MULTIPACTING ANALYSIS FOR THE SUPERCONDUCTING RF CAVITY HOM COUPLERS IN ESS

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Abstract

The European Spallation Source (ESS) linac will consist of three families of superconducting RF cavities to accelerate protons to the required 5 MW for collision with the target. If it is determined that HOM damping is required to limit the effect of beam induced modes, it is quite likely that HOM couplers will be installed. Multipacting in these couplers is a concern as thermally induced detuning of the fundamental notch filter has limited the achievable gradient in other high power machines. It is therefore important to avoid potential multipacting conditions during the design phase. Presented here are simulations using the Track3P code developed at SLAC. Multipacting regions are highlighted, electron trajectories are shown, and suitability of the proposed HOM coupler design is 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, and is designed to accelerate bunches of protons 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 an average current of 50 mA, with a repetition rate of 14 Hz, and a duty factor of 4%. To achieve the 5 MW beam power, the bunches will be 2.86 ms long.
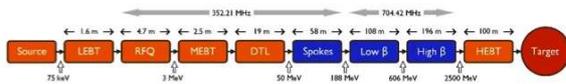

Figure 1: Schematic layout of the ESS accelerator.

The accelerator is a single pass linac without an accumulator ring, and – as shown in Figure 1 – 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.

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, or for the amount of energy being lost in the walls of the coupler to cause it to thermally deform, thus leading to a detuning of the notch. Such detuning 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.

PROPOSED DESIGNS

Currently, there are two alternatives under consideration for the HOM coupler, shown in Figure 2. Each relies on the capacitive and inductive effects caused by the geometry to produce a 'notch' in the transmission of the coupler at the frequency of the accelerating mode. This prevents the Q of the this mode dropping significantly by the addition of these couplers, and protects any downstream electrical components from damage due to the very high RF power in this field.

The left coupler shown in Figure 2 is a rescaling [4] of the design proposed [5] for the TESLA SC cavities. The right coupler shows an alternative proposal [6] involving a SC hook and capacitive plate.
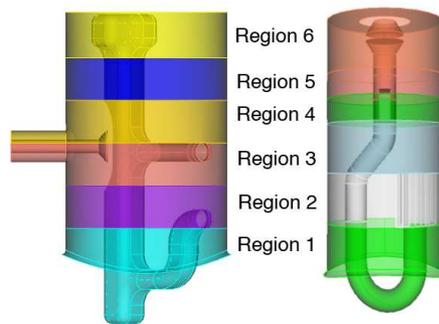

Figure 2: Left, Geometry of a coupler design generated by rescaling of a TESLA-style coupler. Right, Geometry of the alternative design. The regions indicated relate to simulation domains used in their analysis.

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SIMULATIONS

In order to make a decision on which, if any, of these couplers should be installed on the ESS cavities, there are many aspects of their performance to take into account (e.g. the frequency dependence of their scattering parameter matrix, ease of contruction, installation, tuning, etc.). This paper concentrates only on studies of their MP performance.

The code used for this study was the ACE3P electromagnetic simulation suite [7]. The initial step was to use the Omega3P eigensolver module to determine the field distribution and frequency of the fundamental accelerating mode, through which to track the FE electrons. The second step is to use the Track3P module to release electrons from various points on the surface of the coupler, and to track their subsequent motion throughout the volume of the body.

The electrons were released every 3.6° for one cycle of the accelerating mode, and then tracked for a further 19 cycles. Electrons that hit a conducting surface were immediately re-emitted if the collision occurred at a phase of the RF where the electrical field vector was directed towards the surface. Collisions at the opposite phase or with a beam pipe surface "killed" the electron.

The couplers were split into regions, which were simulated in series, and then combined during postprocessing. This takes advantage of the fact that the CPU requirements had a scaling with the number of particles that was stronger than linear, and so splitting the simulation into multiple, serial, domains, allowed the run to complete in a shorter time.

During the simulation, Track3P causes at most one electron to be released after each collision, which is not sufficient to fully model the avalanche condition of MP. To correct this, a postprocessing step is performed, which uses a Secondary Electron Yield (SEY) curve to determine the magnitude of the resonant process. The SEY curve is defined as the average number of electrons emitted due to a collision by an electron of a certain energy. For these simulations, a typical SEY curve for niobium was used [8].

The Track3P simulation was repeated for a range of accelerating voltages up to 25 MV/m (note that the design loaded gradient of these cavities is 18 MV/m).

RESULTS

Re-scaled TESLA Design

Figure 3 shows the impact energies of the resonant trajectories recorded in the Track3P simulation, where the regions identified in the legend correspond to those shown in Figure 2.

When this is scaled by the SEY data, the so-called "enhanced counter function" shown in Figure 4 is obtained. Note that this normalised by the total initial charge.
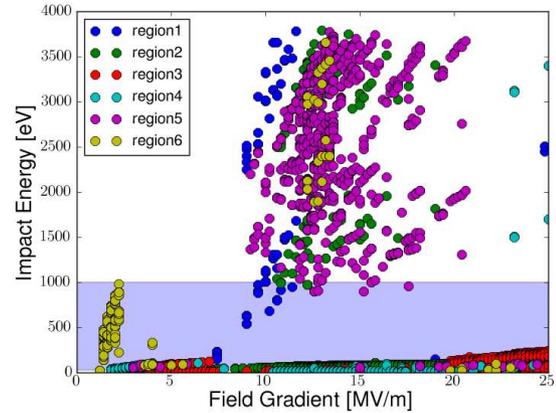

Figure 3: Impact energy of each electron vs the gradient of the accelerating field within the cavity.

Alternative "Hook & Plate" Design

Figure 5 shows the impact energies of the resonant trajectories for the alternative design, and it can be see that the number of such trajectories is considerably lower than that shown in Figure 3.

The enhanced counter function for this design, shown in Figure 6, shows a very large MP band at low field gradient. Figure 5 indicates that this is related to resonant trajectories forming between the large capacitive plate and the nearby wall of the vacuum chamber.

Comparison

Figure 7 shows a comparison between the two coupler simulated. Note that the values of the enhanced counter function were normalised by the total amount of charge emitted at the start of the simulation.

It should also be noted that the alternative design has a large MP band at low field gradient that may cause se-
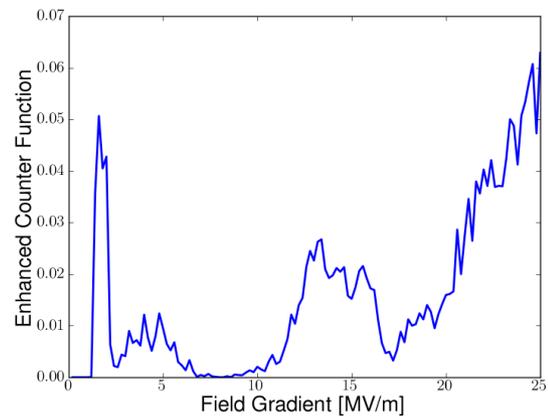

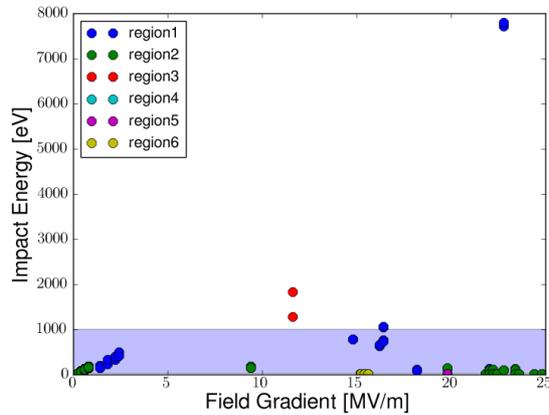Figure 4: "Enhanced counter function" for Tesla-style design.

Figure 5: Impact energy of each electron vs the gradient of the accelerating field within the cavity.

Figure 7: Comparison of the behaviour of the two couplers after normalisation by the total charge emitted during the simulation.

vere problems in ramping up the cavity to full voltage. Although the peaks of the TESLA-style coupler are significantly lower, they extend across a broader range of gradients, and so may reduce the Q across the full range of voltages.

It is expected that alterations to the coupler geometry could be performed in light of these results, however it is thought to be more difficult to remove the large, low gradient, MP band in the alternative design due to the necessity of the large capacitive plate.

DISCUSSION

Although the results of the previous sections indicate that the rescaled TESLA style coupler shown in Figure 2 may be a safer choice for the ESS SC cavities, there are several reasons to be cautious about drawing this conclusion.
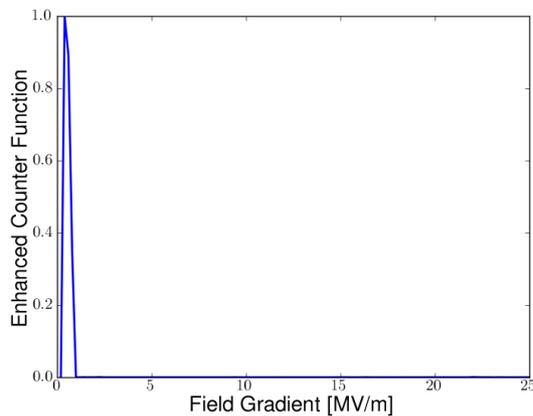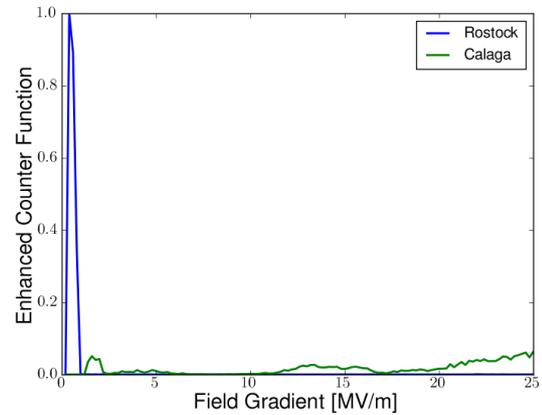
Firstly, it is important to note that there are some assumptions used in Track3P that may strongly affect the results. Of major concern is the fact that the electrons are always emitted normally to the emitting surface, instead of using a statistical range of emisson angles. Such a range may cause resonant trajectories to be diluted by the non-zero chance than an emitted electron will not return to the initial site.

In addition, there is also the issue of whether or not it is possible to "process through" the MP barriers by using the RF to reduce the strength of the emitting sites on the surface of the cavity. If this is possible, then this has the potential to reverse the recommendation tentatively stated at the beginning of this section.

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Figure 6: "Enhanced counter function" for alternative "Hook & Plate" design.