASER

CH1-75A Active Hydrogen Maser is CH1-75 maser modernized option.
The main maser design peculiarities are the following:
- the maser cavity is made of cital – the material with a small linear expansion temperature coefficient ($\sim 2\cdot 10^{-7}/^{o}$ C), that has allowed to get a small maser frequency temperature coefficient ($1\cdot 10^{-15}/^{o}$ C) together with precision multizone two stage thermostat system to maintain $0{,}001^{o}$C temperature accuracy;
- fivelayer magnet screen made of permalloy with high magnetic permeability provides a big shielding factor (~500000) and a weak frequency sensitivity to external magnetic field alteration (less than $1\cdot 10^{-14}$/Gauss);
- superhigh vacuum (~ 10^{-7} mm Hg) in two chamber vacuum system is provided by small dimensions pumps: original construction getter pump for hydrogen pumping and a small efficiency ion pump for residual gases pumping;
- maser storage bulb is covered with a special type phtoroplast providing a small frequency shift due to hydrogen atom collisions with storage bulb walls and this shift high stability;
- maser construction is characterized by small dimensions and weight (90kg).
The cavity autotuning system block diagram of the CH1-75A maser in which the atom line width modulation method is used is shown in fig.1. It differs from CH1-75 cavity autotuning system by having a microcomputer which produces a statistic calculation (averaging, excluding frequency jumps with robust estimation help and etc) of the reversible counter 1 measurements results. The system goes over to the step regime while approaching the cavity detuning zero. For all that the microcomputer control signal gives the information only about the cavity detuning sign and the cavity frequency changes independent on detuning value on the fixed step equal to $(1\div 2)\cdot 10^{-15}$ (relatively to maser frequency).
The microcomputer introduction into the cavity autotuning system has improved maser frequency stability for 1h – 1d time intervals approximately 2 times and has allowed to reach the value $(5\div 7)\cdot 10^{-16}$ per 1 day.
This system permits to perform the cavity autotuning not only with the use of the second active hydrogen maser but also with the use of the passive hydrogen maser or a high stable BVA quartz oscillator. Since frequency instability of the passive hydrogen maser or the quartz oscillator is a few times worse than the active hydrogen maser one, in this case the cavity tuning cycle changes. The count time of reversible counter 1 decreases from 100 to 10 seconds, and the measurements number statistically calculated by the microcomputer increases. In this case it is possible to obtain a maser frequency stability $3\cdot 10^{-15}$ per 1 day in the cavity autotuning regime.
Thus the cavity autotuning with the second active maser gives (3÷5) times better results in frequency stability compared to the cavity autotuning with a passive hydrogen maser or BVA quartz oscillator.

CH1-75A maser frequency instability investigations results for different averaging time intervals are shown in fig.2.
CH1-75A has a built-in precision frequency comparator and a frequency meter that allow to measure the 5 and 100 MHz signals frequency instability.
Thus it is possible having two CH1-75A masers not only to perform the cavity autotuning with maximum accuracy, but also to carry out main maser metrological performances permanent monitoring with the data output to an external PC and to construct frequency instability dependence graphs on time. So the problems connected with the instrument verification are excluded.
The hydrogen maser important characteristic is a systematic frequency drift. CH1-75A maser has a very small drift due to the corresponding cavity making and storage bulb covering technologies. CH1-75A frequency drift without cavity autotuning is $5 \cdot 10^{-15}$ per 1 day. After the long (1year) operation the drift decreases to $(5 \div 10) \cdot 10^{-16}$ per 1 day. The initial frequency drift with the cavity autotuning is $1 \cdot 10^{-15}$ per 1 day and in 1 year time operation it decreases to less than $3 \cdot 10^{-16}$ per 1 day.
The arrangement allowing partly to compensate the maser frequency drift is introduced into the CH1-75A maser construction. The compensation value can be corrected within $1 \cdot 10^{-16} \div 1 \cdot 10^{-14}$ per 1 day range according to the periodic maser frequency comparison results with the reference.
Another important characteristic is a maser life time. On the whole it is determined by the hydrogen atom source, by getter and ion pumps.
The construction improvements made for the latest years, the additional ion pump introduction for cavity pumping have allowed to increase the maser life time to 15 years.

3. ACTIVE HYDROGEN MASER WITH AUTONOMOUS CAVITY AUTOTUNING BY CAVITY FREQUENCY SWITCHING METHOD

Active hydrogen maser with autonomous cavity autotuning by cavity frequency switching method [Refs. 2,3] was developed and preliminary investigations of maser frequency stability were performed. This maser physical package is the same as in CH1-75A maser, but the second varicap for the cavity frequency modulation is introduced. Some measures have been taken in PLL unit for undesirable frequency components excluding. The modulator in the maser is the 5 MHz frequency divider which has a pulse output moment adjustment for synchronous detector signals phasing and 2 half periods pulse duration adjustment for the maser cavity establishment to the spin – exchange tuned frequency.
The preliminary results of maser frequency instability $1{,}5 \cdot 10^{-15}$ per day for 15 days time interval were obtained.

4. CH1-89 PASSIVE HYDROGEN MASER

The recently developed CH1-89 Passive Hydrogen Maser greatly differs from CH1-76 passive maser by the new discriminator construction, providing the better frequency stability, by having a microcomputer, by the extended functional possibilities and by small dimensions and weight.
CH1-89 experimental measured frequency stability is $3 \cdot 10^{-13}\ \tau^{-1/2}$ $(1s \le \tau \le 10^3 s)$, $3 \cdot 10^{-15}$ per 1 day (see fig.3), frequency drift is not more than $1 \cdot 10^{-15}$ per 1 day. The maser has a very small frequency temperature coefficient ($3 \cdot 10^{-15}/\,^{o}C$), a small weight (40 kg) and a long life time (10 years).

5. REFERENCES

1. N.A. Demidov et all. Progress in development of active and passive hydrogen frequency standards at IEM "Kvarz". Proc. of the 11th European Frequency and Time Forum, Neuchatel, Switzerland, 1997, p.p. 572-575.
2. B.A. Gaigerov, G.A. Elkin. Measurement Technics, 1968, № 6.
3. H.E. Peters. Design and performance of new hydrogen masers using cavity frequency switching servos. Proc. of the 38th Frequency Control Symposium, USA, 1984, p.p. 420 – 427.

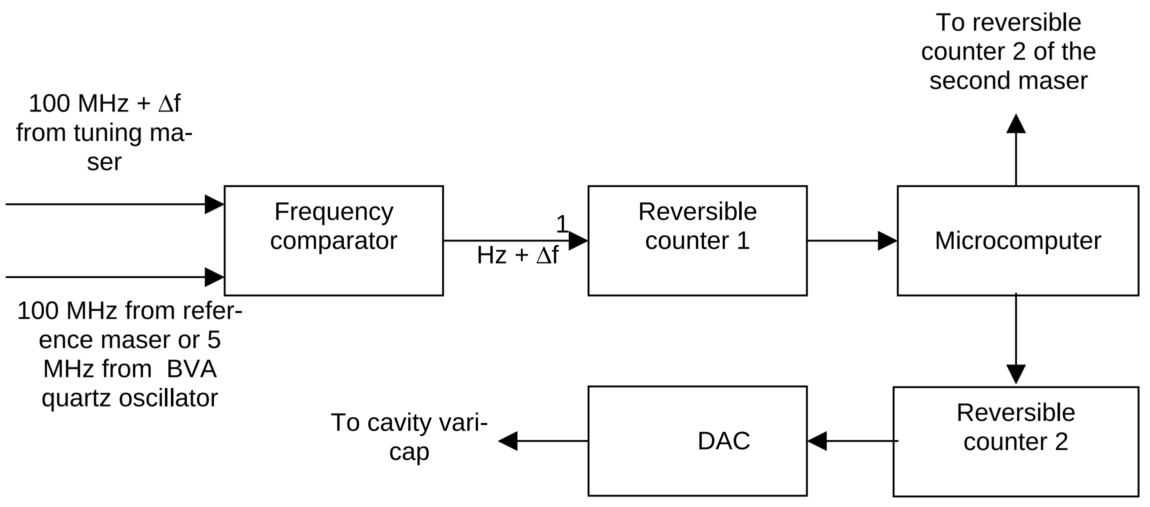
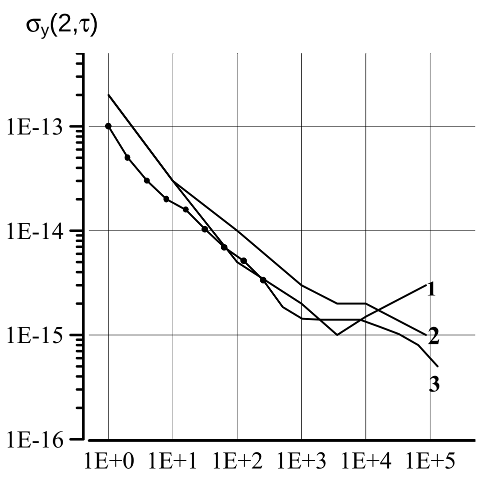


Fig. 1. Cavity autotuning block diagram



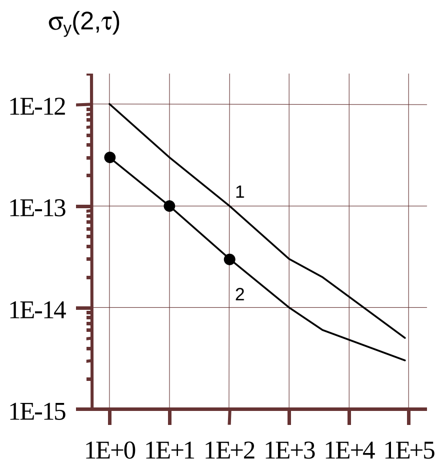
Averaging time, τ, seconds

Fig.2. CH1-75A Active Hydrogen Maser frequency instability dependence on averaging time

1 – without cavity autotuning (specification)

2 - with cavity autotuning on the second maser (specification)

3 - with cavity autotuning on the second maser (experimental results)



Averaging time, τ, seconds

Fig.3. CH1-89 Passive Hydrogen Maser frequency instability dependence on averaging time

1 – specification

2 - experimental results