A Frequency Tunable Gyrotron, Gyrotron FU CW IV

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***Abstract*—A sensitive NMR spectroscopy using a dynamic nuclear polarization (DNP) is an effective method to enhance the sensitivity of such versatile analytical technique. Its high performance realization requires a frequency tunable and powerful radiation source. A new gyrotron is developed with the aim of achieving the wide frequency tuning. The Gyrotron FU CW IV operates at magnetic fields in the range of between 4.9 T and 5.2 T, and continuous frequency tuning in 6 GHz interval can be realized.**

I. Introduction

A sensitive NMR spectroscopy using a dynamic nuclear polarization (DNP) is effective in enhancing the sensitivity of this versatile analytical technique [1-4]. Such enhancement can be achieved by irradiating the sample with a beam of strong electromagnetic wave having submillimeter wavelength.

Among radiation sources in this wavelength range, the high frequency gyrotrons are characterized by their capacity to generate the most powerful radiation. The Gyrotron FU CW II with 8T liquid-He free superconducting magnet was developed as radiation source for 600 MHz-proton NMR spectroscopy. The corresponding frequency of the electron resonance is 394.6 GHz.

Sufficient output level (~20 W) is produced by this gyrotron. The experiment on highly sensitive DNP-NMR spectroscopy will be carried out in the middle of 2008 fiscal year. It is well known that the enhancement the NMR sensitivity depends strongly on the frequency of the irradiating electromagnetic wave. In order to realize a high performance DNP-NMR spectroscopy, a new radiation source with the function of contineous tunability in the frequency range ±0.25 GHz around the nominal frequency. This demand can not be satisfied by a conventional high frequency gyrotron having typical tunability of several tens MHz.

Therefore, a new gyrotron, Gyrotron FU CW IV, is being developed with the aim to achieve such wide frequency tuning.

II. Experimental Results

Fig. 1 shows a cross section of the gyrotron. The gyrotron consists of a 10 T liquid-He free superconducting magnet, a demountable tube, a vacuum pump system and power supplies. In the gyrotron, the similar cavity (radius of 1.915 mm and length of 20 mm) with that of the Gyrotron FU CW II is installed in the magnetic field produced by the superconducting magnet. The radiated power of the TE12 mode is observed by using a pyro-electric detector. In the experiment, the cathode voltage was adjusted at -19 kV. Although the radiated power depends on the magnetic field intensity, the gyrotron output is continuous.

(a)

(b)

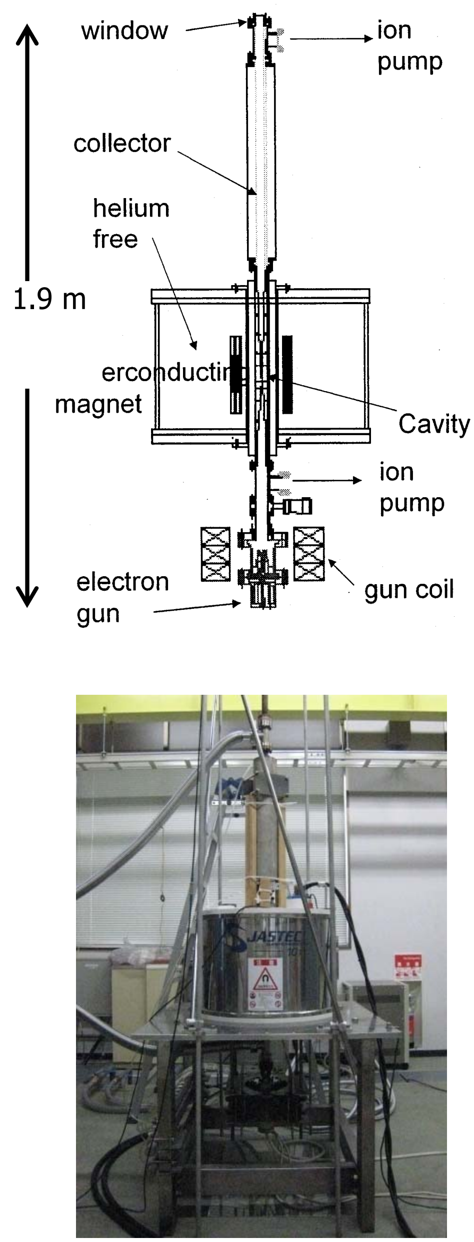

Fig. 1 (a) The cross section and (b) the photo of the Gyrotron FU CW IV.

The frequency was measured by a hetero-dyne detection

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system consisting of a harmonic mixer and a synthesized CW generator as a local oscillator whose frequency stability is higher than 10^{-9} (Fig. 2). The intermediate frequency signal is observed by a spectrum analyzer. The accuracy of the frequency measurement is high enough ($\sim 10^{-8}$) to determine the operating mode.

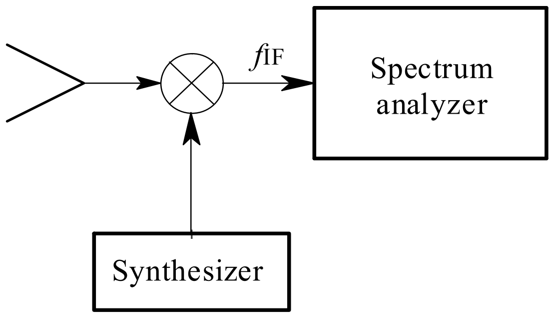

Fig. 2 The frequency measurement system consisting of synthesized CW generator as a local oscillator and harmonic mixer

Fig. 3 (b) shows the measured frequency as a function of the magnetic field intensity. The gyrotron output frequency continuously changes with the magnetic fields and covers a wide range from 134 GHz to 140 GHz operating on the transverse TE_{12} mode but in a sequence of different axial modes TE_{12l}. The peaks on Fig. 3 (a) corresponds to different indices l. The experiment verifies the feasibility of this method of tuning.

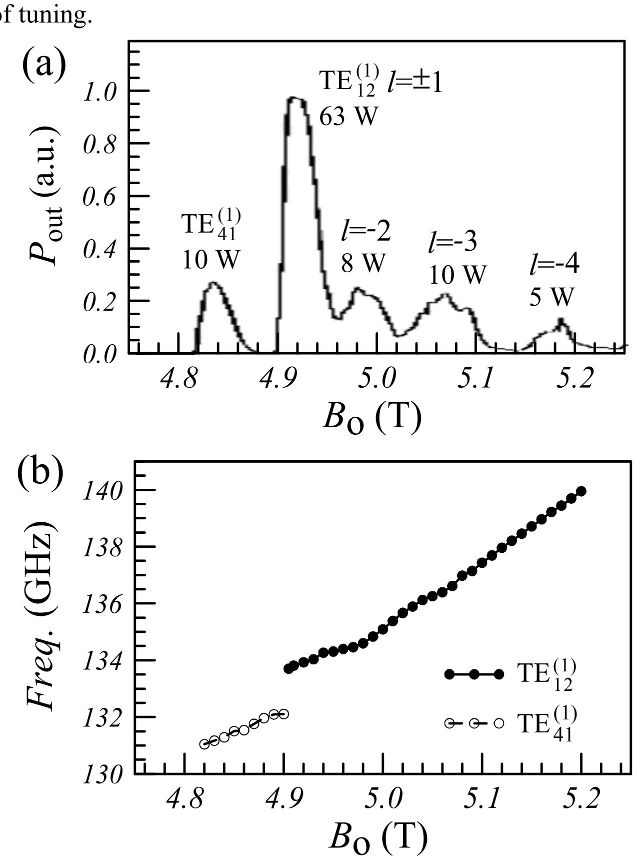

Fig.3 (a) The radiated power of TE_{12} mode and (b) the output frequency as a magnetic field intensity.

Table 1 summarizes an output power measured by a water load together with the magnetic field intensity in the cavity region B_0, accelation voltage of electron beam V_b, beam current I_b, cavity mode, frequency measured by the hetero-dyne detection system.

Fig. 4 shows the output power measured by a pyro-electric detector. The fluctuations of output power are lower than 10% for a long time interval.

Table 1. Operation parameters of gyrotron FU CW IV.

B_0 (T)	P (W)	V_b (kV)	I_b (mA)	f_{meas} (GHz)	mode	N
3.5184	57.6	19	450	96.5625	TE_{01}	1
4.9	57.6	19	450	134.182	TE_{12}	1
6.11	83.8	19	450	168.2578	TE_{22}	1
6.41	47.1	19	450	175.7958	TE_{02}	1
7.309	52.4	19	450	200.8205	TE_{32}	1
7.6476	220	19	450	209.378	TE_{13}	1
8.559	68.1	19	450	227.758	TE_{42}	1
9.06	78.6	19	450	244.3197	TE_{23}	1

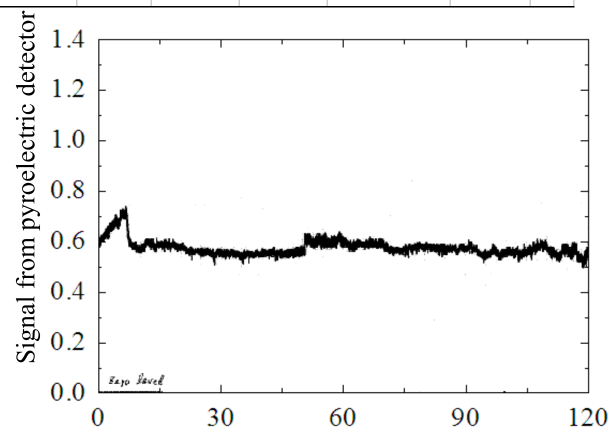

Fig. 4 The time evolution of the gyrotron output power.

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