STUDY AND DEVELOPMENT OF CW ROOM TEMPERATURE REBUNCHER FOR SARAF ACCELERATOR

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Abstract

The SARAF 176 MHz accelerator is designed to provide CW proton/deuteron beams up to 5 mA current and 40 MeV accelerated ion energy. Phase I of SARAF (up to 4-5 MeV) has been installed, commissioned, and is available for experimental work. Phase II of SARAF is currently in the planning stage and will contain larger MEBT with three rebunchers and four cryomodules, each consisting of SC HWRs and solenoids. Phase II MEBT line is designed to follow a 1.3 MeV/u RFQ, is 4.5 m long, and contains three 176 MHz rebunchers providing a field integral of 105 kV. Different rebuncher configurations have been studied in order to minimize the RF losses and maximize the shunt impedance. Different apertures have also been tested with a required of 40 mm diameter by beam dynamics. The simulations were done using CST Microwave Studio. CEA leads the design for SARAF phase II linac including the MEBT rebunchers and has studied a mixed solid copper and Cu plated stainless steel, 3-gap cavity. SNRC is developing a 4-gap OFHC copper rebuncher as a risk reduction. Both designs are presented and discussed in the paper.

REBUNCHER REQUIREMENTS

Main requirements for the MEBT rebunchers are reported in Table 1 [1].

Table 1: Rebuncher Requirements

Requirement	value	units
Frequency	176	MHz
CW Effective Voltage	105	kV
Pulsed Effective Voltage	160	kV
Drift tube aperture	40	mm
Flange to flange distance	280	mm
Optimal β	0.053	

REBUNCHER TYPE

In order to find the most suitable resonator type, a Cu-plated stainless steel 3-gap split spoke geometry and OFHC copper 4-gap cylindrical geometry rebuncher have been studied. The basic structure of the 3-gap rebuncher consists of an outer horizontal cylinder tank with 2 stems which form three acceleration gaps (Fig. 1). The basic structure of the 4-gap rebuncher consists of a vertical cylinder, a fork and a bottom stem which form four acceleration gaps (Fig. 2). For both structures different apertures (30 and 40 mm) have been tested. The rebunchers were designed for $\beta_{beam} = 0.0528$ which corresponds to particle energy of 1.3 MeV/u.

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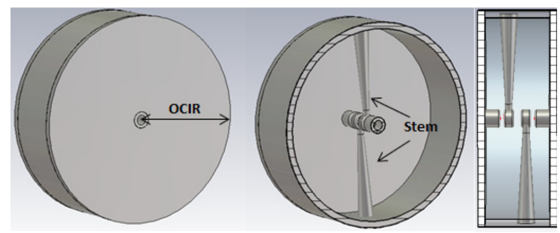

Figure 1: The basic structure of the 3-gap rebuncher.

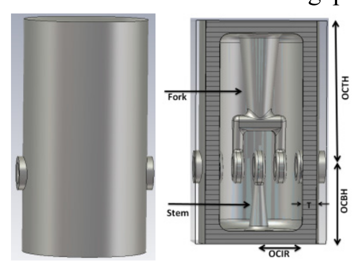

Figure 2: The basic structure of the 4-gap rebuncher.

OPTIMIZATION STUDY

After completion of initial design of the cavity structure for both 3-gap and 4-gap rebunchers, a thorough process of optimization was performed. This optimization process was done using parameter sweeps in CST Microwave Studio [2] and included all the parameters of the resonator structure. These parameters include among others: the structure of the stems and the fork (shape, length and radius), the structure of the drift tube rings (shape, length and radius), the acceleration gap dimension, the outer tank dimensions and the blending radius etc. The EM fields for both structures optimized so that the beam receives the specified energy gain within minimum RF fields, $\frac{E_{pk}}{E_{acc}}, \frac{B_{pk}}{E_{acc}}$, minimum RF losses and maximum shunt impedance.

The optimization was derived for each set of sub component parameters individually. Following each sub-component study, the cavity height was adjusted to reach the linac frequency (Outer Conductor Top Height in case of a 4-gap type, and Outer Conductor Inner Radius in case of a 3-gap type). This is due to the relative low sensitivity of these parameters to the figure of merits under study,

Table 2: Simulated Figures of Merit (@120 kV when applies) for 4-gap and 3-gap Rebuncher (30 and 40 mm aperture)

Aperture diameter	mm	40		30	
		4-gap	3-gap	4-gap	3-gap
Quality factor (Q_0)		7580	9320	7730	8840
R/Q	Ω	593	530	971	872
RF loss	kW	3.2	3.3	1.94	1.87
Shunt impedance	MΩ	4.4	4.3	7.5	7.7
Surface E field (E_{pk})	MV/m	7.13	8.67	4.89	7.61
Surface M field (B_{pk})	mT	10.4	10.5	12.6	7.15
E_{pk}/E_{acc}		8.5	13	7.3	11
B_{pk}/E_{acc}		155	157	189	107
Geometrical Beta		0.055	0.062	0.0528	0.061

$\frac{r}{Q_0}$, $\frac{E_{pk}}{E_{acc}}$ and $\frac{B_{pk}}{E_{acc}}$. The optimization of the 4-gaps top stem geometry is shown in Fig. 3 as an example for a sub-component optimization.

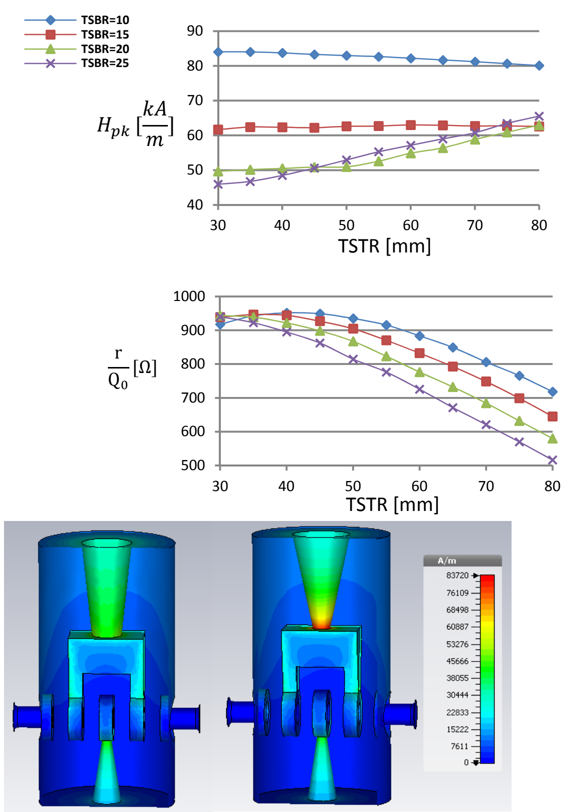

Figure 3: The maximum magnetic field (@ 1 Joule) , R/Q and magnetic field map (@ 1 Joule) for variation of TSTR (Top Stem Top Radius) and TSBR (Top Stem Bottom Radius). The field map are given at :right- TSTR=40mm and TSBR=10mm, left- TSTR=35mm and TSBR=20mm.

Simulated Figures of Merit (@120 kV when applies) for 4-gap and 3-gap rebunchers (for 30 and 40 mm aperture) are shown in Table 2. The 30 mm aperture rebuncher gives a better performance than 40 mm aperture, but the 40mm diameter is dictated by beam dynamics to avoid beam losses. On the bases of the experience cumulated with the SPIRAL2 rebuncher, CEA has designed a 3-gap cavity, which is being manufactured soon and which is expected to have a lower manufacture cost. As a risk reduction activity, SNRC is designing the 4-gap cavity, with features slightly better Figures of Merit and more robust cooling.

3-GAP DESIGN

CEA design is based on the experience cumulated with the SPIRAL2 rebuncher [3], and uses the same mixed technology: Cu-plated stainless steel for the outer tank which is not standing large and high current densities (total RF loss on this part is < 1 kW) and solid copper for the quarter wave stems and for the stem flanges, where most of the power is dissipated and where higher thermal conductivity is mandatory. Solid copper is also used for those parts submitted to high electric field (beam ports and drift tubes), where sparks could destroy the plated layer. Figure 4 shows an artist view of both cavities.

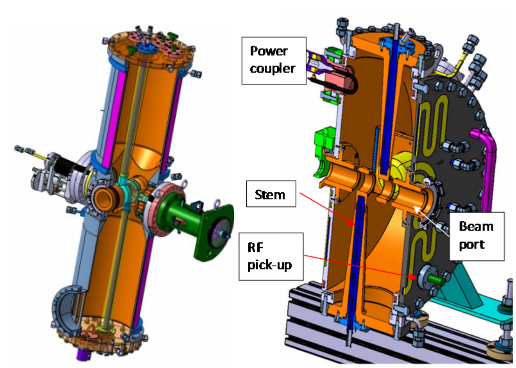

Figure 4: SPIRAL2 and SARAF 3-gap rebuncher cavities.

This choice has led to a rebuncher whose cost is in the range of 100k€/unit for the fully equipped cavity (coupler, tuner, motors, manifold etc).

Main design criteria are the same as for SPIRAL2: three gaps; two straight, conical, water cooled stems, holding drift tubes cooled by conduction; capacitive tuners and

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inductive power coupler with a disk vacuum window. Two symmetrical side plates allow a wide coarse tuning covering simulation and manufacturing tolerances and vacuum deformations, while only one of the plates is moveable and motorized for the fine tuning loop. The stroke is shorter than 2 cm and the fine tuner is grounded through thin silver strips instead of sliding contacts.

Power tests of the three units built for SPIRAL2 have shown performances better than design expectations, but a few manufacturing or assembly difficulties have pushed to some changes in the design for SARAF.

In the SPIRAL2 cavity, all gaskets have a double function: RF contact and vacuum seal and some of them are interfaced with solid copper parts on one side and Cu plated surfaces on the other one. This configuration have been changed as it has shown some limitations in the leakage rate, which was not better than several 10^{-8} mbar·l/sec in some cases. A double gasket has been preferred for SARAF design, with separated functions and more adapted interface materials and/or surface state.

The second improvement is linked to the first one and concerns the type and dimension of the vacuum joints and flanges. The gaskets (which need to be changed each time the assembly is opened, which is likely to happen quite often during the commissioning phase) have been replaced by more usual Al joints, closed in between stainless steel surfaces on both sides, and a standard flange diameters have chosen as a design constraint.

The more visible modification concerns the tank geometry, where the pill-box shape has been preferred to the former vertical cylinder to facilitate manufacture and access for tuner element assembly and maintenance, and to slightly increase the shunt impedance.

The last modification concerns the use of silver strips instead of Cu braids to ground the movable tuner.

Internal holders for the tuners have been placed on the tank bottom with several advantages: to reduce the thickness of the top flange, to limit its deformation and frequency shift under vacuum, to push away higher order modes due to the tuners, and to leave one side flange for the vacuum pump. Figure 5 shows the 3-gap cavity different components.

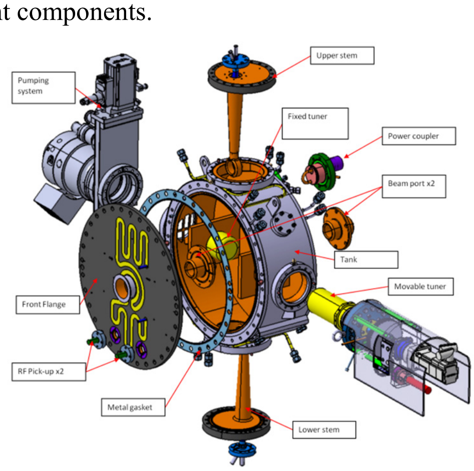

Figure 5: 3-gap rebuncher cavity components.

The RF and thermal studies have taken several margins to grant final performances (see Table 1). Cu resistivity has been increased of 30% to take into account shunt impendence differences observed between measurement and simulation on the SPIRAL2 units. A design effective voltage of 120 kV has been taken to calculate RF loss densities and another 20% margin has been taken for the thermal load to calculate temperature maps and deformations.

Table 3: 3-gap rebuncher expected performance (@120 kV)

Expected performance	value	units
Flange to flange distance	260	mm
Min Frequency	175.8	MHz
Max Frequency	176.4	MHz
First higher mode	220	MHz
Qo	6660	
Surface E field	10.5	MV/m
RF Loss	4.3	kW
Max temperature at gaskets	<50°	°C
Max temperature	<100°	°C
Drift tube displacement	<±0.1	mm

4-GAP DESIGN

The 4-gap cavity (see Fig. 6) is a whole OFHC copper cavity based on ANL conceptual design for SARAF phase II [4]. It consists of a vertical cylinder with a top fork and a bottom stem. In order to reduce the beam deflection by the magnetic field the external gaps drift tubes faces are tilt. The coupler, plunger tuner and pickup flanges are attached to the tank bottom flange. The cooling water to the top fork, bottom stem, coupler and plunger are injected from the top and bottom flanges via internal channels. The cooling of the cavity outer tank is supplied by an outer cooling channel brazed externally to the tank. This design has more complicated cooling design with an expected efficient heat removal due to the whole OFHC structure.

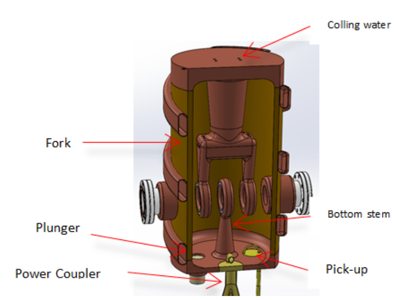

Figure 6: 4-gap rebuncher cavity.

CONCLUSION

Both designs are matched to the required specifications for SARAF phase II MEBT. The CEA 3-gap rebuncher as the leading solution has a matured design. Both cavities are expected to be build and tested during 2017.

REFERENCES

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