SOME CALCULATIONS OF THE RESONATOR IN INR CYCLOTRON

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Abstract

Some calculation methods of the resonator parameters with single dee and two coaxial transmission lines in INR variable-energy cyclotron were described. Also calculated and experimental results have been compared with the original one (two dee system).

Introduction

INR cyclotron has been converted to a three sector focusing variable-energy cyclotron, which is capable of accelerating proton (10-30 MeV) deuterons (10-16 MeV) and α-particles (20-32 MeV) beams. Before conversion, the frequency of RF resonator ranged from 8.3-16.6 MHz by moving a pair of short plate installed in the coaxial lines (fig.1).

According to the conversion project, the highest working frequency for accelerating proton is 20.5 MHz. Therefore the resonator must be redesigned. The first questions was whether to use single dee system or two dee system. A two dee system requires only half the dee-to-ground voltage and half the current on each dee stem as single dee system does to get same gain per turn. However, in single dee system, there is more space for beam probes and deflectors, and higher extraction voltage can be used. Weighing the advantages and disadvantages, the single dee system was chosen primarily, because it was helpful for beam diagnostic and extraction. But the problems has arisen the high current density and power dissipation in the cavity. The calculated maximum shorting plate current will exceed 50 Amp/liner cm, which is not acceptable at top working frequency. A suitable method have to be taken to solve this problem. If two stems were paralleled at the junction part between the dee and stems, the current density will reduce evidently. On the other hand, it is possible to raising the top frequency of resonator (fig.2).

Determination of Dee Size

On the basis of beam dynamic calculations the orbit radius of the beam is about 620 mm before extraction, the betatron amplitude is about 5 mm, the 675 mm has been taken for dee radius. For 75 kV maximum working voltage on the dee, the clearance between dee and ground is 34.5 mm. According to the envelope of particles in central region and refer to some similar cyclotron design, the height of the aperture of dee is 30 mm. In order to increase the axial focusing force in center region, the puller rotates an angle of 20° against the gap-mid line.

Oscillation Frequency

A two dee system with two coaxial lines can work in wanted push-pull or unwanted push-push mode except in the harmonic mode. In this case, resonator frequency can be calculated from the equivalent circuit successively by \( \omega = \frac{1}{\sqrt{LC+Q}} \) and \( \omega = \frac{1}{\sqrt{LC}} \) where L, C are the equivalent inductance and capacitance, Cb is capacitance between two dees. However, the frequency of single dee system with two lines is \( \omega = \frac{1}{\sqrt{LC}} \).

It indicated that the frequency of the later is higher than the former's if both dee have same capacitance. Because of the enlargement of dee area and the decrement of the gap between dee and ground, the actual frequency increment is not more than 20 percent.

Q-value

Q-value can be calculated from the classical relationship \( Q = \frac{2\pi W}{P} \) where W is the total stored energy and P the average power losses in the identical oscillation circuit.
The value of \( W \) and \( P \) for each section are listed in Table 1. We also made a comparison between the single dee system and two-dee system for a given frequency, it has been shown that the \( Q \) value in the new resonator is a little lower than that in old one.

**Table 1. r.f.power inventory (calculated)**

<table>
<thead>
<tr>
<th>system</th>
<th>two dee</th>
<th>single dee</th>
</tr>
</thead>
<tbody>
<tr>
<td>dee voltage (kV)</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Frequency (1/( f_0 ))</td>
<td>12.2</td>
<td>12.2</td>
</tr>
<tr>
<td>Dee stored energy (W)x2( \pi )</td>
<td>1.49</td>
<td>0.745</td>
</tr>
<tr>
<td>Dee skin losses (W)</td>
<td>3582</td>
<td>1791</td>
</tr>
<tr>
<td>Medium dissipation (W)</td>
<td>8400</td>
<td>4200</td>
</tr>
<tr>
<td>Coaxial line stored (W)x2( \pi )</td>
<td>0.017</td>
<td>0.176</td>
</tr>
<tr>
<td>Coaxial line skin losses (W)</td>
<td>2106</td>
<td>6068</td>
</tr>
<tr>
<td>Short plate current (A)</td>
<td>2280</td>
<td>1456</td>
</tr>
<tr>
<td>Short plate losses (W)</td>
<td>400</td>
<td>326</td>
</tr>
<tr>
<td>Contact resistance losses (W)</td>
<td>5128</td>
<td>4240</td>
</tr>
<tr>
<td>Q-Value</td>
<td>1608.4</td>
<td>4247</td>
</tr>
</tbody>
</table>

where \( B \) is the distance for the short plate to move from the maximum wave length \( \lambda_2 \) to the minimum \( \lambda_1 \).

For power test, a "balun" which is similar to the HAENWILL V.E.C. (for matching the unbalance impedance of cavity to the balance impedance of the generator output) was used. The test indicated that either mode can give satisfactory results by changing the loop angle respect to the stem or coupling capacitor with capacitance \( C_k \).

**Measurement of \( Q \)**

The usual method of \( Q \) measurement of cavity with large \( Q \)-value require a well-padded and stabilized oscillator and a detector system which won't affect the cavity \( Q \) value. But this method can't measure the variation of \( Q \)-value during the running period of cyclotron. Alternatively we used RF pulse method to measure \( Q \)-value in which RF pulses were excited within a period of 1ms. The pulse shape can be observed on the CRT and recorded easily by a oscilloscope as shown in fig.4. If the time interval \( T \) for the pulse amplitude from the peak value falling down to the 10 percent of the peak was known, the \( Q \) Value can be computed by \( Q = \pi f 2.3 \) .

In our configuration, \( T \) is about 200 s at the working frequency 12.2 Hz, then \( Q = 333 \).

The accuracy of this method is enough for engineering design.

**Dee Voltage Distribution**

It is shown that the distribution of dee voltage is not uniform at each accelerating radius since the arrangement of dee is differ from the original one. When calculating the nonuniformity, it was subdivided into many small elements and equivalent capacitance, equivalent capacitance and dissipation caused by surface resistance was calculated in each unit. Therefore, the dee voltage distribution can be obtained. By using such method these results (see Fig.5) coincide with the measured value.
Conclusion

The use of the single dee with two lines has yielded a flexible and easy to operate system by only moving the two short plate simultaneously. The resonator can be worked at frequency range from 10 MHz to 22 MHz, with maximum voltage 75 kV at top frequency in INR cyclotron. If we use the inductance coupling mode with a loop at each cavity, the "balun" is not required. The new single dee system has been working satisfactorily since September 1983.

Fig.1. Two-Dee system and equivalent circuit

Fig.2. Single-Dee system and equivalent circuit

(a) Inductance coupling

(b) Capacitance coupling

Fig.3. Two coupling mode in the power test

Fig.4. Pulse shape on CRT

\[ \frac{\Delta V_D}{V_D} = f(x) \]

Fig.5. Dee voltage distribution