MEASUREMENTS OF THE LONGITUDINAL ENERGY DISTRIBUTION OF LOW ENERGY ELECTRONS*

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Abstract

The Transverse Energy Spread Spectrometer (TESS) is an ASTeC experiment designed to measure the energy of electrons from different cathode materials. It is a dedicated test stand for future light sources. A full particle tracking code has been developed in the QUASAR Group, which simulates particle trajectories through TESS. Using this code it is possible to simulate different operational conditions of the experiment and cathode materials. The simulation results can then be benchmarked against experimental data to test the validity of the emission and beam transport model. Within this paper, results from simulation studies are presented and compared against experimental data as a collaboration within the Cockcroft Institute between ASTeC and the QUASAR Group for the case of measuring the longitudinal velocity distribution of electrons emitted from a gallium arsenide cathode using a grid structure as an energy filter.

INTRODUCTION

Sources of cold electron beams are highly desirable for many accelerator applications such as free electron lasers, electron diffraction experiments and electron scattering experiments [1-3]. The emittance of an electron beam, both longitudinal and transverse, measured from a cathode can be understood in terms of the photon energy which excited it, the spot size of the laser on the cathode surface, the material composition of the photocathode, i.e. the electronic band structure and affinity, and the temperature of the cathode. However, as a result of many complicated processes, such as those found within the cathode and the cathode-vacuum interface and include effects due to electron and phonon scattering, surface roughness, surface diffraction etc, the process of electron emission is not fully understood and several studies have been performed to understand it [4-5]. One such experiment investigating electron emission for accelerator purposes is TESS [6-7].

TESS

TESS is designed to measure the energy of electrons emitted from a photocathode under conditions that allow the study of beam emittance without perturbing effects which can lead to emittance growth in an accelerator, for example space charge and effects from radiofrequency acceleration.

A cathode [8] is inserted using a load lock mechanism into TESS and electrons are emitted from the cathode when illuminated by a laser which is incident on the cathode at a grazing angle. The laser spot size on the cathode surface has been measured in a diagnostics section on a virtual cathode to be less than 100 μm. The cathode material of choice for commissioning experiments was gallium arsenide; however other materials, such as metals, are being considered for the future. The electrons are extracted at a low current in the fA regime so space charge effects between emitted electrons are negligible. The electrons from the cathode which is kept at negative potential are accelerated towards three consecutive gold plated grids, photo-etched from a tungsten sheet 35 μm thick and with a pitch size of 500 μm. For longitudinal measurements one of the grids is used to create a retarding field, stopping electrons which do not have sufficient energy to overcome the potential. Once the electrons pass through the grids they are detected by a combination of a two stage multi-channel plate (MCP), a phosphor screen and a 14 bit CCD camera. A mu-metal shield is placed around the cathode and detector to block external magnetic fields for example from the earth.

COMSOL MODEL AND SIMULINK CODE

A code [9], previously used for beam dynamics studies for various accelerators and setups [10] has been adapted to simulate the TESS experiment with different fields applied to the structures (cathode, grids, MCP, etc.) and alternative initial velocity distribution from the cathode. As the electrons are travelling at low velocities, the electric fields need to be known in great detail; in the case of TESS the most complicated region to understand is around the grid structures. Initially an analytical solution was attempted but it was not possible to extract an exact solution for a single grid. With three grids it becomes even more difficult to find an accurate analytical solution, particularly in the wire regions, and so this approach was dropped. The fields were calculated using the finite

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element method with geometry built up in the Comsol Multiphysics package [11].

The geometry of the three dimensional model of TESS built in Comsol is shown in Fig. 1. The geometrical model consists of outer shielding, cathode, MCP and three grid plates. Also shown, is an inset of a zoomed in part of the grid cells. For field calculations a limited number of cells were used that to represent a full grid requiring less computing power and time. Convergence studies investigating the impact of computational accuracy as a function of grid cell number showed that a 7x7 grid cell structure gave the best balance between accuracy and efficiency. To improve tracking time, further a two dimensional axial symmetric model was used for tracking in the drift region from the cathode to the grids.

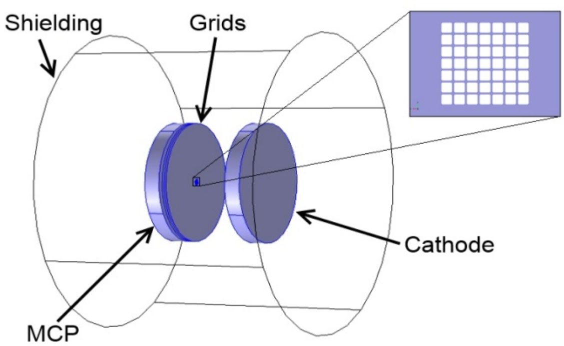

Figure 1: Three dimensional geometrical model of TESS built in Comsol. Inset shows the 7x7 grid structure.

The particle tracking was performed using Matlab-Simulink [12]. The initial particle position is generated on the x-y face on the cathode face where z=0 and is randomly generated to form a normally distributed initial position profile with spot size 40 µm FWHM. The initial velocity distributions are calculated using results of the initial energy distributions determined from TESS [6]. The initial energy distribution N(E_i) corresponds to a Boltzmann distribution of the form:

$$N(E_i) = A \cdot e^{\left(-\frac{E_i}{kT}\right)}$$

Where kT is the mean transverse energy and A is the number of particles with zero initial energy. On this basis one can calculate the initial velocity distribution. When simulating the case of working with a 532 nm laser a value of 100 meV was used and for a 635 nm laser 50 meV was used.

The particles are then tracked through the drift region between the cathode and the grids using calculated fields exported from Comsol to Matlab. Two sets of data are exported, the first is from the two dimensional model and covers a wide distance to just short of the grid structure, the second is from the three dimensional model just before the grid region to the MCP face. As the fields were calculated for a small number of cells, and the TESS grids have many more cells, only the field data between 10 mm before the grid 1 central cell and 10 mm after the grid 3 central cell was exported. As the fields were calculated for a small number of grid cells the field data for the central cell was used for all cells. When the electrons reaches this region, if its position aligns with the metal grid then the velocity of the electron is set to zero and will remain there for the rest of the simulation. Those particles that make it through are accelerated to the MCP where similarly the electrons are set to rest.

LONGITUDINAL MEASUREMENTS

To perform longitudinal measurements with TESS, a grid is used as a retarding potential to stop electrons that have insufficient energy crossing the barrier and reaching the MCP. All the accelerating potential is supplied by the cathode potential and is high enough to limit the transverse component of the beam so that it produces a clear image of the whole distribution on the CCD camera.

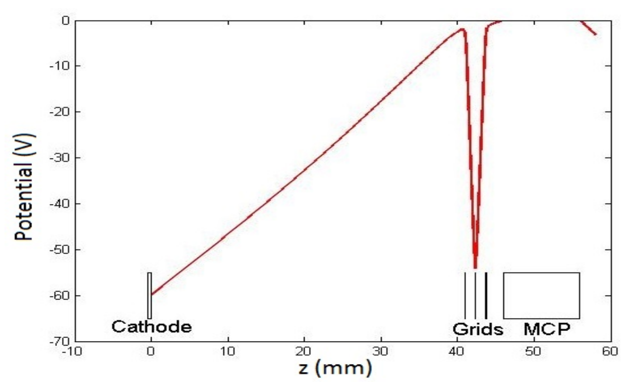

Figure 2: Potential along cutline through the centre of the model.

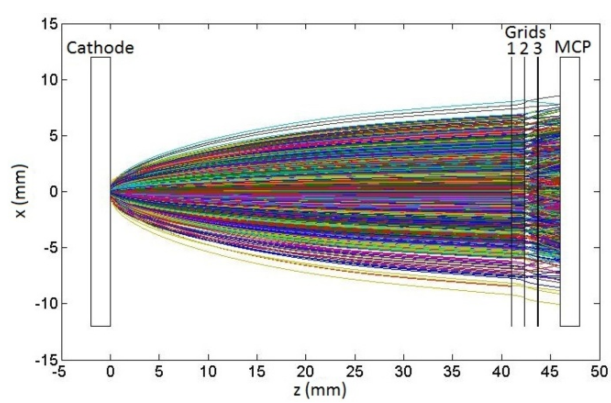

Figure 3: Tracking of particles positions along the z-axis.

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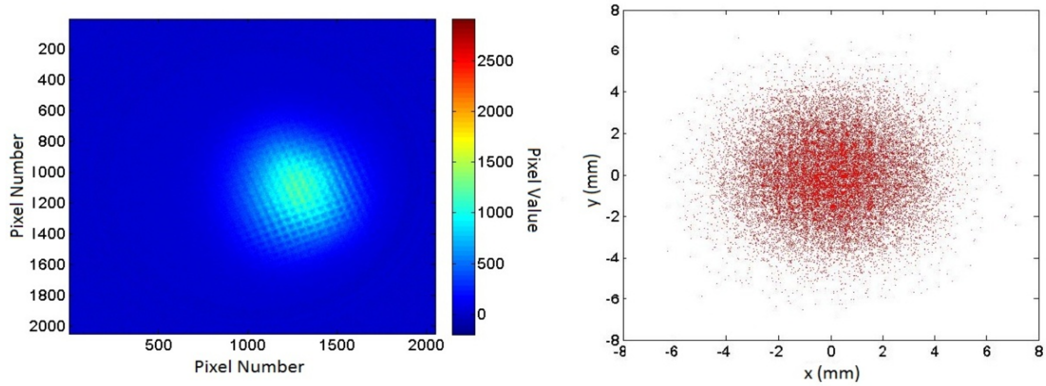

Figure 4: Corrected image shown as a coloured contour image with applied voltages of -60 V on the cathode and -62 V on grid 2 (left) and simulated results on the MCP using the same conditions (right).

Fig. 2 shows the electric potential from the centre of the cathode through the central grid cells to the centre of the MCP plate calculated from the 3D Comsol model applying the cathode and grid 2 voltages as -60 V and all other elements at ground potential. The field between the cathode and grids are as if they were both a flat potential surface and the potential drops once in the grid region but never equal to the applied voltage. Fig. 3 shows the tracking of the particles position along the z axis. In this example the retarding potential was not high enough to stop electrons reaching the MCP and all the particle loss was due to collisions with the grids.

Two wavelengths were used, 635 nm and 532 nm at two cathode voltages, -60 V and -80 V. Grid 2 was scanned in 0.5 V steps around the cathode voltage until the recorded output was at a level similar with the laser shutter closed. The images from the CCD camera were recorded in periods of 15 s which was long enough to obtain an image but not saturate the camera. Along with each data image recorded a dark image was also recorded with the laser shutter closed to allow background subtraction. Fig. 4 (left) shows the background corrected CCD image for a retarding voltage of -62 V applied to grid 2 and when the cathode voltage was -60 V and illuminated by a 532 nm laser. Fig. 4 (right) shows the distribution on the MCP using the tracking code and the same parameters used to produce Fig. 4 (left). The tracking was performed with 75,000 electrons with 36% reaching the MCP face, 2% lost on the grids and the rest being repelled. The grid structure which can be seen in the experimental image can also be made out in the simulated image.

After obtaining the background corrected image the columns and rows of the pixel values were integrated to acquire two signal profiles (horizontal and vertical). A Gaussian curve was fitted to the profiles and integrated to produce an integrated signal. Fig. 5 shows the integrated signal relative to the maximal signal for both horizontal and vertical fittings against the retarding potential applied using a 532 nm laser and a cathode voltage of -60 V. The signal is approximately constant as it approaches the cathode voltage but falls off for increasing retarding voltages until the signal falls to zero between 64 V and 65 V. Numerically differentiating the curves in Fig. 5 will produce a Gaussian peak whose width will represent the convolution of the longitudinal energy distribution of the cathode with the resolution of the instrument. The effect of the instrument settings on longitudinal energy resolution will be further investigated in the near future.

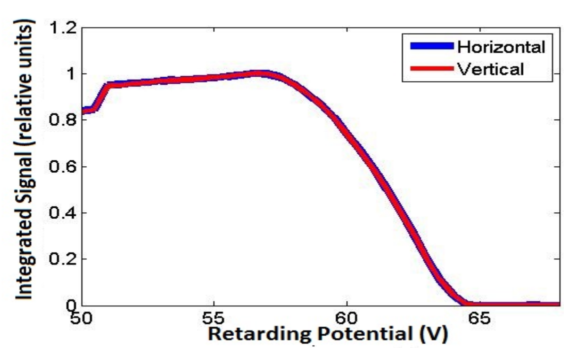

Figure 5: Integrated signal vs. applied retarding potential.

CONCLUSION

This paper presents a code which can reproduce the conditions of the TESS experiment. This code can be used to support the analysis and processing of data for studying the longitudinal energy distribution from a photocathode. It has been developed in Matlab and uses field data calculated from Comsol Multiphysics. Using Comsol over an analytical solution was preferred due to the complicated grid structure. The code gives access to simulations where the impact from different parameters, voltages and initial energy distributions can be explored.

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