HOM COUPLER OPTIMISATION FOR THE SUPERCONDUCTING RF CAVITIES IN ESS

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Abstract

The European Spallation Source (ESS) will be the world's most powerful next generation neutron source. It consists of a linear accelerator, target, and instruments for neutron experiments. The linac is designed to accelerate protons to a final energy of 2.5 GeV, with an average design beam power of 5 MW, for collision with a target used to produce a high neutron flux.

A section of the linac will contain Superconducting RF (SCRF) cavities designed at 704 MHz. Beam induced HOMs in these cavities may drive the beam unstable and increase the cryogenic load, therefore HOM couplers are installed to provide sufficient damping. Previous studies have shown that these couplers are susceptible to multipacting, a resonant process which can absorb RF power and lead to heating effects.

This paper will show how a coupler suffering from multipacting has been redesigned to limit this effect. Optimisation of the RF damping is also discussed.

INTRODUCTION

The European Spallation Source (ESS) [1], currently in an Accelerator Design Update (ADU) stage, will be the world's most powerful next generation neutron source. It is designed to accelerate proton bunches to a final energy of 2.5 GeV for collision with a target designed to produce a large neutron flux for several instrument beamlines.

The time structure requires 2.86 ms long bunch trains with a repetition rate of 14 Hz, and a bunch population such that the average beam power on target is 5 MW.

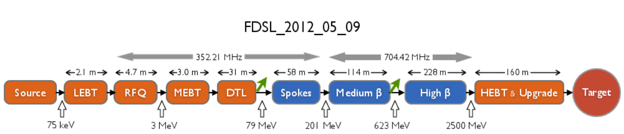

Figure 1: Schematic layout of the ESS accelerator.

The accelerator is a single pass linac without an accumulator ring is shown in Figure 1 and consists of several acceleration technologies.

The beam is accelerated to 50 MeV using normal conducting technology, and then on to the final energy of 2.5 GeV using superconducting RF (SRF) technology – spoke resonators, and two families of elliptical cavities shown in blue.

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A 100 m High Energy Beam Transport (HEBT) then transports the beam to the target.

It has been observed [2] in the Superconducting (SC) linac of the Spallation Neutron Source (SNS) that couplers installed to remove the Higher Order Mode (HOM) power excited by the beam have been the source of many problems, and the evidence points to field emission (FE) and multipactor (MP) as the primary causes of these issues [3].

One concern is that a MP region will develop for a particular accelerating gradient, causing the quality factor, Q, of the cavity to drop below the desired level. Alternatively, MP causing large amounts of energy being lost in the walls of the coupler leading to thermally deformormation, thus leading to a detuning of the notch. Another concern is that arcing in the coupler can cause the HOM filter to short and therefore removing the bandstop filter. Such detuning or arcing may lead to excessive amounts of the fundamental mode being coupled out of the cavity, thus dropping the Q, and risking damage to the HOM monitoring electronics.

Previously, two designs were considered for the HOM coupler. Both act as a filter with a 'notch' at the frequency of the accelerating mode. Previous MP studies [4] were performed on both couplers in order to determine their susceptibility to resonant trajectories.

SIMULATIONS

A FEM code was used for this study [5]. The MP studies were performed as before using Omega3P to calculate the drive fields and Track3P for tracking particles though the fields in order to determine MP zones.

In order to study the transmission properties of the coupler, the S-parameter module S3P is used. The coupler is mounted on a beam pipe taper with a TM01 mode excited at the end of each beam pipe and a TEM mode excited at the coaxial output.

RESULTS

Re-scaled TESLA Design

The re-scaled TESLA design [6] showed MP regions on the flat surfaces of the inner conductor that were closest to the outer wall, in particular at the top where the size is increased and also between the wall and the bottom leg. The first modification involved rounding the majority of these flat surfaces. Once re-tuned, the coupler was joined to a cavity and particles are emitted from the coupler outer surface and tracked for 20 RF cycles to search for resonant tra-

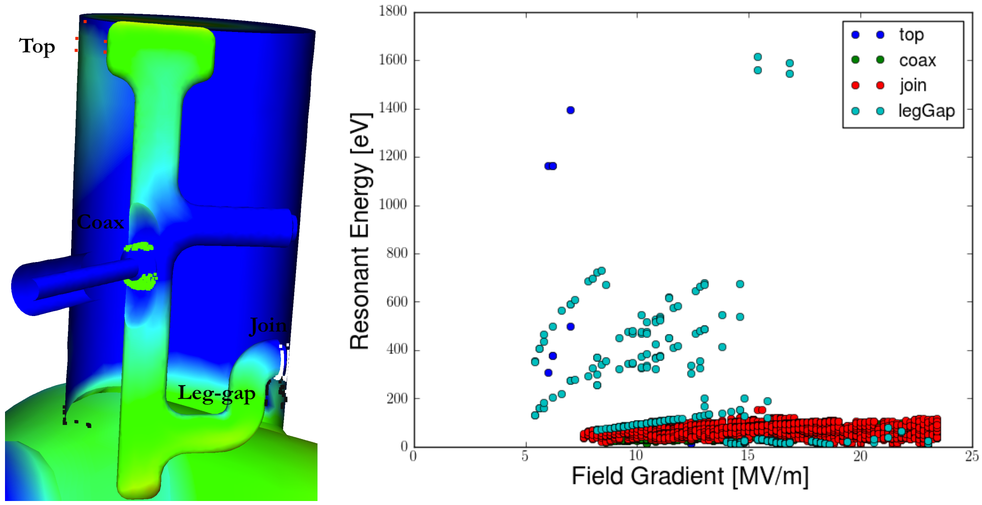

Figure 2: Location of resonant impacts of TESLA design (left) and the resonant energy of the particles at different field gradients.

jectories at different field gradients. The results are shown in Figure 2.

The removal of flat surfaces resulted in a large drop in resonant trajectories at the top of the coupler where less than 1 % of the trajectories were in this region.

A majority of the trajectories were between the outer wall of the coupler and the bottom leg joint which involves a 90° step. In further iterations this join was smoothed which easily suppressed persistent trajectories.

Trajectories also existed at the feedthrough which was to be expected due to capacitive coupling here. The feed though plate was replaced with a concave surface to help minimise resonant trajectories.

The most problematic region was between the outer wall and the bottom leg just below the joint. Although the number of trajectories is lower than at the join, removing these is much trickier. Solutions would be to reduce the radius of the leg further however making it more difficult to tune notch back or remove the bend in the this leg thereby changing the transmission properties.

The main focus for optimising the transmission properties was for the S21 to rise as steeply as possible after the notch in order to damp the first dipole band which typically starts at 900 MHz. Modifying the existing geometry had small changes on this rise and it was determined the rotation with respect to the cavity seem to have the largest effect. In order to increase the damping at lower frequencies, the bandwidth of the notch must be reduced and therefore the size of minimum electric field at the feedthrough. Figure 3 shows the final design where the magnitude of the electric field is larger as compared to Figure 2 and therefore resonances are more likely at the end of feedthrough plate.

It may be possible to improve the transmission further by adding additional elements to the geometry but it is highly desired to keep the coupler design simple and small. A simple method to improve the transmission properties would be to change the diameter of the coupler however the couplers were designed with a dimensional constraint of 50 mm for the diameter.

"Hook" Design

The Rostock design [7] suffered from a severe MP band at low field gradients between the large capacitive plate and the outer wall of the coupler. Initially, ridges were added to the plate in order to suppress the resonant trajectories and simulations showed some improvement however it was decided that removing the plate was a better option.

In order to keep the notch at 704 MHz, the loss of capacitance due to removal of the plated need to be accounted for elsewhere. The simplest method is to increase the radius of the hook. However this places the hook very close to the outer wall and thus, making the transmission very sensitive to errors.

Adding an extra inductive post to the feedthrough results in a double-notch effect as used in a BNL design [8]. This effectively increases the bandwidth reducing sensitivity. The position of the inductive post resulting in two inductive posts either side of the capacitive element also improves the high pass filter properties of the coupler resulting in the transmission curve rising much faster allowing better damping of the first dipole band which typically starts at 900 MHz. The final design is shown in Figure 4.

Comparison

Modification to both the TESLA style and the hook style coupler show a reduction in resonant MP trajectories which may lead to problems. A comparison of their transmission properties is shown in Figure 5 where the dashed line represents the location of the accelerating mode. The modified hook design appears to be the more desirable coupler

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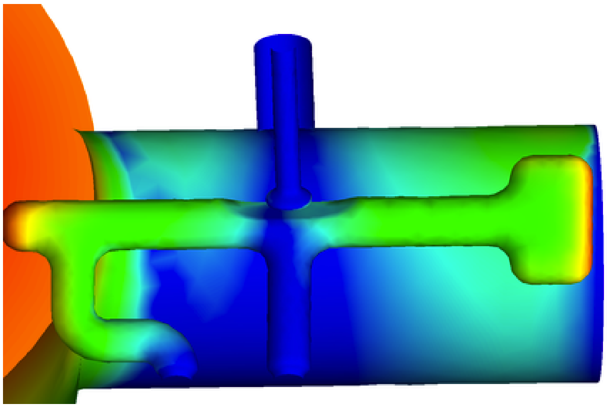

Figure 3: Redesigned TESLA coupler showing electric fields excited at 704 MHz.

due to its wider effective bandwidth provided by the double notch with the transmission remaining below -80 dB for ± 50 MHz around the accelerating mode. Therefore, a massive shift in the notch position would be required for problems to occur such as power from the accelerating mode being coupled out.

The hook design also provides higher damping at lower frequencies. One disadvantage is that this design is more susceptible to vibration resonances due to its single connection to the outer wall by one post however the advantage of this is that with no fixed point lower down, the coupler can be demounted from the cavity. Further optimization is necessary to provide easier tunability of the coupler and improve the mechanical properties.

The rescaled TESLA design is stiffer due to its welded joints and also easier to cool with the two legs providing a closed loop to pass liquid helium through.

SUMMARY

Two possible HOM couplers have been redesigned by improving their transmission properties and simultaneously reducing susceptibility to multipacting. While the initial studies favoured the rescaled TESLA design, after optimisation the hook design has the preferred transmission properties. The hook design is much less affected by resonant trajectories due to its simpler design. It also has the added advantage that if problems do occur it is demountable.

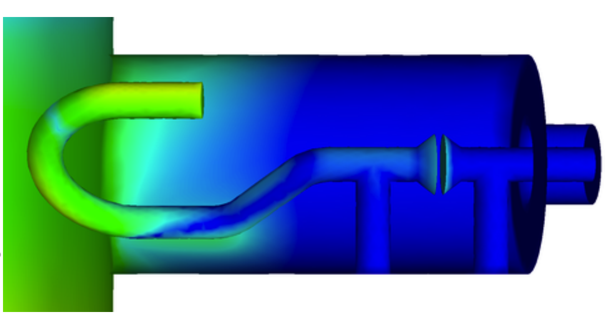

Figure 4: Redesigned hook coupler without plate showing electric fields excited at 704 MHz.

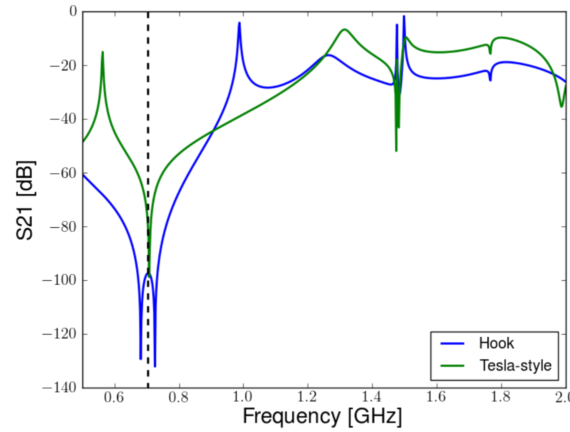

Figure 5: The S21 for both couplers as excited by a TM01 mode.

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