Design of Gyrotron FU CW V for accurate measurement of positronium energy level

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***Abstract*—Accurate measurement of difference between energy levels of positronium is a current important subject in the experimental physics of elementary particles. The frequency corresponding to the energy difference is about 203.39 GHz. At least, 100 watt CW power is requested for the direct measurement. We are now designing such a gyrotron FU CW V consisting of an 8 T superconducting magnet and a demountable tube.**

I. Introduction And Background

RECENTLY, an accurate experimental measurement of either for the positronium decay rate or hyperfine splitting is an important subject in the experimental physics of elementary particles [1]. A direct measurement of positronium's hyperfine splitting by utilizing a frequency tuning gyrotron and a Fabry-Perot cavity is planned to be done at the University of Tokyo. It will utilize a gyrotron oscillator that capable for delivering millimeter wave source with a smoothly frequency tuning centered at 203.39 GHz and with the power level of more than 100 watts in CW operation.

In addition, a high frequency gyrotron operates at low voltage is an attractive source for many applications.

To meet such requirement, we are now beginning to develop such a gyrotron so-called Gyrotron FU CW V, as a fifth member of Gyrotron FU CW Series [2] developed in FIR Center, University of Fukui. The main parameters of oscillator are presented in Table I. The design is then optimized for operating the cathode voltage of the gyrotron as low as possible, while maintaining to achieve power level of 100 watts or more. Cavity is optimized for the usual electron gun type used in Gyrotron FU CW Series with a moderate power level.

Table I Main operating parameters

Frequency, GHz	203.4±0.2
Output power (CW), watt	100
Harmonic (n)	1
Beam current, mA	200
Cathode voltage, kV	5 – 6
Magnetic field, T	7.28-7.4
Compression ratio (B/B_{cath})	100
Beam radius, mm	0.43
Velocity pitch factor (α)	1.1 – 1.3
Total output efficiency (η), %	10
Estimated wall losses, kW/cm^2	< 0.6

II. Results

The gyrotron utilizes an 8 T NbTi superconducting magnet with an air bore diameter 100 mm. The cavity is optimized for high efficiency operation at low voltage of 4 to 6 kV. The main cavity radius and length are 2.389 mm and 14.1 mm, respectively. It is connected to a down tapered section with a length of 5 mm and an angle of 3^o, and an up tapered section with a length of 9 mm and an angle of 3^o. The TE_{03} with frequency 203.39 GHz and total Q factor 2600 is the main operating cavity mode. Fig. 1 shows the cavity cross-section and field profile of the $TE_{0,3}$ mode.

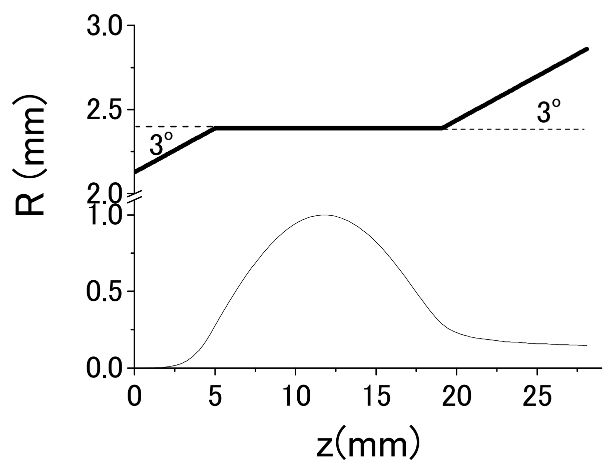

Fig. 1 Cross-section of cavity and field profile of $TE_{0,3,1}$ mode.

The triode-type magnetron injection gun produces high quality helical electron beam. The distance between centers of emitter and cavity are 56.9 cm. Operating magnetic field is around 7.3 T. The required magnetic field in the cathode region to achieve high efficient beam-field interaction is about 0.67 kG. The gun coils are installed surrounding the electron gun to control beam radius and beam quality in the entrance of the cavity. The cross-sectional view of gyrotron is shown in Fig. 2. Cavity is installed in the center of an 8 T superconducting magnet. The water jackets surround the whole tube including electron collector to maintain tube temperature at a permissible level during the gyrotron operations.

Fig. 3 demonstrates calculation results of low voltage operation's capability of this gyrotron. The RF output power and efficiency are plotted as a function of cathode voltage at different pitch factors and with the fixed beam current of 200 mA. It seems that the realistic output power several tens watts

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can be operated at a nominal voltage of 5 kV. The 100 watts power level could be easily produced by utilizing a cathode voltage of 10 kV.

Fig. 4 shows calculation results of RF power for low voltage operation (V_c = 5 kV) as a function of beam current and for different pitch factors. It is seen in Fig. 4 that the output power of 100 watts required for performing a direct measurement of positronimum energy level can be fulfilled by using a portable power supply (5 kV, 300 A).

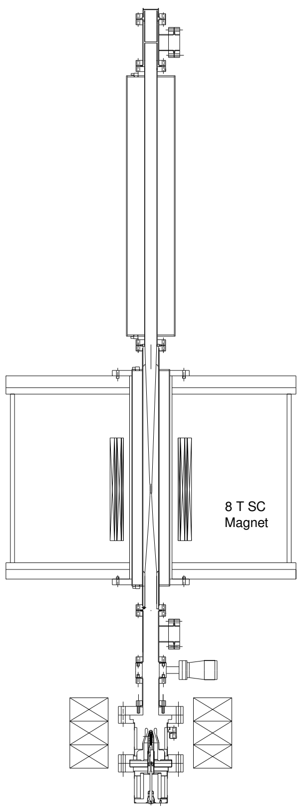

Fig. 2 Cross-sectional view of gyrotron utilizing an 8 T superconducting magnet.

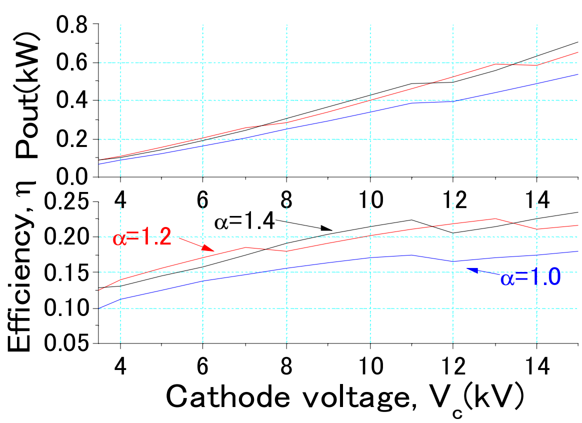

Fig. 3 Calculation result of RF power and efficiency as a function of cathode voltage and at different velocity pitch factor (α=1.,1.2,1.4). Here, beam current is 200 mA, and optimum magnetic fields are ranging from 7.27 to 7.34 T.

Fig. 5 shows the RF power as a function of magnetic field. Here, the cathode voltage is 5 kV and the pitch factor is 1.2. The frequency is tuned from 203.34 to 204.43 GHz by tuning the magnetic field. Other tuning scenarios by means of gyro-BWO and coaxial cavity components will be discussed.

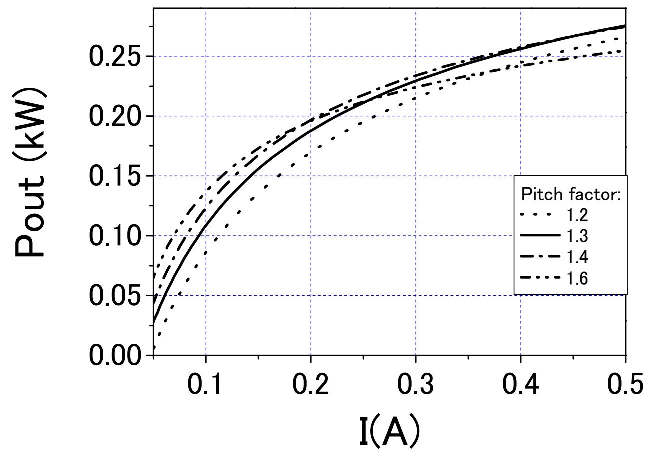

Fig. 4 Calculated RF power as a function of beam current and at different pitch factors (α =1.2, 1.3, 1.4, and 1.6). Here the cathode voltage is fixed at 5 kV.

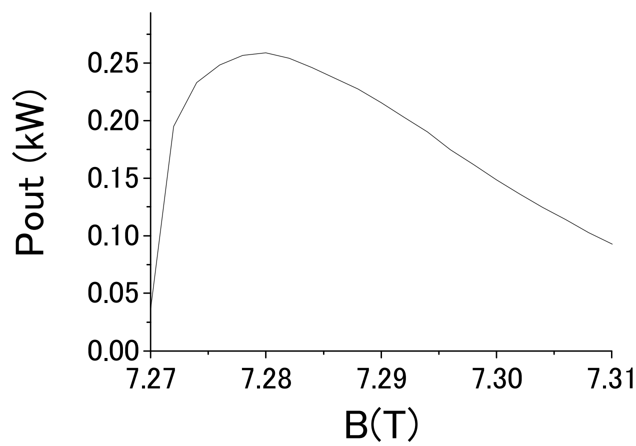

Fig. 5 Calculated RF power as a function of magnetic field. Here, V_c = 5 kV, α =1.2, and R_b = 0.43 mm

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