RF DESIGN OF THE RE-BUNCHER CAVITIES FOR THE LIPAC DEUTERON ACCELERATOR*

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Abstract

Re-buncher cavities are an essential component of LIPAC (Linear IFMIF Prototype Accelerator), presently being built at Rokkasho (Japan). The deuteron beam exiting from the RFQ (Radio Frequency Quadrupole) structure has to be properly adapted to the superconducting RF (SRF) linac. Re-bunchers are placed in the Medium Energy Beam Transport (MEBT) line and their objective is to longitudinally focus the deuteron beam. IFMIF re-bunchers must provide a 350 kV E_0LT at 175 MHz continuous wave (CW). The available length for the re-buncher is limited by the general layout of the MEBT. The high power dissipation derived from the high effective voltage and the short available length is an important design challenge. Four different normal conducting cavity designs were investigated: the pillbox type, double gap coaxial resonators, and multi-gap quarter wave and H resonators. The performance of these cavities was studied with the numerical codes HFSS and ANSYS. The fundamental frequency and field pattern of each re-buncher was investigated in HFSS. This work presents the results of such analyses.

INTRODUCTION

Two re-bunchers are located in the MEBT line [1]. The MEBT is part of the Spanish contribution to LIPAC. The purpose of the MEBT is to transport the 125 mA/5 MeV deuteron beam from the RFQ and match it, longitudinally and transversally, for its injection into the SRF linac. Re-buncher specifications are described in Table 1.

Table 1: MEBT re-buncher specifications

Parameter	Value
Frequency	175 MHz
Maximum E_0LT	350 kV
Beam pipe radius	22 mm

CONFIGURATION CHOICE

A number of cavity configurations have been studied. The first design was a pillbox cavity [2]. Due to the high dissipated power, other designs have been analysed, with an increasing number of gaps to decrease RF losses. RF calculations are the starting point, but also cooling system and engineering fabrication are arguments used to select or discard a cavity configuration. Table 2 summarizes the results of this comparison.

Pillbox re-buncher

The pillbox power consumption is relatively close to the maximum available power (110 kW). Besides, the power density is extremely high, which makes cooling very difficult in practice. These resonant structures concentrate magnetic field near nose cones (see Fig. 1), that is the point where the cooling is more necessary, but the available space for the conducts is small.

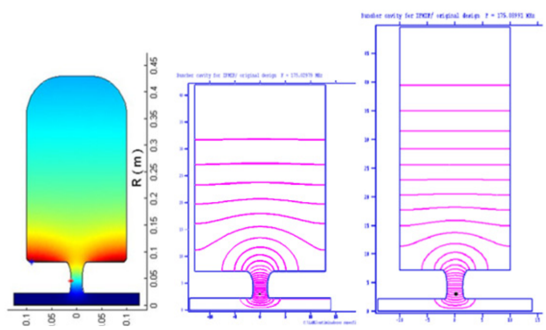

Figure 1: Pillbox re-buncher magnetic (left) [2] and electric (right) field maps.

The pillbox re-buncher manufacturing could be a complex process, mainly because of the size and the high power dissipation.

Another pillbox re-buncher feature is its high capacitive impedance, concentrated at the big nose cones. This causes high frequency sensitivity to deformations, which are maximum at the center due to the atmospheric pressure, as the endplates are supported at the outer rim. Due to these disadvantages, and the proximity of the RF losses value to the maximum available coming from the RF source, other re-buncher designs were evaluated.

Double gap coaxial resonators

Both half wave (HWR) and quarter wave resonators (QWR) are cavities based on RF coaxial lines that are suitable for low frequency operation [3]. These structures present higher mechanical stability than the pillbox. Furthermore, shunt impedance is higher and the efficiency increases.

The most promising candidate, the quarter wave resonator, has been optimized at increasing inner diameter to analyze the RF power variation with that parameter. Low RF losses would ease the cooling design. In any case, power density is still very high.

In comparison with pillbox design, QWR drastically decreases not only the size, cost and manufacturing complexity, but also the power dissipation. In addition, magnetic field is negligible at lower endplate, where a vacuum port can be easily placed, even without any conducting grid.

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Table 2: Comparison results of the RF re-buncher cavities studied for LIPAC (all in copper).

Configuration	Pillbox	HWR	QWR	3-GAP QWR	4-GAP QWR	4-GAP IH	5-GAP IH	Units
Vacuum length (beam axis)	200	240	240	280	280	280	320	mm
Vacuum height	860	876	507	495	495	504	460	mm
Total power	75	41.7	25.8	12.2	9.4	8.5	6.6	kW
Central stem power	-	30.5	18	4.0	1.7	2.2	1.2	kW
Side stem power	-	-	-	-	1990	1447	678	W
Q	24279	11347	10773	11413	10148	11570	11746	--
E peak	24.3	20	20.6	21.0	14.8	16.0	13.9	MV/m
Power density peak	30.3	42	97.4	17.0	13.1	12.0	8.9	W/cm2
Shunt impedance	0.82	1.46	2.36	4.99	6.51	7.19	9.29	MΩ

The HWR power consumption is higher than QWR one, but the cooling system design would be easier because its stem geometry allows a direct cooling channel going across the re-buncher. Nevertheless, the HWR stem complicates the location of a vacuum port. In addition, HWR height is double than QWR one, and RF losses are 50% higher.

The QWR design decreases power consumption compared with the pillbox and HWR cavities, but some important issues should be taken into account:

- Steering effects: there is an asymmetry in the field maps due to the drift tube position.
- Multipactoring inherent to coaxial resonators.

In order to relax these issues, it can be concluded that the study of coaxial resonators with increasing number of gaps is a very interesting strategy. One expects that both power consumption and power density can be further decreased, while the aforementioned drawbacks do not increase.

Multi-gap resonators

Three to five gap resonators are studied in this section: 3 and 4-gap ones are depicted in Fig. 2, while the five gap one is shown in Fig. 3. A significant decrease of RF losses and peak electric field is achieved with each additional gap. The available length is too small to allocate a 5-gap cavity, but due to the significant benefits, the MEBT layout has been changed, increasing that length up to 350 mm. The stem cooling is much easier in the 5-gap design, which clearly compensates the higher fabrication cost.

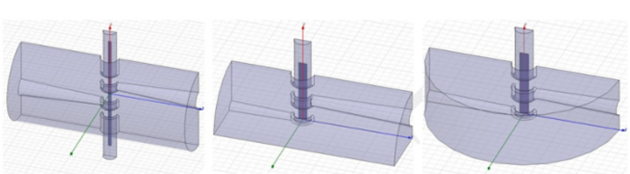

Figure 2: 3 and 4 gap resonators: 3-gap QWR (left), 4-gap QWR (middle), and 4-gap IH (right).

On the other side, RF performance (shunt impedance) of IH type is better than QWR one. The deformation under atmospheric pressure will be higher in the IH model, but acceptable with steel endplates. Multipactoring will happen mainly in regular or symmetric geometries, therefore QWR will be more prone to problems. Finally, an additional advantage is envisaged, as due to the lower required power, both cooling system and RF source requirements are relaxed.

In short, it is reasonable to choose the 5-gap IH cavity as the best candidate for LIPAC rebunchers.

DETAILED DESIGN

The next step is the detailed design of the 5-gap IH cavity. A full model, including the fillet radii necessary for the fabrication (milling tools) and the recesses for the stem bases, has been studied. Two CF100 pumping ports are drilled on the side wall.

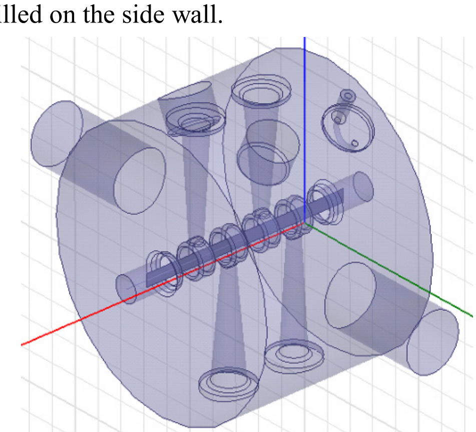

Figure 3: 5-gaps IH cavity.

High order modes

Perturbations due to high order modes in a low frequency linac are usually moderate. However, due to the high beam power, the allowed beam losses are very small, and high order modes have been analysed. Table 3 shows the results. None of the modes is dangerous for the beam.

Table 3: High order modes

Order	Frequency (MHz)	Q	Type	Nearest bunch frequency
1	175.16	11284	π	
2	238.12	9536	3π/4	175
3	285.08	10229	π/2	350
4	329.04	13699	π/4	350
5	486.62	33422	0	525
6	602.88	33089	TE_{11}-like	525
7	698.23	32825	π/4+stems	700
8	720.39	21412	π+stems	700
9	777.43	16972	3π/4+stems	700

Coupler

The coupler will be a loop, that is, of magnetic type. The design is based on the Spiral-2 rebuncher coupler [4]. A transition will adapt the size of the coaxial line coming from the RF source to the input port of the coupler. A ceramic window will keep the vacuum tightness. Beyond the ceramic, the coaxial line diameter is decreased smoothly while keeping 50-ohm characteristic impedance. The inner conductor will be internally water cooled. The magnetic coupler has been placed closed to the stems, where the magnetic field is stronger for a good coupling, while the field perturbation is far away from the beam axis. The impedance matching is properly achieved: S_{11} is -29.8 dB.

Figure 4: 5-gaps IH coupler: Spiral-2 model from [4].

Tuner

Only a magnetic-type tuner is considered. A capacitive plunger is not a convenient solution, because it should be placed at the medium plane: it would be very long, dissipate a significant power and interfere with the pumping ports. There are two plungers, one is manually driven, to compensate frequency mismatch due to fabrication errors (cold tuning), and the other one is powered by a stepping motor controlled from the LLRF system. The motorized tuner shall compensate frequency variation in the order of few per mil of the nominal frequency.

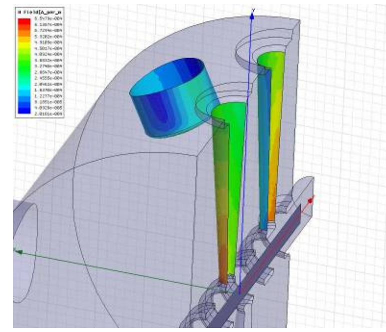

Figure 5: Magnetic field distribution on the tuner.

Symmetric inductive plungers have been modeled as cylinders (see Fig. 5). The tuner size depends on the magnetic field at the plunger position. Therefore, it is a good practice to place them near the stems, but not to close, to avoid excessive heating. The overall RF losses of the cavity increase about 3% when both plungers are inserted at maximum depth.

Manufacturing considerations

The simplest manufacturing approach is to use stainless steel with copper plating for the wall and endplates. The stems and the drift tubes will be machined from bulk OFE copper. The stems will be cooled with concentric circuits: cold water inside and warm water outside. The drift tubes will have not internal cooling conduits. The endplates will be cooled only in front of the stems.

CONCLUSION

This paper has shown the comparison between different cavity configurations to be used as LIPAC re-buncher. The five gap IH resonator structure is the most efficient structure. Tuner and coupler will be of magnetic type.

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