Adjusting the accelerating field distribution of a superconducting CH cavity *

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Abstract: In a superconducting CH (cross bar H mode) cavity, the method of regulating the length of a drift tube is employed to adjust the distribution of the accelerating field. In this article, we simulate the electromagnetic field of a CH structure to illustrate the reason for adjusting the field distribution by varying drift tube length. Meanwhile, that the presence of the drift tube will cause a sharp rise in the maximum electric field is also shown. This phenomenon is contrary to superconducting cavity design principles in which the cavity geometry needs to be optimized to reduce the maximum electric field to avoid field emission. We propose a variable diameter superconducting CH cavity design to solve this conflict. The simulation of the variable diameter superconducting CH cavity shows that this method is feasible.

Key words: accelerating field distribution, CH, superconducting cavity, drift tubes

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1 Introduction

In a cross bar H mode cavity (CH cavity), the cross bar describes the structural characteristics of the CH cavity. The direction of the magnetic field is consistent with the particle movement, so the electromagnetic mode of the CH cavity is called the H mode. The electromagnetic field mode of the CH cavity can be described as the H_{210} mode. The H_{210} indicates that the magnetic field changes twice along the angle, once along the radius, and no change in the normal direction [1].

The structure of the CH cavity is convenient to apply in a multi cell cavity. The multi-cell cavity has high efficiency in acceleration compared to the single cell cavity [2]. So the reason for high acceleration efficiency in a CH cavity is the multi-cell structure. Taking into account the frequency and structural characteristics, the CH cavity is suitable for accelerating protons and heavy ions with beta less than 0.4. In this energy region, particle velocity changes dramatically under the acceleration. The length of each cell of the CH cavity has to follow this change. Different lengths of cells will cause the axis accelerating field to be unbalanced. The unbalance can be corrected by optimizing the length of the drift tubes [3].

With the development of superconductivity, the application of the CH cavity has extended to the superconducting cavity area. The method of adjusting the accelerating field by optimizing the length of tubes has been referenced in the superconducting CH cavity [4]. The drift tubes of a superconducting CH cavity will form a dead zone which cannot be cleaned. The uncleaned surface will cause field emission which will limit the performance of the superconducting CH cavity. Also, the drift tubes concentrate on the local field. This will increase the maximum electric field. The excessive electric field is also the reason for limiting the superconducting CH cavity performance. So the use of the drift tube structure in the superconducting CH cavity will significantly limit the performance.

In this paper, we try to explain the mechanism of adjusting the electric field distribution of a CH cavity by changing the length of the drift tubes. According to this mechanism, an alternative method to adjust the electric field distribution of a superconducting CH cavity is proposed.

2 One slice CH structure simulation

The CST MICROWAVE STUDIO software is employed in this simulation [5]. In order to improve the accuracy of the simulation, only one part of the CH structure has been simulated. The simulation process is to observe the effects of the electromagnetic parameters

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of the CH structure by changing the length of the drift tube.

The CH structure and the boundary conditions are shown in Fig. 1. In order to clearly show the CH structure, the structure comprises two cell lengths. But for parameter comparison, all the data are converted to correspond to one cell length. Three types of boundary condition are used for the simulation. According to the magnetic field distribution characteristics of the CH structure, the magnetic symmetry boundaries are used for the simulation to reduce the amount of grids. The periodic boundaries are used to represent the extension of the multi cells structure of the CH cavity. The electric boundaries cover the CH structure as the cavity wall.

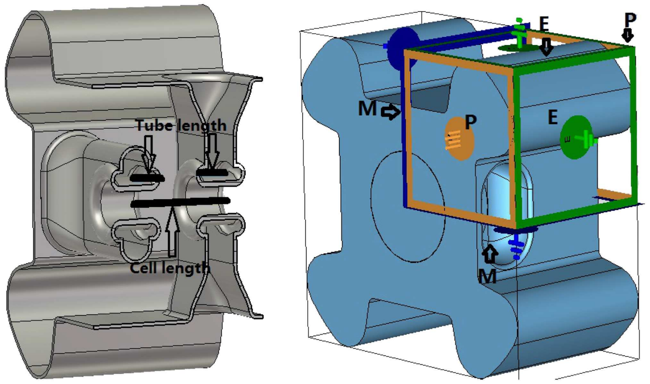

Fig. 1. (color online) The CH structure with two cell lengths (right), and the boundary conditions for the vacuum CH structure (left).

Before the parameter scanning, the CH structure geometrical parameters were optimized to ensure that the frequency is 325 MHz. The length of the drift tube is the main scanning parameter. The diameter changes to ensure the frequency of 325 MHz. The RF parameters including the voltage, $E_\mathrm{p}/E_\mathrm{acc}$ and $B_\mathrm{p}/E_\mathrm{acc}$ are recorded for analysing [6]. The E_p and B_p are the maximum surface electric field and maximum surface magnetic field respectively. E_acc is the accelerating gradient. The length of the drift tube is transformed to the percentage of cell length. The variation of radius and voltage of one cell are shown in Fig. 2. The voltage includes the component of the transit time factor.

As the proportion of the drift tube with cell length increases 13%, the radius of the CH structure falls by 2.3%, and the voltage only has a 2% increase. The variations of the peak field versus the accelerating field are shown in Fig. 3. The $E_\mathrm{p}/E_\mathrm{acc}$ has a growth of 24.1%, while there is only 4.1% increase for $B_\mathrm{p}/E_\mathrm{acc}$.

The length change of the drift tube has little impact on the majority of RF parameters except $E_\mathrm{p}/E_\mathrm{acc}$. These reasons can be seen from the current flow in Fig. 4.

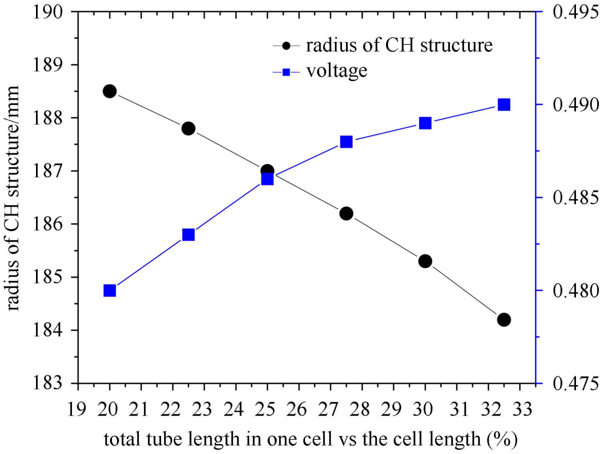

Fig. 2. (color online)The variation of radius and voltage with the length of the drift tube.

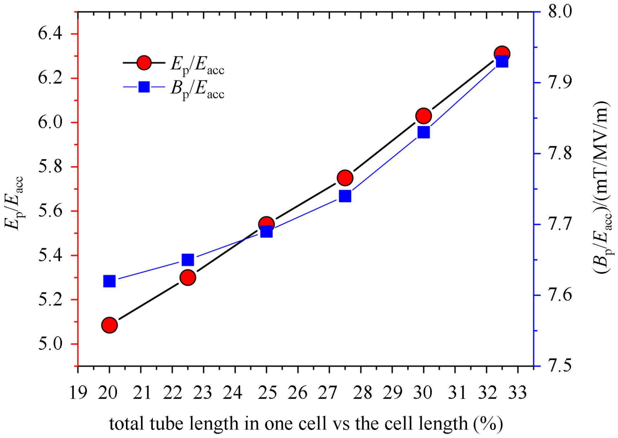

Fig. 3. (color online) The variation of $E_\mathrm{p}/E_\mathrm{acc}$ and $B_\mathrm{p}/E_\mathrm{acc}$ with the length of the drift tube.

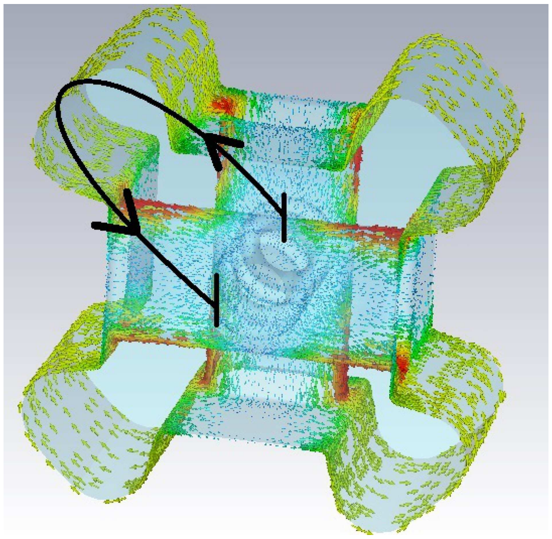

Fig. 4. (color online) The current distribution in the CH structure.

The electric current originates from one stem flow through the shell to another stem. The current eventually forms a loop. The magnetic field which is inducted by the current loop is the H mode field. In the current circuit, the effect of a drift tube is similar to a capacitor. The drift tubes are located at the beginning and end of the current loop. Changing the length of drift tubes will extend the path of the current, but have no effect on the current strength. So the magnetic field generated by the current has no obvious change. According to the law of induction, the voltage between the two drift tubes which is inducted by the magnetic field will not change a lot. There is only 2% deviation in this simulation. In brief, changing the length of the drift tube had no significant effect on the voltage between the drift tubes.

The parallel plate capacitor model can be used to explain the sharp rise of the maximum electric field. In this model the voltage is the product of distance and electric field. In this simulation, the voltage change can be seen as a constant approximation. When the distance between the drift tube shrinks 13%, the electric field also will increase 13% accordingly. Taking into account the electric field concentration caused by the irregular shape of the drift tubes, a 24.1% increase of $E_{\mathrm{p}}/E_{\mathrm{acc}}$ is very reasonable.

From the simulation results of a part of the CH structure, the length variation of the drift tubes has no effect on the voltage, but can obviously make the maximum electric field get worse. One of the optimization directions for the superconducting cavity design is to reduce the maximum surface electric field to avoid the field emission [7]. The role of the drift tube obviously conflicts with this purpose.

3 The mechanism of adjusting the field distribution of the CH cavity

From the one slice of the CH structure simulation, the length changing of the drift tube affects the cavity frequency. This phenomenon can be used to explain the regulatory mechanisms of the CH cavity accelerating field. The details are described as follows.

For a complete CH cavity structure, the velocity of particles is increased by acceleration. The length of the CH cavity cell also increases to ensure consistency with the velocity increase. The length variation of cells makes the capacitance between cells change. So the frequency of each cell in the CH cavity is rising gradually. The uneven frequency distribution in the CH cavity affects the electromagnetic energy transmission. At last, the variation distribution of the electromagnetic energy in the CH cavity leads to the nonuniform distribution of the accelerating electric field. The method of adjusting the length of the drift tube is actually compensated cell capacitance variations. So the uniform frequency distribution of each cell in the CH cavity leads to the uniform accelerating field distribution.

We propose to optimize the diameter of each cell of the CH cavity to achieve the purpose of adjusting the accelerating field distribution. This method can avoid the disadvantages caused by drift tubes in the superconducting CH cavity.

4 The variable diameter superconducting CH cavity simulation

The method of changing the superconducting CH cavity radius to adjust the accelerating field distribution is shown in Fig. 5. The radius of each cell is independently adjustable in the modeling. The basic principle is that the frequency of the CH cavity has an inversely proportional relationship with the diameter [8]. So adjusting the diameter of each cell can compensate the frequency variation of each cell of the CH cavity.

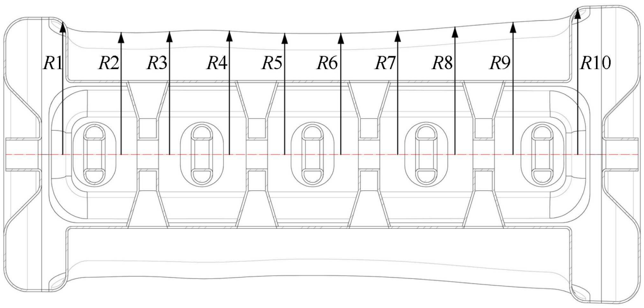

Fig. 5. (color online) The sectional view of the variable diameter superconducting CH cavity.

Table 1. Radii corresponding to different gap positions in the variable diameter superconducting CH cavity.

parameters	size/mm	parameters	size/mm
$R1$	188	R6	187
$R2$	187	R7	191
$R3$	190	R8	197
$R4$	187	R9	202
$R5$	186	R10	204

The frequency of the superconducting CH cavity is 325 MHz. The entrance beta of the superconducting CH cavity is 0.16. There are 10 cells in the CH cavity. The middle of the stems is flat, and gradually enlarges to an oval structure on both ends. The girder is a rectangular structure. The height of the girder changes with each cell radius. The diameter of the cavity wall corresponding to each cell also changes.

After optimization, the radius of the superconducting CH cavity corresponding to different gap positions is shown in Table 1. Before the optimization, the radius is 189.5 mm.

The simulation of electric field distribution for the variable diameter superconducting CH cavity is shown in Fig. 6. Before the optimization, the electric field is concentrated in the front of the cavity. After optimization, the electric field is scattered to the rear of the cavity. At the same time, the maximum electric field of the CH cavity significantly decreases by 14%.

The change of the acceleration field distribution also confirms the result. The accelerating field distribution is shown in Fig. 7.

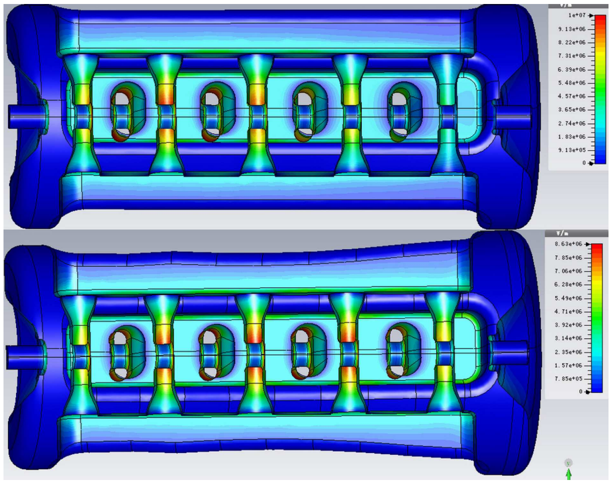

Fig. 6. (color online) The electric field distribution of the superconducting CH cavity.

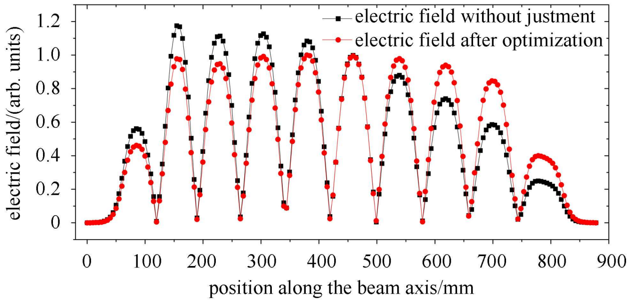

Fig. 7. (color online) The accelerating field of the superconducting CH cavity before and after optimization.

The RF parameters are shown in Table 2. The RF parameters of the variable diameter superconducting CH cavity have been improved too.

After optimizing the diameter of each cell of the CH cavity, the accelerating electric field distribution becomes more uniform. The results show that regulating the distribution of the electric field by changing the radius of each cell is feasible. The variable diameter CH cavity is very suitable for application in a superconducting cavity, because the CH cavity ensures that it is not only easy to adjust the field distribution, but it is also easy to clean to reach a high gradient.

The fabrication of the variable diameter superconducting CH cavity is the same as the copper model CH cavity [9]. The explosion view of the variable diameter superconducting CH cavity is shown in Fig. 8. The differences are the girders and the cavity wall, as the dimensions of girders and cavity wall have variation. In practice, the girders and cavity wall are stamped by aluminum alloy dies, so the size variation can be easily achieved by processing the variation dies. The variation weld is not a big problem for electron beam welding, as we can grind the weld. The necessary processing technology for the variable diameter superconducting CH cavity can be transferred from the existing superconducting CH cavity processing. So production of the variable diameter superconducting CH cavity is feasible.

Table 2. The RF parameters of the variable diameter superconducting CH cavity and the conventional CH cavity.

parameters	conventional	variable diameter
frequency/MHz	325	325
voltage/MV	5.43	5.32
$E_{\mathrm{p}}/E_{\mathrm{acc}}$	5.8	5.1
$(B_{\mathrm{p}}/E_{\mathrm{acc}})/(\mathrm{mT/MV/m})$	8.73	8.2

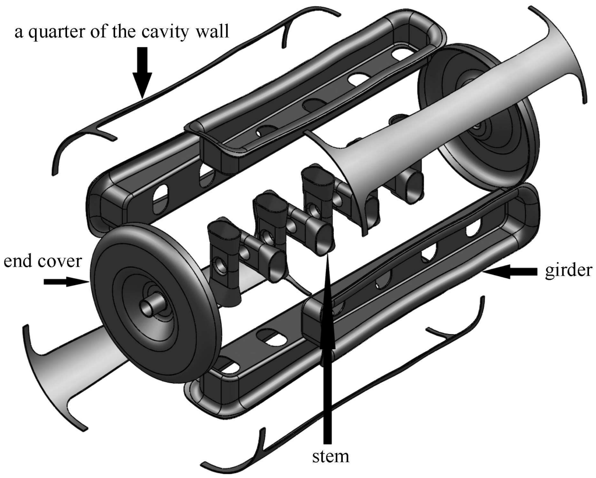

Fig. 8. The explosion view of the variable diameter superconducting CH cavity.

5 Conclusions and outlook

Adjusting field distribution has been a factor limiting the development of the superconducting multicell cavity. The variable diameter CH cavity provides another option for solving this problem. This adjustment method eliminates the problem of cleaning a superconducting cavity. So the variable diameter superconducting CH cavity is reasonable to achieve high gradient.

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