Electromagnetic characteristics of the CH cavity *

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Abstract: In this paper, we present the RF simulation, the fabrication and the normal RF test of a six-cell copper model cross bar H mode (CH) cavity. The CH cavity was researched and developed at the Institute of Modern Physics for Injector II of the superconducting linac of the accelerator driven system of China, operating at a frequency 162.5 MHz, β=0.065. The deep drawing and electron beam welding were employed to fabricate this cavity, which would be used to develop the superconducting CH cavity in the future. The results of the normal RF test agree with the simulation of the electromagnetic properties, such as the electric field distribution on the cavity axis, frequency and Q factor.

Key words: CH, superconducting, copper cavity, RF test

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1 Introduction

The cross bar H mode (CH) structure will be used in a multi-cell drift tube cavity which can be used to accelerate the low energy and medium energy proton. The operating mode in the CH cavity is H210 [1]. Compared with other low-beta cavities, the CH cavity with multi-cell structure has a high real acceleration gradient. In previous practice, the CH type of cavity was used as a normal temperature cavity. With the development of a superconducting cavity, the approach of promoting the CH cavity used in the field of the superconducting cavity is attractive in seeking a more effective superconducting cavity type. In a superconducting CH cavity, the cross bar is helpful in order to rigidize the cavity mechanically. Furthermore, the liquid helium will flow across the cross bar to cool down the cavity conveniently.

In the present plan for the China Accelerator Driven System (C-ADS), the superconducting cavity will be used to accelerate a proton from the initial energy 2.1 MeV to 1.5 GeV [2]. Adopting a superconducting CH cavity in the low energy section will greatly decrease the number of cavities. The research of the superconducting CH cavity was carried out by the Institute of Modern Physics.

The fabrication of the niobium superconducting CH cavity is difficult because of its complex mechanical structure and strict requirements. The superconducting cavity is usually fabricated by electron beam welding (EBW) to avoid contamination. However, EBW has strict requirements on the precision of the niobium parts, and then machining is essential. After the welding, the dimensional change is different for each CH cavity part which will affect further assembly welding. Additionally, the appropriate process will be verified for protecting the surface of the niobium.

The electromagnetic structure of a six-cell copper model CH cavity has been simulated. This cavity was built by deep drawing and EBW, and the normal RF testing results agreed with the simulation. Through this work we can better understand the electromagnetic characteristics and prove the possibility of fabricating such a complex CH structure. The research on the copper model CH cavity will promote the development of the superconducting CH cavity in the future.

2 Basic electromagnetic characteristics

The aiming frequency of the copper model CH cavity is 162.5 MHz which is consistent with the low energy superconducting linac Injector Ⅱ for C-ADS. The optimal beta of this model cavity is 0.065, which is expected to demonstrate the extreme low beta application. In the very low beta region, the difference between each cell length is very slight and equal cell length is used in this copper model CH cavity for simplicity. In order to make

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the beam dynamic design easy, we choose six cells in the copper model CH cavity, which is enough to show the complexity of the CH cavity. The diameter of the beam tube is 40 mm.

The electromagnetic field of the copper model CH cavity was simulated by the software CST [3]. There are five crossed stems and four girders in this cavity. The shape of the girder is rectangle and all the edges have been rounded off. The stems are very flat rectangles with a hole to add a tube. The ends of the cavity are of a conical structure.

The two adjacent cross bars can be seen as a pair of plate electrodes. The electric field starts from one stem and terminates at the other one to form the acceleration field in the cavity. The surface current flows from the stem to the girder, and terminates in the cavity wall. The current flowing induces the magnetic field around the girder. This electromagnetic field structure is shown in Fig. 1.

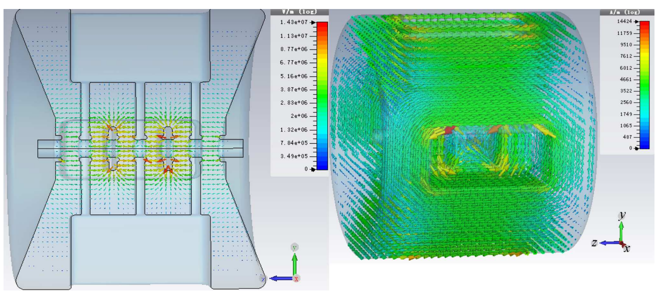

Fig. 1. The cross section view of electric field for the copper model CH cavity (right), and the magnetic field for the copper model CH cavity (left).

The RF parameters of the copper model CH cavity can be adjusted by changing the geometric parameters of the girders and stems. The final frequency was adjusted by changing the diameter of this cavity. The sizes of some parts were modified to be more conducive to the processing and the final frequency of this cavity was 163.13 MHz. The RF parameters of the copper model CH cavity are shown in Table 1. The parameters of $E_{\mathrm{p}}/E_{\mathrm{acc}}$, $B_{\mathrm{p}}/E_{\mathrm{acc}}$, G and R/Q will affect the performance of the superconducting cavity, which can be optimized by regulating the geometric parameters of the cavity [4].

Table 1. The RF parameters of the copper model CH cavity.

parameter	simulation
frequency/MHz	163.13
Q_{o}	15163.5
G	50.4
$(R/Q)/\Omega$	613.5
$E_{\mathrm{p}}/E_{\mathrm{acc}}$	6.7
$(B_{\mathrm{p}}/E_{\mathrm{acc}})/(\mathrm{mT/MV/m})$	8.4

3 Fabrication

Fabricating the copper model CH cavity is to testify the procedure of manufacturing the superconducting CH cavity. Therefore, all the machining processes and accuracy requirements were formulated according to the requirement of the superconducting cavity. The material of the copper model CH cavity was a 3 mm oxygen free copper sheet. The details of the copper model CH cavity are shown in Fig. 2. All parts of this CH cavity were formed by deep drawing in aluminum alloy dies. Then, the parts were trimmed to the final size. Before welding, these parts were stress relieved at 600 ℃ and baked for 2 h in a UHV furnace. All of the parts were electron beam welded together in a vacuum chamber. The welded joints of this cavity which need to be ground for the copper have obvious spatter after electron beam welding.

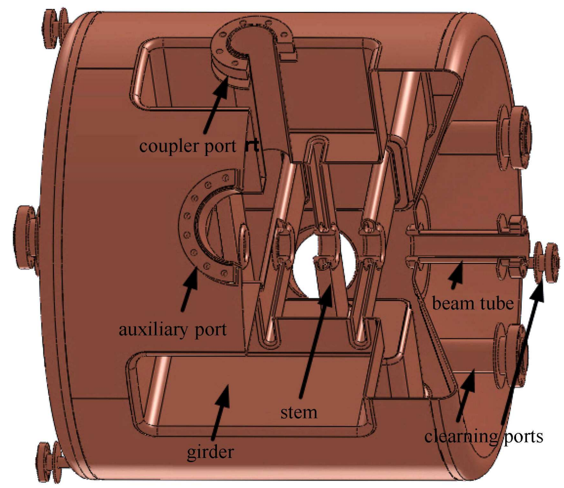

Fig. 2. The mechanical drawing of the copper model CH cavity.

During the fabrication, the most complicated assembly and welding were in the middle section of the copper model CH cavity. It included five stems, four girders and four pieces of cylinder. These parts were assembled together by aluminum alloy jigs. The gap between the parts was less than 0.2 mm. The shrinkage after welding would make the jigs tight, so a suitable fixture design is needed.

4 RF testing

A simple testing stand was set up, as shown in Fig. 3. The stand was used to test the electric field distribution and the frequency adjustment ability of the CH cavity.

In the process of testing, two ports were used. There was an antenna in the coupler port with weak coupling. The auxiliary port was strongly coupled by a loop. The frequency, Q_{load} and S parameters were measured by a network analyzer. The Q_0 was derived according to the Q_{load} and S parameters [5]. The test results are listed in Table 2.

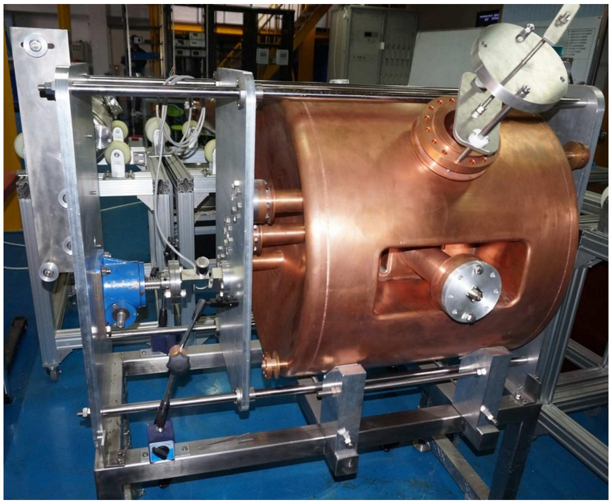

Fig. 3. The testing stand for the copper model CH cavity.

Table 2. The test parameters compared with the simulation for the copper model CH cavity.

parameters	simulation	measurement
frequency/MHz	163.13	163.20
Q_0	15163.5	12128.2

The deviation of the cavity frequency between simulation and testing is small, which shows the electromagnetic simulation for the complex CH cavity is reliable. The measured frequency is higher than the simulation, because the fabricated cavity is smaller than the simulating structure. The parts of this cavity were shaped by aluminum alloy dies. The dies were machined according to the simulated structure precisely. But the parts had rebounds after stamping with the dies which made the sizes of the parts small. The EBW had shrinkage too. These small shrinkages of the cavity size led to the rise of frequency.

The tested Q_0 reached 80 percent of the simulated Q_0. The reduction of Q_0 could be ascribed to the surface roughness and the oxidation of copper.

The field distribution along the axial was measured by the perturbation method [6]. That was to pull an aluminum bead along the cavity axis and record the phase shift as a function of the bead position. To make sure the bead was in the center of the tube, an organic glass with a hole was set up on the tube flange to fix the wire position. The comparison of the measured electric field along the axis with the simulation is shown in Fig. 4.

The measured electric field structure is almost in agreement with the simulation. These results confirm that the electromagnetic mode in the cavity is the accelerating field we need.

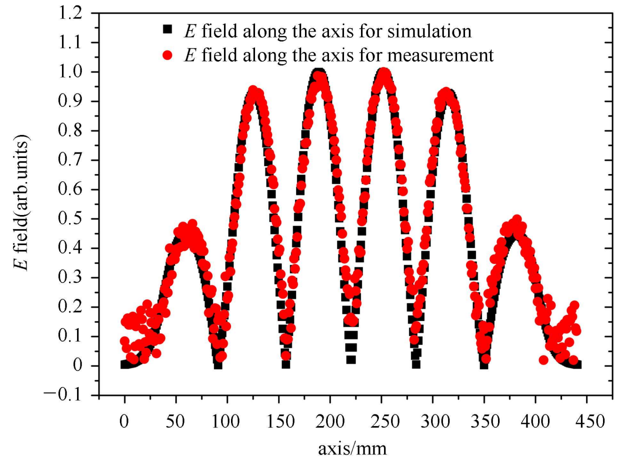

Fig. 4. The test electric field along the axis with the simulation field in the copper model CH cavity.

The possible tuning mode for the CH cavity squeezed the two end tubes. In the test frame, a manual squeezer was used to push the cavity, which simulated the tuning process. At the same time, a force detector was used to detect the change of the force. The result is shown in Fig. 5.

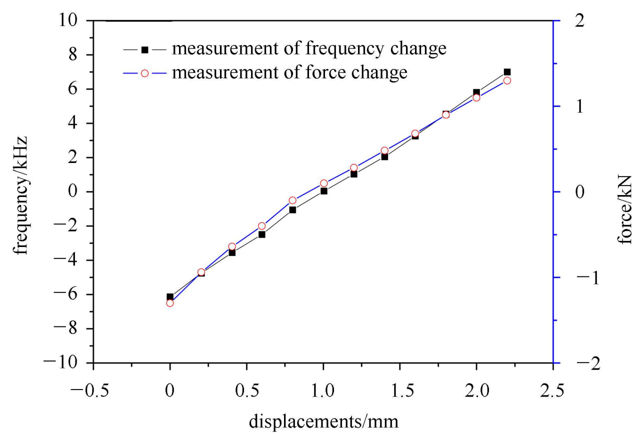

Fig. 5. The change of the frequency and force by squeezing the copper model CH cavity.

The tuning sensitivity of this copper CH cavity is 5.9 kHz/mm. It is a small value compared with other types of cavity applied in this energy region. The tuning sensitivity was determined by the frequency characteristic of this cavity. The volume of the CH cavity at the frequency of 162.5 MHz was huge. The squeezed 1 mm of the two end tubes of the cavity would induce the 0.3 percent volume change of the cavity. According to perturbation theory, the frequency will change by less than 0.3 percent. In this cavity, the volume change not only occurs in the electric field area, but also in the magnetic field region and the effects on the frequency change are opposite. The offset function results in the small change of frequency. In operating this cavity, low sensitivity means high ability to resist interference, which will be easy for the tuner system. On the contrary, if the frequency deviation is large during fabrication, the squeezing method is unable to compensate for the deviation of frequency.

5 Conclusions and outlook

A copper model CH cavity has been built and tested. From the measured result of this cavity, the accuracy of simulating the complex cavity is acceptable. The process for this cavity can also be used directly in the superconducting CH cavity in the future. The auxiliary structure of the CH cavity should be carefully considered in our next work.

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