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THERMAL AND STRUCTURAL ANALYSIS OF THE 72.75 MHz LINCE RFQ*

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Abstract

The 72.75 MHz LINCE RFQ [1] is designed to function at room temperature. Effective operation of the RFQ cavity requires efficient water cooling in order to dissipate significant resistive power non-uniformly distributed on the copper walls and vanes. This amounts to about 10 kW for one 0.5 m long RFQ section. Cylindrical cooling channels have been designed and optimized by varying their diameter and position in order to minimize the frequency shift generated by thermal displacements. The article reports results of power loss simulations coupled with electromagnetic modelling studies and their consequences on the RFQ performance in terms of resonant frequency and thermal deformations.

INTRODUCTION

The four-vanes RFQ is designed for LINCE high intensity accelerator complex [2]. The structure provides a 72.75 MHz resonating mode with a 1.3 MHz margin controlled by the tuners [1]. The initial beam is made of 2 ns long bunches of 40 keV/u and the aim of the design is to achieve 500 keV/u. The modulation was simulated using the DESRFQ code [3] with 82 kV inter-vane potential on a vane tip tested in ANL [4].

A complete loop of coupled numerical studies is achieved as shown in Fig. 1. The **RF Analysis** has been carried with COMSOL [5] resulting in an estimate for the resistive power losses. These are scaled and coupled with **Heat Transfer** model in order to obtain a temperature map at the vanes surface. The next step is the optimization of the cooling system according to the heat map. Two optimization for channel position, channel diameter, fluid and velocity temperature are carried out. The final heat flux is coupled to a **Solid Mechanics** study to estimates the stress and displacements due to thermal expansion. The frequency shift is obtained through a new RF study of the deformed structure.

RF ANALYSIS

The first study has been done with DESRFQ and Track [6] codes. Eigenfrequency studies have been done using COMSOL software, as shown before [1]. For the last version of the study the whole structure with modulated vanes was simulated and a 73.25 MHz for the quadrupole mode TE_{211} resonance is obtained.

Heat Map

Resistive power losses are calculated and that show the maximum loses are in the window corners as it is show in

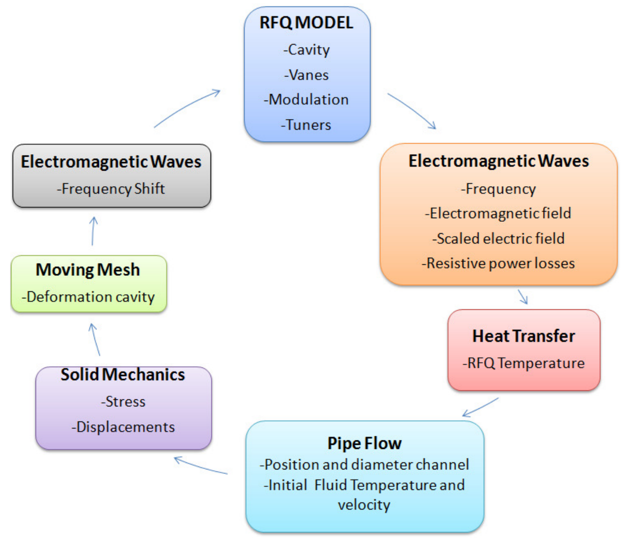

Figure 1: Study steps.

Fig. 2. This study is coupled with a non-isothermal pipe flow simulation in a quarter symmetry model (section) of the RFQ. The total resistive power dissipated by the RFQ working mode at 67.35 MHz is 10.67 kW. A cooling system must be design to control the heat dissipation in the RFQ.

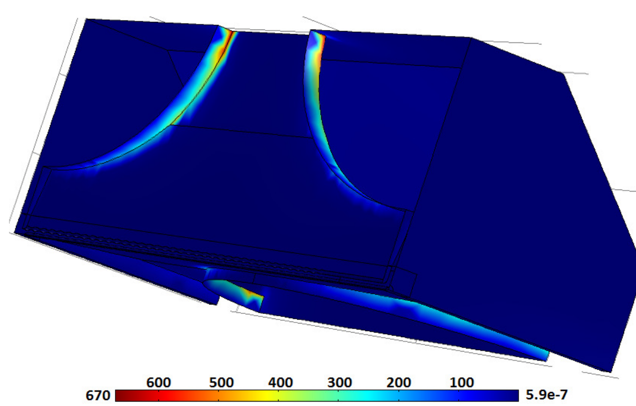

Figure 2: Resistive power losses [kW/m].

COOLING SYSTEM

According with the resistive power losses two models have been proposed as shown in Fig. 3. An initial cooling channel of rectangular profile has been considered due to its mechanical simplify as shown in Fig. 3(top) but proved unsatisfactory in the tip vanes. Therefore the second model Fig. 3(bottom) was studied whit better results.

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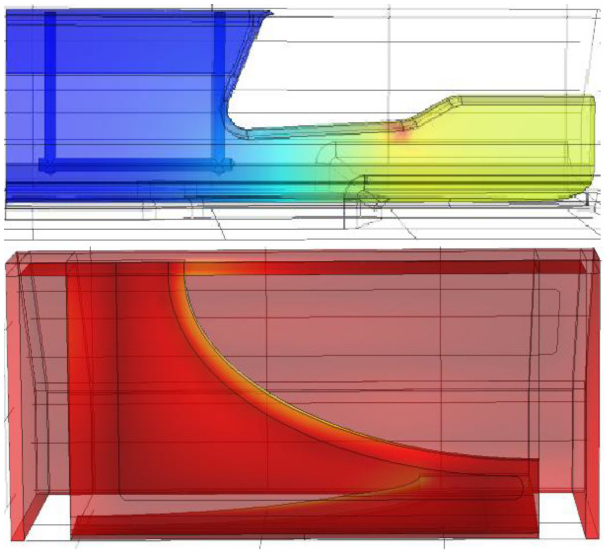

Figure 3: System cooling models.

Position and Diameter Optimization

Thermal simulations have been done with the variation of the position and diameter using sweep parametrization. The ranges for the simulation were 10 mm to 17 mm and 7 mm to 14 mm for the position and diameter respectively. While the geometry of the channels is constant its position relative to the vane changes as shown in Fig. 4.

Figure 4: Flow rate along the cooling channels.

The aim of the study is to find temperature variations at different locations of the structure. Several geometric entities were selected to analyze the temperature during a time interval from 0 s to 8000 s. The selected entities were: 1. the RFQ volume, 2. the RFQ surface, 3. intermediate point on a side, 4. intermediate point on the vane tip, 5. line at the vane tip and 6. point near to the maximum power losses.

The data obtained for the volume and surface studies show that the initial temperature of 16.15 °C decrease to 16 °C. At the point located in the middle of the vane length, results show that the required diameter at the sides of the cavity may be lower than in the vanes, which is expected, considering that on the side walls the power losses are lower. The results for the line in the tip vane shown in Fig. 5, finding minimum values of 14 mm and 10 mm for the position and diameter respectively. The point 6 remains constant temperature during the time analyzed.

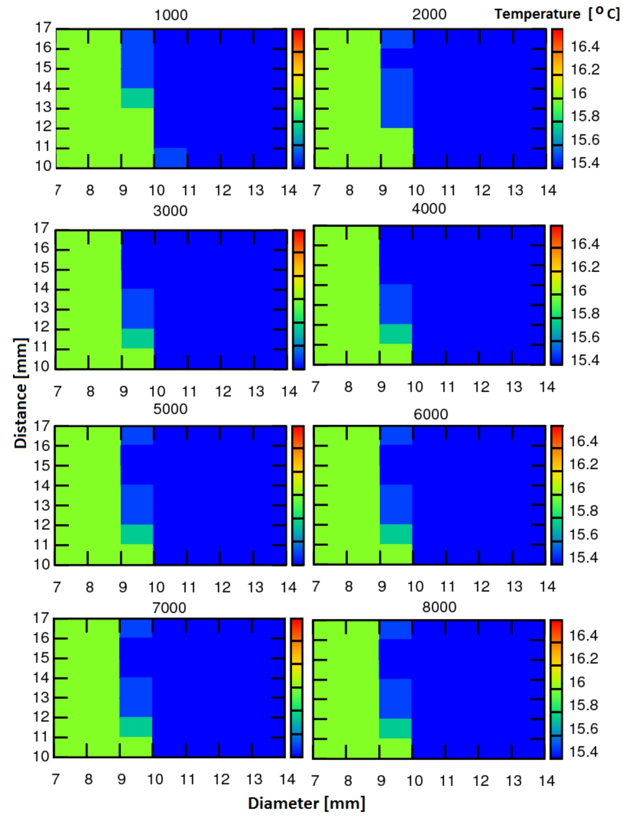

Figure 5: RFQ cavity temperatures as a function of the position and diameter of the cooling channel.

Temperature and Velocity Optimization

The aim of this section is to analyze the temperature dynamics in the structure temperature in function of the initial fluid conditions, temperature and velocity. The select ranges are 0 m/s to 5 m/s and 15 °C to 20 °C for the velocity and temperature, respectively. The same entities as before and time range are considered. All the results show that for higher temperatures of the fluid heat dissipation is smaller and by increasing the fluid velocity, the dissipation is greater as shown in Fig. 6. The maximum value for the fluid temperature is 20 °C and the minimum initial velocity is 3 m/s.

Selected values are shown in Table 1, the values may vary within the range shown in the same table, and this variation depends on the needs of future studies.

FREQUENCY SHIFT

The remaining heat flux is coupled to a solid mechanics study which estimates displacements. The last step is to run

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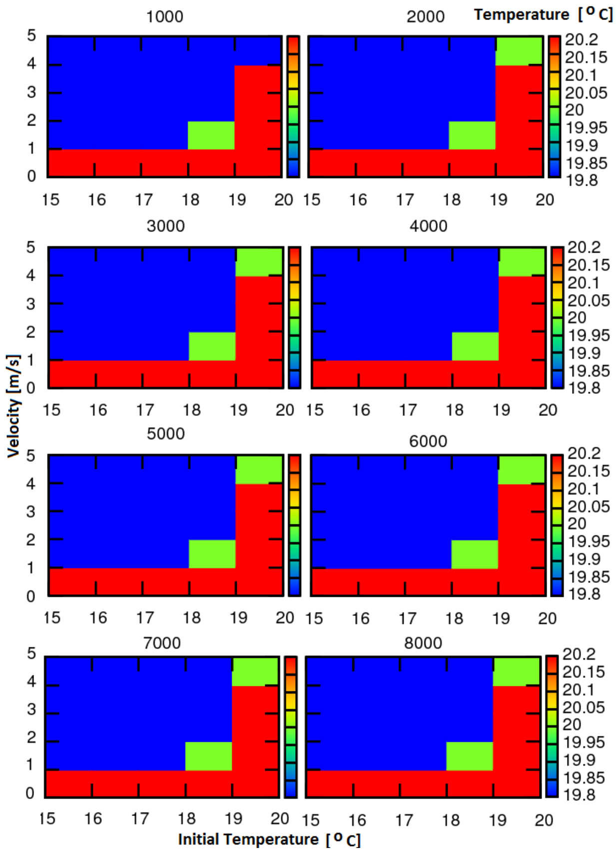

Figure 6: RFQ cavity temperatures as a function of the initial temperature and velocity of the fluid.

Table 1: Parameters

Parameter	Value	Interval	Units
Diameter	14	10-14	mm
Position	16	14-17	mm
Initial Temperature	18	15-19	°C
Initial Velocity	4	3-5	m/s

all the coupled modules with the selected parameters and obtain the frequency shift due to the thermal expansion.

Mechanical Stress

As shown in Fig. 7 the maximum values of the mechanical stress are in the corners of the RFQ ends and in the elliptical windows. A maximum value of 22.6 MPa at the corners of the support surface of the structure is recorder. The surface which exhibits the most pressure is the support side. Given the above, the importance of a detailed analysis of the effect on support sides becomes obvious.

Displacement

Results for the displacements show maximum values at the ends of the vanes of 64.7 µm for the x axis and 98 µm as shown in Fig. 8 for y axis both in the direction of the beam,

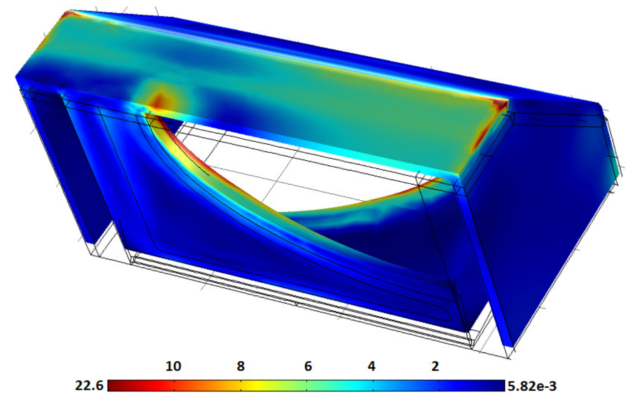

Figure 7: Mechanical stress map for the RFQ cavity [MPa].

and 2.04 µm on sides of the cavity. The difference between the displacements in the x and y axis are due to the RFQ support area considered fixed constraint.

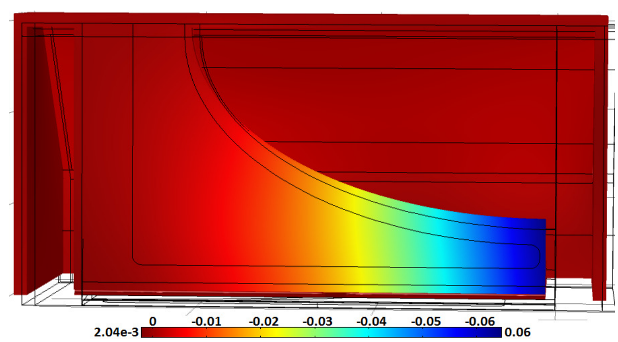

Figure 8: Displacement in x axis [mm] on the vanes.

With the parameters from the table 1 the frequency shift is 7.37 MHz. More details studies are considered in order to improve frequency shift estimates.

CONCLUSIONS

A method has been developed to study electromagnetic, thermal and mechanical effects as coupled studies implemented in COMSOL. With the main goal of minimizing the frequency shift of the RFQ, more detailed simulations shall be carried out refining optimization parameters and initial conditions.

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