STRUCTURE OPTIMIZATION STUDIES OF 142.8 MHZ SUB-HARMONIC BUNCHER

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Abstract

The structure optimization studies of 142.8 MHz sub-harmonic buncher have been carried out with two-dimensional Finite Difference Method software-Superfish and three-dimensional Finite Integration Method software-MAFIA. The method of optimizing the cavity structure is presented in this paper, and the optimized structure of the cavity is also decided. The simulation results of Superfish and MAFIA are analyzed and compared, and both of them are consistent with the design data.

INTRODUCTION

BEPCII injector linac will adopt the two-bunch acceleration scheme for doubling the positron injection rate to the storage ring, so it is very important to have a new pre-injector with good bunching performance. Two sub-harmonic bunchers were introduced to the BEPCII future pre-injector, which consists of a thermionic electron gun, two SHBs (SHB1 and SHB2), a traveling wave prebuncher and a traveling wave buncher. The primary electron bunch needs more than 9 nC charge, the bunch length at the buncher exit needs to be limited as short as 10 ps to meet the longitudinal acceptance of downstream RF accelerating structures.

To ensure a precise injection timing and make the injection flexible, sub-harmonic buncher frequencies and the linac frequency must be phase-locked to the ring frequency. In the BEPCII design the ring frequency of 499.8 MHz and the linac frequency of 2856 MHz have been decided, so the common frequency of 17.85 MHz can be selected. As a consequence, the two SHBs' frequencies can be chosen to be 142.8 MHz and 571.2 MHz.

The design and optimization of the 142.8 MHz sub-harmonic buncher are described in this paper, and the optimized structure of the cavity is also decided. In the process of optimizing the cavity structure, Superfish was used to optimize most of the cavity parameters, such as the length of the short drift tube, the acceleration gap distance and so on; MAFIA was used to optimize the tuner's position and size.

DESIGN GOAL

In optimizing the structure of the SHB1 cavity, many parameters need to be optimized, such as the cavity dimension, the Q-value, the shunt impedance, the maximum surface field, the tuning range of the cavity and so on.

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The resonant frequency of the 142.8 MHz cavity is relatively low, so the cavity length needs to be as short as possible for a reasonable cavity size.

Given the stored energy of the cavity, the higher the Q, the less the rf loss; or given rf loss, the higher the Q, the higher the electric field. On the other hand, the higher the Q, the larger the phase shift $\Delta\Phi$ caused by the frequency error $\Delta f/f$ (since $\Delta\Phi = Q \times \Delta f/f$). Because copper was selected as the structure material of the cavity, the Q-value needs to be about 7000. By the beam dynamics simulation with PARMELA-code, the energy gain of SHB1 needs to be higher than 100 kV at least. Since the power source available at present is limited to 10 kW, so the shunt impedance needs to be about 1.1 MOhm.

The cavity needs to have a low maximum surface field to reduce the possibility of electric breakdown. The Kilpatrick breakdown field of the 142.8 MHz cavity is about 12.9 MV/m. So for a 10 kW input power, the maximum surface field in the cavity needs to be about 7 MV/m for the safe operation.

The tuner range needs to be as large as possible without affecting the field distribution of the cavity. For the 142.8 MHz cavity, the required tuner range is about 400 KHz.

STRUCTURE OPTIMIZATION

Length of the short drift tube

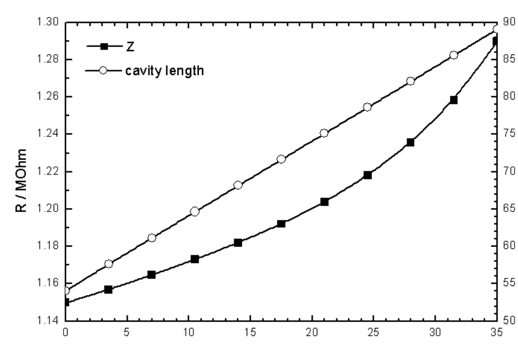

Figure 1: Shunt impedance, cavity length vs length of the short drift tube.

Figure 1 shows the dependence of the shunt impedance and the cavity length on the length of the short drift tube. It shows that as the length of the short drift tube increasing, although the shunt impedance of the cavity increases, the cavity length is also increases. To keep the cavity as short as possible, the length of the short drift tube needs to be as small as possible.

Figure 2 shows the distribution of the axial field with different lengths of the short drift tube. If the length of the short drift tube is too small, the axial electric field distribution in the cavity will not be the one we want. Therefore, the length of the short drift tube was chosen to be 35 mm.

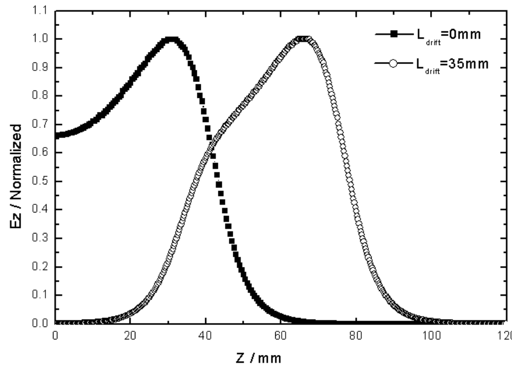

Figure 2: Distribution of the axial field with different lengths of the short drift tube.

Outer radius of the drift tube and inner radius of the cavity

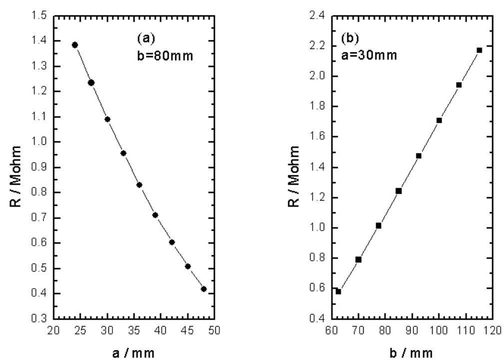

Figure 3: Shunt impedance vs cavity dimensions; (a) outer radius of the drift tube, a; (b) inner radius of the cavity, b.

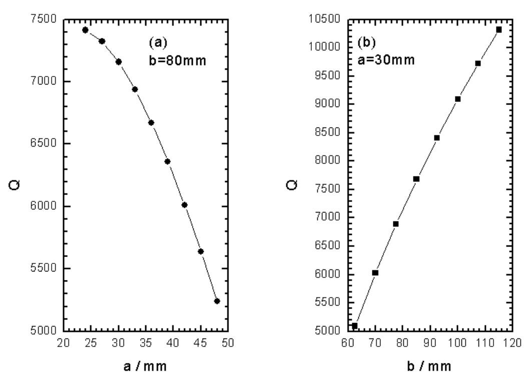

Figure 4: Q-value vs cavity dimensions; (a) outer radius of the drift tube, a; (b) inner radius of the cavity, b.

Figure 3 shows the dependence of the shunt impedance on the cavity dimensions. Figure 4 shows the dependence of the Q-value on the cavity dimensions. By these figures, the following results can be obtained: The larger the outer radius of the drift tube (a), the smaller the shunt impedance (R), and the lower the Q-value; the smaller the inner radius of the cavity (b), the smaller the shunt impedance (R), and the lower the Q-value.

Hence, to have a required shunt impedance and low Q-value, the outer radius of the drift tube and the inner radius of the cavity are selected as 27 mm and 77.5 mm, respectively.

Acceleration gap

In optimizing the acceleration gap, the shunt impedance and the maximum surface field need to be considered. The longer the acceleration gap, the lower the maximum surface field, as shown in Figure 5. In addition, when acceleration gap becomes wider, the shunt impedance decreases, but only a little. Finally a 40 mm acceleration gap was chosen.

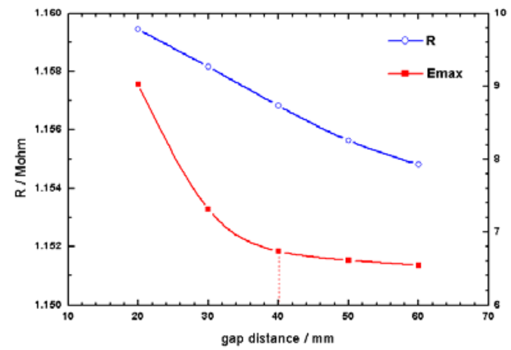

Figure 5: Shunt impedance, maximum surface field vs acceleration gap.

Surface field

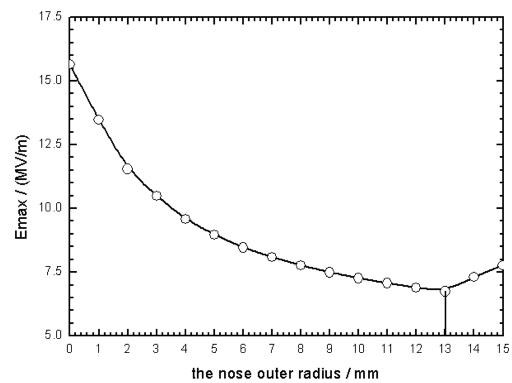

Figure 6: Maximum surface field vs the nose outer radius.

The maximum surface field exists at the nose of the long drift tube and near the acceleration gap. Its maximum value depends on the thickness of the drift tube and the shape of the nose. In general, the thicker the drift tube, the lower the maximum surface field. To reduce the maximum surface field, a thickness of 15 mm has been selected, so the range of the nose outer radius is 0-15 mm, the beam radius is 12 mm.

With the sum of the nose outer radius and the nose inner radius to be 15 mm, the relation between the maximum surface field and the nose outer radius is shown in Figure 6. It was found that the lowest value of the maximum surface field can be obtained when the nose outer radius is 13 mm. The value of the maximum surface field is about 7 MV/m.

Tuner

According to MAFIA calculation, if the distance between the cavity axis and the tuner axis is 52.5 mm, and the diameter of the tuner rod is 20 mm, a frequency change of 370 kHz can be obtained by a total stroke of 40 mm.

Water cooling

The long drift tube has a long length of about 50cm. It is very sensitive to the frequency change. So the water cooling is necessary to keep the cavity frequency's stability.

In the 142.8 MHz cavity, the long drift tube and both end plates are water-cooled, and the cooling water flow through the wall of the long drift tube.

Main structure of the cavity

According to the optimization results presented in 3.1-3.6, the structure and main dimensions of the optimized cavity are shown in Figure 7.

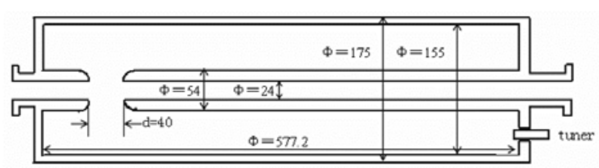

Figure 7: Structure and main dimensions of the optimized cavity (unit: mm).

COMPARISON OF THE SIMULATION RESULTS

Table 1: Cavity design data and simulation results

	Design	Superfish	MAFIA
Frequency[MHz]	142.800	142.811	142.793
Q-value	7000	7070	7209
Shunt Impedance [MΩ]	1.1000	1.1568	1.1750
$E_{surface,max}/E_{gap,max}$	--	2.4833	2.6075
$E_{surface,max}$ [MV/m] (P_{in}=10kW)	7.00	6.74	6.91
V_{gap}[kV]	105.00	107.55	104.70
Tuning Range [MHz]	--	--	142.69-143.06

Superfish and MAFIA are used to calculate the structure of the optimized cavity, their results are shown in table 1.

Although there are some differences between the Superfish (two dimensional code) and MAFIA (three dimensional code) simulation results, they are still consistent with the design data. Since the optimization of the tuner must be done in three dimensions, so only MAFIA can be used to calculate this problem.

Figure 8 shows the comparison plot of the normalized axial field distribution calculated by Superfish and MAFIA. Figure 9 shows the electric field distribution in the whole cavity. All of these figures show that both MAFIA and Superfish calculation results are consistent with the design data again.

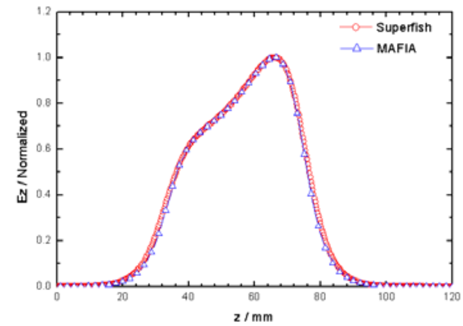

Figure 8: Comparison of the normalized axial electric field distribution.

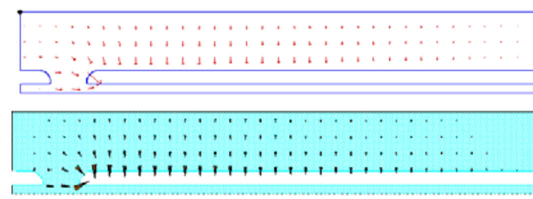

Figure 9: Electric field distribution; (a) Superfish simulation result; (b) MAFIA simulation result.

CONCLUSION

By a great deal of calculations with Superfish and MAFIA, the method of optimizing the cavity structure is studied, and the optimized structure of the cavity is also decided. The simulation results of Superfish and MAFIA are analyzed and compared, both of them are consistent with the design data.

ACKNOWLEDGEMENTS

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