# HB2TF

## Report Activity 2023 at INFN-LNF

L. Faillace (Resp. Loc.), D. Alesini, F. Cardelli, A. Gallo, L. Piersanti, Vaccarezza, INFN-LNF.

## 1 CALL overview

High Brightness Beams Test Facility, HB2TF, is a CALL funded by the INFN CSN5 for the development of a High Brightness Beams Test Facility (HB2TF) at the INFN-LASA laboratory for the period 2023-2025. This CALL is a collaboration between the following participant units of the INFN: Milano, LNF, LNL, LNS, Bologna and Napoli.

The electron bunches produced by the DC Gun exhibit an elongated longitudinal profile to prevent emittance dilution. In order to minimize nonlinear energy spreading caused by the RF waveform in the planned booster, after the gun it is necessary to compress the bunches to a shorter length. Since the beam is still non-relativistic, the simplest method of bunch compression is through velocity bunching. To achieve this, we proposed a sub-harmonic bunching solution by using two $\beta < 1$, 650 MHz spherical re-entrant shape copper cavities. The beam energy prior to entering the first and second cavities is assumed to be 300 keV and 638 keV, respectively.

## 2 Bunchers' RF Design

The particular frequency of the buncher was selected to be a sub-harmonic of an anticipated 1.3 GHz SC booster cryomodule. Within this context, and with the initial collaboration of the KEK buncher team, the geometries of the buncher cavities were initially formulated in 2D using Superfish. The design was based on the KEK cERL buncher cavity [1] and scaled to the desired frequency. The buncher cavity has been then designed in 3D with commercial electromagnetic solvers Ansys HFSS [2] and CST [3]. The geometrical structure of vacuum is shown for Buncher 1 in fig. 1. In fig.2, we show the 3D mesh and profile for E and H field in Buncher 1. The parameter "g" is the effective gap length that is 17 cm, corresponding to a cavity $\beta = 0.74$. In tab.1, we outline the main RF parameters of the two bunchers.

The analysis has been performed by employing the eigenmode solvers, with the objective to confirm the correctness of the results in terms of operating frequency and electric field of the employed $TM_{010}$ operating RF resonant mode. The overall comparison among different solvers is resumed in tab.2 for Buncher 1.

## 3 Thermal Analysis

We intend to manufacture the cavity using bulk copper, which can be processed into two halves using a high-precision lathe machine. These halves will then be joined together through brazing in a high-temperature furnace. Cooling channels will be incorporated into the outer shell of the cavity. We have initiated thermal analysis using the CST code, assuming an average RF power dissipation of 10.3 kW by the cavity walls. The inner diameter of the channels is 1.5 cm, with

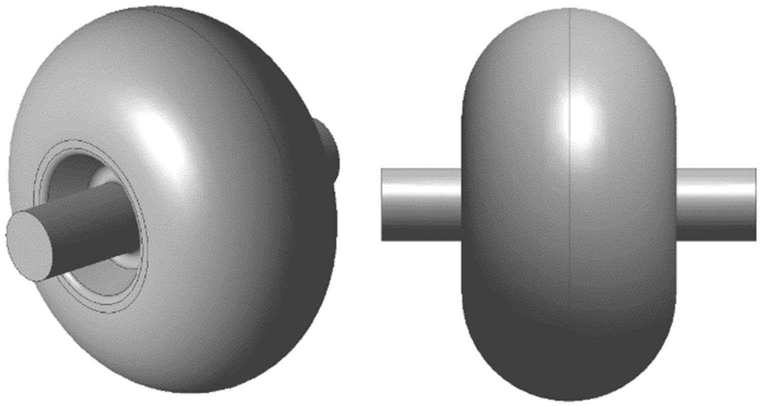

Figure 1: *Buncher 1 geometry (only vacuum volume shown).*

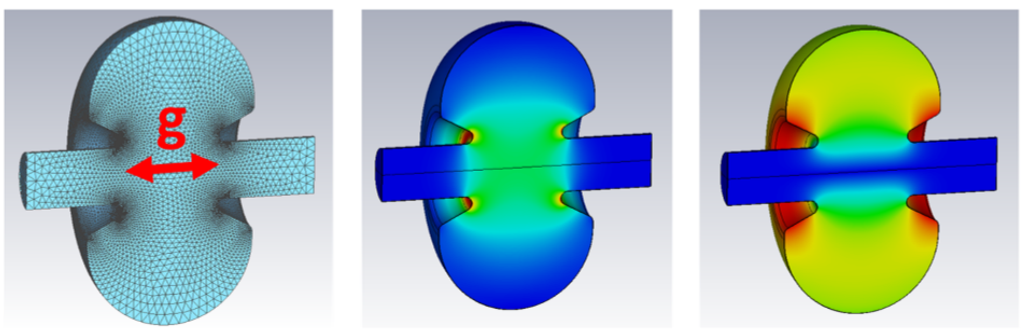


Figure 2: *3D mesh and profile for E and H field in Buncher 1. Parameter "g" is the effective gap length that is 17 cm corresponding to a cavity beta 0.74.*

Table 1: *Main RF parameters of the two bunchers.*

| | Buncher 1 | Buncher 2 |
|---|---|---|
| $f_0$ ($\pi$-mode) [MHz] | 650 | 650 |
| $\beta$ (v/c) | 0.74 | 0.906 |
| Input beam energy [MeV] | 0.3 | 0.638 |
| E-field ampl. [MV/m] | 2.7 | 2.7 |
| Cell per cavity | 1.0 | 1.0 |
| Active cavity length [m] | 0.171 | 0.209 |
| Cavity quality factor Q0 | 32000 | 36700 |
| Ext. Quality factor Qext | 30200 | 32400 |
| $R/Q$ [$\Omega$] | 195.7 | 223 |
| Geometry factor $G$ [$\Omega$] | 211 | 244 |
| $E_{pk}/E_{acc}$ | 3.07 | 3.88 |
| $B_{pk}/E_{pk}$ [mT/(MV/m)] | 0.96 | 0.96 |
| $B_{pk}/E_{acc}$ [mT/(MV/m)] | 2.94 | 3.73 |

Table 2: *Buncher 1 figures of merit through different solvers.*

| Parameter | Superfish | CST | HFSS |
|---|---|---|---|
| Radiofrequency, $f$ [MHz] | 650.372 | 650.180 | 650.3504 |
| Quality Factor, $Q$ | 31710 | 31699 | 31691 |
| Shunt impedance, $R_{sh}$ [M$\Omega$/m] | 6.209 | 6.210 | 6.1144 |
| On-axis Electric field peak, $E_{peak}$ [MV/m] | 2.7 | 2.7 | 2.688 |
| Surface Max Electric field, $E_{max}$ [MV/m] | 6.13 | 6.29 | 6.536 |
| Input RF power, $P_{input}$ [MW] | 10.28 | 10.26 | 10.28 |

a water flux of 10 l/min and a water temperature of 30 °C considered. The simulation results, depicted in fig.3, reveal the temperature distribution inside the copper, with a maximum hot spot of 45.2 °C compared to 54.2 °C for passive ambient cooling. The resultant temperature gradient of approximately 15 °C is anticipated to induce a frequency shift of about 187 kHz, which is expected to be corrected through adjustment using an in-vacuum plunger. Additionally, a parallel multi-physics analysis, integrating electromagnetic coupling with thermal effects, is underway via Ansys Workbench with HFSS and Thermal solvers, providing further validation of the cooling model's consistency.

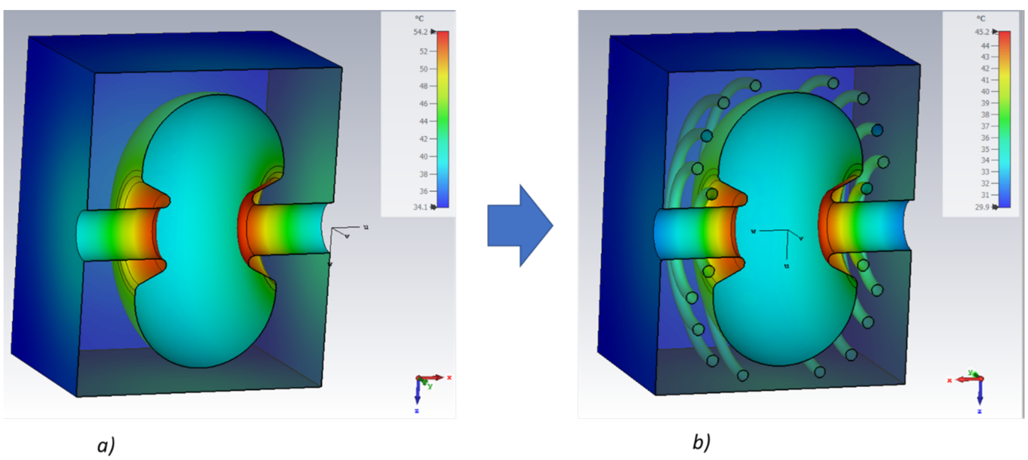


Figure 3: *CST thermal analysis of the buncher cavity dissipating the target power of 10.3 kW. The effectiveness of the proposed cooling scheme is proved by comparing the passive air cooling on the left (picture a) with the active cooling on the right (picture b).*

## 4 Publications in 2023

- D. Giove et al., A high brightness beam test facility for ERL applications, 14th International Particle Accelerator Conference,Venice, Italy (May 2023).

### References

1. T. Takahashi et al., "Development of a 1.3 GHz BUNCHER Cavity for the Compact ERL", in proc. Of 5th International Particle Accelerator Conference (IPAC2014), Dresden, Germany,

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