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FABRICATION AND TESTS OF THE RE-BUNCHER CAVITIES FOR THE LIPAC DEUTERON ACCELERATOR*

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Abstract

Two re-buncher cavities will be installed at the Medium Energy Beam Transport (MEBT) of the LIPAc accelerator, presently being built at Rokkasho (Japan). They are IH-type cavities with 5 gaps and will provide an effective voltage of 350 kV at 175 MHz. The cavity consists of a cylindrical main body and two endplates in stainless steel with an internal copper coating. The stems and drift tubes are machined from bulk OFE copper. The fabrication techniques for the cooling pipes, the input coupler and the pick-up are presented. Material choices and fabrication process are discussed. The first re-buncher is already fabricated. RF low power tests have been made to measure resonant frequency, S-parameters and Q-factor before and after the copper plating. The electric field map has also been measured with the bead-pull method.

INTRODUCTION

Two re-buncher cavities will be installed in the MEBT line [1], as part of the Spanish contribution to LIPAC. Electromagnetic and mechanical calculations have been performed leading to a conceptual design of a 5-gap IH type cavity with 350 kV effective voltage, nominal frequency of 175 MHz and total power loss of 6.6kW [2].

DESIGN AND FABRICATION

A complete detailed design of all the components of the cavity has been performed. The cavity has an internal diameter and length of 486.6 and 320 mm, respectively. The gaps are 32 mm wide. The aperture is 44 mm diameter. Two of the drift tubes are bolted directly on the end plates. The other four are fabricated in one piece with the four stems.

The main design objectives were to achieve the nominal frequency and the requested electric field distribution. Special care has been put into the internal dimensions of the cavity and the size, position and profile of the drift tubes. A general overview of the cavity is shown in Fig. 1. A description of the most important design and fabrication concepts is included below for the different components.

Cavity Shell

The cavity shell is composed of a central body (cylindrical part) and two end plates, all of them made in 316L stainless steel.

The central body has been fabricated from a plate which was bended and TIG welded on the contact line. Additionally, two 316L rings were welded around both rims to allocate the holes for the end plates bolting. The ports (two vacuum pump connections and the housings for the tuners, pickup and spark detector) were also TIG welded on appropriate holes.

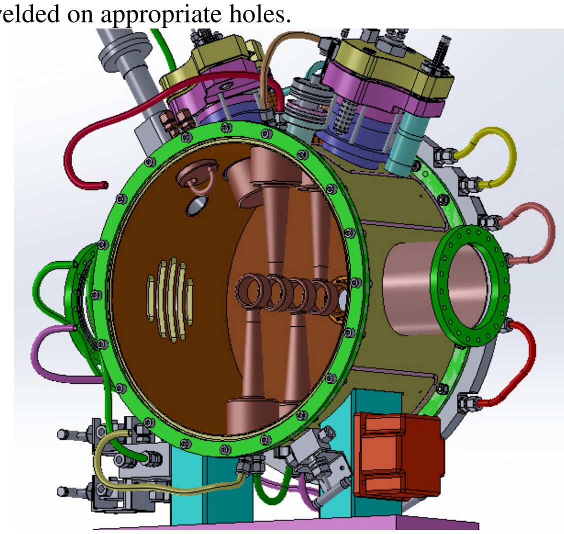
Figure 1: 3D model of the re-buncher cavity.

The central body is cooled by two copper tubes soldered to its exterior surface, on a groove with the convenient layout. This groove, together with the holes for the ports, was performed on a horizontal machining centre.

The cooling through holes for the end plates cooling was performed with a special tool for long drills.

An electrolytic 100 µm copper coating was performed on the internal surfaces of all these parts, to achieve a good electric conductivity. Previously, a few micron layer of nickel was deposited to guarantee the proper adherence of the copper coating.

Cooling Pipes

A custom tooling was necessary for the off-plane bending of the copper tubes to ensure a good matching with the groove. The welding of the tubes to the body was performed with Sn-Pb, by applying local heat with a blowtorch. A custom soldering flux was prepared for the correct preparation of the stainless steel surface.

Stems and Drift Tubes

An aluminium version of the stems (without cooling conduit) and drift tubes was firstly fabricated to perform a low power RF measurement to check the actual resonant frequency. In fact, a frequency around 0.5 MHz below the nominal one was obtained. The main origin of the deviation is that all the stems were too long, 0.1 mm

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above nominal. A narrower tolerance band (±0.05 mm) was stated for the final stems.

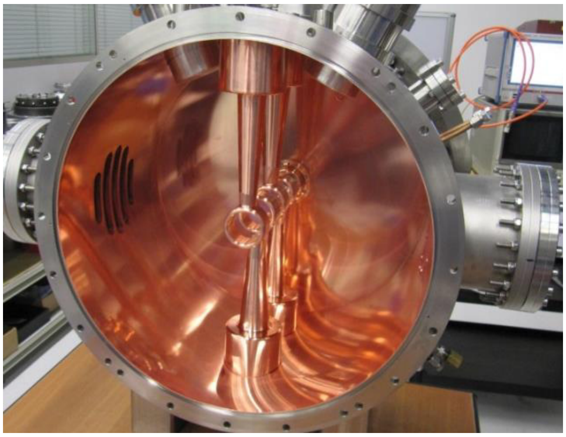

Figure 2: assembly of the cavity with the copper stems.

The stems (Fig.2) and their drift tubes were fabricated in one piece of Oxygen-free copper (OFC). Strict tolerances were applied to the plane face for the housing on the central body (flatness and perpendicularity with the stem axis), the pin holes and the position, size and shape of the drift tubes front profile.

The stems have a conical shape with an increasing section as we move away from the drift tubes in order to carry on the increasing RF current while keeping the same power deposition density. The last portion of the stems features a bigger cylindrical section, to ease the assembly and to allow room both for the gaskets and the screws.

The length of that cylindrical section was used for a fine tuning of the frequency. It was initially fabricated 5 mm longer than its nominal size. The frequency was measured and, by using the calculated sensitivity with the electromagnetic model [2], the final dimension was decided and the stems were re-machined in the lathe.

The cooling is performed through internal holes performed in the stems, ending as close as possible to the drift tube wall. A water distributor is inserted into the cooling holes with the objective of guiding the water.

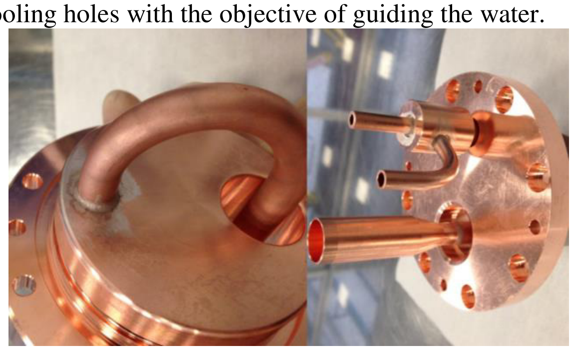

Figure 3: coupler after the first brazing step: inner (left) and outer (right) sides.

Input coupler

The power coupler (Fig. 3) was based on the design of the Spiral-2 re-buncher coupler [3]. It has been made in OFC. It is connected to a 1” 5/8 rigid RF coaxial line. The vacuum sealing is made by an alumina ring. The induction loop is made from a ϕ10 mm copper tube with another copper tube (1/4”) inserted into it for guiding the cooling water (water entering inside of the small tube and returning in between the pipes).

The different copper parts and the ring will be joined by a two-step brazing process. The ring has been previously metallised to increase the alumina wettability.

Pickup Probe

The pickup probe was fabricated from a commercial feedthrough with a RF “N” connection on its outer side. On the inner side, a ϕ3 mm copper pin was soldered both to the end of the feedthrough pin and to the surface of the feedthrough flange, creating in this way the loop for the inductive coupling.

Tuners

The buncher has two tuners with a ϕ80 mm piston with a ±20 mm stroke each. One of them will be moved manually and will aim to compensate the static errors of the resonant frequency: fabrication and assembly tolerances and deformation under vacuum. The other one is actuated automatically by a stepper motor which will be driven by the Low Level control system and will perform the dynamic fine adjustment.

Both tuners have been designed specifically for this cavity. They consist primarily on two plates (one fixed and one moveable) guided by two linear ball bearings. A ball screw (driven by a stepper motor or by a manual actuator, respectively) produces the displacement of the movable plate.

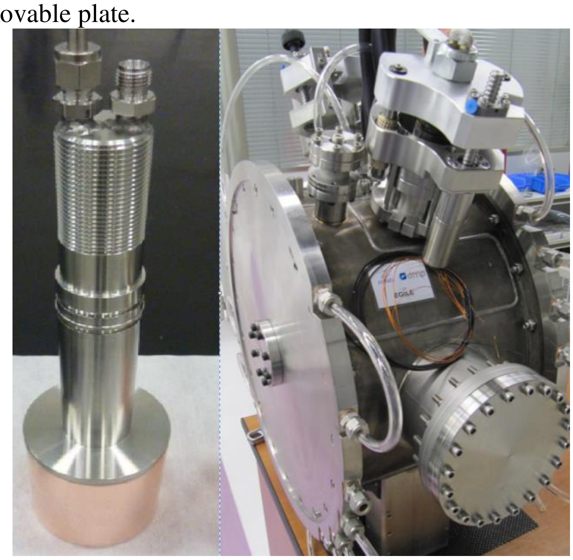

Figure 4: Tuner piston core and copper shell after brazing (left) and assembled cavity (right).

The piston, attached to the movable plate, consists of a stainless steel core with a vacuum brazed copper shell at the end (Fig. 4, left). A groove for the cooling water is kept between them. A bellow allows the plunger movement under vacuum.

Vacuum Gaskets

At several joints in the cavity (end plates, stems, coupler, tuners) a good vacuum sealing together with a

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good conductivity for the RF currents was required. For this purpose elastic copper (high current density) or aluminium (low) gaskets [4] were selected. The copper gaskets are of delta-type to allow a lower axial force for the sealing.

LOW POWER RF MEASUREMENTS

Resonant Frequency and Q Factor

At this moment, the coupler has not been finished. The RF measurements are made by exciting the cavity with a pickup probe at the coupler port. This creates an under-coupling with respect to the almost critical coupling that should be obtained with the final coupler.

After a fine tuning of the frequency by refining the length of the cylindrical part of the stems, a resonant frequency of 174.93 MHz in atmospheric pressure and 175.007 MHz in vacuum has been measured with tuners at nominal position. From the simulations, a frequency increase about 100 kHz is expected with the final coupler.

The tuning bandwidth was also measured. A range of ±405 kHz has been measured by bringing the tuners to their extreme positions, very close to the calculations (±408 kHz [2]).

The measured loaded Q-factor was 4790 (a value of 4801 was expected taking into account the effect of the undercoupling).

Finally, a bead-pull test was performed to measure the electric field along the beam axis. A cylindrical nylon bead with a volume of 687.9 mm^3 was used. The bead was not calibrated, nor the exact permittivity was known. Therefore, the bead-pull results presented in this paper should be taken as preliminary. The S_{11} parameter was measured at several positions of the bead, which was introduced in the cavity attached to a thread moved by a stepper motor. The electric field was calculated by the frequency displacement method [5], by the expression:

$$\frac{\Delta f}{f} = -\frac{3}{4}\frac{V}{U}\varepsilon_0\frac{\varepsilon_r - 1}{\varepsilon_r + 2}{E_0}^2$$

in which f and E_0 are the unperturbed frequency and electric field at the bead position, respectively, Δf is the variation in the resonant frequency due to the perturbation, V is the volume of the bead, U is the total energy stored in the cavity (0.0714 J according to the simulations), ε_0 is the vacuum permittivity and ε_r is the relative permittivity of the bead material.

The resonant frequency was obtained from the S_{11} curves by interpolation. The phase shift technique described in [5] could not be used due to the high Q and high frequency displacement that took the phase out of the valid region for that method.

The results (Fig. 5) show an excellent relative magnitude of the field at the different gaps or at different offsets from the beam axis. The measured results are, on the other side, consistently below the calculations (around 9%). This difference alone could be explained by an uncertainty in the relative permittivity of the bead that was used in the test. A bead-pull test is scheduled with a calibrated bead in the near future.

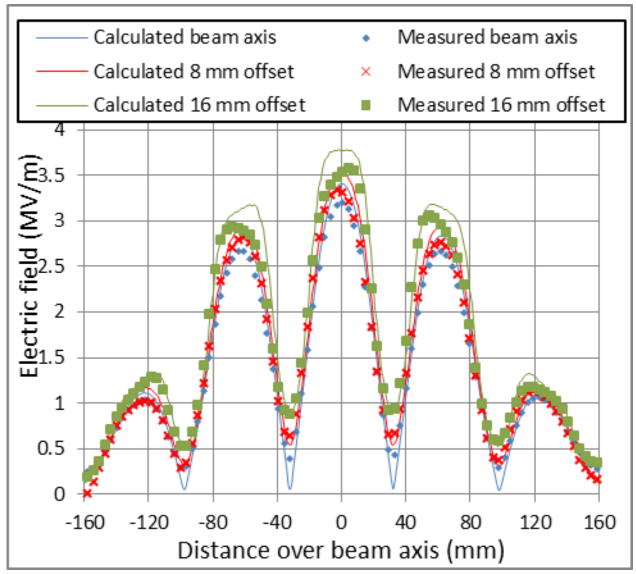

Figure 5: calculated and measured electric field at the beam axis and two off-centred lines.

CONCLUSION

The most significant concepts of the fabrication of the re-buncher cavity for LIPAc have been presented. The first re-buncher is almost fabricated (except the power coupler). Low power RF tests have been performed on it, with an excellent matching with the simulations.

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