A THz gyrotron FU CW III with a 20T superconducting magnet

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***Abstract*- The latest gyrotron included Gyrotron FU CW Series, Gyrotron FU CW III is introduced in detail. It consists of a 20T superconducting magnet, a demountable gyrotron tube, a 30 kV, 0.5 A, CW power supply for electron gun and additional coils in a gun region. The gyrotron has achieved the breakthrough of 1 THz and frequency step tunability up to around 540 GHz for fundamental operations and up to 1.08 THz for second harmonic operations. Application of the gyrotron to high frequency DNP-NMR is considered breafly.**

I. IINTRODUCTION

RECENTLY, gyrotrons with high field pulse magnets have achieved a breakthrough of 1 THz. [1),2)] It is great success for gyrotrons to be included in THz radiation sources with an advantage of high power output 0.1 to 10 kW. Such high power THz radiation can be used for many applications to high power THz technologies, for example, NMR at 1GHz with Dinamic Nuclear Polarization (DNP), X-ray Detected Magnetic Resonance (XDMR) experiment with high power THz radiation, accurate measurement of energy level of positronium, etc. In such applications, pulse operations of THz gyrotrons are not enough. Now, FIR FU began to develop Gyrotron FU CW Series for high power THz technologies.

The recent gyrotron FU CW III with a 20 T superconducting magnet is designed for high frequency operations up to 1 THz by using second harmonics. It was already constructed and tested successfully. In this paper, the results are presented.

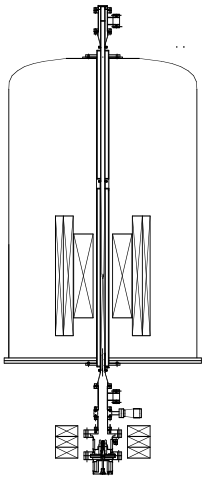

Fig.1 The cross section of Gyrotron FU CW III

Fig.2 The photo of Gyrotron FU CW III

II EXPERIMENTAL APPRATUS

Fig. 1 and Fig. 2 show the cross section and the photo of Gyrotron FU CW III. It consists of a 20 T Superconducting magnet, a demountable gyrotron tube and additional gun coils. Main designed parameters are shown in Table 1.

Table 1 Specification of Gyrotron FU CW III

Total height from electron gun to the window: 2.4 m
Superconducting magnet :
Maximum magnetic field : 20 T
Inner bore : 50 mm
Cavity :Radius: 1.95 mm, Length : 10 mm,
Designed frequency : 1013.7 GHz at the second harmonic,
Main cavity mode : $TE_{4,12}$, Q-factor : 23720
Operation mode: Complete CW
Operating magnetic field: 19.1 T for : $TE_{4,12}$
Triode-type electron gun:
Cathode radius: 4.5 mm,
Maximum cathode current: 1 A,
Cathode voltage: 30 kV
Gun coils:
Maximum input current: 300 A,
Maximum magnetic field: 0.183 T
Pumping bores:
1. Near the electron gun, 2.Near the output window
Water cooling jackets are installed at a cavity and a collector regions.

III OPERATION RESULTS OF GYROTRON FU CW III

Fig. 3 shows output power measured by a pyroelectric detector after an output window as a function of magnetic field intensity B_0 . B_0 is swept from 2 T to 20 T. Many radiation peaks appear, corresponding to the resonant field intensities for cavity modes. Cavity modes of almost all peaks have been identified. From the measurement of the output power for each radiation peak, typical output power is ranged from 100 to 200 W. Maximum frequency is 541 GHz.

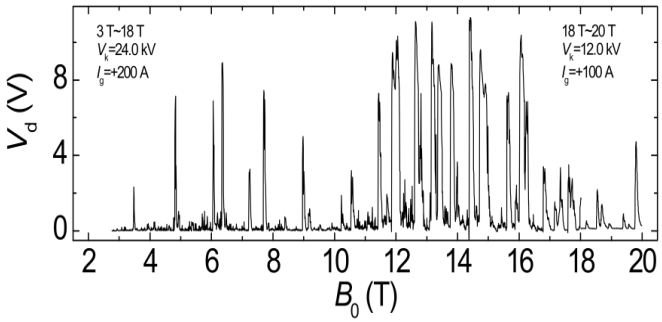

Fig. 3 0utput power at fundamentals measured after an output window as a function of magnetic field intensity B_0

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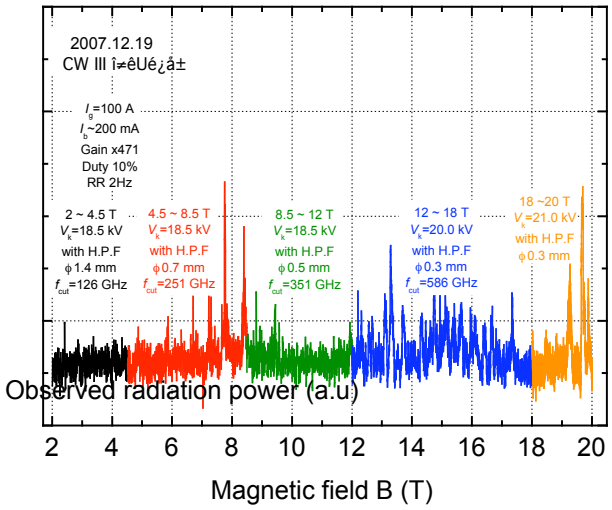

Fig. 4 Output power at the second harmonic resonance measured after high pass filter as function of magnetic field

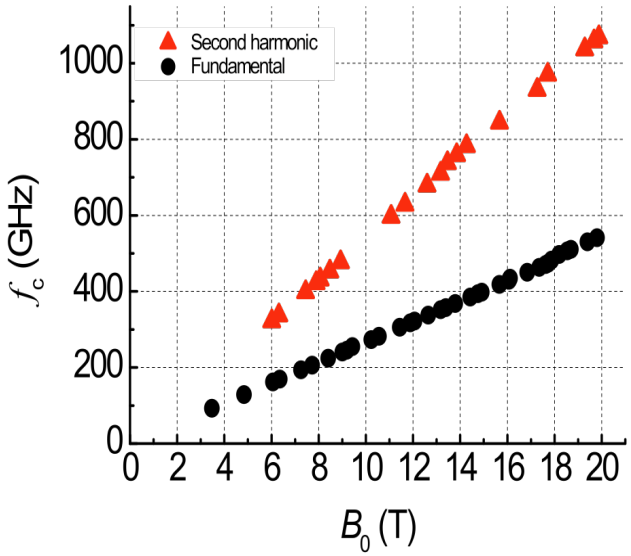

Fig. 5 Observed frequencies at the fundamentals (solid circles) and expected frequencies as electron cyclotron frequencies (triangles) as functions of magnetic field intensity B_0

Radiation power resulting from the second harmonic operations can be observed by using high pass filters with appropriate cut-off frequency. Fig. 4 shows observed radiation power after high pass filter as function of field intensity. Fundamental operations are removed from the observed radiation power. When magnetic field is varied from 2 T to 20 T , many radiation peaks appear at the second harmonic operations.

In Fig. 5, observed frequencies at the fundamentals are plotted by solid circles as a function of magnetic field intensity. Output power resulting from second harmonic operations was measured by a pyroelectric detector after high pass-filters. Expected frequencies for second harmonics are plotted as electron cyclotron frequencies by triangles. The magnetic field intensity is changed from 2 T to 20 T. The highest frequency is achieved by the complete CW operation near 20 T at second harmonic. It may be 1,080 GHz. Output powers at second harmonics are several tens W. In the case of output power measurement, the operation of the gyrotron is pulse mode. Typical repetition rate and duty ratio are 1 Hz and 40 percent, respectively. CW operation is achieved easily by extending the duty ratio. The output power is not changed, when the duty ratio is extended

IV APPLICATION TO HIGH FREQUENCY DNP-NMR

Gyrotron FU CW III can be applied for high frequency DNP-NMR experiments. Table 1 shows consideration on possibility of the application. For high frequency DNP-NMR, requested frequencies of ESR are shown in the column indicated by f_{ESR} and frequencies which Gyrotron FU CW III has achieved near the frequencies of f_{ESR} in the column of f_{meas}.

We can use the gyrotron for high frequency DNP-NMR even at 1 GHz. In the case, we should make precise design of the cavity optimized for each frequency of DNP-NMR.

V SUMMARY

In summary, Gyrotron FU CW III with a 20 T superconducting magnet has achieved high frequency operations beyond 1 THz in CW operation mode. It can be applied for many high power THz technologies, for example, high frequency DNP-NMR even at 1 GHz. Now, we are planning to develop next CW gyrotrons for measurement of energy levels of positronium and XDMR experiment.

Table 1 Measured output powers and frequencies for several cavity modes which may be applicable to high frequency DNP-NMR experiments

f_{NMR}, MHz	f_{ESR}, GHz	f_{meas}, GHz	$P_{meas.}$ W	Modes m,n	N (Gyrotron)
600	394.6	394.3 390.9	32 178	0,6 4,4	2 (FU CW II) 1(FU CW III)
700	460.4	456.2	220	6,4	1(FU CW III)
800	526.2	569.5	/	7,5	2(FU CW III)
900	591.9	616.4	/	6,6	2(FU CW III)
1000	657.7	672.0	/	1,9	2(FU CW III)

References

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