Progress on Passive H-maser for Compass System

Ren-fu Yang, Jing Li, Hai-bo Chen, Ji-hong Zhang, and Lian-shan Gao
Beijing Institute of Radio Metrology & Measurement, Beijing, P. R. China
E-mail: yangrenfu@163.com

Abstract

The Rubidium atomic frequency standard is at present the basic clock technology for the Chinese Compass Navigation payload. What's more, hydrogen atomic clock will become another critical satellite equipment for the navigation system. In this work, the authors report the latest progress in a space borne passive hydrogen maser for Chinese Compass satellites. The preliminary measurement result of long-term frequency stability in our passive H-maser on ground is 2E-14 over averaging time of ten thousand seconds.

Keywords: Hydrogen atomic clocks; Time and Frequency; GNSS; COMPASS system

1. INTRODUCTION

The hydrogen atomic clock was developed and realized in the early 1960s by N. Ramsey at Harvard University [1-3]. Its found is an extension of the attempt to increase the precision of atomic beam magnetic resonance by narrowing the atomic linewidth, i.e., the Ramsey's separated oscillatory field's technique. In a passive mode of hydrogen atomic clocks, when the quality factor is smaller than 0.172, and a microwave interrogation signal whose frequency is close to the atomic transition frequency is injected to the microwave cavity, a steady-state simulated emission can still be observed. The passive hydrogen atomic clock approximates as a microwave amplifier [4]. Since utilization of magnetron microwave cavity, the passive hydrogen clock has smaller volume than the active hydrogen clock.

Due to its excellent frequency stability performance and relatively small volume, the passive hydrogen clock can be utilized in satellite of global navigation system. The passive hydrogen atomic clocks have been the baseline clock technologies for the experimental satellites of Galileo navigation system in the first time to fly [5,6], which is a very successful try. The Compass system (also known as Beidou-2, BD-2) is a project to develop an independent global satellite navigation system by China in recent years. In order to improve to precision of position and navigation, the passive hydrogen atomic clock is the one of candidates as the spaceborne master clocks of BD-2 system. The satellite-based passive hydrogen atomic clocks are always being developed by Beijing Institute of Radio Metrology and Measurement (BIRMM) in China.

2. PROGRESS AND RESULTS

2.1 Practical realization of the satellite-based hydrogen clock

In our satellite-based hydrogen atomic clocks, a beam of hydrogen atoms is formed by dissociating the hydrogen molecular in a RF discharge. A state selector with quadrupole field configuration deflects the hydrogen atoms of high hyperfine states into a quartz bulb (volume ~400 cm^3). The residual gas of inner vacuum system was absorbed by the getter pump situating near dissociator. A Teflon layer coats inside the bulb in order to prolong coherence time of atomic ensemble and microwave field. Surrounding the bulb, a 1.42 GHz hyperfine transition field is produced by a magnetron microwave cavity. The frequency of the microwave field in the cavity is always equal to that of the injected signal by a servo loop. The cavity is tuned at an angular frequency very close to the atomic transition angular frequency. A weak static magnetic field (c-field) paralleling the cylindrical axis of microwave cavity establishes the quantization axis. The microwave cavity is enclosed within four layers of high permeability magnetic shielding. The transmission mode is using in our hydrogen clocks. An interrogation signal whose frequency is closed to the atomic transition frequency is injected in one coupling loop and the amplified signal is picked up by another one. Both of coupling loops situate the points of maximum magnetic field on the middle of cavity wall.

2.2 Design and simulation of microwave cavity

Since the characteristic of microwave cavity of satellite-based hydrogen atomic clocks is very complicated, tiny changes of any geometry parameter influence the oscillating mode obviously. The typical cylinder cavity has two main parameters of cavity length and radius. Cavity frequency and Q value vary with these two parameters delicately. In addition, the detailed structure of microwave cavity must also consider the practical conditions such as the bulb's size and the efficiency of sate-selector.

Through our calculation and analysis based on finite element method, when cavity length is 194mm and radius is 65mm, the frequency and the Q value are 1.43 GHz and 14988, respectively. According to simulation results of the optimized parameters, the magnetron microwave cavity is fabricated precisely. The measured frequency and the Q value are 1.49GHz and 10547 in experiment, respectively. Contrasting with calculation, the cavity frequency is consistent very well, but the Q value is a bit smaller than that of calculation. This is due to some error's accumulations in calculation and experimental machining. The magnetic filed distribution inside microwave cavity of satellite-based hydrogen atomic clocks is plotted by HFSS soft as shown in Fig. 1. In centre zone, the magnetic filed is very uniform along the axial direction.

2.3 Activation and test experiment of getter pumps

The getter pumps can provide very economical and compact pumping in hydrogen atomic clocks. Since the pumping speed is directly proportional to the total surface area of the getter metal, it is as possible as to increase the ratio of surface to volume for our titanium getter materials. Activation is another obligatory process to prepare the getter surface for pumping. When the getter material is exposed to air, the material's surface is covered by reacted gases of oxides, nitrides, etc. The getter material will be essentially inert and does not provide an active getter-pumping surface. The washing reaction of alkali (NaOH) and acid (HNO_3+HF) in getter surface must be operated several times. According to characteristic of titanium alloy, we design the appropriate procedure of activation. The compositive picture of our experiment system in getter activation and test process is shown in Fig. 2.

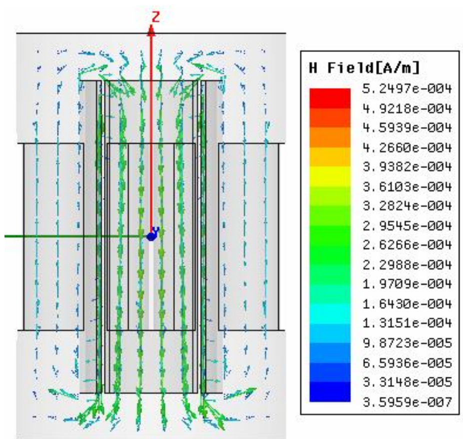

Fig 1. The distribution of magnetic field in the microwave cavity of hydrogen atomic clocks.

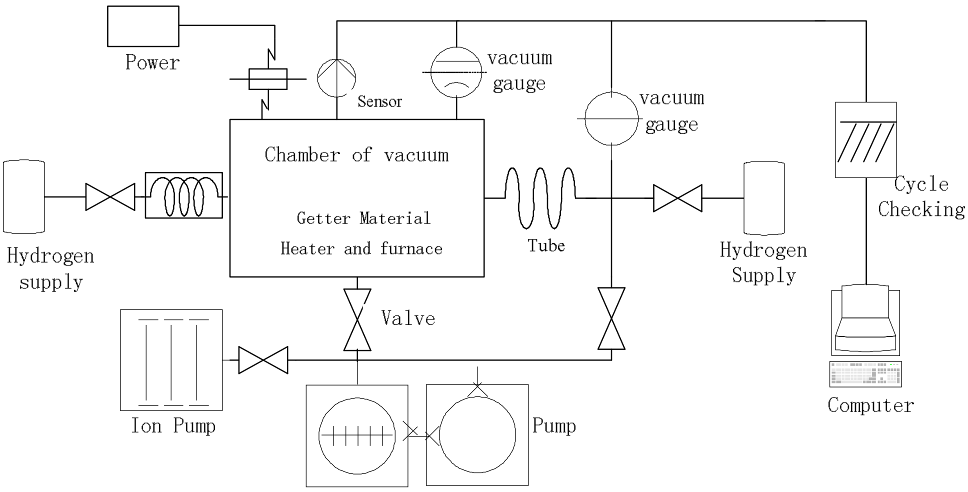

Fig. 2 The activation and test experiment system of getter material in BIRMM.

The getter material is annealed and baked at 800℃ during 24 hour under ultrahigh vacuum system. After the activating and outgassing, a newly clean and active surface of titanium getter can begin to react with the active gases. When holding the pressure value of vacuum gauge below 5E-5 Pa and stable hydrogen flow in about 600 Pa·L/day, an absorbed experiment of fleet hydrogen flow in getter pump runs several days. In result, the getter pump in our satellite-based hydrogen atomic clocks can absorb about 1.77 mol (39.2 L hydrogen gas at an atmospheric pressure) hydrogen atoms in total. The theoretical life of getter pump of hydrogen clocks can persist on at least 10 years.

2.4 Atomic gains in hydrogen clocks

Atomic gain and operational linewidth of the passive hydrogen maser are the fundamental parameters to the final clock characterization. As shown in Fig. 3, the interrogation power dependence of atomic gain and operational linewidth at resonance for four different flux controlled by a nickel pressure regulator has been measured when other operating parameters hold at normal settings.

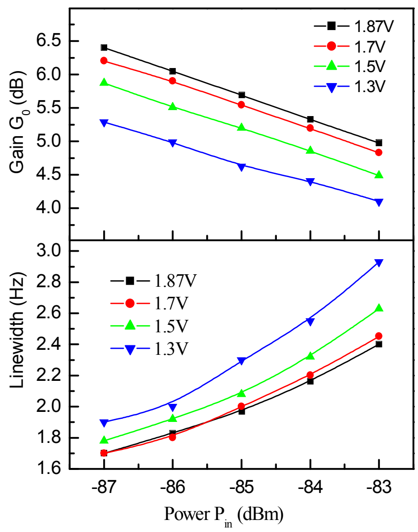

Fig. 3 Interrogation power dependence of atomic gain and operational linewidth at resonance for four different hydrogen pressures.

As decrease of interrogation power, the gain of our passive hydrogen clocks increases linearly and linewidth decreases concomitantly. Comparing experimental results at four different fluxes of hydrogen atom, higher hydrogen flow can lead to larger gain and narrower atomic linewidth. When the interrogation power sets -85 dBm and the voltage between ends of the Ni regulator is 1.87V, we obtain the gain of 5.7 dB and the linewidth of 2.0 Hz.

2.5 Preliminary result of the frequency stability

Fig. 4 shows the preliminary measurement result of the frequency stability of experimental clock settings at short- to medium- term averaging times up to about 100,000 s. Long-term frequency stability in our passive H-maser on ground is 2E-14 over averaging time of ten thousand seconds. By optimizing the operating parameters, the frequency stability in our passive hydrogen clocks could be improved further by controlling some systematic effects, especially thermal noise.

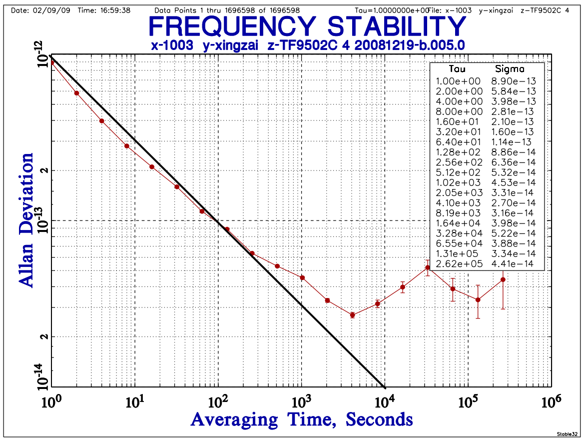

Fig. 4 Preliminary result of frequency stability of a passive hydrogen atomic clock in BIRMM.

3. CONCLUSIONS

In conclusion, the experimental settings and preliminary results of satellite-based hydrogen atomic clock in BIRMM have been performed. Microwave cavity was investigated and simulated in detailed using finite element method. The activation and test experiment system of getter materials was introduced. The vacuum pump of the hydrogen clock can ensure 10 years lifetime. A good gain or linewidth was obtained. The preliminary frequency stability also was measured.

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