RF AND HEAT FLOW SIMULATIONS OF THE SARAF RFQ 1.5 MEV/NUCLEON PROTON/DEUTERON ACCELERATOR

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Abstract

SARAF linac, currently under construction, will consist of a medium energy (up to 40 MeV) high current (up to 2 mA, CW, upgradeable to 4 mA) RF superconducting linac for protons and deuterons. The linac front end ia based on a 4-rod RFQ. The 250 kW dissipated power to run a CW deuteron beam is four times the power needed to run a CW proton beam and three times the power per unit length ever applied in a similar four rods RFQ prior to the design of the SARAF RFQ. In order to reach the high end goal a rigorous study has been conducted in SARAF. The study includes the main findings following RFQ conditioning activities and a full scale RF simulation followed by a thermo- hydraulic analysis

INTRODUCTION

The SARAF 3.8 m long 4-rod RFQ [1] is operating at 176 MHz, designed to bunch and accelerate a 4 mA CW deuteron/proton beam to 1.5 MeV/u, see Fig. 1.

Figure 1: The SARAF four rods RFQ.

The electrodes voltage for accelerating deuterons is 65 kV, produces a maximal field of 22 MV/m. The RFQ injected power is induced by a loop coupler through one of the 39 RF coupled cells, see Fig. 2.
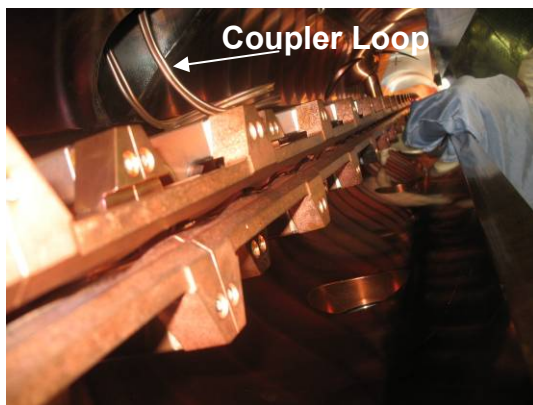

Figure 2: A layout of the RFQ internal structure.

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An RF cell is composed of two adjacent stems, 94 mm apart, a common base plate and two pairs of electrodes with a negative polarity between the pairs, while each pair is supported by every second stem, see Fig. 3.
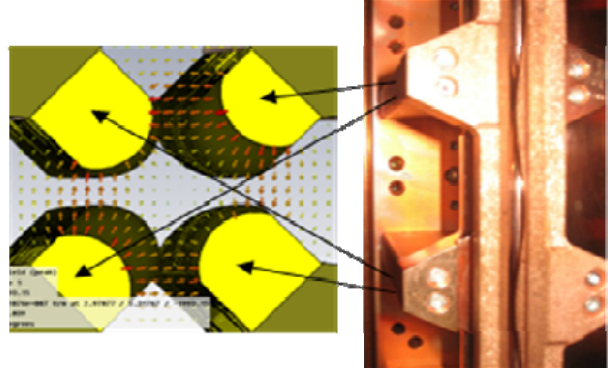

Figure 3: Top and side views of the two electrode pairs.

The pre beam dynamics design defined the electrodes modulation to achieve gentle bunching and synchronous acceleration based on fix voltage between the electrodes along the RFQ. 14 tuning plates were placed between adjacent stems along the RFQ, with adjustable height on top of the base plate. This enables the RFQ to reach the desired resonance frequency, with a flat voltage between the electrodes. At high power, local high surface currents in the RFQ might cause overheating which will lead to out-gassing and in turn to sparking. Therefore, there is a vital need for a detailed RF simulation combined with a thermal simulation of the RFQ. Thermal simulation is done in order to determine a priori the areas that heat up uncontrollably at high power, to enable CW beam operation with deuteron, by modifying the RFQ including the cooling system. We used CST MWS to simulate the RF currents and fields in a 3D detailed model of the SARAF RFQ. The correct eigenmode was reproduced and both feeding power quality factor $Q_E=3100$ [2] and the dissipation quality factor $Q_0=5600$ are in reasonable agreement with twice the measured load value- $2Q_L=3800$. The heat load generated by the simulated surface currents at critical areas along the RFQ with CST MWS was the input for thermal analysis using CST MWS thermal solver and ANSYS. These simulations explored our findings along the RFQ conditioning activities.

SIMULATIONS

The electromagnetic simulations were performed with the CST eigenmode solver on a full 3D geometry model of the RFQ internal surface including the coupler port (4" OD tube), see Fig. 4.
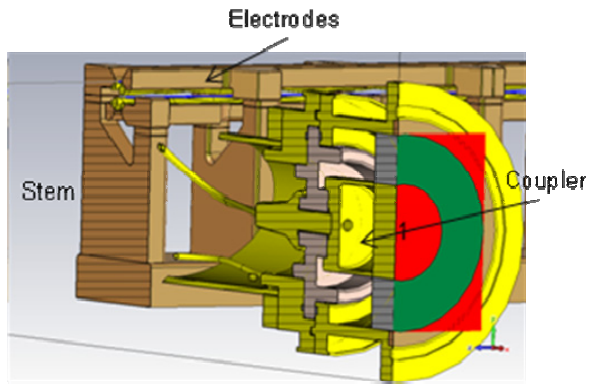
Figure 4: Partial view of the 3D RFQ geometry model.

The simulated RFQ surface currents at the resonance mode are shown in Fig. 5. The simulation generates the expected mode.
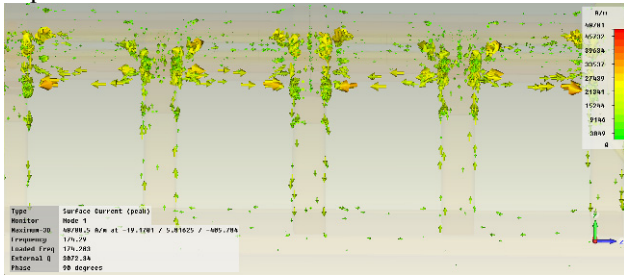

Figure 5: RFQ surface currents at the resonance mode.

The internal cooling lines surfaces and the RFQ tank body were added to thermal simulation. Realistic heat transfer coefficients were evaluated based on the specified flow in each cooling line and the cooling line cross section. The full scale simulation for 200 kW dissipated power is shown in Fig. 6.
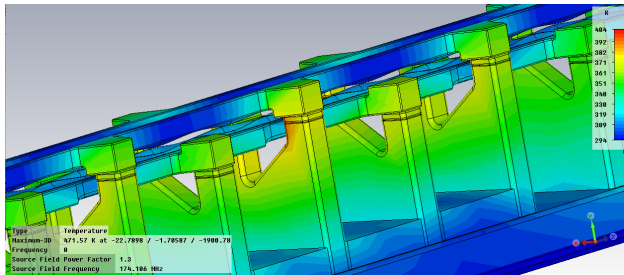

Figure 6: RFQ simulated temperatures for 200 kW dissipated power.

STUDY OF MAIN FINDINGS THROUGH THE RFQ CONDITIONING ACTIVITIES

(a) The plunger cup was melted during normal operating conditions (Fig. 9). The local plunger resonance range, measured along the micro switch feasible axial plunger range, found to be beyond the loaded 176 MHz frequency, see Fig. 8. Therefore, local resonance of the plunger cannot explain this melting [3].

The simulated temperatures on the tank external surface are in good agreement with our measurements during the conditioning activities. These include the high measured temperatures around 50°C at the end flanges and at the

tank bottom near the base plate at the high energy side (Fig. 7). The accumulated specified water mass flow rates at the base plate multiplied by the heat capacity constant and the measured differences between the inlet and outlet temperatures is in good agreement with the simulated heat flow rate along the base plates cooling lines.
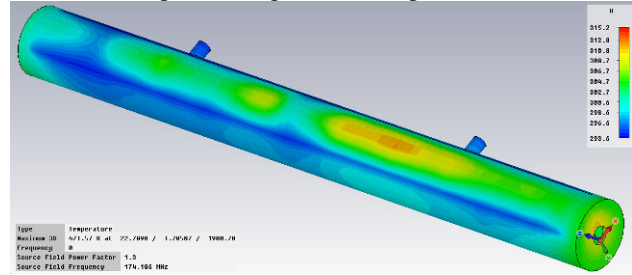

Figure 7: External RFQ tank simulated temperatures for 200 kW dissipated power, bottom view.
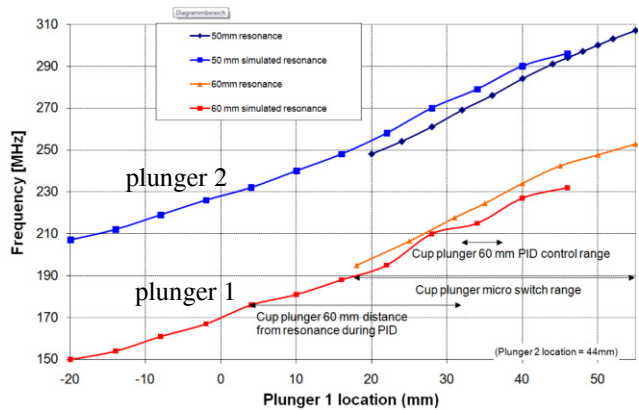

Figure 8: Calculated plunger 1 resonance at 176 MHz is 60 mm or 20 MHz away from the loaded frequency.

A one piece robust plunger with a smaller cup diameter to reduce the surface currents and the heat load was redesigned. The silver plated copper beryllium RF fingers on the mobile copper plunger stem were frequently broken. Therefore, the plunger stem was electroplated with rhodium to prevent cold welding. The one piece robust plunger cup was reinforced to the movable plunger assembly to avoid eccentric fluctuation of the plunger stem during the axial movement through the RF fingers.
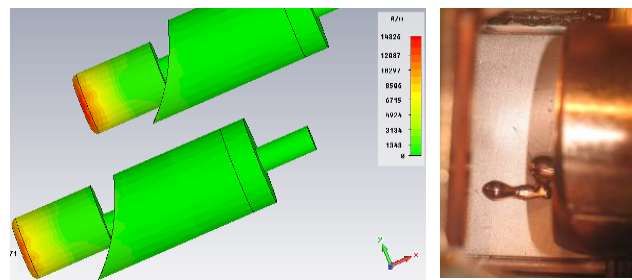

Figure 9: The melted plunger and the Simulated plunger surface currents at normal operating condition.

(b) The design of a four rods RFQ build to accelerate a CW deuteron beam enhanced additional cooling lines along the extended electrodes profile. Local cutting of the

bottom electrodes back side along each second stem reduced significantly these parasitic fields and doubled the RFQ operational power, see Fig. 10.
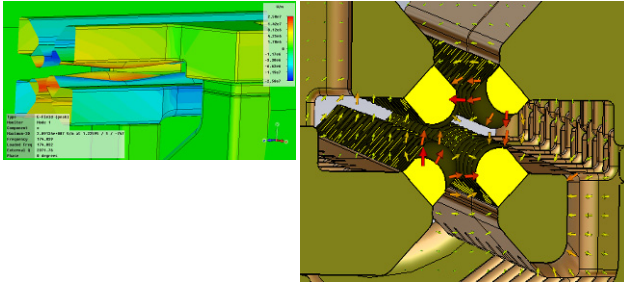

Figure 10: Local cutting reduced the parasitic fields.

The RFQ resonance frequency was increased since the electrodes capacitance was reduced. The tuning plates along the high modulation section with lower capacity per unit length were removed and the field flatness along the last section, prior to the entrance to the superconducting linacwas distorted. The horizontal distance between the electrodes at the last section was reduced by 400 μm. The field flatness was reproduced by CST MWS eigenmode simulation. Simulation sensitivity study suggested that reducing the vertical distance by 600 μm at the last section will enable insertion of an additional tuning plate at the last section, see Fig. 11. This modification was one of the contributors to the achievement of establishing a stable 1 mA, 3 MeV CW proton beam at the superconducting linac [4].
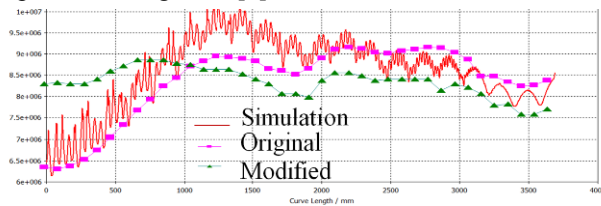

Figure 11: The Original, the simulated and the modified field flatness along the RFQ.

(c) Discoloration of the stainless steel copper electroplated end flanges originated by the overheated O-ring adjacent to the base plate and last stem area caused by induced surface currents (Fig. 12). Drilling internal cooling lines in the end flanges and improving the base plate end flange RF contact eliminated the phenomena.
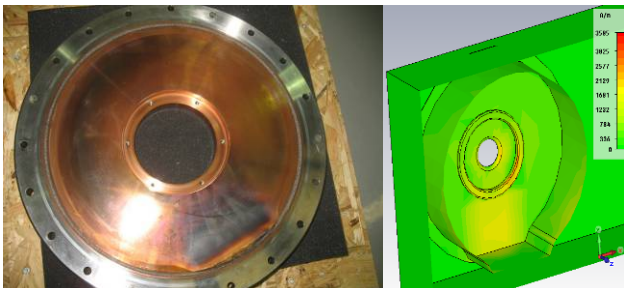

Figure 12: The high end flange Discoloration prior the replacement with end flange with internal cooling lines.

(d) The massive tuning plate silver plate might be the reason for local silver plated areas near two tuning plates

that were connected with screws to the base plate. In this stage the nonessential screws were removed, see Fig. 13.

Figure 13: The burned 70*2μm silver plated Inconnel spring contact due to poor heat conductivity of the former tuning plate and the new design with a massive brazed 1500 μm silver plate on top of the tuning plate.

(e) The RFQ coupler port external surface reached around 50°C at 190 kW RFQ dissipated power. Due to standard vacuum procedure the coupler port welding is at the internal tank surface only and practically the port is almost thermally isolated from the massive 50 mm stainless steel tank envelope thickness by a 100 μm gap. Adding a water cooling plate at the tank surface with an internal feed line for a gap heat transfer fluid reduced the ANSYS simulated maximum temperature, see Fig. 14.
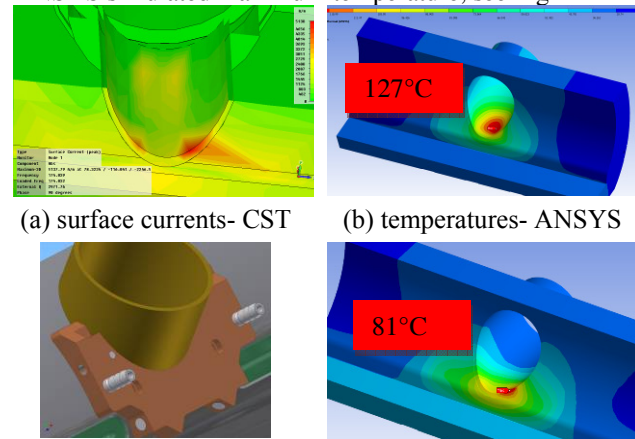

(a) surface currents- CST   (b) temperatures- ANSYS

(c) adding cooling plate   (d) modified temperatures

Figure 14: Coupler port thermal analysis at 190 kW.

CONCLUSION

A verified detailed full 3D RF simulation accompanied by thermal and mechanical analysis is vital to the development of a high end project like the SARAF RFQ.

REFERENCES

[1] P. Fischer et al., linac 2006, Knoxville, August 2006, THP064, p. 728 (2006).
[2] P. Balleyguier, "Extrnal Q Studies for APT SC-Cavity Couplers", proceedings of LINAC'98, Chicago, IL, 23-28 August (1998) page 133.
[3] A. Bechtold, "SARAF RFQ towards 62.5 kW/m", NTG, August (2009).
[4] L. Weissman et al., WE102, these proceedings.