THERMAL ANALYSIS OF RF CAVITY FOR CYCIAE-100

S.M. Wei[1 #], T.J. Zhang[1], B. Ji[1], J.S. Xing[1], X.L. Jia[1], Y.J. Bi[1, 2], Z.G. Li[1], S.Z. An[1], F.Yang[1], Y.Z.Liu[1]

[1]China Institute of Atomic Energy, Beijing, 102413, China
[2]Department of Engineering Physics Tsinghua University, Beijing, 100084, China

Abstract

To provide the accelerating voltages, 60 kV at the central region and 120 kV at the extraction region, two 100 kW amplifiers are used to drive two cavities respectively, which are installed in the two opposite valleys of the compact magnet.

When the Q value is 10300, about 28.1 kW RF power loss occurs on each cavity based on the numerical simulation by a finite difference code. However, due to some non-ideal factors during the fabrication process, one may estimate the actual Q value at ~6000. As a result, the loss on each cavity will be approximately 48.2 kW.

In the light of the method above, the thermal analysis of RF cavity is carried out accordingly. From the mechanical 3D CAD model, the geometry of the cavity is extracted and input into a FEM code for thermal analysis. Various configurations of water cooling system, including the Dee, RF Liner, short plate, inner stem, outer stem, side wall and back wall, are investigated. In this paper, the design of the water cooling system for RF cavity is optimized and demonstrated in detail. The result of this theoretic design has been applied in the detail design of the RF cavity

INTRODUCTION

As one of the main projects at China Institute of Atomic Energy (CIAE), the completion of Beijing Radioactive Ion-beam Facility (BRIF) [1] will be of significant importance widely and it can be widely used in fundamental and applied researches, e.g., neutron physics, nuclear structure, material and life sciences, medical isotope production [2]. The 100MeV compact cyclotron CYCIAE-100, is the major and critical part of this project designed at CIAE for the generation of high intensity proton beams. It consists of four straight sector magnets with fixed field, RF system, ion source, injection system, extraction system, water cooling system and etc. When the construction is finished, this cyclotron will be capable of providing a 75 MeV ~ 100 MeV, 200 μA ~ 500 μA proton beam.

As a crucial part of the cyclotron, the RF system is made up of amplifiers, RF cavities, cables, coupling capacitance and correlative equipment to provide the accelerating voltages that increase along the radius, i.e., 60 kV at the central region and 120 kV at the extraction region. Two 100 kW amplifiers are used to drive the two cavities respectively, which are installed in the two opposite valleys of the compact magnet. Figure 1 shows the model of the RF cavity with two stems in CYCIAE-100.

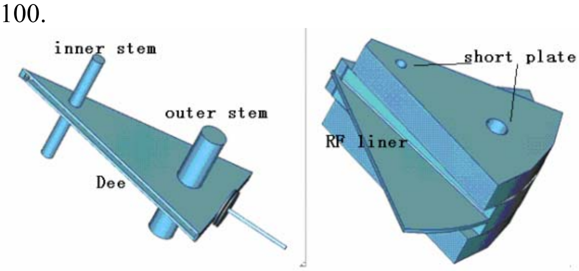

Figure 1: The RF cavity model of CYCIAE-100 with two stems

When the cyclotron is in operation, part of the RF power loss will occur on the cavity, resulting in the temperature rise of the cavity, and then distortion of the cavity. The RF resonance frequency will change because of the cavity distortion. As a consequence, the water cooling is required to keep the temperature rise of the RF cavity within a reasonable range so that the RF resonance frequency will remain stable.

The power loss on the cavity is calculated by the numerical simulation program MICROWAVE and the thermal analysis is carried out based on the power distribution. For the stability of RF resonance frequency, water cooling of the RF cavity is optimized in detail.

POWER DISTRIBUTIONS ON THE RF CAVITY [3]

The numerical simulation was conducted using a finite difference code to describe the power loss on the RF cavity. From the result of the numerical simulation, it can be seen that when the Q value is 10300, about 28.1 kW RF power will be lost on each cavity. However, due to

Table 1: The power distribution on each RF cavity

Q value	Total power loss on each cavity /kW	Power distribution / W						
		Dee	Inner stem	Outer stem	Wall	Short plate	Capacitance	RF liner
Q=10300	Q=10300	6280	7920	5840	3246.8	1408	76	3324
Q=6000	Q=6000	10800	13600	10020	5575	2417	130	5706

weisumin@tsinghua.org.cn

some non-ideal factors during the fabrication process, one may estimate the actual Q value at ~6000. As a result, the loss on each cavity will be approximately 48.2 kW. Table 1 shows the power loss on Dee, inner stem, outer stem, wall, short plate, capacitance and RF liner of one RF cavity at different Q values, i.e., 10300 and 6000 respectively. Figure 2 shows the power distribution on one cavity, in which the red region represents the high power loss and the green region indicates the low power loss.

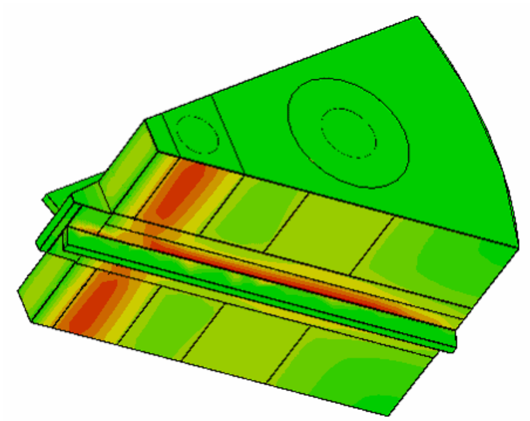

Figure 2: The power loss distribution on the RF cavity

Table 1 and Figure 2 show that the power loss on inner stem and the edge of the Dee are higher than that on other parts, and as a result the water cooling of these areas are specially needed to be optimized.

THERMAL DISTRIBUTION ON THE RF CAVITY

Based on the power distribution of the RF cavity, the thermal analysis is carried out by the 3D finite element software ANSYS CFX. It is a powerful and robust software to calculate the heat transfer problems [4]. From the mechanical 3D CAD model, the geometry of the cavity and water cooling tube are extracted and input into CFX to calculate the solid-liquid heat transfer and simulate the thermal distribution on the cavity.

The first picture in Fig.3 shows the power distribution on the Dee and inner stem, outer stem while Q value is 10300. According to this result, we can simulate the thermal distribution. Figure 3 also shows the thermal distribution on inner stem and Dee. The water cooling tube in inner stem is a helical tube inside the stem. The flow velocity of water is 1.5 m/s and the liquid pressure between entrance and exit is about 1kg/cm2. In this condition, the temperature rise of inner stem is about 3.2°C at Q value 10300 and 5.6°C at Q value 6000. The flow velocity of water in Dee is about 3 m/s, and the liquid pressure is about 1.5 kg/cm2. The temperature rise of Dee is about 12.6°C at Q value 10300 and 18.3°C at Q value 6000. Table 2 shows this temperature rise.

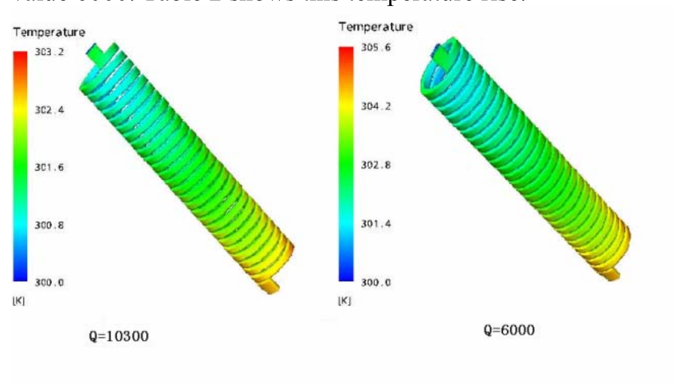

Figure 4: Temperature rise of cooling water in inner stem at different Q value

Table 2: Temperature rise of inner stem and Dee

Q value	Temperature rise / °C	
	Inner stem	Dee
Q=10300	3.2	12.6
Q=6000	5.6	18.3

Figure 4 shows the shape of the water cooling tube in inner stem and the temperature rise of cooling water at different Q values, and both calculations adopts the same water flow velocity.

OPTIMIZATION OF THE WATER

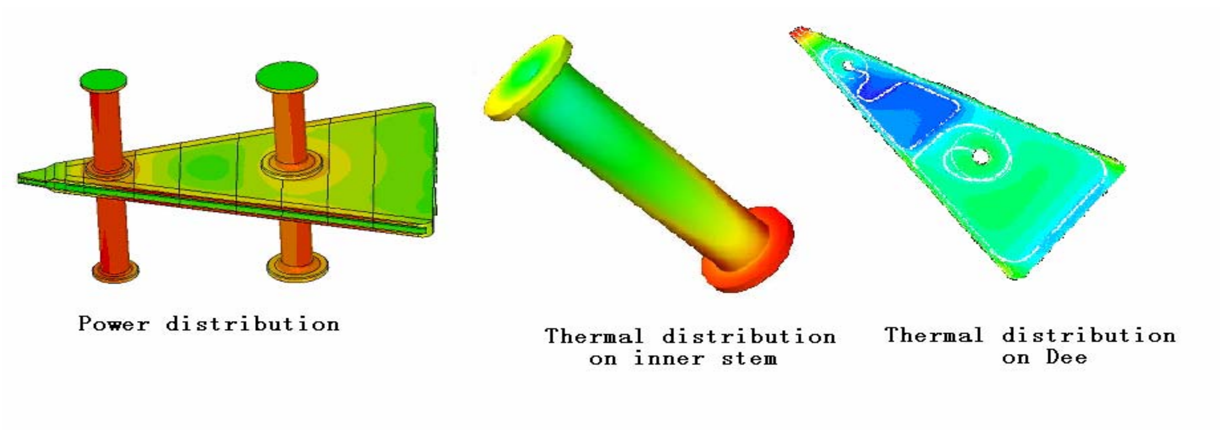

Figure 3: Thermal distribution of inner stem and Dee

COOLING

The water cooling system of the cavity is designed to effectively keep the temperature rise of RF system within a reasonable range. Given the fact that a layout with fewer water cooling tubes will cause higher temperature rise, and more water cooling tubes will result in the distortion of RF cavity, the optimization of the water cooling system is inevitable to enable the stability of the RF resonance frequency. Taking Dee as an illustration, the purpose of this optimization is to reduce the number of water cooling tubes while the temperature rise is still acceptable.

Figure 5 shows two different shapes of water cooling tubes in Dee. The thermal analysis demonstrates that the temperature at edge of the Dee is obviously higher than other area, and consequently the water cooling tube must be through the edge but not necessary to locate in the middle of the Dee. The initial design for the tube is displayed in the left picture in Fig.5. Since the structure is complicated and the section of the tube is 13mm×13mm with a Φ10mm hole inside, it places much difficulty on the machining. In view of that, the optimization of this tube is carried out as shown in the right picture in Fig.5. It can be seen that the tube previously in the middle of the Dee is taken out while the one on the edge is retained. Through this modification, it is easier for machining and meanwhile exerts less impact on the distortion of RF cavity. There is no distinct difference in temperature rise for the two conditions.

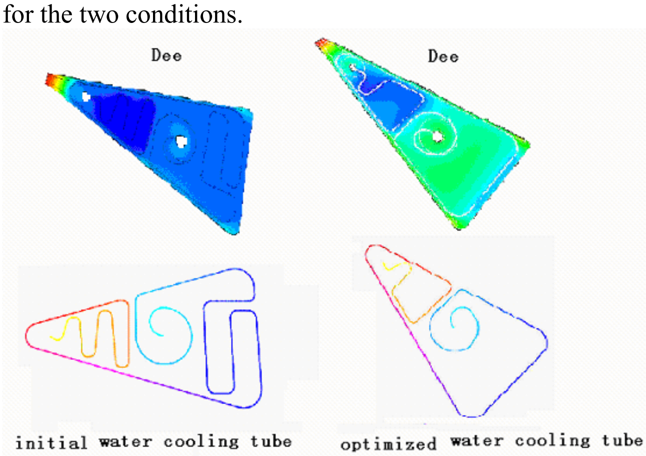

Figure 5: Water cooling tube optimization of Dee

CONCLUSION

The RF system is one of the most challenging parts of CYCIAE-100. It is designed to provide the accelerating voltages--- 60 kV at the central region and 120 kV at the extraction region. Given the fact that the power losses on the cavity can arise the temperature rise of the cavity and then further influence the RF frequency, thermal analysis is carried out and based on that the water cooling system is designed to keep the stability of RF frequency.

In the meantime, RF power losses on the cavity are simulated by a finite difference code at Q value 10300 and 6000 respectively, and thermal analysis is conducted on this base using a finite element software ANSYS CFX. The geometry of the cavity is extracted from the mechanical 3D CAD model and input into the CFX for thermal analysis. According to the thermal distribution of RF cavity, the water cooling system of RF system is designed and optimized to keep the temperature rise under control.

Now all the theoretic design is finished and will be applied in the detail design.

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