

# DESIGN OF THE FLAT-TOP ACCELERATION SYSTEM FOR THE JAERI AVF CYCLOTRON

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## Abstract

A flat-top acceleration system for the JAERI AVF cyclotron has been designed. The fifth harmonic of the fundamental frequency is used to obtain uniform energy gain. To determine optimum parameters of the flat-top system, a cold model test was carried out and flat-top waveforms of the voltages were observed successfully in the whole range of the fundamental frequency. An rf power required for generating a flat-top dee voltage of 30 kV was estimated to be about 1 kW. The design of the flat-top cavity is being modified using the MAFIA code.

## 1 INTRODUCTION

The JAERI AVF cyclotron provides a variety of ion beams for the research in biotechnology and materials science. A microbeam is extremely useful for elucidation of the dynamics of cellular repair and the intracellular process of functions such as apoptosis. The present microbeam [1] is produced by using a collimator with an aperture of about 10  $\mu\text{m}$  in diameter. The size of the microbeam spot needs to be reduced to 1  $\mu\text{m}$  to improve the precision of the biological experiment. The energy spread of the cyclotron beam is required to be reduced to  $\Delta E/E = 2 \times 10^{-4}$  to focus the beam with quadrupole magnets.

A flat-top (FT) acceleration system for the JAERI AVF cyclotron has been designed to minimize the energy spread for the microbeam production. The FT system is especially useful to improve extraction efficiency and beam quality as well.

The JAERI AVF cyclotron, which has been operating since 1991, is of the model 930 of Sumitomo Heavy Industries, Ltd. The cyclotron has a K-number of 110, an extraction radius of 923 mm and a sector number of 4. The cyclotron has a pair of quarter-wavelength ( $\lambda/4$ ) coaxial type resonators with a movable-short [2]. A maximum acceleration voltage is 60 kV in a CW mode. The diameters of inner and outer tubes of the coaxial cavity are 300 mm and 1000 mm, respectively. A final amplifier, a grounded-cathode tetrode (EIMAC 4CW50,000E), is inductively coupled to the resonator through a tunable loop. The range of the fundamental frequency is 11 to 22 MHz. Harmonic modes of 1, 2 and 3 are used to cover a wide range of energy.

In general, the third- or fifth-harmonic of the

fundamental frequency is used for the flat-top acceleration [3, 4]. The amplitude of the higher harmonic superimposed to the fundamental waveform is estimated to be  $1/N^2$  times the fundamental voltage. We have adopted the fifth-harmonic to save output power of an amplifier. An additional coaxial cavity for the fifth-harmonic flat-topping is capacitively coupled to the main resonator. The fifth-harmonic voltage in the frequency range of 55 to 110 MHz is required to cover the whole region of the fundamental frequency. To determine parameters of the FT system, a cold model test was carried out using the model of an FT resonator that was preliminarily designed by RIKEN for their cyclotron [5]. The model of the FT resonator was mounted on the main resonator of the CYRIC 930 cyclotron in Tohoku university. The RF system is basically the same as that of the JAERI AVF cyclotron. The main cavity of the CYRIC cyclotron has a preparatory port to install the model of the FT resonator.

We have modified the design of the FT cavity on the basis of the results of the model test, and optimum

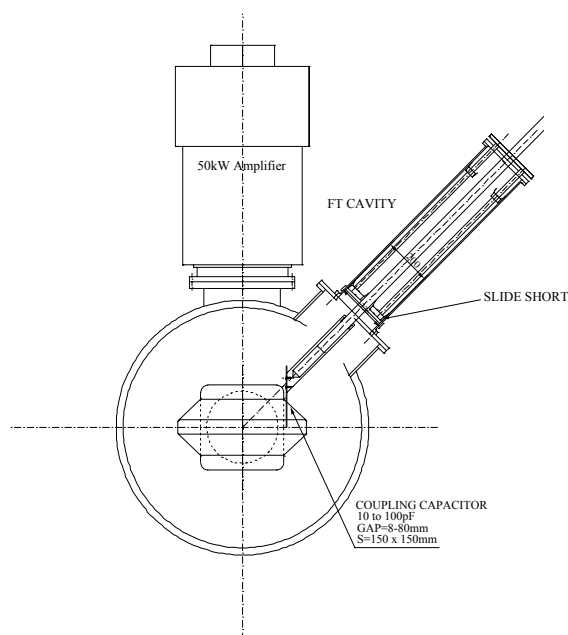


Figure 1: Cross sectional view of the main cavity and the model of the FT cavity. The FT cavity model is capacitively coupled to the main cavity with an electrode plate of 150 x 150 mm<sup>2</sup>.

parameters were investigated using the MAFIA code [6] to downsize the FT cavity itself and to decrease power dissipation. The compactness of the cavity is indispensable condition due to the limited space for mounting the FT cavity.

## 2 A COLD MODEL TEST

Figure 1 shows the cross sectional view of the model of the FT cavity coupled to the main resonator with a capacitive coupler (C3) of 150 mm square. The diameters of inner and outer tubes are 40 mm and 200 mm, respectively. The FT cavity model was attached to the outer tube of the main resonator at a distance of 1820 mm from the center of the cyclotron. The gap of C3 varies between 5 and 50 mm. The position of a movable-short (L3) was adjustable between 40 and 1000 mm.

In this work, a network analyzer and two signal generators were used for measuring Q-value and resonant frequency and for generating the FT waveform on the dee electrode. The fundamental signal was fed into the resonator through the loop coupler of the main cavity, and the fifth-harmonic one through a capacitive coupler mounted on the FT cavity. The input impedance of the FT cavity was adjusted to  $50 \Omega$  to keep matching condition. A resonance signal was observed with a capacitive pick-up for monitoring. The dividing ratio of the pick-up is about 1/1000 in the frequency range of 11 to 22 MHz.

After the movable shorting plate of the main resonator was fixed to the desirable position, C3 and L3 were adjusted to obtain the resonance frequency five times as high as the fundamental one. The frequency dependence of Q-values of the fundamental and fifth-harmonic resonances is shown in Fig. 2. Installation of the FT cavity model didn't change the Q-value of the fundamental resonance. The frequency of the fundamental resonance shifted slightly due to the installation of the FT cavity model. The frequency change was compensated by a capacitive tuner. In order

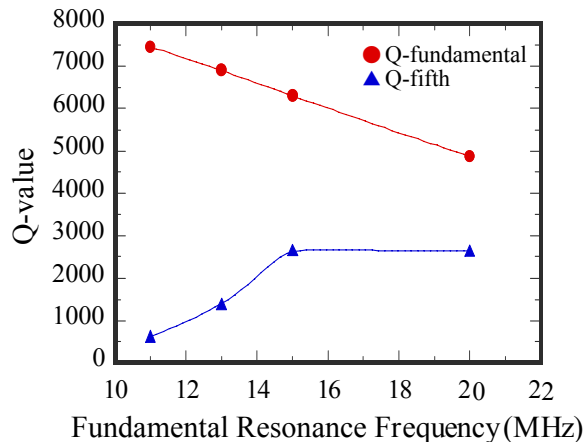


Figure 2: Frequency dependence of Q-values of the fundamental and fifth-harmonic resonances.

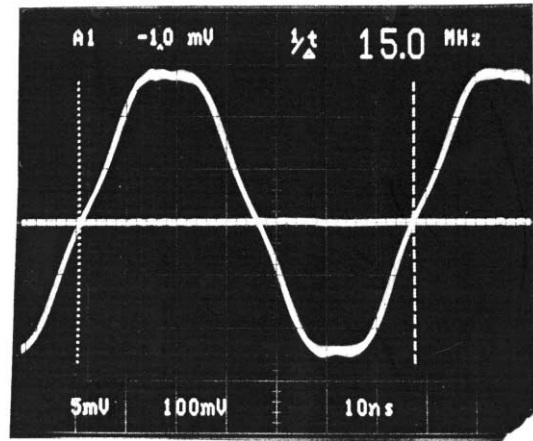


Figure 3: Flat-top waveform observed at the dee voltage pick-up when the fundamental frequency is tuned to 15 MHz.

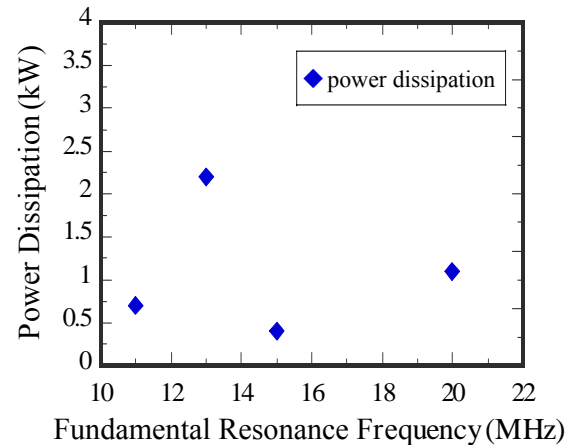


Figure 4: Power dissipations estimated on the assumption that the fundamental voltage was 30 kV.

to generate the FT waveform, two signal generators were synchronized by using time base signal from one to the other. The induced FT waveforms were observed successfully at the fundamental frequency of 11, 13, 15 and 20 MHz. The FT waveform obtained at 15 MHz is shown in Fig. 3. Assuming that the fundamental voltage was 30 kV, power dissipations for the fifth-harmonic frequencies estimated from the amplitude levels of the signal generator and the pick-up signal are shown in Fig. 4. It indicates that a few kW output power of an amplifier is required for achieving the FT acceleration. The power dissipations were corrected on voltage distribution along the acceleration gap of the dee electrode and on frequency dependence of the pick-up capacitor.

### 3 DESIGN OF THE FT CAVITY USING THE MAFIA CODE

The design of the FT cavity is being improved by the investigation of the resonator characteristics with the MAFIA code. The resonance frequencies of the  $\lambda/4$  and  $3\lambda/4$  modes were evaluated to determine the reliability of a mesh used for the calculation with the MAFIA code. The calculated frequencies were consistent with the measured ones. The cold model test was simulated to calculate the fifth-harmonic frequencies. In the case of the fundamental frequency of 15 MHz, the power dissipation was found to be minimized using the FT cavity consisting of a 70 mm diameter inner- and a 300 mm diameter outer-tubes. The power consumption was estimated to be 80 % of the result in the cold model test.

In principle, the amplitude of the fifth-harmonic voltage should be 1/25 of the fundamental one to acquire a uniform energy gain when a voltage distribution along the acceleration gap is uniform. However, the resonator actually has position dependence of a voltage distribution, which varies with the resonance frequency. Figure 5 shows the calculated voltage along the acceleration gap of the dee for the fundamental frequency of 15 MHz. The amplitude is normalized by the voltage at a distance of 50 mm. The fifth-harmonic amplitude decreases by 30 % at

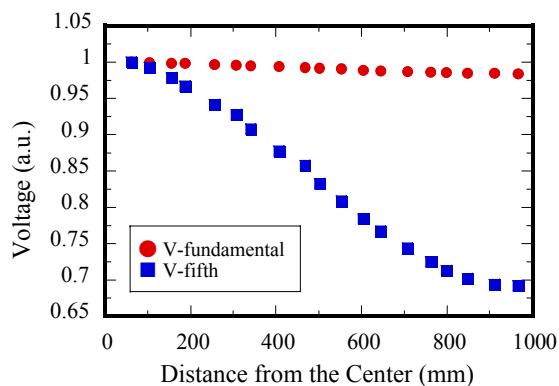


Figure 5: Voltage distribution along the acceleration gap. The fundamental and fifth-harmonic frequencies are 15 MHz and 75 MHz, respectively.

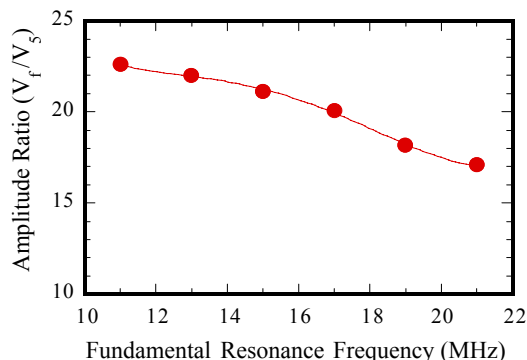


Figure 6: Inverse of the FT amplitude considering the voltage distribution along the acceleration gap.

900 mm. On the other hand, the fundamental one has a little decrease. Therefore, the fifth-harmonic amplitude needs to be optimized for each frequency to uniform the energy gain just before extraction. The ratio of the fifth-harmonic amplitude to the fundamental one was estimated with the curvilinear integration of the fitting curve. Figure 6 shows the ratio of the fundamental amplitude to the fifth-harmonic one as a function of the fundamental frequency.

### 4 CONCLUSIONS

The design of the FT system for the JAERI AVF cyclotron is being optimized through the preliminary model test and the calculation using the MAFIA code. The compactness of the FT cavity will be realized with power dissipation of a few kW in the whole range of the fundamental frequency.

Both the FT acceleration and the microbeam systems will be installed in March, 2002. Furthermore, the design of the central region will be modified to restrict beam phase acceptance precisely. The beam buncher will be renewed in the near future for bunching the injected beam within the defined phase acceptance.

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