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DESIGN OF HOM COUPLERS FOR SUPERCONDUCTING 400 MHz RF CAVITIES

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Abstract

The Future Circular Collider (FCC) is one possible future successor of the Large Hadron Collider (LHC). The proton-proton collider center-of-mass collision energy is set to 100 TeV with a beam current of 0.5 A. To reach this goal a stable acceleration is critical and therefore higher order modes (HOM) need to be damped. To avoid a high power level in the HOM dampers, further described as couplers, the loaded Q-factor should be below 1000 for the cavity with mounted HOM couplers. Besides a low Q-factor the R/Q value should also be in the range of 1 Ω or below. Two different types of couplers are used to achieve a high damping. The two types are a narrowband Hook-type HOM coupler and a broadband Probe-type HOM coupler. The recent results of the design of the HOM couplers attached to a superconducting 400 MHz RF cavity will be presented.

INTRODUCTION

The RF acceleration section of the proton-proton collider with a length of approx. 1.4 km will consist of 24 single-cell 400 MHz cavities with 2 MV/m or 48 cavities with 1 MV/m [1]. The cavities will be close to the LHC-type TESLA cavities. The cavity used for the RF simulations is shown in Fig. 1 with its parameters summarized in Table 1.

Table 1: Cavity Design Parameters

Design Parameters	Value
resonance frequency	400 MHz
$\beta\lambda/4$ length	160 mm
beam pipe aperture	300 mm
cavity radius	343.6 mm
bend radius outside cavity	25 mm
bend radius inside cavity	104 mm

FCC

The FCC is one possible upgrade of the LHC and will have an approx. 100 km long tunnel. During the runtime of the FCC there will be three phases:

- An electron-positron collider further called FCC-ee.
- A possibly proton-electron collider further called FCC-he.
- A proton-proton collider further called FCC-hh.

The FCC-ee is planned to have four different stages. The first stage is set to produce a high current Z boson beam with 1.4 A. After a run time of 4 years the second stage will run for one year and will involve W bosons. The third stage aims at higgs boson research for 3 years. The last stage contains $t\bar{t}$ reactions with an acceleration voltage of in total 10.9 GV and a current of 5.4 mA for 6 years [2]. During those 14 years the FCC-ee will continually be modified and upgraded. For the ensuing FCC-hh a heavy ion operation is also planned. Further information of the FCC-hh is listed in Table 2.

Figure 1: Hook-type coupler (left) and Probe-type coupler (right)

Table 2: FCC-hh Parameters

Currently Planned Parameters	Value
collision energy cms	100 TeV
dipole field	16 T
circumference	97.75 km
beam current	0.5 A

To avoid coupled bunch instabilities and to have a stable acceleration of the beam HOM couplers are required [3].

HOM COUPLER TYPES

There are several types and ways to design a HOM coupler. This publication will focus on two types of HOM couplers, seen in Fig. 1. The Hook-type coupler is in general a narrowband coupler while the Probe-type coupler is a broadband coupler. The Probe-type coupler is compared to the Hook-type coupler, which is 238 mm high, 10 mm higher. The distance between the Hook-type coupler and the enclosing pipe is 18 mm and between the Probe-type coupler and the enclosing pipe 7.5 mm.

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Figure 2: Cross section along the xy plane of the cavity. The FPC is located at the top and the HOM couplers are located at the bottom.

CURRENT RF RESULTS

The following simulations are realized with the CST Studio Suite. The fully parameterized, used model is shown in Fig. 2 and Fig. 3. It consists of a 400 MHz elliptical cavity, a Fundamental Power Coupler (FPC), one empty pipe for diagnostic elements and four HOM couplers. For the simulation of the S21 parameter a simplified Model was used. The used model has still two HOM couplers, one of each kind, to take the influence of the second coupler into account. Port 2 is located at the back of a HOM coupler and Port 1 at the crossover from the cavity and the beam pipe with the mounted HOM couplers. The results are shown in Fig. 4 for the Hook-type coupler and in Fig. 5 for the Probe-type coupler in the frequency range from 300 MHz to 2 GHz. The relative power injected from the fundamental mode into a HOM coupler is of the order of −60 dB to −70 dB.

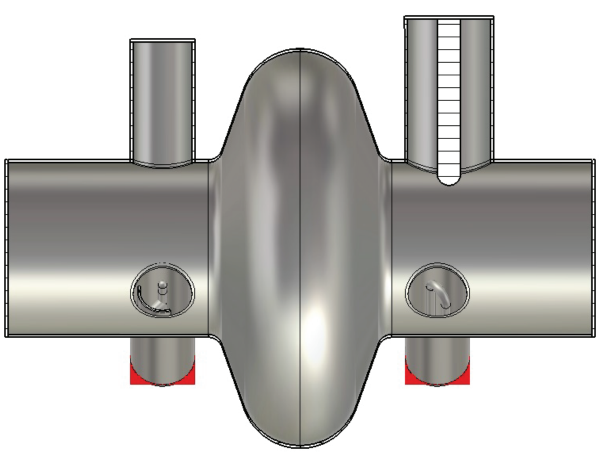

Figure 3: Cross section along the beam axis of the cavity. One of each type of HOM couplers is placed left and right from the cavity.

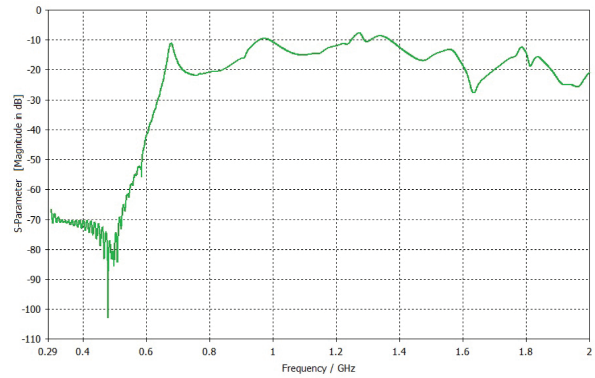

Figure 4: S21 parameter of the Hook-type coupler simulated with the simplified model.

To further study the efficiency of the HOM couplers three more factors are needed. First, the simulation has to determine the loaded quality factor Q_l, which can be calculated with Eq. (1).

$$\frac{1}{Q_l} = \frac{1}{Q_0} + \frac{1}{Q_{ext}} \tag{1}$$

For our simulations it's sufficient to just compute the external quality factor Q_{ext} since $Q_0 \gg Q_{ext}$ and therefore $Q_l \cong Q_{ext}$. To ensure a stable operation of the HOM couplers each one of them should not be loaded with more than 1 kW. The power can be calculated wit Eq. (2), which is a worst case scenario in which every HOM falls onto a multiple of the beam harmonic and the entire beam current excites only this mode [4].

$$P_{HOM} = I_b^2 \frac{R}{Q} Q_l F_n^2 \tag{2}$$

F_n^2 is the frequency-dependent power form factor and I_b^2 the average beam current. Assuming an R/Q value of 1 Ω, Q_{ext} should not exceed a factor of 1000 [5]. The next factor is the shunt impedance R/Q. Should Q_{ext} exceed the factor of 1000 is it important to ensure a low R/Q value of this particular higher order mode. The last factor is the deposited power in the HOM coupler. In the presented simulation the

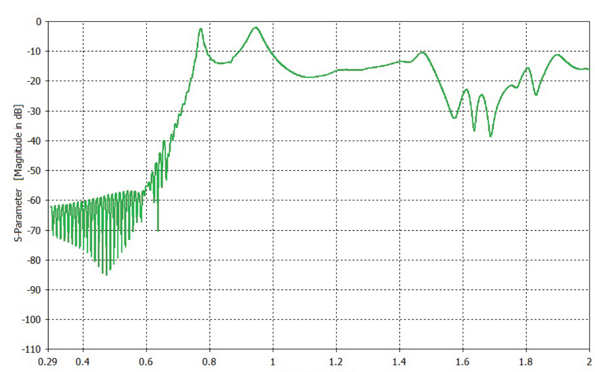

Figure 5: S21 parameter of the Probe-type coupler simulated with the simplified model.

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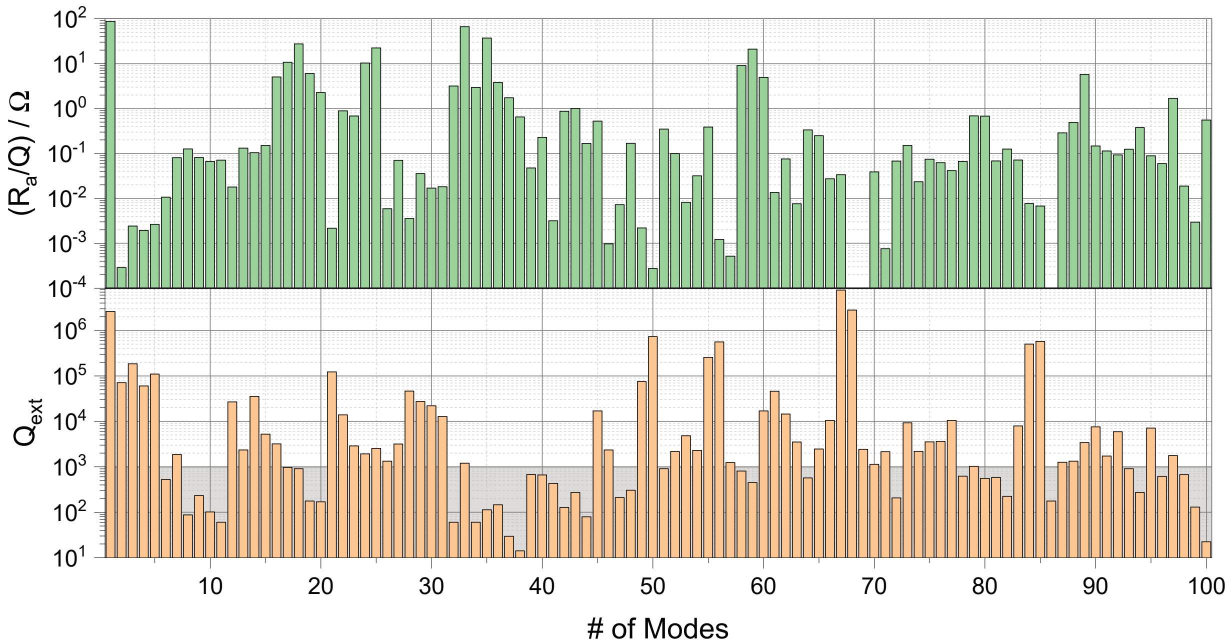

Figure 6: Shunt impedance of the first 100 modes (top) and the corresponding external quality factors (bottom) with the threshold of 1000 plotted in light grey in the background.

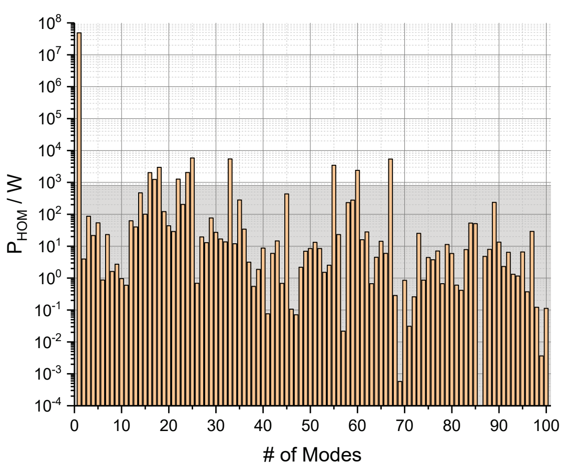

Figure 7: Deposited power in one HOM coupler of the first 100 modes with a threshold of 800 W plotted in light grey in the background.

first 100 modes were calculated with a frequency range from 400 MHz to 1.3 GHz. Figure 6 shows Q_{ext} in comparison to R/Q. Most of the higher order modes have either a low R/Q value or a Q_{ext} value below 1000. For those modes where both cases do not apply the deposited power becomes crucial, which is shown in Fig. 7.

CONCLUSION

Figure 6 shows, that ten modes besides the fundamental mode are above the threshold of 1 kW. One disadvantage of the used model is, that it also simulates non-trapped modes and not only trapped modes inside the cavity. It's a pessimistic model which also simulates improbable resonant modes. None of those 10 modes is a trapped mode inside the cavity, so the expected deposited power is much lower. The current design is sufficient enough to damp higher order modes till 1.3 GHz. To further reduce Q_{ext} some improvements on the model are planned. Also simulations with a higher frequency range are ongoing.

REFERENCES

[1] A. Butterworth, "Options for the FCC Superconducting RF System", FCC week 2018, https://indico.cern.ch/event/656491/contributions/2932243/attachments/1629685/2597142/AB_Options_RF.pdf

[2] M. Benedikt and F. Zimmermann, "Future Circular Collider Study Status and Plans", FCC week 2018, https://indico.cern.ch/event/656491/contributions/2932205/attachments/1628761/2595133/180409_FCC-Amsterdam_Statuspresentation_V2.pdf

[3] D. Angal-Kalinin and L.Vos, "Coupled Bunch Instabilities in the LHC", in *Proc. of EPAC'02*, Paris, France, June 2002, pp. 290–292.

[4] R. Calaga, B. Salvant, "Comments on Crab Cavity HOM Power", CERN, Geneva, Switzerland, CERN ACC note 2015-024, 2015.

[5] Z.T. Zhao, V. Rodel and E. Raebel, "Estimation of the Higher-Order Mode Power in the 400 MHz Superconducting Cavities of the LHC", CERN, Geneva, Switzerland, CERN SL/Note 97-10, 1997.