Thermal analysis of DTL in the SSC-LINAC*

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Abstract: A linear accelerator as a new injector for the Separated Sector Cyclotron at the Heavy Ion Research Facility of LAN Zhou is being designed. The Drift-Tube-Linac (DTL) has been designed to accelerate $^{238}U^{34+}$ from 0.140 MeV/u to 0.97 MeV/u [1]. The 3D finite element analysis of thermal behavior is presented in this paper. During operation, the cavity will produce Joule heat. The cavity will not work normally due to the high temperature and thermal deformation will lead to frequency drift. So it is necessary to perform thermal analysis to ensure the correct working temperature is used. The result of the analysis shows that after the water cooling system is put into the cavity the temperature rise is about 20 degrees and the frequency drift is about 0.15%.

Key words: finite element method, coupling field, frequency drift, ANSYS code

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1 Introduction

Due to the skin effect, during operation the DTL tank will produce Joule heat. The cavity will not work normally due to the high temperature and thermal deformation will lead to frequency drift. So it is necessary to perform thermal analysis to ensure the correct working temperature is used. A water cooling system is put into the cavity to control the temperature.

Finite element analysis is widely used to solve this kind of problem. We use the finite element method to calculate the temperature and the deformation of the cavity. The software used for this analysis is the ANSYS code. The ANSYS code is a powerful code for calculating the coupling field.

2 Model and analysis process

Figure 1 shows the main structures of the cavity. The model that we use for the analysis consists of two parts: the cavity and the vacuum. The cavity will be made of copper. We can see from Fig. 1 that the cavity has many capacitors near the drift tubes. The capacitors are used to modify the frequency when frequency drift occurs. The main parameters of the DTL tank are summarized in Table 1.

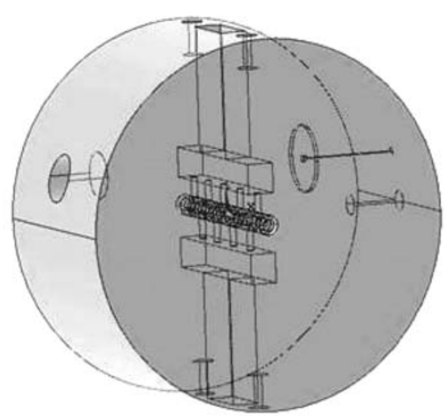

Fig. 1. The sketch drawing of DTL tank.

Figure 2 shows the finite element model. Three types of element in the ANSYS code are used in this analysis: the solid element, the high frequency element and the surface element. The solid element is used to perform the thermal and structural analysis, the high frequency element is used to determine the

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Table 1. The main parameters of the DTL cavity.

cavity radius/mm	cavity inside length/mm	cavity outside length/mm	T shape plate thickness/mm	diameter of drift tube/mm
530	588.82	660	200	32

resonant frequency and the surface element is used to transfer the result from high frequency analysis to thermal analysis. For reasons of calculation simplification, we ignore the capacitors that do not affect the thermal result and mesh the model with the triangle mesh.

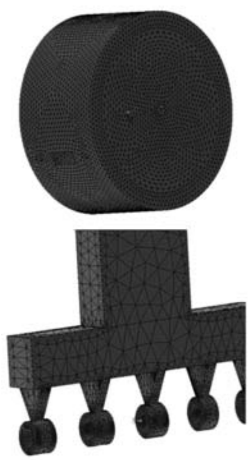

Fig. 2. The finite element model.

The analysis includes the following steps.

1) Analyze the high frequency field.

2) Couple the result from the first step to the thermal analysis and calculate the thermal result, such as temperature field.

3) Couple the thermal result to the structural analysis to calculate the structural result, such as displacement, stress and so on.

4) Couple the structural result back to the high frequency analysis and find the influence of the deformation to the resonant frequency.

The material properties of each particular part are shown in Table 2.

Table 2. The material properties of each particular part.

material	copper	vacuum	water
relative permittivity		1	
relative permeability		1	
thermal conductivity/(w/m·k)	397		0.6
density/(kg/m^3)	8900		4200

3 Analysis result

The first information of the result is the resonant frequency. The value of the resonant frequency is about 51.49 MHz and the quality factor is about 16533. This result is reasonable to compare with the designed value, which is 53 MHz.

So we couple the high frequency analysis result to the thermal analysis and put the water cooling system into the cavity. See Fig. 3. As we can see the water cooling system is put into the whole DTL tank through the drift tube to the T shape plate sides.

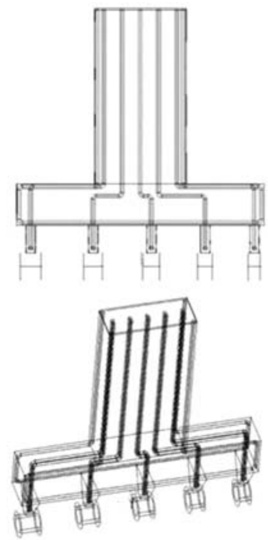

Fig. 3. The water cooling system (half model).

Before calculation, two boundary conditions, which are the heat flux and the convective heat transfer coefficient between the water and the cavity, must be determined.

The heat flux can be determined by the following formula:

$$H_{\text{flux}} = 1/2 \times R_{\text{S}} \times H^2, \tag{1}$$

R_{S} is the surface resistance relating to the resonant frequency. H is the magnetic field strength calculated by high frequency analysis.

The convective heat transfer coefficient between the water and the cavity can be determined from the theory of heat transfer:

$$Re = vd/u, \tag{2}$$

v is the water flow velocity, d is the water tube diameter and u is the water viscosity.

$$Pr = upc/K, \tag{3}$$

p is the density, c is the constant pressure specific heat and K is the thermal conductivity.

$$Nu = ad/K, \tag{4}$$

a is the convective heat transfer coefficient.

We know water's properties and flow velocity, so from the Reynolds number, the Prandtl number and the Nusselt number we can calculate the convective heat transfer coefficient, which is in the Nusselt number. We assume that the water temperature is 30°.

We apply the convective heat transfer coefficient and the heat flux as the boundary conditions to the cavity model and calculate the temperature and the thermal deformation of the cavity. Fig. 4 shows the temperature distribution. The maximal temperature is 53°. We assume the initial temperature to be 30°. So after the water cooling system is put into the cavity the temperature rise is about 23°, which is acceptable.

From the thermal analysis we know the temperature gradient and couple the result to the structural analysis to calculate the displacement and stress.

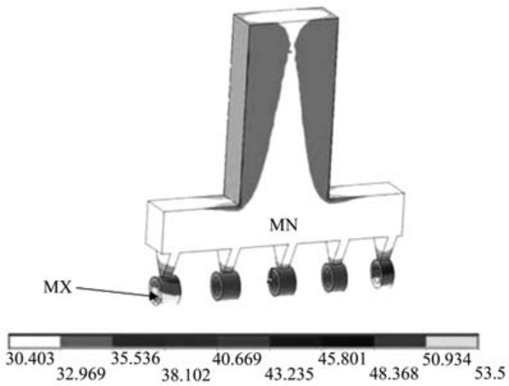

Fig. 4. Distribution of the temperature.

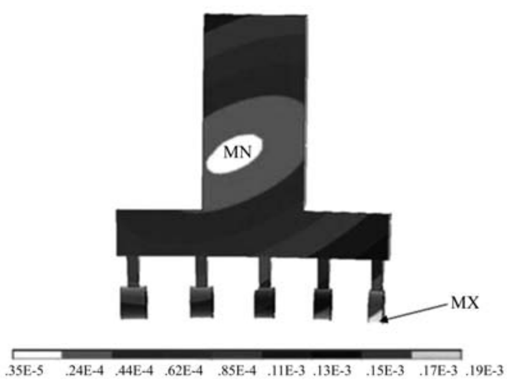

Fig. 5. Distribution of the displacement.

Figure 5 shows the distribution of the displacement. The maximal displacement caused by the temperature gradient is about 0.18 mm. Fig. 6 shows the distribution of the thermal stress. The maximal thermal stress is about 23 MPa. As the cavity is made of copper, it can work normally.

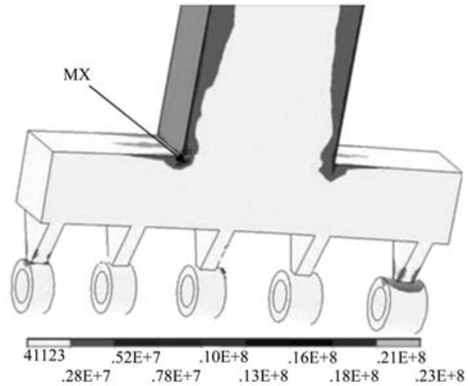

Fig. 6. Distribution of the thermal stress.

4 Temperature tuning

When the temperature changes, the cavity will produce thermal deformation, which will cause frequency drift. Because of the deformation, we calculate the high frequency field again and find that the resonate frequency is 51.57 MHz. The change in frequency is about 0.079 MHz. The change percentage is 0.15%. When detuning occurs, the efficiency of the power feed will decrease and the beam quality will worsen. In order to avoid this phenomenon, it is necessary to adjust the frequency to its original frequency. For temperature detuning, mechanical methods such as squeezing or stretching the end face of the cavity is usually used [2].

5 Summary

In summary, we present the thermal analysis of the DTL cavity with the water cooling system. The results provide a reasonable way to design the water cooling system. From the result we know that after the water cooling system is put into the cavity, the temperature rise and the thermal stress are in reasonable ranges, so the cavity can work normally. Due to the assumption of the water temperature, we can not know the temperature gradient of the water. So in a future work, it is necessary to build a fluid model to calculate the water temperature, which will be more in line with the actual situation.

References

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