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DESIGN, FABRICATION, AND TEST OF A 175 MHz, BETA = 0.18, HALF WAVE RESONATOR FOR THE IFMIF-DONES SRF-LINAC*

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Abstract

The IFMIF-DONES facility will serve as a fusion-like neutron source for the assessment of materials damage in future fusion reactors. The neutron flux will be generated by the interaction between the lithium curtain and the deuteron beam from an RF linear accelerator at 40 MeV and nominal CW current of 125 mA. The last accelerating stage is a superconducting (SRF) Linac hosting five cryomodules.

This SRF-Linac is equipped of two types of 175 MHz half wave superconducting cavities (HWRs). The first type of cavities (cryomodules 1 and 2), characterized by beta equal to 0.11, have been studied and qualified in the frame of IFMIF/EVEDA project. The development of the second type of cavities (cryomodules 3, 4, and 5), with higher beta of 0.18 is presented in this paper.

A prototype has been designed, fabricated and tested in a vertical cryostat at CEA. The measured quality factor at nominal accelerating field (4.5 MV/m) is 2.3 10^9, above the target in accelerator configuration (10^9). Moreover the quality factor stays above 10^9 up to 10 MV/m.

The next step is the fabrication of a helium vessel to be welded on the prototype, and the development of a dedicated frequency tuning system.

RF DESIGN

The SRF-Linac for IFMIF-DONES [1], represented in Fig. 1, hosts two cryomodules with low beta (LB) HWR cavities and three cryomodules with high beta (HB) HWR cavities, all the cavities working at 175 MHz [2, 3].

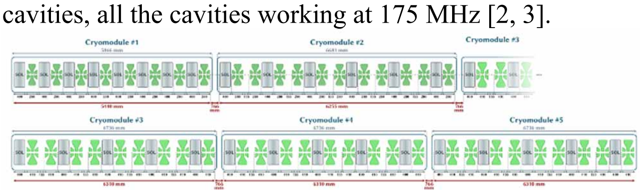

Figure 1: Layout of the 5-cryomodules SRF-Linac. Cavities are in green and solenoids in grey.

The design and qualification of the LB accelerating unit (low beta cavity equipped with its tuning system and power coupler) have been developed in the frame of IFMIF/EVEDA [4].

Table 1: RF Design Requirements

Frequency	175 MHz
Beam current	125 mA
Beam aperture	50 mm
Nominal gradient, Eacc_nom	4.5 MV/m
Optimal beta	0.18
Quality factor @ Eacc_nom	10^9

The HB cavity, with a beta equal to 0.18, is aimed to reach a nominal gradient of 4.5 MV/m with a quality factor at least equal to 10^9 (see Table 1). The RF design has been optimized to reach all requirements, while limiting the peak field (see Fig. 2), and allowing RF power transfer to the beam. Both electric and magnetic peak fields at nominal gradient remain under the ones of the low-beta cavity (see Table 2). The external coupling range for the optimization of the RF power transfer to the beam in given in Table 2. For the nominal beam current and gradient, this range corresponds to an amount of RF input power between 100 and 140 kW. Moreover, it has been checked that this external coupling range could be reached with an antenna penetrating the 100 mm coupler port.

Table 2: RF Design Parameters

Max E field @ E_{acc_nom}	21 MV/m
Max B field @ E_{acc_nom}	36 mT
External coupling	4.5 10^5-6. 5 10^5

The high power RF couplers were validated up to 100 kW in the IFMIF/EVEDA project [5]. In order to fulfill the needs with margin, we plan some upgrades of the couplers to reach RF power as close as possible to 200 kW.

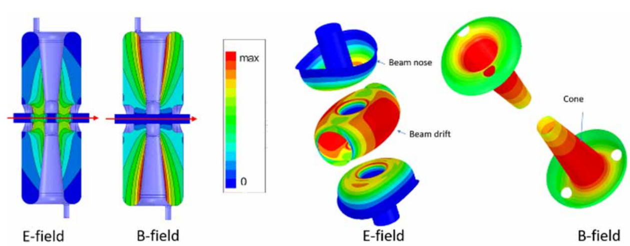

Figure 2: E and B field patterns in the DONES HB cavity: on cut planes (left) and on inner surfaces (right).

MECHANICAL DESIGN

The cavity body is made of bulk niobium (Nb), while the flanges are made of niobium/titanium (Nb/Ti) (Fig. 3). The

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thickness of the cavity walls is fixed to 3 mm except for the half-torus which thickness is increased up to 4.3 mm to guarantee an adequate stiffening. Mechanical calculations have shown that with the optimized shapes, the maximal stresses due to Lorentz's forces or liquid helium pressure variation remain smaller than niobium yield stress.

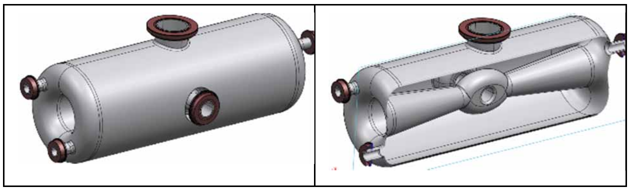

Figure 3: CAD views of the HB cavity.

The cavity walls and coupler port are made from 3.4 mm thick Nb sheets. The central drift and the beam tubes were made from Nb blocks (Fig. 4).

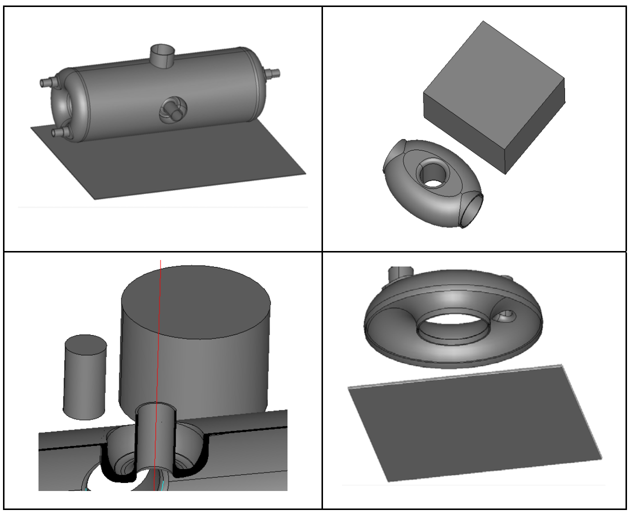

Figure 4: From left to right and from top to bottom: CAD views of cavity main body, drift tube, beam tube and half torus and corresponding Nb parts.

The Nb/Ti flanges have been designed to be compatible with the future implementation of a helium tank.

CAVITY FABRICATION

The cavity body is made out of high purity niobium (Residual Resistivity Ratio RRR > 300).

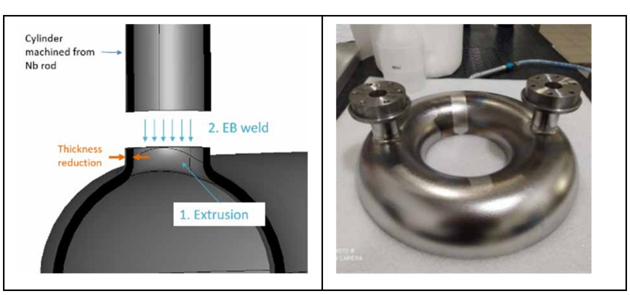

Figure 5: HPR tube and welding principle (left). Half torus with HPR ports (right).

The top and bottom half tori are manufactured by deep drawing from 4.3 mm thick Nb sheets. The welding of the High Pressure Rinsing (HPR) ports on these tori was identified as a delicate operation. The solution applied by the manufacturer (Zanon R&I) consists of extruding the basis of the HPR ports from the tori, cutting and milling to get the adequate surface and Electron Beam (EB) welding of the HPR tube (see Fig. 5).

The RF resonance frequency of the HWR is very sensitive to the internal dimensions of the resonator, and it was anticipated that fabrication tolerances could not be tight enough to reach the frequency within the required precision. To overcome this issue, a specific tuning procedure enabling to recover the cavity target frequency was implemented at the company premises. To this intend, overlengths are kept on each side of both inner and outer conductors so that some corrections can be made at intermediate steps of fabrication. The tuning procedure consists in a sequence of blank assembly and frequency measurements in different intermediate configurations in order to define the length to be cut before next welding.

The final frequency after the last weld of the manufacturing process differs from less than 30 kHz from the target frequency. The cavity after delivery at CEA is shown in Fig. 6.

Figure 6: HWR prototype.

CAVITY PREPARATION

To achieve the expected RF performances, the surface of the Nb cavity is cleaned by chemically etching away the surface layer damaged during the fabrication. For this cavity, the thickness to be removed on the inner cavity wall was estimated to 200 µm. However, the final chemical etching measured after this operation is 140 µm in average.

The cavity was then subjected to High Pressure Rinsing (HPR), to remove any chemical and particulate residue from the niobium surface. However, the HPR device was not optimized for this cavity and only one cycle could be carried out when two are usually necessary. We estimated that these surface treatments, even non ideal, should be sufficient, and after clean room assembly, the cavity was baked out at 120 °C under vacuum during 48 hours.

FIRST TESTS IN VERTICAL CRYOSTAT

The vertical cryostat is equipped with a magnetic shield to decrease the parasitic magnetic field below 2 µT. The cavity is inserted in the cryostat and cooled down to 4.2 K.

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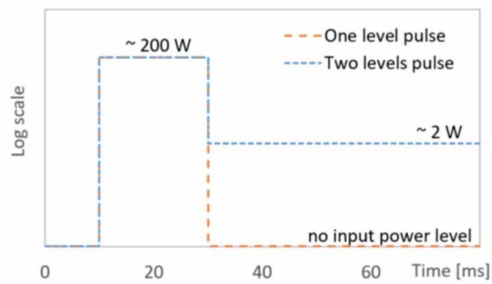

Figure 7: One and two levels pulses.

During the power ramp up of the cavity, a multipactor barrier appeared at very low field (<< 1 MV/m), which prevented the RF field from developing in the cavity. Breaking through this barrier requires injecting some hundreds of watts during tens of ms. After adjusting the power level of the pulse (Fig. 7, *one level pulse*), it has been possible to cross the multipactor barrier, but the field in the cavity dropped down immediately at the end of the pulse to values within the multipactor range. By improving the pulse shape using two power levels pulse (Fig. 7, *two levels pulse*), it became possible to keep the field above the multipactor barrier when the injected power drops down from the higher level to the lower.

During the first run (Fig. 8), a new multipactor barrier appeared between 2 and 3.5 MV/m, which could be conditioned within one hour. The Q_0 starts to drop at 3 MV/m, which is generally the signature of field emission. One Geiger-Müller (GM) detector, placed in the test area for safety control, measured an increase of the radiation rate above 3 MV/m, which could corroborate the field emission phenomenon. The cavity reached an accelerating field of 4.3 MV/m without quenching.

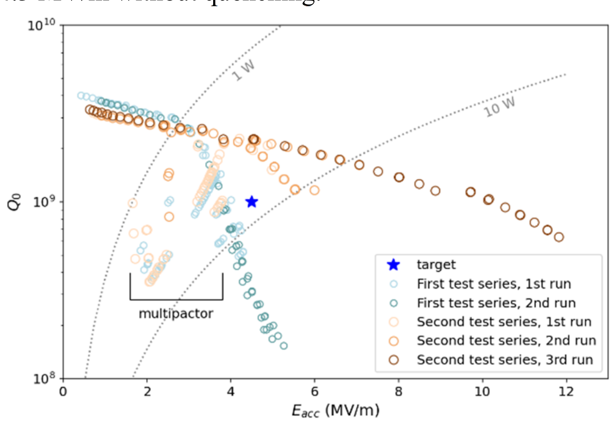

Figure 8: Q_0 vs E_{acc} curves for the two series of test.

A second run was carried out a few days later, the cavity being kept at 4 K in the meanwhile. The multipactor in the 2-3.5 MV/m range was easily processed, and the cavity field increased up to 5.25 MV/m (Fig. 8). Other values like Q_0 are unchanged with respect to the first run. However, the quality factor at 4.5 MV/m is 3 10^8, which is below the targeted value of 10^9.

IMPROVED PREPARATION AND RESULTS

The field emission at rather low field is typical of surface pollution, which is compatible with the non-optimal surface preparation (chemical etching too light, and one HPR cycle instead of two). Before a new test, two improvements are thus achieved:

- The cavity is subjected to a new chemical treatment, resulting in a total etching of 225 µm.
- A new HPR tooling is designed and fabricated, for better cavity positioning and to allow larger amplitude to the spray nozzle positions; then two complete HPR cycles are realized.

After new clean room assembly and new cavity bake-out, a second series of test in vertical cryostat is carried out.

The new Q_0 vs E_{acc} curve is shown in Fig. 8, showing three successive runs.

During the first run the multipactor barrier was conditioned. During the second run, the cavity was conditioned gradually up to 6 MV/m, resulting in Q_0 increase. Finally, during the third run, the input power was increased up to the maximum available power of 90 W, corresponding to an accelerating field close to 12 MV/m, without quench.

- The quality factor at nominal accelerating field (4.5 MV/m) is 2.3 10^9, more than twice the target (10^9).
- The quality factor stays above 10^9 up to 10 MV/m.

CONCLUSION

A cavity prototype for the high beta section of the SRF-Linac for IFMIF-DONES has been fabricated and tested in a vertical cryostat at CEA. The cavity performances have exceeded the target specifications. As a next step, the cavity will be equipped with a helium tank while a dedicated tuning system will be developed.

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