Meshing Challenges in Simulating the Induced Currents in Vacuum Phototriode

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Abstract

Vacuum phototriodes (VPT) have been used as photodetectors for many years in particle physics experiments. For example, they were used in the OPAL experiment at LEP and are currently used in the endcap Electromagnetic Calorimeter of the CMS experiment, at CERN's Large Hadron Collider. Existing VPTs are fast, low-gain devices that are able to operate in strong magnetic fields at angles up to approximately 40 degrees from the axis of cylindrical symmetry. Photoelectrons are released from the photocathode and are accelerated through a fine metal anode mesh (array of squares holes) to a solid dynode. The dynode generates secondary electrons which are accelerated and collected at the anode.

We have simulated a commercial VPT structure using COMSOL Multiphysics®. The model includes a very fine, thin anode mesh with a 10 μm pitch and 50% transparency. The electron trajectories and induced currents on the anode are modelled using the electrostatics and charged particle tracing interfaces within COMSOL Multiphysics® . The electrostatics interface was used to simulate the electric field within the VPT with cathode, anode and dynode potentials of 0 V, +1000 V and +800 V respectively. These are the maximum operating potentials for a commercial device used in the CMS experiment, which is simulated. The charged particle tracing interface is used to generate the electron trajectories and enables us to determine the time-dependent currents with and without an external magnetic field applied. The secondary emission feature within COMSOL Multiphysics® is also used to simulate the secondary emission particles created upon collision of the primary particles with the dynode. These are accelerated back towards the anode, some of which may pass through the anode and turn around to repeat their trajectory. For the final stage, probes are used within the model to analyse the findings of the simulations. A parameter of critical practical importance is the induced current on the anode. This is calculated using Ramo's theorem with an appropriate weighting potential. The current is calculated automatically at each time step.

Numerous challenges were encountered, the most difficult is to apply a finite element mesh within COMSOL Multiphysics® of the VPT. The main issue being the many orders of magnitude difference in scale between the VPT electrode diameter of approximately 20 mm and the fine anode mesh with a thickness of 2.5 micrometres. Over 8.5 million domain elements are produced and each of which is typically a factor of one hundred to one thousand times smaller than the separation of the electrodes or their surface areas. This created issues of inverted boundary at corners, problems with the minimum element size and issues with memory utilisation and computation time. The results presented here used a PC with a four-core (plus hyperthreading) Intel i7 processor and 48 Gbytes of RAM.

This paper discusses the simulation challenges, the steps to enable a realistic area of mesh to be simulated and finally we present results on the induced current as a function of time for a device operating in magnetic fields up to 4T in strength.

Figures used in the abstract

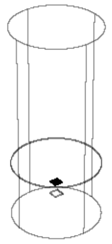

Figure 1: Vacuum Phototriode Particle Trajectory