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ESRF-EBS 352 MHz HOM DAMPED RF CAVITIES

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Abstract

For the new ESRF-EBS Storage Ring (SR), HOM damped RF cavities were needed to cope with the reduced thresholds for Longitudinal Coupled Bunch Instabilities (LCBI). The 352 MHz cavities were designed at the ESRF based on an improved version of the 500 MHz EU/ALBA/BESSY structures. A short description of the cavity design will be presented as well as an overview of the fabrication, the preparation and the performance of 13 such cavities for the ESRF-EBS SR. A study of the impedance of a whole cavity equipped with its ancillaries (HOM absorbers, ion pump and tuner) will be presented. One of the three HOM absorbers, the smaller one on top of the cavity, was finally not installed on the machine. The reasons and a detailed analysis in terms of HOM impedances that justifies this choice will be reported.

INTRODUCTION

The design of the HOM damped RF cavities for the ESRF-EBS SR (see Fig. 1) has been detailed in [1]. The major improvement, with respect to the original BESSY/ALBA design, concerns the gaps between the ridges of the HOM dampers and the sleeves of the cavity ports, which lead to unexpected thermal problems [2].

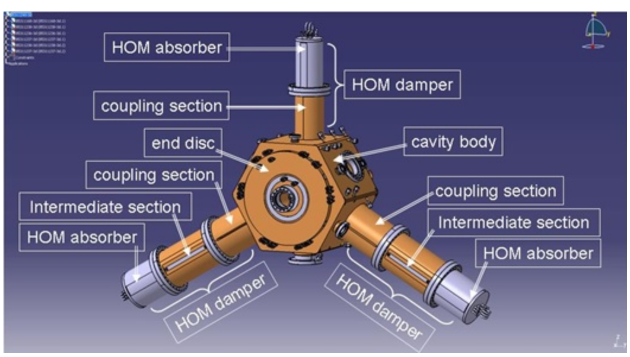

Figure 1: Overview of the main components of the ESR-EBS cavity.

This robust mechanical design together with a protocol ensuring a high quality cleanlinless standard during the production and assemblying phase, allowed excellent performances of the cavities during the whole commissioning phase of the ESRF-EBS SR.

In parallel with the cavity production, we encoutered severe issues in the production of the HOM absorbers. We needed to move to a different design and this obliged us to launch a campaign of studies to refine the characterization of the impedance behavior of these cavities. In particular, at this stage, it has been imperative to verify that the new design was as good as the original one but also to study if the presence of the small absorber on the top of the cavity was really necessary to damp all the unwanted modes.

This latter point is of particular interest, as the HOM absorbers install ferrite tiles brazed on a metallic body. In case of a defective ferrite tile detaching from its support, this tile will fall down directly into the cavity and most probably inside the ion pump. The possibility of removing this small absorber would definitely cancel out this risk.

These studies have been performed using GdfidL, but a parallel approach, using frequency domain tools as HFSS and then a reconstruction technique to derive the impedance, has been implemented to cross-check and to complement GdfidL's results.

In the following, after a brief overview of the cavity performances for the ESRF-EBS SR, a full characterization of the HOM Damped cavities in terms of longitudinal and transverse impedance performances will be described.

COMMISSIONING AND OPERATION

ESRF-EBS cavities have been produced by RI-Research Instruments in Germany. The installation of whole subcomponent has been perfomed at the ESRF followed by one week of bake-out. The preparation of the very first cavity, prior bake-out, needed one month as we had to study how to optimize all the cablings and water pipe connections. For the rest of the cavities we have been able to prepare each cavity between two and three weeks bake-out included. Due to the excellent quality of the RI production and to our assembly procedure ensuring a high quality cleanliness standard we obtained an excellent vacuum behavior at the end of the preparation phase prior RF conditioning ($<10^{-10}$ mbar).

Clean surfaces implies faster RF conditioning: in average, only two weeks to RF conditioning a cavity up to 750 kV.

The excellent behavior of these cavities has been confirmed also during the commissioning phase when we have been able to reach the nominal 6.5 MV in line with the beginning of ESRF-EBS SR commissioning with beam (at a latter stage of the commissioning, lowered to 6 MV to optimize the lifetime). During the whole commissioning period we experienced only a few issues in the mechanics of the tuners. At each time corrective actions have been applied and since then no further problems occured. On the 25th of August 2020 we went back to USM operation. Since then we experienced very few trips mainly related to some "phsysiological" breakdown or pressure activity, immediately recovered [3]. The most severe issue has been an air leak on the coupler of Cav12 in cell 25 that did not impact the operation: the cavity has been put in passive mode and the coupler has been successfully exchanged during the winter shutdown 2020. Since January 2021 the cavity is back in operation.

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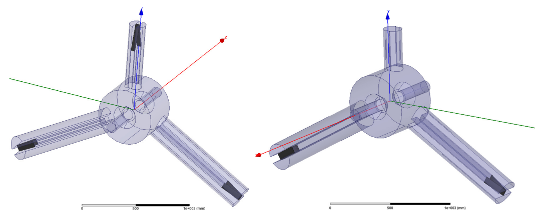
IMPEDANCE STUDIES

An exhaustive description of the impedance behavior of ESRF-EBS HOM Damped cavities can be found here [4].

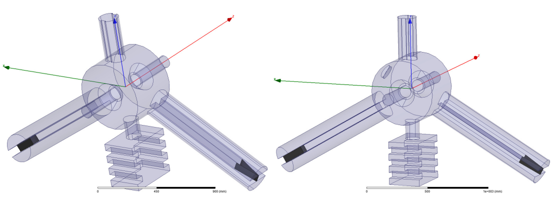
Figure 2 shows the 3D models that have been used in GdfidL to analyze the impact of the removal of the small absorber on the top of the cavity.



(a) All absorbers (b) W/o small absorbers

Figure 2: 3D Models for GdfidL, in brown the ferrite loads.

In absence of the small absorber, it is also important to analyze the structure including the main ancillaries, ion pump (IP) and tuner that may introduce or enhance trapped modes. Figure 3 shows the 3D models used in the simulations.



(a) With IP (b) With IP and tuner

Figure 3: 3D Models for GdfidL including the ancillaries, in brown the ferrite loads.

Longitudinal Impedance

The effect of the removal of the small absorber can be seen in Fig. 4. The absence of the small absorber is fully transparent for frequencies below 1 GHz as expected (cut-off frequency of the coupling section of 1.05 GHz). Above 1 GHz both impedances are not remarkably differing except around 1.18 GHz.

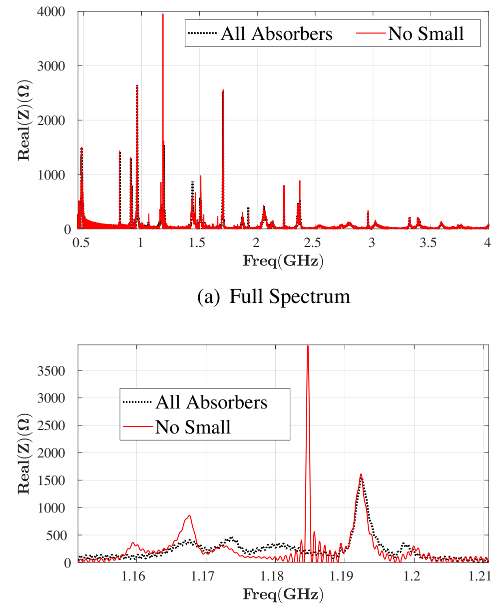
Reconstructed Impedance with HFSS

In parallel with GdfidL, HFSS has been used to evaluate external quality factors (Q_n^{ext}), frequencies (f_n), and loss factors (k_n) of all the modes within the cavity up to 2 GHz[1]. From these quantities, it is possible to reconstruct the wake-potential [5] using the following formula, Eq. (1) [6]:

$$W(z) = 2\sum_n k_n \cos\left(\frac{\omega_n z}{c}\right) \exp\left[-\frac{\omega_n}{2\,Q_n^{\text{ext}}}\frac{z}{c}\right] \qquad (1)$$

where $k_n = \frac{|V_n|^2}{4\,U_n}$ is calculated directly in HFSS, being V_n the voltage on axis of the mode n and U_n its energy, $\omega_n = 2\pi f_n$, c the speed of the light and z the longitudinal coordinate.

[1] Above this frequency we exceeded the available computational resources. However the discrepancies between HFSS and GdfidL results, rely in acceptable limits.



(a) Full Spectrum

(b) Detail

Figure 4: Effect of the removal of the small absorber for the structure in Fig. 2.

This technique allows to complement and validate GdfidL's results. Indeed, being HFSS a frequency domain solver, the ferrite can be easily modeled as a frequency dependent material. In addition external Q's will be directly calculated while in GdfidL, being a time domain solver, one needs a rather long simulation to fully resolve high Q resonances. The results can be seen in Fig. 5 and confirms that a mode at 1.18 GHz pops up, also the mode at around 1.7 GHz is impacted. The effect of the IP and the tuner can be seen in Fig. 6. The effect of the IP is beneficial for the resonance at 1.18 GHz while the tuner does not have a relevant impact. The longitudinal impedance and LCBI thresholds are shown in Fig. 7.

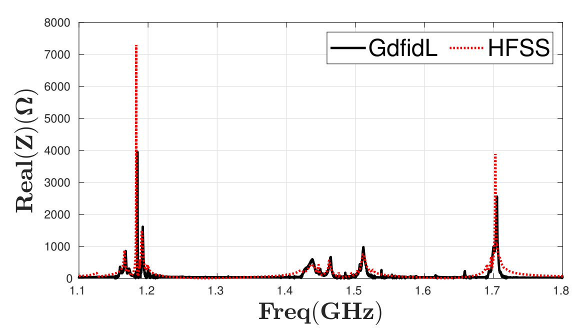


Figure 5: Longitudinal impedance as from GdfidL and HFSS.

Transverse Impedance

The ESRF-EBS SR as well as the former one, is operated with a chromaticity overcompensation and a transverse feed-

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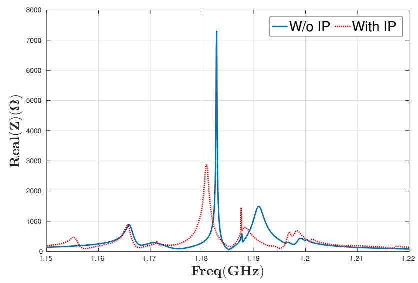
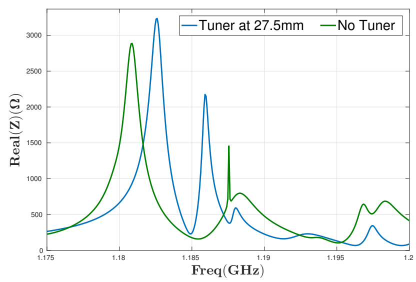


(a) With and w/o IP



(b) With IP and with w/o tuner

Figure 6: Impact of the ancillaries when the small absorber is removed, HFSS reconstructed results.

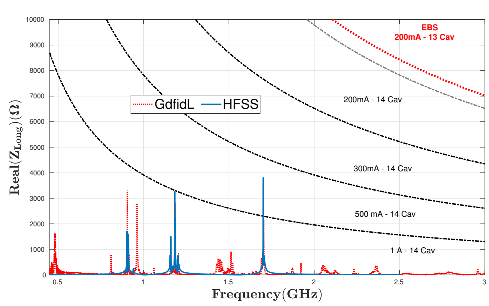


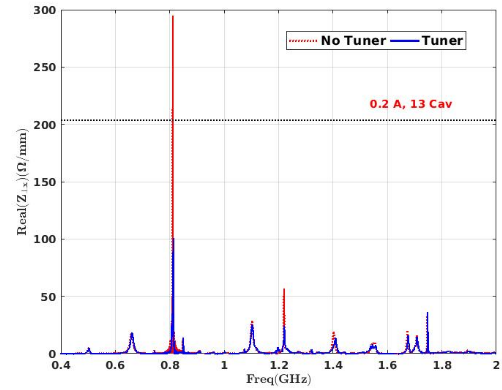
Figure 7: Longitudinal Impedance without the small damper and with all the ancillaries (IP and tuner).

back system is efficiently in use. Since its commissioning, more than 30 years ago, the former SR (which was equipped with 5-cell cavities, LEP type) has never suffered from HOM driven transverse coupled bunch instabilities (TBCI). Nevertheless a characterization of the transverse plane is anyhow welcome also in view of possible further, future upgrades.

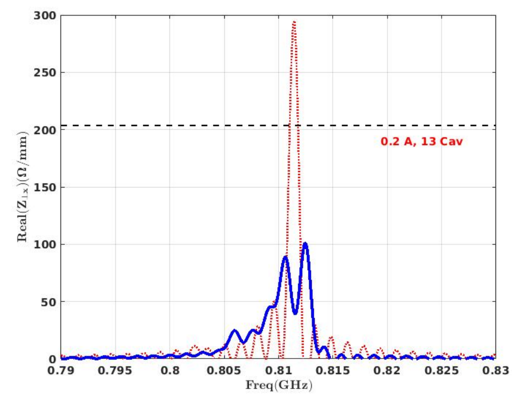
GdfidL results show that only the horizontal plane exceeds the TCBI, see Fig. 8, at about 811 MHz (TM110 mode). But it is also visible that the effect of the tuner at its nominal position is beneficial for this resonance (basically it looks splitting the two polarizations of the TM110). So far we did not experience any transverse instability in the ESRF-EBS SR.

CONCLUSION

The ESRF-EBS cavities have been successfully installed, commissioned and presently operating in USM with a very high reliability. These cavities do not install the small absorber on the top confirming the studies here presented.



(a) Full spectrum



(b) Detail

Figure 8: Transverse horizontal impedance with and w/o tuner.

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