

MULTIPACTOR SIMULATIONS OF THE SPL POWER COUPLER

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Abstract

Multipactor is a major factor in many RF power couplers, causing long processing times that can be difficult for large machines. The SPL coupler is proposed to have a conical matching section between the window and the coaxial section however this section must be checked for multipactor. Multipactor simulations of the coupler up to a few MW's of power were performed using a variety of different codes and the results were compared. Simulations were performed in the conical and straight coaxial sections.

SPL COUPLER

The Superconducting Proton Linac (SPL) is a proposed part of the upgraded LHC injector chain. It takes protons from Linac4 and will accelerate these to 4/5 GeV [1]. The protons will be accelerated using superconducting cavities operating at a frequency of 704.4 MHz. To achieve the expected gradient of 19-25 MV/m the cavities require a pulsed input power of 1000 kW for 2 ms pulses at 50 Hz, giving an average power of 100 kW. This leads to many issues that need to be addressed in the input power coupler, one of which is multipactor [2]. Multipactor is a resonant electron phenomenon related to secondary electron emission, where the electron motion is coupled to the RF fields in the coupler. This can lead to exponential growth in electrons causing coupler damage and impedance mismatch. Many power couplers are prone to multipactor and many studies have been performed on multipactor in straight coaxial waveguides. A common method of suppressing multipactor is to apply a DC bias voltage between the inner and outer conductors of the coaxial waveguide and will be studied in future.

In this paper we concentrate on the SPL-LHC air cooled cylindrical window design. This design has a conical outer coaxial section between the window and the coaxial waveguide. It was suspected that this section could cause multipactor problems and this was to be investigated.

MULTIPACTOR IN COAXIAL WAVEGUIDE

The coaxial waveguide is to be 50 Ω with an outer diameter of 103 mm. As an initial benchmark, multipactor was studied in straight coaxial waveguide using three separate codes which were then compared. The three codes used were RKpactor [3], CST Studio Suite - Particle Studio [4, 5], and Multipac [6].

RKpactor is a flexible Fortran code written at Lancaster University and optimised for identifying multipactor trajectories. It tracks one particle at a time with high

accuracy in pre-defined RF fields. This code can use imported fields or use analytically described fields. Analytically described fields were used for the straight multipactor calculations, where as imported fields from CST studio suite were used for the full coupler with the conical coaxial section. A 4th order Runge-Kutta algorithm is then used to track the particles in this field. The secondary emission yield (SEY) function follows the Gopinath description [7] and a peak yield of 1.6 was chosen for these simulations. The multipactor order is different for each band, the first order multipactor occurring at a power of around 8.5 MW and the band at powers just below 1 MW (close to the SPL operating power) is 9th order. The ninth order resonant trajectory in the straight 50 Ω coaxial waveguide carrying 1 MW of forward power is shown in Figure 1. As can be seen the multipactor does not impact on the inner conductor and there are nine field reversals before the electron impacts back at the outer conductor. There is also a small drift of the trajectory along the waveguide (not shown in figure). Multipactor is identified in the code by the number of secondaries produced for a persistent (resonant) trajectory and growth of the electron current. If these reach user defined values a multipactor 'event' is recorded and the number of phases that give events is plotted versus power.

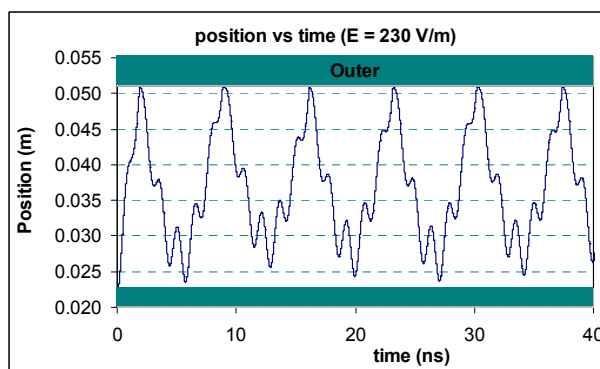


Figure 1: Electron position versus time generated in RKpactor for an inner surface electric field of 230 V/m.

In Particle studio the RF fields are initially solved using Microwave studio [4] which is also part of the CST studio suite, a high mesh is used (4 Million cells over one wavelength) in order to obtain sufficiently accurate surface fields. These fields are then imported into the tracking solver. In the tracking solver, electrons emitted from the walls at an instant in time are tracked in the RF fields ignoring the fields of the particles themselves. When an electron hits a wall the secondary emission and scattered electrons are calculated from the method

described by Furman and Pivi [8]. The secondary electrons are then also tracked in the fields allowing the number of electrons to increase or decrease with time depending on the trajectories and electron impact energy.

In the simulation the electrons are launched along the outer conductor such that electrons are launched at every accelerating phase. Around 90 electrons are launched initially so that the phase difference between electrons is around 2 degrees. The secondary emission of copper [8] is used with the peak SEY reduced to 1.6 to account for clean surfaces.

In order to ascertain if multipactor has occurred or not we record the average secondary emission yield <SEY> over the simulation. This is calculated by dividing the total number of secondary electrons created in the simulation by the number of electrons that impact of the walls of the simulation. If multipactor occurs this number will be larger than 1.0 signifying that more than one secondary is produced on average for every electron impact and the number of electrons is increasing in time.

The results for travelling waves show several distinct multipactor bands at various power levels in both codes which are in excellent agreement, as can be seen in Figure 2 and Table 1. The CST results also show a consistent multipactor between 50 kW and 1.5 MW with a curve similar to the SEY curve. This does not appear in the RKpactor results and indeed [2]. This peaks at a power level of around 500 kW, where the electric field on the outer conductor is about 170 kV/m. As the peak SEY for copper occurs at an impact energy of 250 eV, this surface electric field could accelerate an electron to this energy over 1.5 mm which is similar to the mesh size hence this effect may be mesh related and needs to be investigated further.

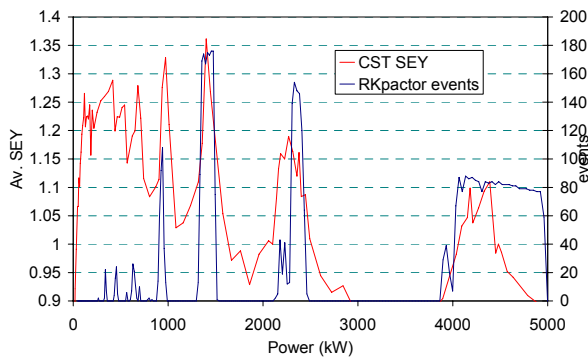


Figure 2: Comparison of multipactor in straight coaxial line predicted by CST and RKpactor. CST is plotted against <SEY> and RKpactor is plotted against ‘events’ for various peak powers.

Table 1. Multipactor Bands power levels predicted from CST and RK pactor

Multipactor Band Power (kW)	
CST	RKpactor
120	NA
170	NA
200	260
290	340
420	460
540	560
620	630
700	700
970	940
1400	1420
2270	2330
4380	4130

MULTIPACTOR IN CONICAL COAXIAL LINE

It was considered that the conical coaxial outer conductor may cause the multipacting bands seen in the straight coaxial line to spread out causing multipactor at almost all power levels. In simulations however it was found that the angle of the outer conductor, and hence the surface electric field, caused the electrons to drift upwards. The typical electron trajectories can be seen in Figure 3.

2D simulations were performed in Multipac approximating the fields in the coupler with artificial boundary conditions. The simulations in CST and RKpactor were full 3D simulations. The fields in conical coax section were found to be asymmetric due to the impedance matching in the rectangular to coaxial transition section so 3D simulations are likely to be important.

However it was found that at the top of the cone there is a small step down to a smaller outer radius before the cylindrical window. This step creates a tight corner which electric field lines connecting both sides. Simulations in CST and in Multipac suggest that a two-point multipactor can occur in this region as can be seen in Figure 4 and 5. Multipactor trajectories found by RKpactor in this region are not reliable due to poor positional accuracy of fields in the CST external output file dump arising partly from a requirement to limit file sizes to 10 GB.

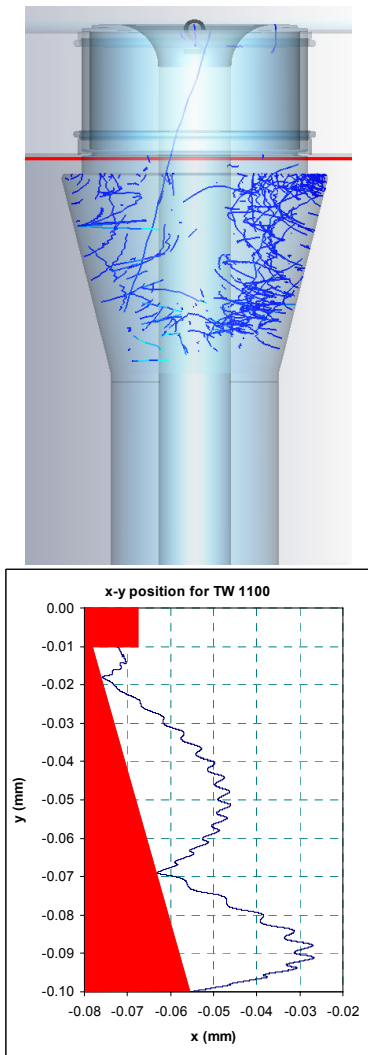


Figure 3: Electron trajectories in the conical coaxial section as visualised in a) CST and b) RKpactor.

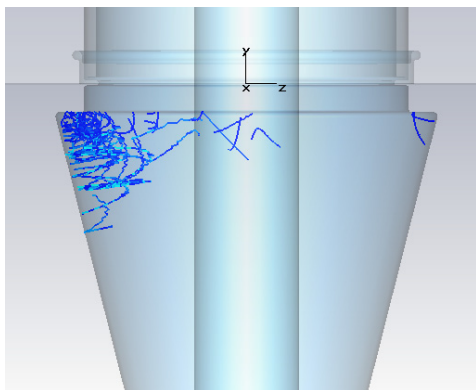


Figure 4: Plot of multipacting trajectories in the corner of the conical section simulated in CST.

a)

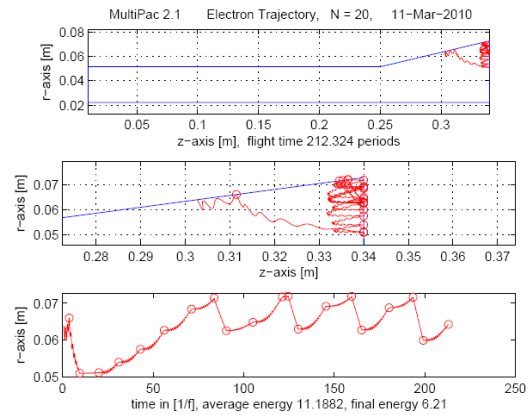


Figure 5: Simulation of Multipactor in the corner section of the cone from Multipac.

b)

CONCLUSION

Multipactor has been studied in coaxial waveguide as a benchmark for future multipactor simulations of the SPL power coupler.

RKpactor was found to accurately predict multipactor bands were an accurate field pattern could be obtained, however for large complex geometries such as power couplers the importation of fields needs to be improved.

CST was found to accurately find all multipactor bands predicted by the other codes, however seems to find spurious multipactor when the voltage across a single cell is around the peak impact energy for the SEY curve.

Multipac also accurately predicted multipactor however was only able to do 2D simulations in this study.

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