PROTOTYPING OF A 352 MHZ, BETA=0.17 SUPERCONDUCTING COAXIAL HALF WAVE RESONATOR

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Abstract

We have designed a 352 MHz superconducting coaxial half wave resonator, with optimum β=0.17. The cavity has a mechanical design similar to the β=0.31 one developed at LNL in 2004. It is very compact (232 mm real-estate length) and it is equipped with a side tuner not exposed to liquid helium, to make it insensitive to pressure fluctuations. Operation is foreseen at 4.2 K. This cavity fills the gap from 5 to ~25 MeV between the LNL proton RFQ, under construction, and and the existing β=0.31 half wave resonator. This allows a 5÷100 MeV proton linac working at 352 MHz with 2 types of coaxial HWR cavities with large velocity acceptance, thus able to accelerate also other ion species (e.g. deuterons). A similar scheme was previously proposed for Spoke resonators; the aim of the HWR choice is compactness and cost reduction. The same design scheme is suitable for 176 MHz HWRs with β=0.09 and β=0.15. The β=0.17 cavity is presently under construction in the SPES R&D program at LNL; first test results are expected by the end of 2005.

THE LNL PROGRAM IN HWR DEVELOPMENT

Superconducting coaxial Half-Wave Resonators (HWR) [1] have many characteristics that make them well suited for the low-energy part of high power, wide-β linacs. Their optimal rf frequency range is 150÷350 MHz, which lies between the optimal ranges of Quarter-wave and Spoke resonators. Compared to both, HWRs have a 10÷30% lower shunt impedance; however, they are free from beam steering, that affects quarter wave resonators above ~100 MHz, and they are more compact than Spoke resonators and usable at lower frequency and β. Coaxial HWRs allow efficient acceleration in the 0.06<β<0.4 range; they can fill the gap between RFQs and elliptical superconducting cavities in high power cw linacs requiring large velocity acceptance.

LNL is developing 352 MHz and eventually 176 MHz HWRs in the framework of the SPES [2] and EURISOL [3] projects, requiring linac sections able to accelerate 5 mA cw proton and deuteron beams up to 85 MeV. We planned 4 prototypes: β=0.17 and 0.31 working at 352 MHz; β=0.085 and 0.15 at 176 MHz. All cavities have a similar design, characterized by a double wall coaxial structure with integrated Helium vessel [4]. Common features are also the 30 mm beam port aperture and a side tuner, welded to the outer conductor, not exposed to helium pressure. The cavities are of 2 types (flattened and cylindrical, referred to the inner conductor shape) with real-estate lengths 232 and 286 mm flange-to-flange, respectively. The different frequencies are obtained by simply changing the resonator length (roughly λ/2), in a scheme similar to the one used for the LNL Niobium quarter wave resonators [5]. The coaxial structure make them very compact and stiff.

All flanges are of the Conflat type to allow, if required, vacuum separation between the rf-beam volume and the cryostat one. A 1+5/8" port for a coaxial rf coupler is located at the resonators equator; the recent increase from 3 to 5 mA in the SPES beam current specifications could require an increase of the coupler port diameter in the future.

The first prototype with β=0.31 of the cylindrical type was constructed and tested in 2004 [6]. The second, β=0.17 flattened one, is presently under construction.

352 MHZ, LOW-β CAVITY DESIGN

The 352 MHz, β=0.17 (low-β) cavity design was obtained from the β=0.31 (medium-β) one by changing the gap-to-gap distance from 125 to 60 mm (geometrical β_0=0.14). This required reduction of the coaxial resonator diameters to 80%, flattening of the inner conductor cylinder near the beam axis to obtain a 30 mm long drift tube, and prolonging the beam ports inward to obtain 30 mm gaps. The side tuner diameter was also reduced by 80%; the decrease of the 1 mm membrane mobility was compensated by a higher tuning sensitivity.

The resonator shape was optimized by means of the code HFSS. The rf parameters of the low- and medium-β 352 MHz resonators are shown in Table 1.

Table 1: 352 MHz HW Resonators rf parameters.

β_0	0.17	0.31	
U/E_a^2	0.067	0.086	$J/(MV/m)^2$
B_p/E_a	11.4	10.4	$mT/(MV/m)$
E_p/E_a	6.6	3.9	
R_{sh}/Q_0	1230	1180	Ω/m
$R_s \times Q_0$	55	66	Ω
Tuning df/dh	~200	~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*

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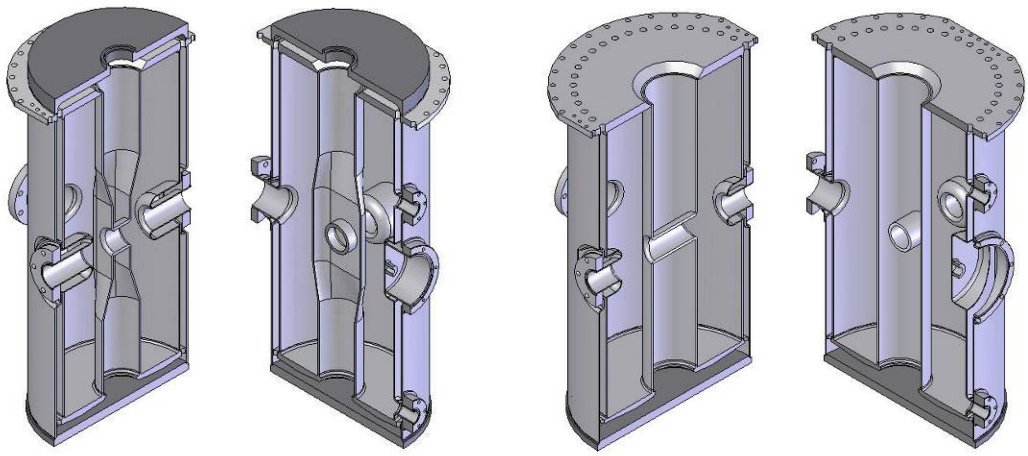

Figure 1: Sketches of the 352 MHz, β_0=0.17 (left) and β_0=0.31Half-Wave resonators.

The design peak fields in operation are below 33 MV/m and 60 mT. The tighter low-β HWR structure required by the lower beam velocity, compared to the previous resonator, is characterized by higher E_p/E_a; thus the design gradient was lowered from 6 to 5 MV/m. The resulting energy gain of 0.9 MeV/q, however, considering the rather short real estate length, is fully satisfactory for our scope.

BEAM STEERING

We have studied the beam steering caused by the side tuner. This effect is significantly weaker in the low-β resonator and 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 (Figure 2).

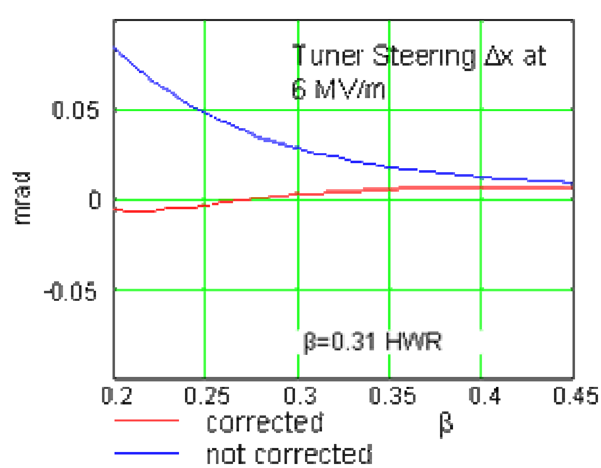

Figure 2: Tuner horizontal steering compensation in the β=0.31 HWR, at operation E_a and ϕ=-30 deg synchronous phase. Blue line: resonator aligned on axis; red line: resonator aligned off axis by 0.4 mm for compensation.

We have studied also the beam steering effect caused by the quadrupolar symmetry of the resonators. We found that quadrupole steering, at operation phase and gradient, is below 0.03 mrad in the useful velocity range, and considerably weaker than natural rf defocusing especially at low velocity, where the beam dynamics is more demanding (see Figure 3).

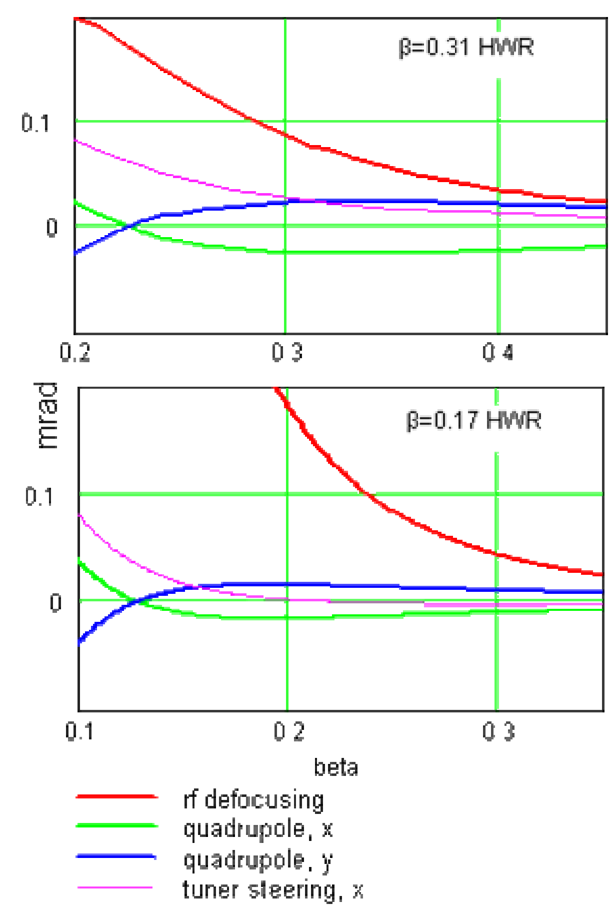

Figure 3: Quadrupolar steering and standard rf defocusing 1mm off axis, and tuner steering on axis (before compensation) in mrad, vs. β at operation E_a and ϕ=-30 deg synchronous phase. Top: medium-β cavity at 6 MV/m; bottom: low-β cavity at 5 MV/m.

Figure 4: Parts of the low-β 352 MHz HWR under construction. From top: inner conductor, tuning cup, beam ports, outer conductor and outer vessel, shorting plates.

HWR CONSTRUCTION

The low beta cavity construction has started in 2005. The construction procedure, compared to the medium-β cavity one, includes two more steps: the flattening of the inner conductor and the welding of the Titanium top flange of the liquid Helium vessel (this flange, in previous resonators, was made of stainless steel and connected to the resonator by means of screws and an indium seal). The cavity tuning is done in 2 steps:

1. adjustment of the inner conductor length with dummy tuner and beam ports;
2. adjustment of the tuning cup position after welding of all other resonator parts (except for the helium vessel), and final welding.

After welding of the tuning cup, the resonator inner surface is accessible only through the rf and beam ports, located in order to facilitate chemical polishing and make possible high pressure water rinsing of the whole rf surface. The resonator construction is presently in an advanced stage; its completion is expected within spring. Chemical polishing and first testing are foreseen in autumn 2005.

CONCLUSIONS

After prototyping of a β=0.31, 352 MHz cavity, the LNL R&D program in superconducting Half-Wave resonators for low- and medium-β high power cw linacs is proceeding with the construction of a β=0.17, 352 MHz cavity, which will be completed and tested within 2005. The design of these HWRs will be the basis for further 176 MHz HWR prototypes with β=0.085 and 0.15.

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