DESIGN OPTIMISATION OF THE EURISOL DRIVER LOW-BETA CAVITIES

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Abstract

The low-beta section of the proposed EURISOL driver Linac is based on 176 MHz superconducting half-wave resonators (HWR) with optimum velocity β_0=0.09 and 0.16. These cavities are an evolution of the 352 MHz ones, previously developed in the same framework, having similar dimensions and components except for their length and RF frequency. They are characterized by a double wall, all niobium structure with light weight, good mechanical stability and a side tuner cooled by thermal conduction. The new 176 MHz Half-wave cavities design includes a removable tuner, which allows to improve tuning range, mechanical stability and accessibility to the cavity interior. A β_0=0.13 cavity was also designed with the same concepts for possible use in linacs with different velocity profiles.

INTRODUCTION

The driver accelerator of the proposed radioactive beam facility EURISOL [1] includes a low-β section based on 176 MHz superconducting Half-Wave resonators (HWRs) with β_0=0.09 and 0.16 (Fig. 1). Similar resonators, with β_0= 0.17 and 0.31 working at 352 MHz, have been previously prototyped in the EURISOL framework [2]. The 176 MHz HWRs design could be obtained by doubling the 352 MHz resonators lengths while keeping their diameters (to fit the frequency and β_0 requirements). The main characteristics of this HWR modular structure, that can be easily adapted to different optimum β, and its advantages have been previously described in Ref. [2]. As a result of this scaling, two problems arose: a reduction of the relative tuning range, due to the larger stored energy of the new resonators, and an increase of the sensitivity to Helium pressure and Lorentz force, due to their larger size. These problems could be tackled by means of a new design of the tuner and by simple reinforcements of the cavities. Each author should submit the PostScript and all of the source files (text and figures), to enable the paper to be reconstructed if there are processing difficulties.

NEW TUNER DESIGN

The old HWR tuner (in cavities of Fig.1) was based on a 1 mm thick membrane, welded to the cavity walls and cooled by thermal conduction, which can be elastically deformed in a high electric field region. This vacuum-tight tuner can be used also in cryostats with double vacuum (one for the beam and cavity interior, and another one for thermal isolation outside resonators and beam pipes). However, to match the 100 kHz tuning range specifications, while keeping acceptable rf power density and acceptable stress in the Nb material in spite of the larger volume and stored energy of the 176 MHz cavities, a new tuner was designed.

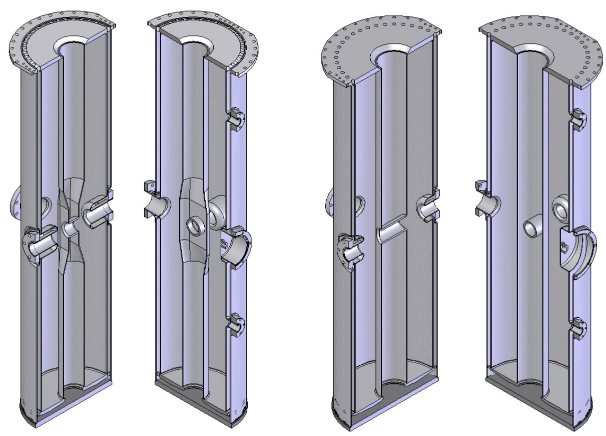

Figure 1: Cut-off views of the β_0=0.09 (left) and 0.16 HWRs with the old tuner design.

We were inspired by vacuum-tight side tuner of the IFMIF HWRs [3].However, since we decided that the low-β cryostats of EURISOL could be of the single vacuum type (the single vacuum TRIUMF ISAC-2 cryomodules reached world record gradients in operation [4]) we could adapt to HWRs a TRIUMF-type slotted tuner design which was successfully used in quarter-wave resonators of ALPI [5]. The new tuner is based on a large plate, with radial slots and curvatures that allow more than 10 mm stroke with low force requirements (Fig. 2).

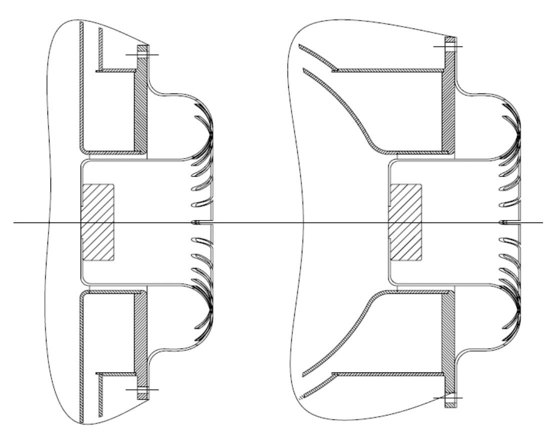

Figure 2: Vertical and horizontal cross sections of the new tuner connected to the HWR.

The same tuner could be easily made also vacuum-tight. The plate is connected to a large flange, it is removable and cooled by thermal contact. Only the central cup is protruding in the RF region providing capacitive tuning; the current induced in the plate flows to the resonator through an RF contact. The rf power loss on the tuner is compatible with cooling through a simple thermal contact. The temperature distribution on the tuner surface was simulated using the code ANSYS (Fig. 3) assuming a conservative rf surface resistance of Rs=50nΩ. The maximum temperature increase ΔT calculated on the tuner is below 0.1 K at the center of the tuning cup in all cavities. The maximum magnetic field on the RF joint never exceeds 1 mT during operation; this value was experimentally proven in operating low-β superconducting QWRs.

The large aperture required by the new tuner has the advantage of providing good access to the HWR interior for surface preparation and inspection. The tuner sensitivity is about 10 kHz/mm and the tuning range is about 100 kHz.

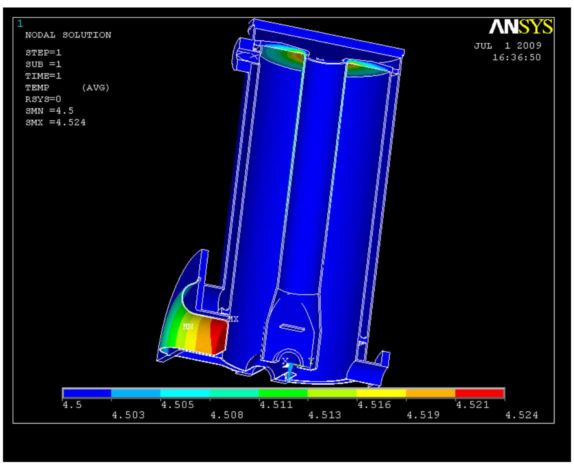

Figure 3: Temperature distribution in the tuner in operation at 6 MV/m (cavity β0=0.09).

In order to avoid as much as possible multipacting (MP) levels the design was optimized by means of the CST electron tracking code. One level at low accelerating field, caused by electron resonance located at the cylindrical section of the tuner (between tuner and outer wall), could not be eliminated (Fig.4). The toroidal section was shaped in order to move all other levels out of the operation gradient of 6 MV/m.

Table 1: Accelerating Field Levels in MV/m at MP Onset

Cavity β_0	0.09	0.16
1st level E_a (MV/m)	0.18~0.56	0.17~0.31
2nd level * E_a (MV/m)	24.0	21.6
2nd level ** E_a (MV/m)	18.0	16.2

* With tuner in center position. ** With tuner 5mm in.

The movement of the tuner toward the inner conductor does not affect the 1st level, while the second level changes without invading operation gradient (see Tab. 1).

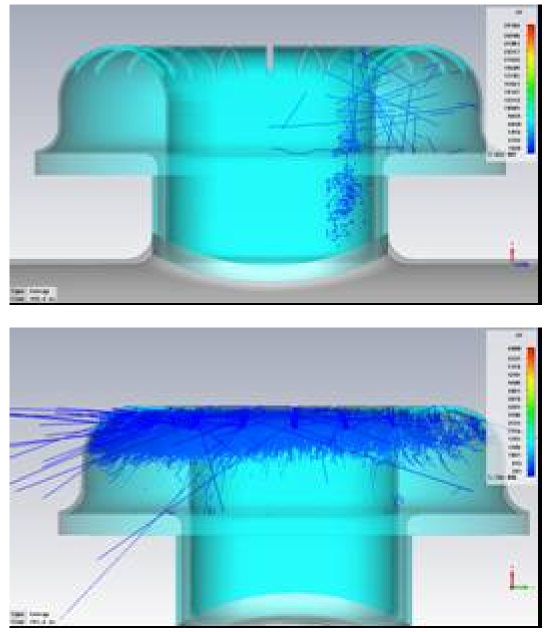

Figure 4: Electron trajectories in MP calculated for the β_0=0.16 cavity tuner. Top: E_a=0.24MV/m, after 240ns; Bottom: Eacc=26.34MV/m, after 292ns.

β_0=0.13 HWR DESIGN

A β0=0.13 HWR of the same type has been designed with the aim of providing a possible cavity for linacs with different velocity profiles (Fig.5). Its design parameters are shown in Table 2.

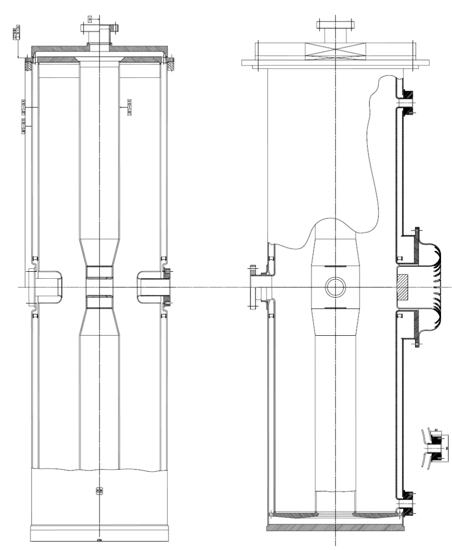

Figure 5: The β_0=0.13 HWR.

Table 2: Design Parameters of the 0.13 HWR

Parameter	Value	Units
□0	0.13	
Frequency	176	MHz
QBCS	4.6×10^{9}	
Design $E_{acc}(E_a)$	6	MV/m
U/E_a^2	0.178	$J/(MV/m)^2$
B_p/E_a	9.9	mT/(MV/m)
E_p/E_a	5.2	
R_{sh}/ Q_0	569	□/m
R_s* Q_0	37.2	□
Active Length L	224	mm
Max. Length L_{re}	262	mm
Aperture Diameter	30	mm

CAVITIES MECHANICAL STABILITY

Mechanical stability is critical in superconducting resonators due to their rather small RF bandwidth. In the EURISOL HWRs, the bandwidth is about 1 kHz, dominated by the beam loading requirements of the RF coupler. Although this value looks rather comfortable, it is desirable to keep the cavity as stable in frequency as possible. The main sources of instability for this kind of cavities are the liquid helium pressure fluctuations and Lorentz force detuning. A simple way of increasing stiffness would be increasing the wall thickness, presently 2 mm in our case. However, thin walls are desirable to maintain good cooling and low cavity cost and weight. Another source of instability is related to mechanical resonant modes. Stiffening can in this case increase the frequency of the modes, moving them above the main sources of mechanical noise, while mechanical damping, also applicable to HWR resonators, can reduce the amplitude of the mechanical oscillations and the related rf frequency shift [2], [6].

To limit deformation under He pressure of the inner conductor flattened profile in the β_0=0.09 and β_0=0.13 HWRs, small reinforcing ribs have been added. Lorentz detuning is dominated by the inward displacement of the beam ports (fig.6): this could be limited by welding two rings connecting outer vessel and outer conductor together near the beam ports.

Table 3: He Pressure and Lorentz Force Detuning

Cavity β_0	df/dp (Hz/mbar)	$df/dEacc^2$ $(Hz/(MV/m)^2)$
0.09	1.7	-1.9113
0.13	4 (2.8*)	-3.9 (-2.2*)
0.16	2.5	-0.6

*With 3 mm thick Nb sheets

Mechanical modes have also been calculated with the ANSYS code for all cavities (Fig.7). The lowest frequency mode, usually the most dangerous, was found respectively at about 98 and 109 Hz in the 0.09 and 0.16 HWRs, linked to the cryostat at the cavity top (EURISOL requirement), and at about 160 Hz in the 0.13 HWR, linked to the cryostat at the cavity middle. The same modal analyses on prestressed model (under 1 bar pressure) led to similar results.

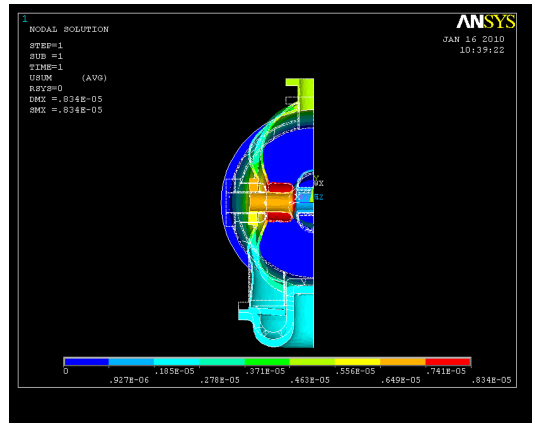

Figure 6: Displacement (enhanced view) caused by Lorentz force in the 0.13HWR.

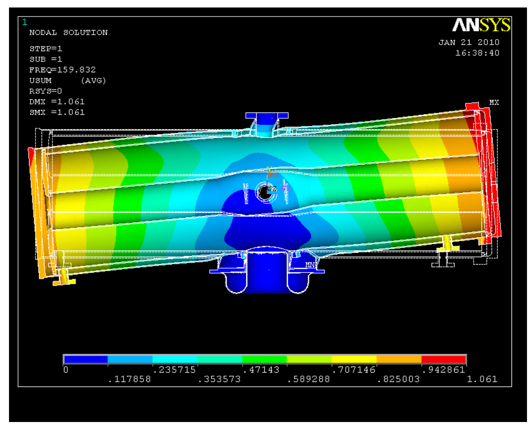

Figure 7: 1st mechanical mode in the 0.13 HWR.

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