HOM COUPLERS FOR CERN SPL CAVITIES*

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Abstract

Higher-Order-Modes (HOMs) may affect beam stability and refrigeration requirements of superconducting proton linacs such as the SPL, which is studied at CERN as the driver for future neutrino facilities. In order to limit beam-induced HOM effects, CERN considers the use of HOM couplers on the cut-off tubes of the 5-cell superconducting cavities. These couplers consist of resonant antennas shaped as loops or probes, which are designed to couple to modes of a specific frequency range. In this paper the design process is presented and a comparison is made between various design options for the medium and high-beta SPL cavities, both operating at 704.4 MHz. The RF characteristics and thermal behaviour of the various designs are discussed.

INTRODUCTION

The SPL [1] is a R&D project at CERN with the focus on neutrino or radioactive beam facilities. The SC linac is composed of two types of cavities operating at 704.4 MHz in pulsed mode and with geometrical β of 0.65 and 1 [2].

As for SNS and ESS, extensive studies were done with respect to HOMs and their impact on the performance of the cavities [3, 4]. In spite of the experience of SNS[1], the use of HOM dampers is considered necessary because of the large variety of beam patterns to be accelerated in this machine. The design goal of the HOM filter is to block the transmission of the accelerating mode, while transmitting HOMs, which have significant (R/Q) values.

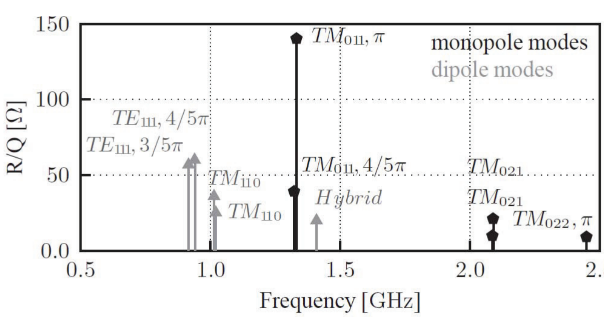

Figure 1: HOMs with the highest (R/Q) for the high beta cavity (maximum value in the covered velocity range [3]).

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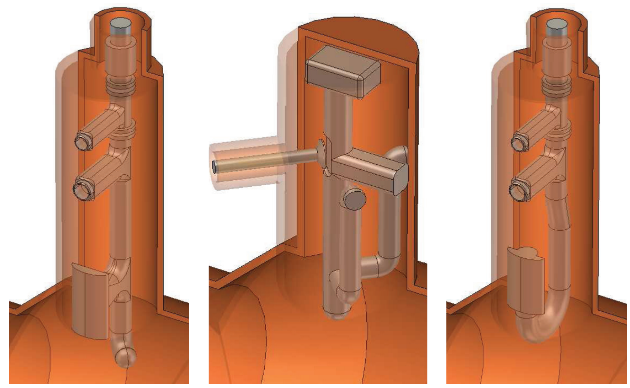
[1] Too large power coupling through several HOM ports, vacuum leaks at feedthroughs of the coupler and problems with multipacting [5].



(a) (b) (c)

Figure 2: Design approaches of HOM coupler: a) probe coupler, b) modified TESLA design, c) hook coupler [6].

The primary focus in finding an appropriate design lies in the RF transmission behaviour, which has to be optimized according to the operating frequency (high damping) and the HOM spectrum (low damping) of the cavities (Figure 1). Besides this issue the multipacting sensitivity and resulting heat loss play a very crucial role because they can seriously affect the accelerator operation. Finally, the complexity of the mechanical design as well as the tolerances are limited to keep the costs at a reasonable level. The currently favoured designs shown in Figure 2 feature very different advantages and disadvantages such as good monopole coupling, dipole coupling, robustness and tunability, which are discussed in the following.

RF OPTIMIZATION

For analysing and optimizing each coupler design, simplified replacement circuit models were used (Figure 3). Capacities and inductances are determined with respect to

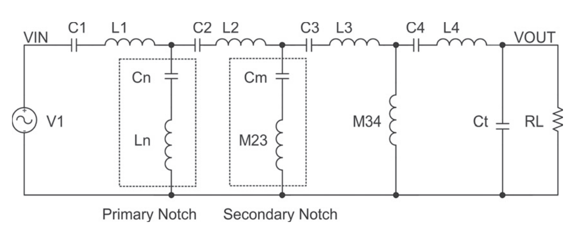


Figure 3: Replacement circuit model for the electric coupling of the probe design (a). Two notches result in a higher notch bandwidth.

HOM spectra [3] and afterwards synthetized to a coupler model using transmission line theory [7].

This approximation is then refined using 3D simulations with CST MWS® and HFSS™. For analysing the pure transmission characteristic, only the HOM tube with the coupler was considered for the simulation. The bottom side of the tube terminated with a waveguide port, excites monopole as well as dipole modes, whereas the TEM mode is excited on the coaxial output. Basically two S-Parameters are of interest: The TM_{01}-TEM transmission describing monopole coupling and the TE_{11}-TEM transmission to investigate the dipole coupling. The results for the RF optimized couplers in the high β case are shown in Figure 4.

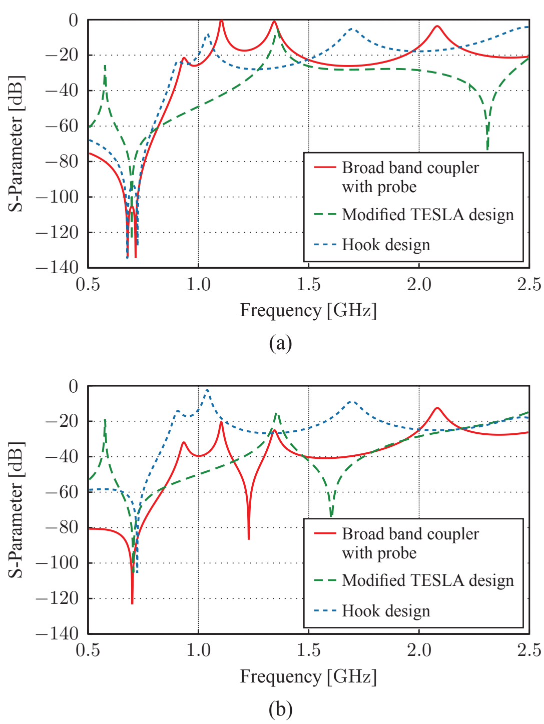


Figure 4: S_{21} of the couplers. a) TM_{01}-TEM transmission (monopole coupling), b) TE_{11}-TEM transmission for the most favourable polarization (dipole coupling).

The probe and hook design feature a relative large bandwidth for the notch filter at 704.4 MHz caused by a second inductive post to the feedthrough [8] (Figure 2 and 3) . The modified TESLA design has a very narrowband notch filter, which is however much easier to tune.

Moreover the hook design shows a good dipole coupling (especially for the first dipole band at $\sim$ 900 MHz) and might be an interesting option for circular machines. But for a linear machine such as the SPL, dipole HOMs are considered less problematic. Hence, we focus on monopole modes in the following.

According to the HOM spectra of the cavities [3] the hook coupler and even a simpler version without a second inductive post is more eligible for the medium β case. The same is true for the TESLA design. This is due the fact that monopole HOMs are located at a higher frequency region between $1.5 - 1.8$ GHz instead of at 1.3 GHz for the high β cavity (Figure 1).

Mechanical restrictions for the Tesla design makes it more difficult to optimize the coupler for the HOM spectrum of the high β cavities rather than for the HOM spectrum of the medium β cavities. The use of a flange and its relatively long distance to the beam pipe (46 mm) together with a small tube diameter (45 mm) limits the potential of optimizing the transmission properties in the high β case.

On the other hand the classical TESLA design [6, 8], which is easier to construct than the version shown in Figure 2 is already good enough for the medium β cavity. The probe design is the best option for the high β cavity.

MECHANICAL ISSUES

The couplers shown in Figure 2 are already redesigned with respect to mechanical aspects such as tolerances, limited diameter of the coupler posts as well as tuning possibilities. Furthermore an inner circuit to provide the flow of liquid helium at 2 K is considered as shown in Figure 5. However it is not yet decided whether active cooling is really necessary.

The TESLA design has the advantage of a closed loop

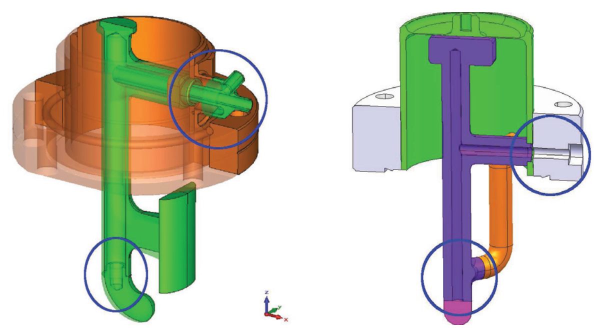


Figure 5: Mechanical sketch including the cooling circuit. Parts of the cooling circuits are emphasized.

for the liquid helium because of its shape whereas both the hook and probe coupler require a double walled inner conducter. In general the latter mentioned designs are more expensive to fabricate.

A further problem of the hook and probe design is the acentric position of the main post, which is a result of the small tube diameter. Due to the cool-down process and the associated contraction of the coupler, the minimum feasible tolerance for the distance of the capacitive plate to the tube wall is $\sim \pm 0.2$ mm. Since the notch frequency is extremely sensitive to this distance a double notch was introduced [8] as seen in Figure 3 and 4 a) to increase the bandwidth of the notch filter and thereby to relax tolerances. Tuning can be applied by modifying the position of the upper post, which affects the secondary notch, hence the overall notch characteristic.

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In case of the TESLA design the notch filter is adjustable by pulling and pushing the upper plate of the pick-up tube, which affects the notch capacity directly. A tolerance of ± 0.02 mm, which is necessary for the narrowband notch is therefore reachable.

HEAT LOSS INVESTIGATION

The power dissipation has different causes such as surface resistance, multipacting and field emission. This section is focused solely on heat generation due to the surface resistance.

The simulations are performed with HFSS™ for the computation of the surface loss density coupled with ANSYS® to compute afterwards the thermal behaviour and the heat transfer on the coupler surface.

The surface resistance for bulk niobium can be assumed with ~ 50 nΩ related to the temperature (2 K), RRR (300) and frequency including the residual resistance [9, 10]. Nevertheless a value of 200 nΩ is used for simulations as a worst case scenario. Even for this case the surface loss and heat generation are extremely low as shown in Figure 6. A temperature increase of around 2 K is not enough to get a higher surface resistance than 200 nΩ. In addition,

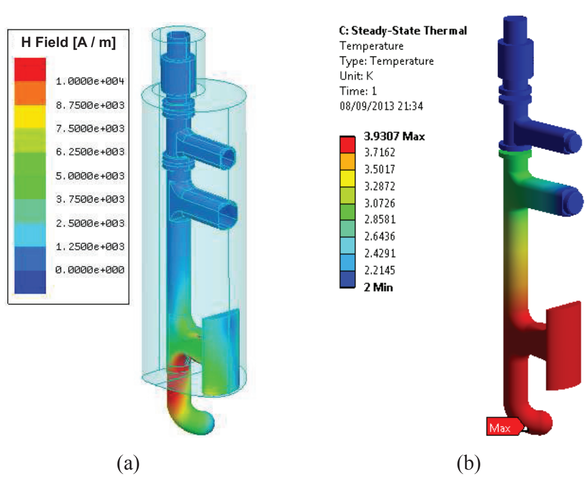

Figure 6: a) H-field as indicator for surface loss density. b) Resulting temperature distribution (coupler assumed as bulk niobium [11, 12], feedthroughs are fixed to 2 K).

the results are applied to CW mode (cavities for SPL operate in pulse mode with a duty cycle of 4%). The results are summarized in table 1.

Table 1: Surface Loss and Temperature Increase

Part	Overall surf. loss [W]	T_{max} [K]
Probe design	$10.1 \cdot 10^{-3}$	3.93
TESLA design	$12.8 \cdot 10^{-3}$	2.84
Hook design	$10.0 \cdot 10^{-3}$	4.08
Flange	$< 1 \cdot 10^{-4}$	2.01
Coupler tube	$11.5 \cdot 10^{-3}$	2.08
Cavity Cell	101.5	2.89

CONCLUSIONS

Three designs of HOM coupler for the SPL cavities have been analysed and designed with respect to RF transmission characteristics, mechanical limitations as well as aspects of heat load.

The monopole HOM spectrum of the high β cavity is best handled by the probe coupler, which is characterised by higher bandwidth as well as steeper slope between stop band and pass band in comparison to the TESLA design. However the hook and the TESLA designs and even simpler mechanical versions of these are sufficient for the monopole HOM spectrum of the medium β cavities.

The power dissipation caused by the surface resistance does not constitute a problem for the cryo design even without active cooling. It is expected that the main part of heat loss is a result of multipacting, which will be in the focus of further studies.

The results of previous studies for ESS [6, 8] have exhibited that designs as the hook coupler are in general more sensitive to multipacting only because of the capacitive plate closed to the beam pipe. Further studies will show whether it is necessary to remove this plate.

OUTLOOK

In parallel to multipacting studies two prototypes for the probe and TESLA design will be fabricated for doing first tests on a 5-cell high-beta copper cavity at room temperature.

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