ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-TUPOMS028

3HC – THIRD HARMONIC NORMAL CONDUCTING ACTIVE CAVITY COLLABORATION BETWEEN HZB, DESY AND ALBA*

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Abstract

A collaboration agreement between the HZB, DESY and ALBA institutions was signed on 2021 in order to test the 3rd harmonic normal conducting, HOM damped, active cavity designed and prototyped by ALBA [1]. The test will involve low power characterization of the fundamental mode, bead pull measurements to fully determine the HOM characteristics, a full high power conditioning to validate the power capability of the cavity, and finally, the installation of the cavity in the BESSY II storage ring in order to test the cavity in real conditions with beam. In this paper the low power, bead pull and conditioning results will be presented. The cavity has been installed at BESSY II on May 2022 to be tested after the summer shutdown.

INTRODUCTION

The interest of the three parties of the collaboration on harmonic cavities is motivated mainly by the 4th generation upgrade projects that are under development by each of the parties, i.e. ALBA II [2], Petra IV [3], MLS II and BESSY III [4].

ALBA has designed and built a prototype of a 3rd harmonic normal conducting, HOM damped, active cavity [1], and the goal of the collaboration is to fully test this cavity in order to validate its performance, with the final goal of installing it at the BESSY II ring to be actively tested with beam.

The cavity is active, so it is part of a whole 1.5 GHz RF system, which is composed by different parts provided by the different members of the collaboration:

- 1.5 GHz cavity prototype – by ALBA
- 15 kW solid state amplifier – by HZB
- Waveguide system – by DESY
- Digital LLRF – by ALBA
- Controls – by HZB

CAVITY

The cavity is a down-scaled version at 1.5 GHz, of the 500 MHz HOM damped normal conducting cavity installed in ALBA, which was based on the EU-design developed at BESSY [5].

With the main difference that the damping mechanism of the HOMs at the end of the dampers it is not an in-vacuum ferrite absorber, but a broad band antenna which couple the power to an external load, so called *TransDampers*, see Figure 1.

Detailed information of the cavity design can be found at [6], and of the prototype construction† and acceptance test at [1].

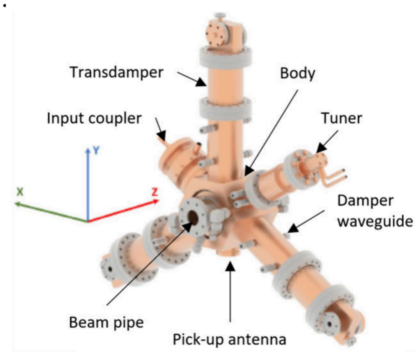

Figure 1: 1.5 GHz cavity, HOM damped with Ridged Circular waveguide and *TransDampers*.

E-M SIMULATIONS

At the design stage, electromagnetic simulations of the fundamental and of the HOMs were performed, but with the final design which was used for the construction of the prototype, the simulations have been repeated within the collaboration, together with the Institut für Teilchenbeschleunigung und Elektromagnetische Felder (TEMF).

After simulating the modes, at the moment of its identification, it was realised that due to the small cavity body of a 1.5 GHz cavity the HOM couplers attached to it are relatively large, resulting in disturbed higher modes which cannot be classified into TM- and TE-types. Only mixed forms appear, which can be called HEM modes (Hybrid Electromagnetic modes).

The electrical axis and beam axis of the cavity does no longer coincide, and sometimes the electrical axes are also skewed. This is mainly due to the fact that the three HOM couplers are distributed asymmetrically in longitudinal direction. In addition, each mode splits up to a passband of four coupled modes, due to the three HOM dampers plus the cavity body. Thus, a tremendous number of modes are formed, with most of the modes being irrelevant to particle dynamics.

The aforementioned phenomena lead to the following consequences: the undisturbed, non-attenuated cavity cannot be compared to the attenuated cavity at all; and the

* Collaboration agreement RCN-CIN202100124, BOE Resolution 8506 of May 14th, 2021. Published in May 21st, 2021.

† The prototype construction was co-funded by the European Regional Development Fund (ERDF) within the Framework of the Smart Growth Operative Programme 2014-2020.

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shunt impedances calculated, or measured by the classical methods, especially the transverse shunt impedances, are not suitable for checking the impedance budgets.

According to the previous remarks, we have chosen the following method to calculate a mode spectrum with CST-MWS.

A beam slightly offset from the beam axis excited the HEM-modes, with a very small beam offset 5 mm horizontally and 5 mm vertically from the beam axis. The excited electric fields in three different directions were then determined in the central plane of the cavity and plotted against frequency.

Figure 2 shows the electric field spectrum in the beam direction (green curve), and in the two directions perpendicular to it.

Table 1 shows the longitudinal R/Q-values of those modes from the spectrum in Figure 2 with R/Q-values larger than 1,65 Ω (1% of the fundamental mode). For the calculation of the R/Q-values the transit time factor was taken into an account.

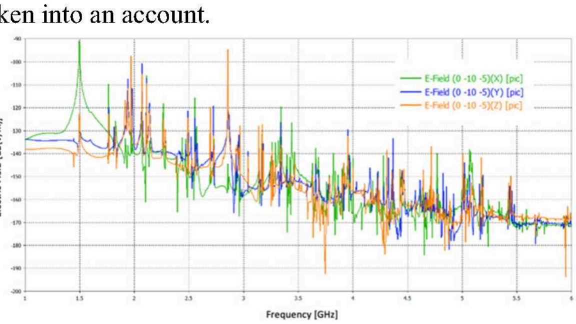

Figure 2: The electric field spectrum of HEM-modes excitable by a slightly off axis beam.

Table 1: A List of HEM-modes from the Spectrum with Longitudinal R/Q-values Larger than 1,65 Ω

Mode Number	Frequency [GHz]	R/Q [Ω]
4	1,500	165.5
11	1,821	3.4
14	1,905	2.1
20	1,994	6.3
27	2,105	47.6
31	2,189	3.4
32	2,198	8.7
61	2,885	7.0
62	2,885	1.7
87	3,271	2.0
100	3,364	3.5

The only mode with a relatively strong value is the mode 27 at 2.1GHz, a TM011 like mode, which is potentially important for longitudinal beam dynamics. We have cross-checked mode list against longitudinal beam coupling impedance by launching a Gaussian bunch with a bunch length of 4.0 mm. The Figure 3 shows the magnitude of the impedance along with the estimated coupled bunch instability (CBI) threshold. The spectrum appears relatively clean, all the HOMs are sufficiently damped, and are well under the operation threshold of BESSY II.

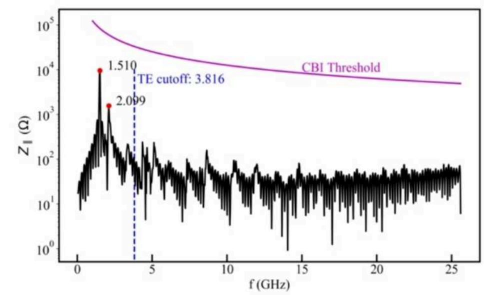

Figure 3: Coupled bunch instability threshold (CBI) for BESSY II, and HOM spectrum.

BEAD PULL MEASUREMENTS

Measurement System

A fully automated system was developed and build at HZB in order to perform the bead pull measurements to characterize the HOMs of the cavity. In Figure 4 some details of the system are shown.

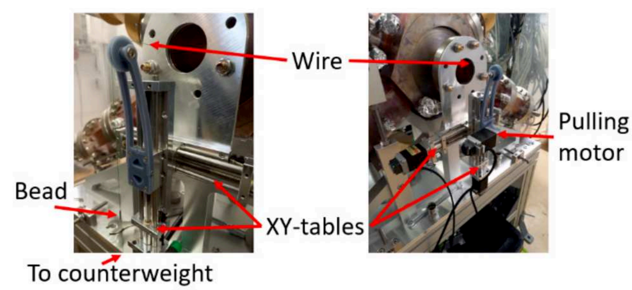

Figure 4: Bead pull measurement system.

The bead pull system consists of two motorized two-coordinate tables to move a bead in the transversal plane, and a motor to pull the bead longitudinally. A VNA, synchronized with the longitudinal motion of the bead, tracks the phase variation of the cavity mode at a fixed frequency. Metal syringe needle (10mm x ⦸1.3mm), metal ball (⦸3.3mm Pb), or a dielectric ball (⦸10mm) were used as beads. A GUI was developed to automate the measurement for pre-chosen set of frequencies on a transversal mesh.

Experimental Results

The first measurement was performed on the fundamental mode, to confirm the expected shunt impedance from the simulation and from the fabrication acceptance test [1]. In Figure 5 can be seen the result of the bead pull measurement, which gives the expected value, as in table 2.

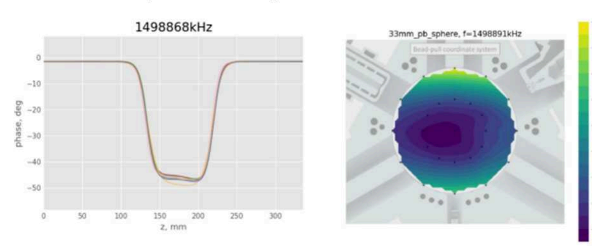

Figure 5: Bead pull measurements of the fundamental mode at 1.5GHz.

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Table 2: Fundamental Mode Measured with Bead Pull

Frequency [GHz]	Impedance [MΩ]	Q_L
1.499	1,46	9200

Figure 6 shows an example of the measured data of two HOMs.

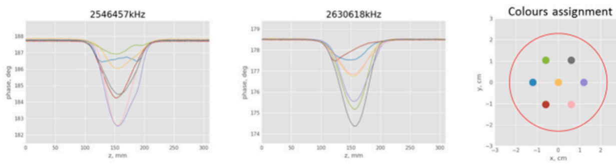

Figure 6: Measured data from two HOMs, for different bead pull position (mesh in the picture on the right, red circle is the vacuum chamber inner radius).

The full data analysis of the HOMs measurements have not been yet done, since many modes have been measured and the data analysis it is not straight forward, mainly due to the fact that most modes are not ideal TM or TE modes. This is due to the strong asymmetry of the cavity caused by the many open ports (input power coupler, plunger, three damping arms and the diagnostics pick-up loop) and the very small volume of a 1.5GHz cavity, as mentioned in the previous e-m simulation paragraph.

In any case, we have performed a worst-case estimation of the impedance value of the considered most dangerous modes with the result that they are below the critical threshold of BESSY II, as simulated, so the installation of the cavity in the ring has been considered safe. Test in the storage ring shall demonstrate it in the near future.

CAVITY CONDITIONING

High Power Test Bench System

The cavity was installed in the testing infrastructure SUPRALAB@HZB, at the HoBiCaT bunker with all the infrastructure and safety requirements in place.

The pictures of the Figure 7 show the cavity, the solid-state amplifier (SSA) with the waveguides exiting in vertical from the SSA, and the controls and Digital LLRF, installed in the lab.


Figure 7: a) Cavity, b) Solid State Amplifier, and c) Controls and Digital LLRF.

Conditioning Results

After installation of the systems, cross checking of cooling and cabling connections, commissioning of the controls and the digital LLRF, the high power RF conditioning started in mid-April.

After a couple of weeks combining pulsed conditioning and continuous power vacuum cleaning, the power of 14 kW was reached, with a very moderate temperature increase on the different hot points of the cavity, demonstrating the proper cooling of the cavity; and reaching a good vacuum, below 1e-8 mbar.

Finally, a three days test of continuous operation at 12.5 kW was performed, as shown in Figure 8.

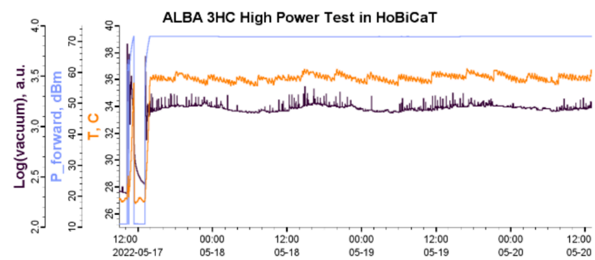

Figure 8: Three days power test. Vacuum level (in log scale), forward power (in dBm), and temperature (at coupler flange) at 12.5kW cw power.

CONCLUSION AND NEXT STEPS: INSTALLATION IN BESSY II

After all the tests performed in the lab, it has been demonstrated that the cavity complies with all the expected requirements in terms of fundamental shunt impedance, HOM damping, and power capability.

So, at the end of May the cavity was moved, and installation in the tunnel started. Figure 9 shows the cavity installed in the tunnel.

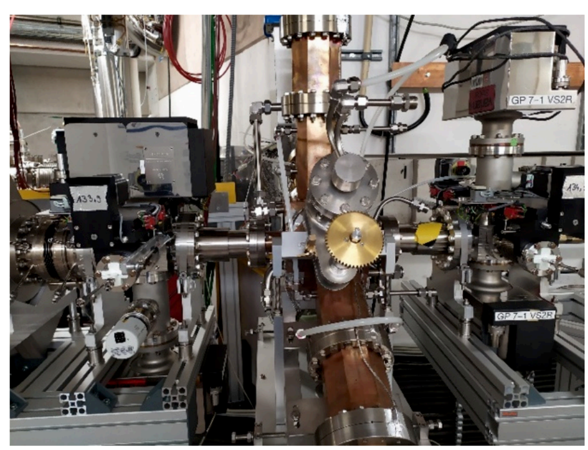
Figure 9: Third harmonic cavity installed in the BESSY II storage ring.

The restart of BESSY II is foreseen in August 2022. Along the month, several tests with beam will be performed in order to demonstrate the feasibility of the 3rd harmonic active RF system for bunch elongation and lifetime increase.

If successful, the cavity may be running in users' operation of BESSY II until the end of 2022.

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