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MULTI-PHYSICS ANALYSIS OF TWO BUNCHERS FOR CIFNEF

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Abstract

The Compact Intense Fast NEutron Facility (CIFNEF) project will accelerate and deliver a 5 MeV deuteron beam onto targets to produce a high-intensity neutron beam. A 2.5 MHz pulsed deuteron beam with bunch width within 2 ns is needed at the targets. To fulfil the special requirements of the beam dynamics, two types of bunchers are adopted for CIFNEF. One is a 10.156 MHz buncher, used in the low energy beam transport (LEBT) line to longitudinally focus the 50 keV deuteron beam to the RFQ longitudinal acceptance, with an effective voltage of 4 kV. A lumped element model is adopted because of the low frequency, consisting of an inductance coil in parallel with the capacitance of the drift tubes. The other buncher is an 81.25 MHz buncher, used in the high energy beam transport (HEBT) line to longitudinally focus the 5 MeV deuteron beam to 2 ns. A Quarter Wave Resonator (QWR) with 2 gaps is used to provide an effective voltage of 150 kV. Thermal and structural analyses have been carried out on these two bunchers. Detailed simulations of these two bunchers are presented and discussed in this paper.

INTRODUCTION

The CIFNEF is proposed by the Institute of Heavy Ion Physics at Peking University, aiming to accelerate and deliver a 5 MeV deuteron beam onto lithium targets to provide a high-intensity neutron beam. The linac used in CIFNEF consists of an ion source, a low energy beam transport (LEBT) line, a radio frequency quadrupole (RFQ), a medium energy beam transport (MEBT) line, an interdigital H-mode drift tube linac (IH-DTL), and a high energy beam transport (HEBT) line. To meet the requirement for beam quality, a 10.156 MHz buncher and an 81.25 MHz buncher are adopted in the LEBT line and the HEBT line, respectively. The basic requirements are listed in Table 1.

Table 1: Basic Requirement Parameters of the LEBT and the HEBT Bunchers

Parameters	Value: The LEBT buncher	Value: The HEBT buncher
Resonant frequency	10.156 MHz	81.25 MHz
$v/c=\beta$	0.0073	0.073
$\beta\lambda/2$	107.8 mm	134.8 mm
Effective voltage	4.0 kV	150.0 kV

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THE LEBT BUNCHER

The model of the LEBT buncher is illustrated in Fig. 1. A lumped element model is adopted because of the low frequency. This buncher includes two main parts. The upper part is a cylinder containing three drift tubes. Two of the drift tubes are bolted onto the end plates. The other tube is supported by Poly Tetra Fluoro Ethylene (PTFE). The lower part is a cube whose dimensions are 360 mm by 250 mm by 275 mm. A ten-turn coil inside the cube is linked to the middle drift tube. The inductive coil is in parallel with the capacitance of the drift tubes to generate the resonant frequency of 10.156 MHz. The parameters of the LEBT buncher are listed in Table 2.

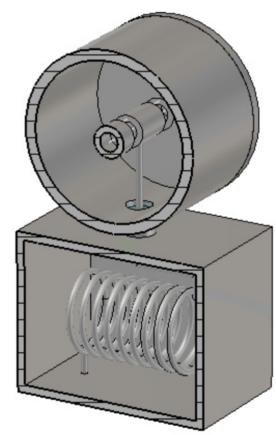

Figure1: Model of the LEBT buncher.

Table 2: Parameters of the LEBT Buncher

Parameters	Value (mm)
Cavity length	215.6
Cavity internal diameter	150.0
Beam aperture radius	36.0
Gap length	30.0
Coil diameter	137.0
Coil wire diameter	12.0
Coil length	240.0

The multi-physics analysis includes electromagnetic, thermal and mechanical analyses. Firstly, RF electromagnetic analysis is used to analyse the high frequency field and to obtain the thermal surface losses. Secondly, the thermal surface losses are coupled into a thermal analysis to calculate the temperature field distribution. Thirdly, the thermal analysis results are passed to the mechanical analysis to determine displacement distribution and stress. Finally, the mechanical results are coupled back to the RF analysis to evaluate the frequency

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shift due to the thermal deformation. In this paper, CST [1] is used for this analysis.

RF Analysis

The geometrical parameters of this buncher are optimized to obtain the resonant frequency. In the RF simulation, the RF frequency is 10.163 MHz, which is close to the design frequency of 10.156 MHz. The quality factor is 2188.8. The simulation results from CST MWS and ANSYS HFSS [2] are listed in Table 3, showing good consistency.

Table 3: Simulation Results with CST and ANSYS

Parameters	Frequency (MHz)	Quality factor
CST MWS	10.163	2188.8
ANYSY HFSS	10.160	2071.1

Thermal Analysis

Due to the low effective voltage, the power loss is estimated to be only 3 W, so there is no need to add a cooling system to this cavity. We applied the thermal surface losses as a heat flux to calculate the resultant temperature distribution, which is shown in Fig. 2. The initial temperature is assumed to be 291 K (18°C). The maximum temperature is 311 K, located at the centre of the coil.

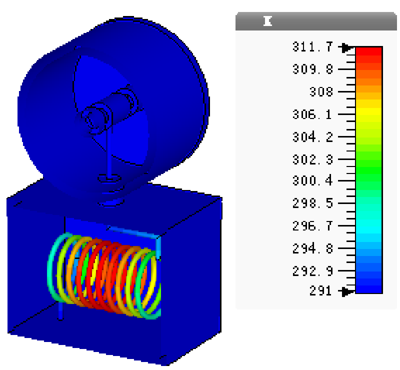
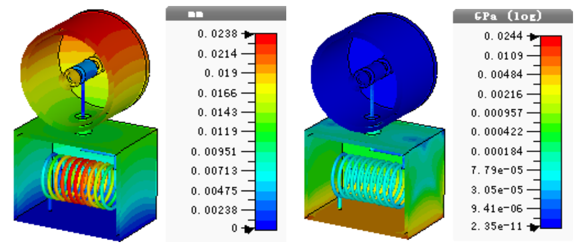


Figure 2. Temperature distribution of the LEBT buncher.

Mechanical Analysis

The result simulated in the thermal analysis is used as the boundary condition for the mechanical analysis. Determining the displacement due to the temperature distribution is essential for estimating the frequency. Figure 3 shows the calculated displacement and the Von Mises stress. The maximum displacement is 23.8 µm, located at the centre of the coil. The maximum Von Mises Stress is 24.4 MPa. As the buncher is made of copper, this stress level is tolerable [3].

As the final step, the displacement distribution is coupled to the RF analysis to calculate the deformed cavity frequency. The deformed cavity frequency is 10.161 MHz. The change is approximately 2 kHz. This deviation can be compensated using a frequency tuning device.



(a) (b)

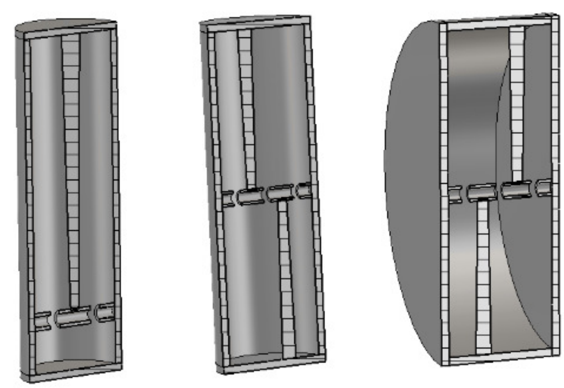
Figure 3: Distribution of displacement (left) and Von Mises stress (right).

THE HEBT BUNCHER

A 2.5 MHz pulsed deuteron beam with a bunch width within 2 ns is needed at the targets. To satisfy the special requirements of the beam dynamics, an 81.25 MHz QWR buncher is used in the HEBT line to longitudinally focus the 5 MeV deuteron beam. The multi-physics analysis follows the same procedure above.

RF Analysis

Before simulation, we have studied QWR, HWR, and IH structures to find the appropriate structure. Figure 4 shows the schematic of these structures. Table 4 is the structure caparison at 81.25 MHz, β=0.073 using CST MWS. Among these bunchers, the QWR has the smallest dimensions. So the QWR buncher is adopted.



(a) (b) (c)

Figure 4: The schematic of different structures. (a) QWR, (b) HWR, (c) IH.

Table 4: Structure Comparison at 81.25 MHz, β=0.073

Parameters	QWR	HWR	IH
Height (mm)	1005.0	1400.0	1260.0
Length (mm)	309.5	460.0	460.0

The main parameters of this buncher obtained using CST MWS are presented in Table 5. The RF analysis was also studied using ANSYS HFSS for mutual authentication. In ANYSY HFSS, the frequency and quality factor are 81.33 MHz and 8977, respectively. The results coincide well with the results simulated in CST.

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Table 5: Main parameters of the HEBT Buncher

Parameters	Value	Unit
Frequency	81.32	MHz
Quality factor	9346.0	
Cavity height	1005.0	mm
Cavity diameter	309.5	mm
Aperture radius	20.0	mm
Gap length	30.0	mm
Stem radius	20.0/35.0	mm

Thermal and Mechanical Analysis

The power loss obtained in the RF analysis has been coupled to the thermal analysis to calculate the temperature distribution. Table 6 summarizes the losses in the different parts of the HEBT buncher. The stem and the shell produce the most thermal losses. It is necessary to add a water cooling system to these two components. As shown in Fig. 5, there are two types of cooling channels. One is a sleeve type in the stem, whose diameter is 32 mm. The other is helical type in the shell, whose diameter is 5 mm.

Table 6: Summary of Losses in Different Parts of the HEBT Buncher

Components	Losses
Tube	2.5 W
Stem	2226.3 W
Shell	653.33 W

The heat transfer coefficient h can be obtained by the Dittus-Boelter correlation [4]:

$$h = \frac{\mathrm{Nu}\, k}{D} \tag{1}$$

Where $k = 0.6$ W/mK is the water heat conductivity coefficient and D is the diameter of cooling channel. Nu is the Nusselt number which is defined as:

$$\mathrm{Nu} = 0.023 \cdot \mathrm{Re}^{0.8} \cdot \mathrm{Pr}^{0.4} \tag{2}$$

$$\mathrm{Pr} = \frac{C_{\mathrm{p}} \mu}{k} \tag{3}$$

$$\mathrm{Re} = \frac{v D \rho}{\mu} \tag{4}$$

Where v is the water's velocity, $\mu = 0.001\ \mathrm{Ns/m^2}$ is the viscosity of water, $C_{\mathrm{p}} = 4.2$ kJ/kg is the heat capacity of water, $\rho = 998\ \mathrm{kg/m^3}$ is the density of water, and Re and Pr are the Reynolds number and the Prandtl number, respectively.

Assuming that the velocity of water is 3 m/s, according to the Dittus-Boelter correlation, the heat transfer coefficient in the stem and shell are calculated to be 9000 W/m·K and 11400 W/m·K. The heat transfer coefficient and thermal surface losses are applied to the HEBT buncher to calculate the temperature field. Fig. 5 also shows the temperature distribution of the HEBT buncher. The maximum temperature is 295.15 K, located at the stem. As the initial temperature is assumed to be 291 K, the maximum temperature rise is only 4 K when this cooling is applied.

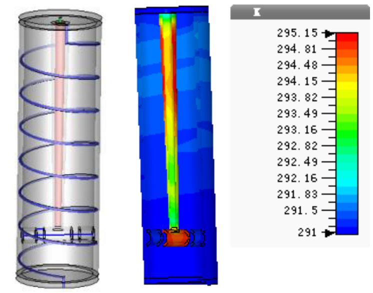

Figure 5: The layout of cooling system (left). The temperature distribution of HEBT buncher (right).

After thermal analysis, the temperature distribution is coupled to the mechanical analysis to simulate the thermal deformation. The displacement distribution is given in Fig. 6. The maximum displacement is 29.9 µm, located at the middle drift tube.

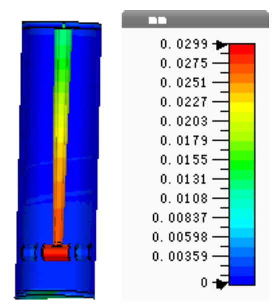

Figure 6: The displacement distribution of HEBT buncher

The mechanical results are coupled back to the RF analysis to determine the frequency shift due to thermal deformation. Compared with the frequency obtained in the first RF analysis, the frequency shift is -1.8 kHz. This deviation is as low as 0.002%, and can be compensated by a frequency tuning device.

CONCLUSION

For the CIFNEF project, two types of bunchers have been studied. Multi-physics analyses of these two bunchers have been described. The LEBT buncher uses a lumped element structure, because of its low frequency. For the HEBT buncher, a cooling system has been adopted to ensure normal operation. The results show that the temperature rise and frequency shift of these two bunchers are in the reasonable range.

REFERENCES

[1] CST Simulation packages, `http://www.cst.com`

[2] ANSYS, `http://www.ansys.com`

[3] Robert H. Perry, *Engineering Manual*. Third edition, Mcgraw-Hill Book Company Press, 1976.

[4] YANG Shi-Ming, TAO Wen-Quan. *Heat Transfer*. Fourth edition. Higher Education Press, 2006.