

LOW- AND INTERMEDIATE-BETA, 352 MHz SUPERCONDUCTING HALF-WAVE RESONATORS FOR HIGH POWER HADRON ACCELERATION

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Abstract

A $\beta=0.17$, 352 MHz superconducting Half-Wave resonator was designed, constructed and tested at INFN-LNL in the framework of the SPES and EURISOL projects. This cavity, together with the $\beta=0.31$ HWR of similar design that was previously built and tested in the framework of the SPES project, allows acceleration of hadron beams in the 5-100 MeV/u energy range, as required in many high power linac projects like the first part of the EURISOL proton driver. Main features of this structure, compared to other ones developed elsewhere with different geometries for similar applications, are compactness and mechanical stability and relatively low cost. The low- β cavity reached 5.1 MV/m at the nominal rf power and peak fields of 81 mT and 39 MV/m.

INTRODUCTION

Superconducting coaxial Half-Wave Resonators (HWR) have optimum efficiency in the rf frequency range of 150-350 MHz and in the beam velocity range of $0.06 < \beta < 0.4$. This makes them very well suited for acceleration of high power hadron beams, that require RFQ injectors of similar frequencies and beta. At 352 MHz, very common in proton RFQs, HWRs can be made with very compact size, low cost, stable construction and high rf performance. This makes them very attractive for filling the gap between RFQs and elliptical superconducting cavities in high power cw linacs.

The LNL program in superconducting HWR development for 5 mA cw proton and deuteron beams up to 100 MeV was described in ref. [3]. It includes 352 MHz cavities with $\beta=0.17$ and 0.31 (and eventually 176 MHz HWRs with $\beta=0.09$ and 0.15) with similar design, characterized by a double wall coaxial structure with integrated Helium vessel [1] with beam port aperture diameter of 30 mm (Figure 1). The cavities are of 2 types, flattened and cylindrical, referred to the inner conductor shape (see Fig. 2) with real-estate lengths 232 and 286 mm flange-to-flange, respectively. The coaxial structure make them very compact and stiff, even if the resonators are made mainly of 2 mm Nb sheets.

A 1+5/8" port for a coaxial rf coupler is located at the resonators equator at one side of the outer conductor. A tuning cup is welded at the opposite side. To improve the

frequency stability against pressure fluctuations, the membrane which provides tuning is cooled by thermal conduction and not exposed to liquid helium. Two more 16 mm ports are available for rf probes. The rf parameters of the low- and medium- β 352 MHz resonators, calculated with the HFSS code, are shown in Table 1.

These resonators are planned for cryostats with common vacuum between the rf-beam volume and the cryostat one. All ports, however, are equipped with flanges that allow, if required, vacuum separation. The first prototype with $\beta=0.31$ of the cylindrical type was constructed and tested in 2004 [2]. The second, $\beta=0.17$ flattened one, was tested this year.



Figure 1: The INFN-LNL low- β (left) and medium- β 352 MHz superconducting Half-Wave-Resonators.

THE 352 MHz, $\beta=0.17$ CAVITY

The 352 MHz, $\beta=0.17$ (low- β) cavity is characterized by the flattened inner conductor and the protruding beam ports, that allow 30 mm gaps and 60 mm gap-t-gap distance (geometrical $\beta_0=0.14$) The helium vessel is completely welded to the resonator.

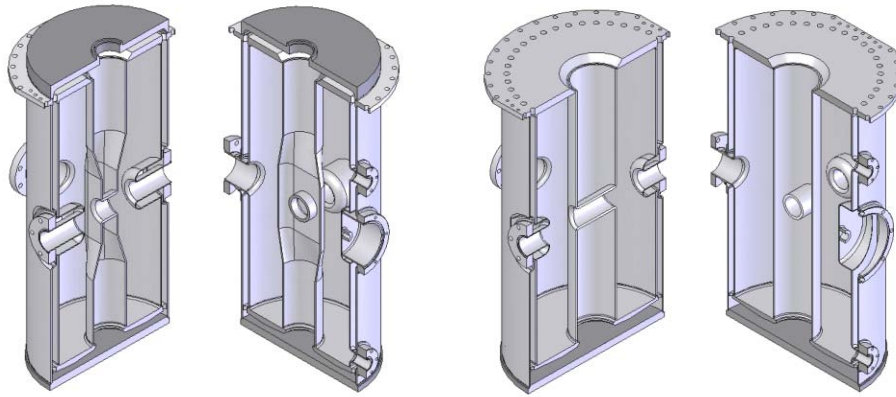


Figure 2: Sketches of the 352 MHz, $\beta_0=0.17$ (left) and $\beta_0=0.31$ Half-Wave resonators, cut in two perpendicular planes.

The outer wall is made of normal grade niobium, while the top and bottom flanges are made of titanium (in previous models, including the $\beta=0.31$ HWR, the top flange was made of stainless steel and connected to the cavity by means of an indium seal). This allows very simple handling and assembly in cryostats of different types. The design specifications in operation are 5 MV/m with 10 W rf power, with ~ 60 mT and ~ 30 MV/m peak fields, for 0.9 MeV/q energy gain. Similar values have been proposed for Spoke cavities of similar β .

The beam steering effect caused by the quadrupolar symmetry of the resonators, at operation phase and gradient, is below 0.03 mrad (with beam 1 mm off-axis) in the useful velocity range, and considerably weaker than natural rf defocusing especially at low velocity, where the beam dynamics is more demanding.

We have studied the beam steering caused by the side tuner. This effect, in the low- β resonator, is negligible compared to rf defocusing. In the medium- β HWR, the rf defocusing itself can be used to compensate tuner steering within 0.01 mrad by simply displacing the cavity 0.4 mm aside [3].

The low beta cavity was constructed in 2005 in Italy (Zanon SpA, Schio, Italy).

Table 1: Resonators parameters

β_0	0.17	0.31	
U/E_a^2	0.067	0.086	$J/(MV/m)^2$
B_p/E_a	12	10.4	$mT/(MV/m)$
E_p/E_a	5.8	3.9	
R_{sh}/Q_0	1230	1180	Ω/m
$R_s \times Q_0$	55	66	Ω
Tuning df/dh	~ 70	~ 107	kHz/mm
Active length L	180	224	mm
Maximum Length L_{re}	232	286	mm
Aperture a	30	30	mm
Design E_a	5	6	MV/m

The construction procedure, compared to the medium- β cavity one [1], includes two more steps: the flattening of the inner conductor and the welding of the Titanium top flange to the liquid Helium vessel. The cavity tuning required intermediate frequency test of the cavity, assembled but not welded yet. The final frequency adjustment was done by positioning and welding the tuning cup. In this prototype, we found that the final position of the tuner would have been much closer to the inner conductor than expected. Aiming to high rf performance, we decided to avoid risks and we welded the tuner in the design position; this resulted in a 2 MHz higher frequency that can be easily compensated in future resonators with ~ 2 mm longer conductors.

$\beta=0.17$ RESONATOR TESTING AT 4.2 K

The resonator underwent CP at CERN and was tested at Legnaro before any high pressure rinsing (HPR). A new low-power, 1+5/8' movable coaxial coupler was mounted at the coupler port. To detect possible temperature changes determined by insufficient cooling, a thermometer was connected to the center of the tuner. In spite of the tight geometry, no significant multipacting (MP) was detected, neither at room temperature nor at 4.2K. We have done relatively fast cooldown, crossing the 150-60 K region with most of the resonator within about 1 hour. The test results are shown in figure 3.

The measured low power Q was 7.9×10^8 . After 2 hours Helium conditioning with ~ 150 W, the nominal 5 MV/m field was reached. The measured field at the nominal 10 W power was 5.1 MV/m (10.2 MV/m with the Iris-to-iris E_a definition), corresponding to 0.92 MeV/q energy gain. The maximum gradient was $E_a=6.8$ MV/m, limited by quench. The maximum peak fields were $E_p \sim 39$ MV/m and $B_p \sim 81$ mT.

The resonator was very stable against He pressure and Lorentz force, with $df/dP=-4.3$ Hz/mbar and $df/dE_a^2=8$ Hz/(MV/m)² with the tuner membrane left free. We have phase- and amplitude-locked the resonator reliably at about 4 MV/m, with little overcoupling.

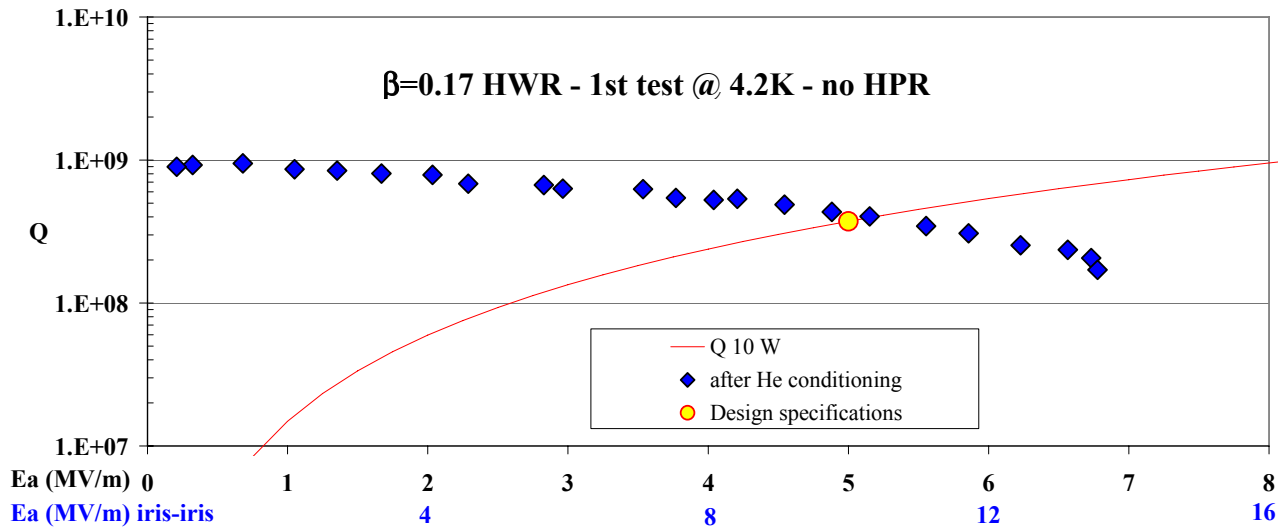


Figure 3: Q vs. E_a graph at 4.2 K of the $\beta=0.17$ resonator. The yellow mark represents the design specifications of 5 MV/m at 10 W. Accelerating length: 180 mm = total resonator internal length; to express the accelerating field with the iris-to-iris definition, the E_a values must be multiplied by 2.

The low- β resonator performance reached the design specifications and showed the possibility of operation at the required gradient.

$\beta=0.31$ TESTING AT 4.2 K

The medium- β resonator was tested in 2004, as described in ref. [2]. It showed only little MP at 4.2K around $E_a=0.17$ MV/m, that could be easily conditioned with a few watts rf power. From the mechanical point of view, also this resonator was very stable. The maximum peak fields reached were 31 MV/m and 82 mT, limited by quench. The maximum gradient was 7.9 MV/m (10.1 MV/m with the Iris-to-iris E_a definition). The accelerating field at the nominal 10 W rf power was 5.5 MV/m, corresponding to ~ 1.2 MeV/q acceleration.

Due to improper dimensioning of the old coupler, however, we could apply only little rf and Helium conditioning during the test, since most of the power was reflected back to the rf source. We planned to re-test the cavity after readjustment of the rf coupler, to allow He conditioning (in the low- β unit, for comparison, this brought the peak electric field from 25 to 39 MV/m).

CONCLUSIONS

The test of the $\beta=0.17$ cavity, after the $\beta=0.31$ one, showed that double-wall, 352 MHz HWRs can be excellent candidates for the first part of high power, cw proton and hadron linacs. These resonators have high performance, small size, easy handling and preparation, very good mechanical characteristics and relatively low cost. They can be arranged in different kinds of cryostats, with either common or separate vacuum. During the tests,

little or no multipacting was observed. The side tuner solution, that decouples the tuner from helium pressure, did not cause any performance limitation. For the future, R&D work is planned to further increase the cavity tuning range in order to relax construction tolerance. Further testing of the $\beta=0.31$ cavity after HPR with a matched coupler is also planned. Extension of this 352 MHz design to 176 MHz HWRs is foreseen.

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