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FURTHER DESIGNS OF HOM COUPLERS FOR SUPERCONDUCTING 400MHz RF CAVITIES

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Abstract

The Future Circular Collider (FCC) is one possible future successor of the Large Hadron Collider (LHC) at CERN. The proton-proton collider center-of-mass collision energy is set to 100 TeV with a beam current of 0.5 A. To achieve this energy a stable acceleration is critical and therefore higher order modes (HOM) need to be damped. HOM dampers, further characterized as couplers, need to fulfill several criteria to be efficient. As a first property the couplers should assure a longitudinal impedance of higher order modes of below 10 kW. Furthermore, the loaded Q-factor should be below 1000 and the corresponding R/Q value should be in the range of 10 Ω. Besides the Hook-type and Probe-type HOM coupler two additional designs were simulated. The recent results of the different couplers attached to a superconducting 400 MHz RF cavity will be presented.

FCC

The FCC will be equipped with 48 single-cell 400 MHz cavities with 1 MV/m or 24 cavities with 2 MV/m [1]. The cavities used in the approx. 1.4 km long RF acceleration section of the proton-proton collider will be similar to the TESLA-type cavities used in the LHC, summarized in Table 1.

Table 1: FCC-hh and Cavity Design Parameters [2] [3]

Currently planned parameters	Value
circumference	97.75 km
collision energy cms	100 TeV
beam current	0.5 A
dipole field	16 T
resonance frequency	400 MHz
$\beta\lambda/4$ length	160 mm
beam pipe aperture	300 mm
cavity radius	343.6 mm
bend radius inside cavity	104 mm
bend radius outside cavity	25 mm

HOM couplers are required to provide a stable acceleration of the beam and to avoid coupled bunch instabilities [4].

HOM COUPLER TYPES

Besides the Hook-type coupler and the Probe-type coupler this publication will introduce two new types of coupler, seen in Fig. 1. The new types of coupler are based on the principle of a high-pass filter and a band-stop filter.

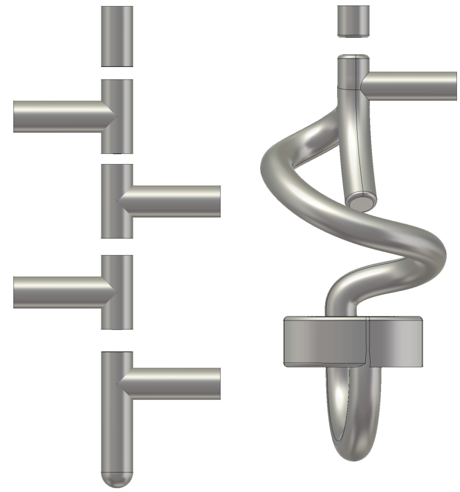

Figure 1: high-pass coupler (left) and band-stop coupler (right).

CURRENT RF RESULTS

The simulations consist of a 400 MHz elliptical cavity, four HOM couplers, a Fundamental Power Coupler (FPC) and one empty pipe for diagnostic elements and are made with CST Studio Suite. The full model is shown in Fig. 2 and Fig. 3. A more simplified Model was designed for the simulation of the S21 parameter. The used model was equipped with only one HOM coupler to avoid

Figure 2: Cross section along the xy plane of the cavity. The angular coordinate of the HOM couplers was optimized and differs from the left to the right side of the cavity.

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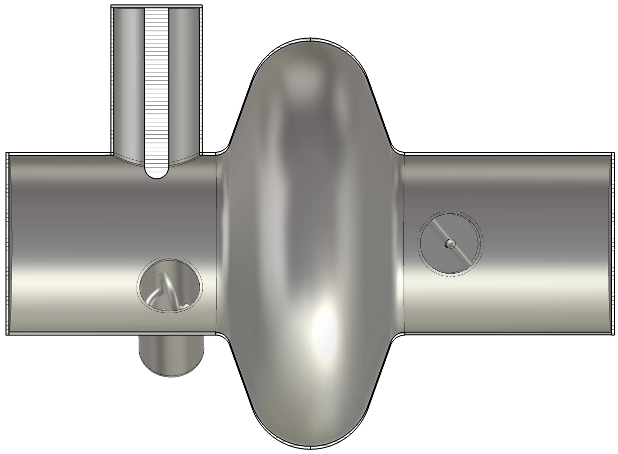

Figure 3: Cross section along the beam axis of the cavity. Besides the fundamental power coupler on the left side one of each new type of HOM couplers is placed left and right from the cavity.

the influence of the second coupler. Port 1 is located at the crossover from the cavity and the beam pipe with the mounted HOM couplers and Port 2 at the back of a HOM coupler. The results are shown in Fig. 4 for the Band-stop-type coupler and in Fig. 5 for the High-pass-type coupler in the frequency range from 300 MHz to 3 GHz. The relative power injected from the fundamental mode into a HOM coupler is of the order of −50 dB to −80 dB. To examine the efficiency of the new HOM coupler-types the simulation needs to calculate the loaded quality factor Q_l, which can be determined with Eq. (1).

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

It's sufficient to compute the external quality factor Q_{ext} since $Q_0 \gg Q_{ext}$ and therefore $Q_l \cong Q_{ext}$. To provide a stable operation the HOM couplers should assure a longitudinal impedance of below 10 kΩ [5]. The impedance can be

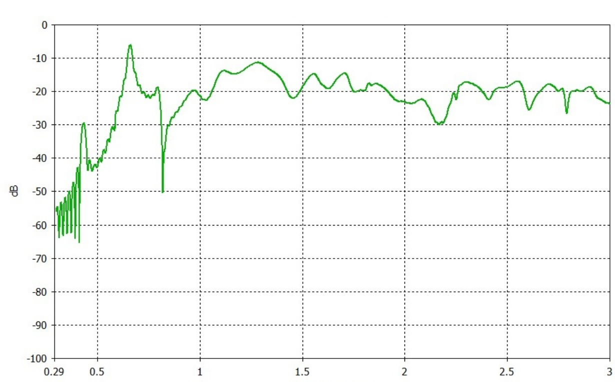

Figure 4: S21 parameter of the Band-stop-type coupler simulated with the simplified model.

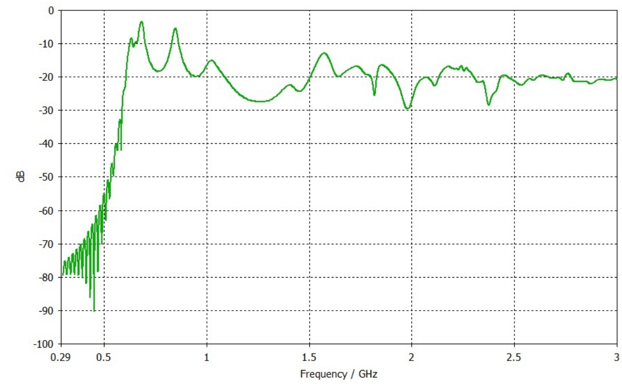

Figure 5: S21 parameter of the high-pass-type coupler simulated with the simplified model.

calculated wit Eq. (2).

$$R = \frac{U_a^2}{P} = \frac{R}{Q} Q_{ext} \tag{2}$$

Q_{ext} should not surpass a factor of 1000 considering a R/Q value of 10 Ω. In the presented simulation 200 modes were calculated with a frequency range from 400 MHz to 1.65 GHz. 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 impedance becomes essential, which is shown in Fig. 6. Figure 7 shows R/Q in comparison to Q_{ext}.

CONCLUSION

Besides the fundamental mode 26 out of 200 modes are above the threshold of 10 kΩ, as shown in Fig. 6. With the established optimized HOM coupler design only 15 modes are above the threshold. The model used in the simulation is a pessimistic model which also simulates improbable resonant modes, therefore not only trapped modes inside the cavity are simulated but also non-trapped modes. The current designs are sufficient enough to damp higher order modes till 1.65 GHz. Studies to find the most efficient combination of

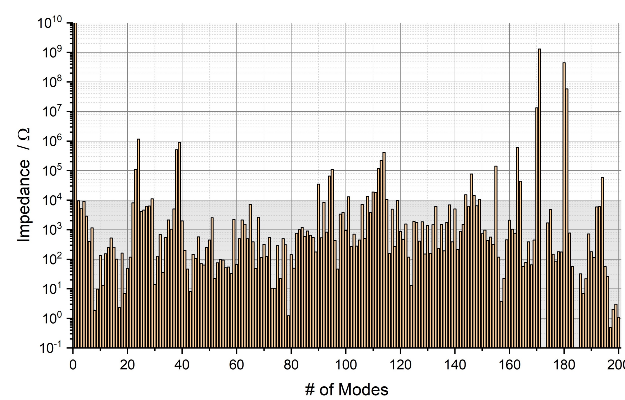

Figure 6: Longitudinal impedance of the first 200 modes with a threshold of 10 kΩ plotted in light grey in the background.

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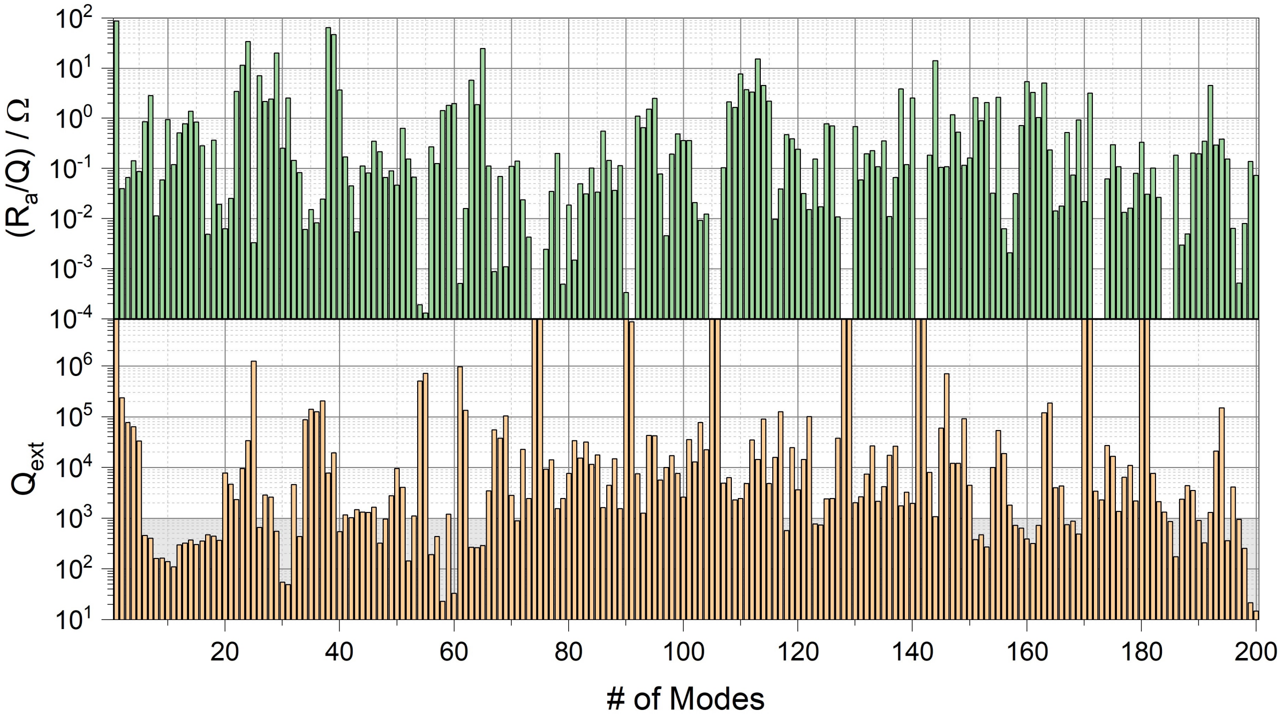

Figure 7: External quality factors (bottom) with the threshold of 1000 plotted in light grey in the background and the corresponding Shunt impedance of the first 200 modes (top).

the four designs are planned. Also simulations with three cavities in a row are ongoing to examine non-trapped modes further and to rule out improbable resonant modes.

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