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SUMMARY OF THE COMMISSIONING OF THE ACTIVE HARMONIC EU CAVITY

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Abstract

First results of the the commissioning of the harmonic normal conducting HOM damped active cavity prototype, in the framework of the collaboration agreement signed in 2021 between ALBA, HZB and DESY showed a good performance of the cavity after bead-pull measurements and high power commissioning [1, 2]. The cavity was then installed in the BESSY II ring in summer 2022 to perform tests with beam. In this contribution we present the summary of the first tests with beam of the cavity including HOM damping capability of the cavity, single bunch lengthening and lifetime measurements.

INTRODUCTION

Many synchrotron facilities worldwide are nowadays planing to upgrade their machines towards 4th generation low emittance storage rings [3–5]. In these new facilities, with a very small transversal beam size, the use of harmonic RF systems becomes mandatory to achieve a reasonable beam lifetime and minimize the Touschek effect.

Simple and cost effective normal conducting passive harmonic cavities are nowadays quite common and have demonstrated good performance. Nevertheless, active systems, at the expense of higher complexity and price, can bring many advantages such as providing optimum lengthening in the whole current range, with special focus on single bunch operation. Also, the low level RF control provides more stable fields inside the cavity, thus making it thermally more stable and preventing unwanted plunger movements. Finally, the active system allows to implement dedicated feed-forward or feedback in the LLRF control to be used for instabilities mitigation or Transient Beam Loading compensation [6, 7].

In this contribution we summarize the first tests and results of the active EU harmonic HOM damped normal conductive cavity installed in BESSY II and operating with beam. A more detailed publication of the tests results is to be published soon [8].

HARMONIC EU CAVITY

ALBA has designed a 1.5 GHz normal conducting HOM-damped cavity based on the 500 MHz EU HOM-damped cavity design [9, 10] in order to be used as an active third harmonic RF cavity. In this new design the ferrites have been replaced by transitions to coaxial N-type connectors, named "transdampers" in order to extract the power of the HOMs to external loads [11]. This allows a direct measurement of the HOMs excited by the beam and prevent possible catastrophic failures such as ferrites falling from vertical dampers into the cavity body. Figure 1 shows the prototype during the acceptance tests.

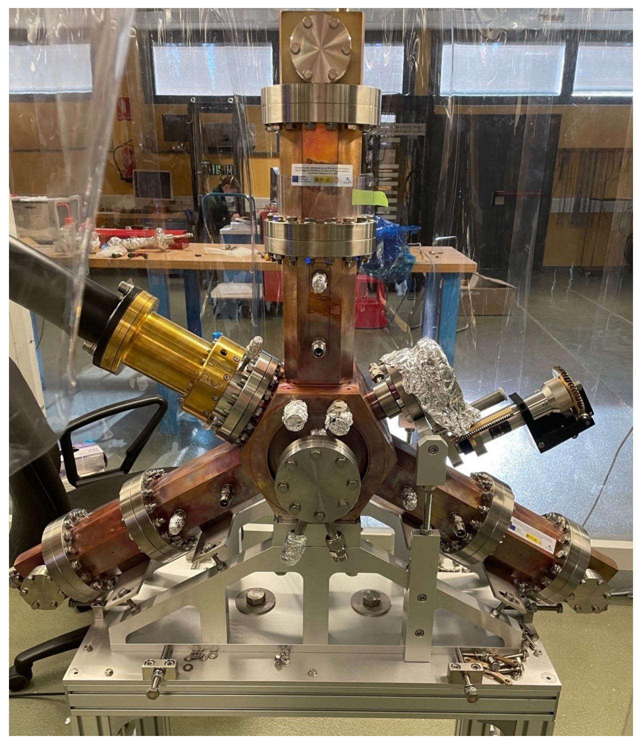

Figure 1: Harmonic EU cavity prototype during the acceptance tests at ALBA.

The body of the cavity is of the pillbox type with nose cones. Three circular ridged waveguides extract the HOMs from the body with a cut-off frequency of 1.72 GHz to avoid damping the fundamental mode. At the end of the waveguides the transdamper takes the HOM power out. Each transdamper consists of a circular ridged waveguide to rectangular waveguide taper and a broadband transition from rectangular waveguide to coaxial using a cone antena and a feedthrough.

RF power is fed to the cavity from an EIA 3-1/8 coaxial line. Two alumina disks hold the inner conductor in place and provide vacuum isolation. A rotatory inductive loop at

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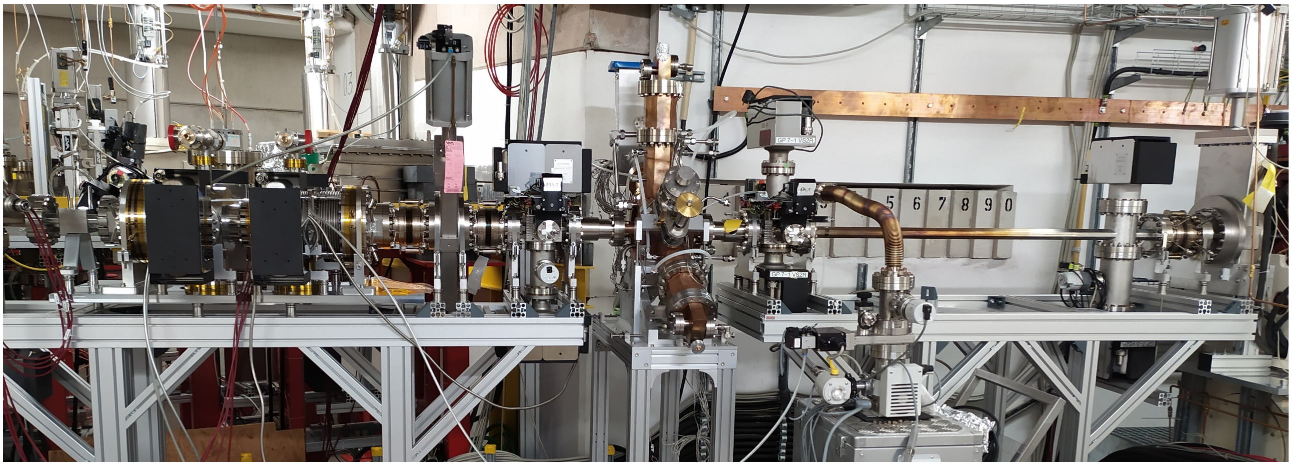

Figure 2: Harmonic EU cavity installed in the BESSY-II storage ring.

the end of the coaxial line couples the power to the cavity body and allows the adjustment of the coupling factor β. Resonant frequency adjustment is done by a 35 mm diameter cylindrical plunger.

Table 1 shows the the main EU harmonic cavity parameters.

Table 1: Harmonic EU Cavity Parameters

Parameter	Value	Unit
Frequency	1.5	GHz
Maximum voltage	200	kV
Shunt impedance	1.1	MΩ
Unloaded quality factor Q_0	14000	-
Tuning range	12.4	MHz

TESTS WITH BEAM

Following the successful lab tests consisting of low power measurements, high power conditioning and bead-pull measurements the cavity was installed in the BESSY II storage ring as shown in Fig. 2. Table 2 shows the the main BESSY II parameters.

Table 2: Main BESSY II Parameters

Parameter	Value	Unit
Frequency	500	MHz
Beam energy	1.7	GeV
Radiation losses	178	keV
Harmonic number	400	-
Main RF voltage	1.2	MV
Maximum current	300	mA

Several tests have been done in order to check the performance of the cavity.

Shunt Impedance

In order to characterize the shunt impedance, the cavity was optimally tuned in the passive mode for different currents in multi-bunch up to 90 mA. The power coming from the high power coupler was measured in the reflected channel of the bidirectional coupler installed close to the cavity and maximized by moving the plunger. Knowing the coupling coefficient, the shunt impedance value can be obtained and is R_S = 1.08 MΩ as shown in Fig. 3. This value is consistent with the one measured during the bead-pull measurement shown in Table 1.

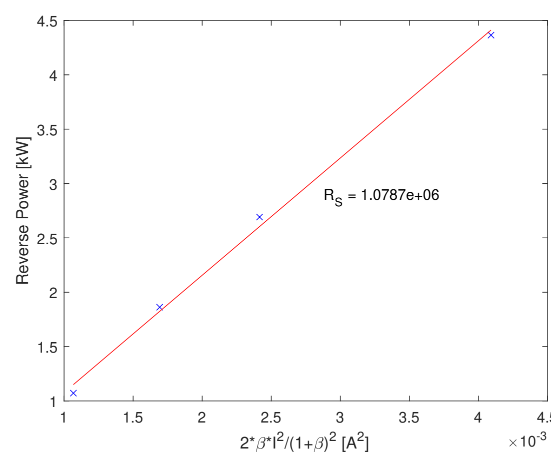

Figure 3: Reflected power signal for different currents and cavity optimally tuned.

HOM Measurements

In order to evaluate the capability of the transdampers to mitigate the HOMs induced by the beam inside the cavity, a single bunch at 1 mA was stored and the spectrum in the pick-up antenna was recorded in two situations: with the transdampers matched with a 50 Ω load and without load, i.e. in open-circuit. In the open-circuit situation the absorbed

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power by the damper arms is reflected back to the body of the cavity, thus eliminating the damping effect.

Figure 4 shows the spectrum in both situations of matched and open-circuit transdampers while the cavity was kept in passive mode, i.e. without external generator power. It is seen that the transdampers are able to significantly attenuate all modes below 3 GHz, while keeping the fundamental mode unperturbed. Specifically, the TM011 at 2.095 GHz quality factor is reduced by more than 90%.

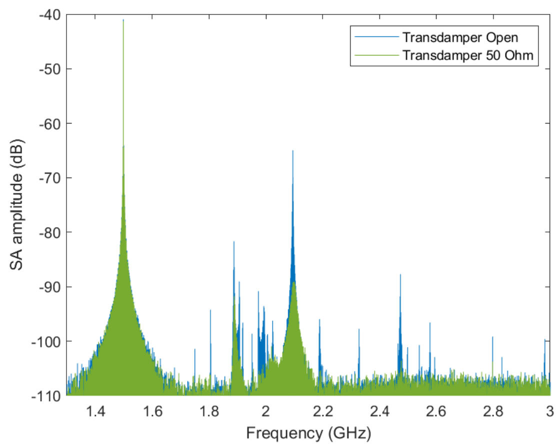

Figure 4: Spectrum of the cavity voltage signal for matched and open-circuit terminated transdampers.

Single Bunch Charge Distribution and Lifetime

4 mA in single bunch was stored and the harmonic voltage swept in order to demonstrate the lengthening capability of the cavity. Since only one harmonic cavity has been installed in the BESSY-II Storage Ring with maximum harmonic voltage of 200 kV, the main RF was set to 450 kV to assure that optimal quartic potential conditions can be achieved with enough margin at 125 kV of harmonic voltage.

The single bunch charge distribution was measured using a high-resolution streak camera and the results are shown in Fig. 5.

Also the current trends for the same single bunch conditions during a fixed period of 100 s were measured in order to confirm the improvement of the Touschek component of the lifetime. Figure 6 shows the current trends and linear fitted beam lifetimes for minimum and maximum harmonic voltage.

From these measurements it can be induced that the beam lifetime Touschek component improvement is higher than a factor 3.

CONCLUSION

The harmonic EU cavity designed by ALBA and commissioned within the framework of the collaboration with HZB and DESY has been successfully commissioned in the BESSY-II ring, demonstrating the lengthening capabilities in the single bunch case and ultimately improving its Touschek associated lifetime.

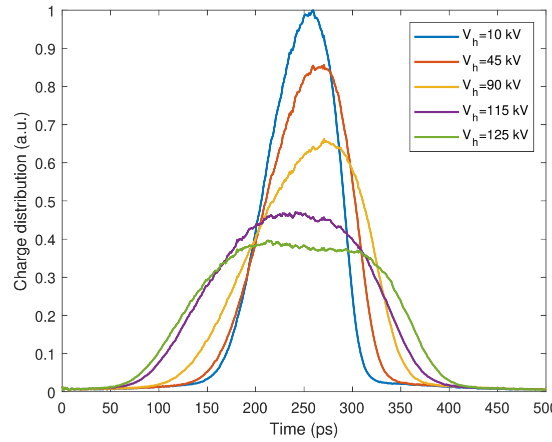

Figure 5: Bunch profiles for different harmonic voltage with main voltage at 450 kV.

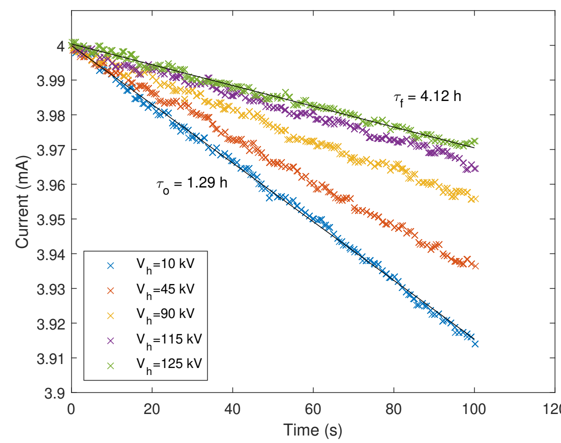

Figure 6: Current trends for different harmonic voltages values with main voltage at 450 kV.

Also some of the main cavity performance aspects have been demonstrated and crosschecked with the analytical and low power measured values, such as the damping capability of the transdampers or the cavity shunt impedance.

Finally, the complete active harmonic RF system, including the 1.5 GHz SSPA, the LLRF control [12] and the associated control and interlock system has been successfully tested.

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