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SIMULATION OF AN ELECTRON SOURCE BASED CALIBRATING SYSTEM FOR AN IONISATION PROFILE MONITOR

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INTRODUCTION

The IPM Operation Principle

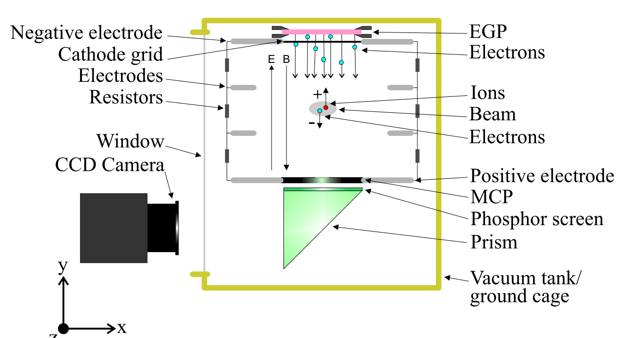

Figure 1: Working principle.

A sketch of the operating principle of the IPM, is shown in Fig. 1. The operating principle of the IPM is based on the ionisation of rest gas atoms and molecules by the passing beam due to the imperfect vacuum. In Fig. 1 the beam is passing in the z-direction, into the paper. Ions and electrons are liberated, and drift up or down respectively, due to the applied electric field. The electric field is created by applying high voltage to the electrodes at the top and bottom of the cage. The voltages applied are typically -1 to -2 kV for the upper electrode (cathode), and +1 to +2 kV for the lower electrode (anode). Consequently the direction of the electric field is in the +y-direction. The distance between the cathode and anode is 84 mm. The lateral electrodes of the IPM, connected through resistors, are included to increase the homogeneity of the electric field. The function of the cathode grid is to prevent secondary electrons, created when ions hit the grounded chamber, from returning into the HV cage of the IPM.

The electron distribution in space, reflecting the transverse density distribution of the particle beam, is forced down to the anode by the applied electric field. A Micro Channel Plate (MCP) measuring 5.08 cm by 5.08 cm is situated at the anode, and this is used to image the distribution. The function of the MCP is to amplify the electrical current from the incoming electron distribution. The amplified electron distribution then hits a phosphor screen. The phosphor screen converts the electron distribution into a photon distribution, which is viewed by a CCD camera, via a prism. A magnetic field of up to 2000 Gauss is added in addition to the electric field. The direction of the magnetic field is in the -y-direction, as indicated in Fig. 1. The magnetic field, together with the initial velocity, cause the electrons to spiral at a small radius, while the electric field forces them down towards the anode.

A New Calibration System

One of the difficulties encountered with the current IPMs, is the too rapid and non homogenous ageing of the MCPs. The ageing mainly affects the area of the MCP where the beam is imaged, causing a local decrease in the gain of the MCP. The reduction of the gain is caused by changes in the channel wall secondary emission coefficient due to electron scrubbing. The MCP is only capable of emitting a limited number of electrons during its lifetime, after a large number of electrons have been emitted, the gain is gradually reduced [2].

Because the MCP images the beam more or less in the same position throughout its lifetime, the gain is reduced more in the centre of the MCP than at the edges. With time, this causes distortion to the images created of the beam. In the LHC the IPM is intended as a continuos beam observation device. The ageing of the MCPs is therefore an important issue, as regularly replacement of the MCPs is both difficult and costly, and would have to be done during machine shutdown.

To measure the ageing effect, and to be able to compensate for it, a remote controlled, built-in calibration system is to be developed. The calibration system consists of an elec-

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tron source, placed above the cathode grid, which can emit electrons during periodes where there is no beam present. This electron field can then be used to measure the gain of the imaging system, and improve the images acquired during operation of the IPM. Two electron sources were considered for use in the system, a heated wire grid and an Electron Generator Plate (EGP). EGPs produced by Burle, Inc. [3] are specified to emit homogenous fields of electrons covering the complete area of the MCPs used in the IPM [15, 4]. Based on previous experience with a heated wire grid, an EGP was chosen as the electron source [1]. The EGP was placed 6 mm above the cathode wire grid and 90 mm above the MCP. In this paper, simulations of an IPM incorporating an EGP for calibration purposes is presented.

SIMULATIONS

The computer simulations were split into two main parts: Simulations of the electrical field, and simulations of the paths of the electrons. To compute the electrical fields, the computer program Maxwell 3D Field Simulator (M3DFS) from Ansoft Corporation [5] was used. The program used to calculate the paths of the electrons through the electric and magnetic fields was Garfield [6]. Garfield was originally developed at CERN by Rob Veenhof for simulation of gaseous detectors. The program reads the results of the electrical field simulations created by M3DFS from file, and then calculates the path of the electrons.

The electric field simulations were done using the finit element method for the electrostatic case [7, 8, 9]. The equation which is solved by M3DFS is in general the Poisson equation [10]

$$\nabla \cdot (\epsilon \nabla \Phi) = -\rho_f = 0, \tag{1}$$

where ϵ is the permittivity and Φ is the scalar electric potential. ρ_f is the free charge, which is equal to zero in the electrostatic case.

The path of the electrons through the IPM chamber is calculated by the Garfield program, integrating the expression for the acceleration given by

$$\mathbf{a} = \frac{q}{m}\gamma^{-1}\big(\mathbf{E} + \mathbf{u} \times \mathbf{B} - \frac{1}{c^2}\mathbf{u}(\mathbf{u} \cdot \mathbf{E})\big), \tag{2}$$

where $\mathbf{a}$ is the acceleration, q and m is the charge and mass of an electron, γ is the relativistic constant, $\mathbf{E}$ and $\mathbf{B}$ is the electric field and magnetic field, $\mathbf{u}$ is the velocity and c the speed of light. The numerical method used by the Garfield program is Runge Kutta Fehlberg integration [6].

The resulting field from the electrons present in the drift volume will be negligible compared to the applied electric field in the IPM, even for the highest density of electrons recordable by the MCP [11]. Consequently, the effect of electron-electron interactions can safely be disregarded in the computations. An algorithm that does not take electron-electron interactions into account is therefore chosen to be used in the Garfield simulation program.

To the authors knowledge, no data or theoretical calculations for the energy distribution from single EGPs are published. However, Burle, Inc. has conducted measurements for Z-Stack configuration EGAs [12]. The results are assumed to be similar, but with somewhat lower average energy than for the electrons emitted from a single EGP [13].

The measured results from Burle, Inc. can be fitted to the shape of an *exponential distribution* [14] for the energy U

$$p(U) = \frac{1}{\beta}e^{-U/\beta}, \tag{3}$$

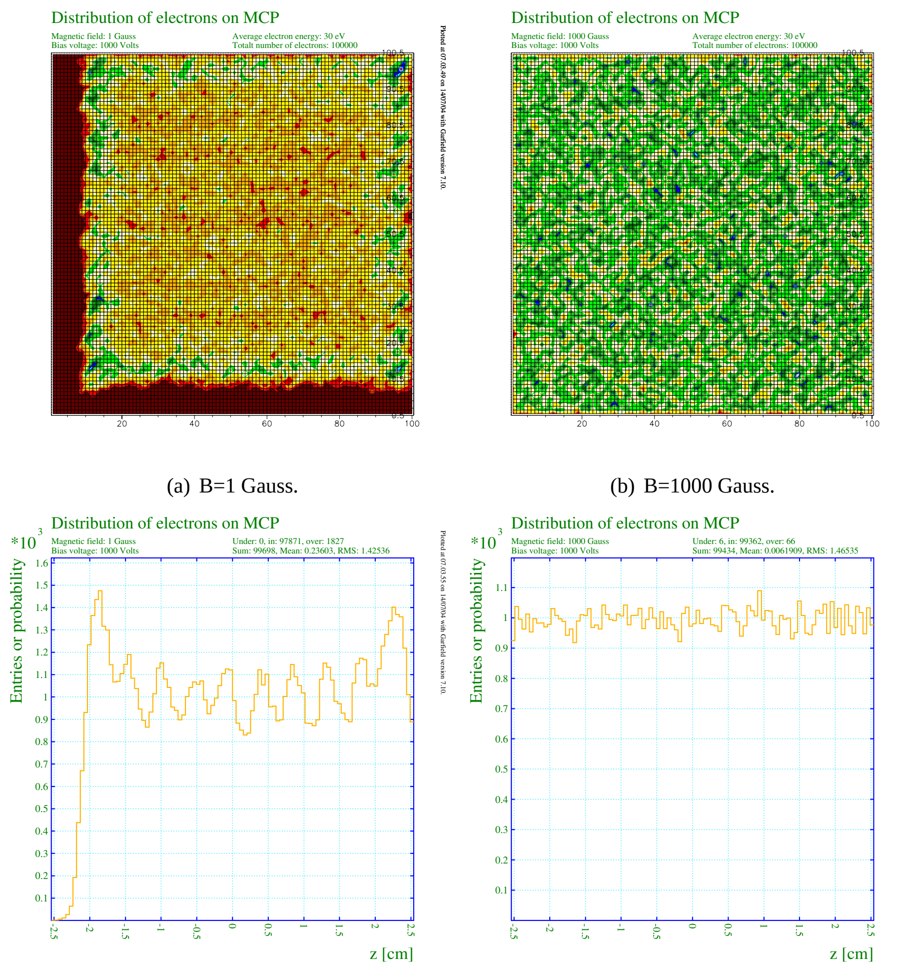
where the parameter β is the average energy of the electrons. For the measured results the average energy is in the range of 34 to 40 eV, however these measurements were done using a Z-Stack configuration EGA, not a single EGP as will be used in the IPM. Since it is expected that the average energy will be lower, an estimate of 30 eV is therefore used in the simulations. This coincides with values obtained from measurements of emittance from single MCPs, where the distribution is reported to be exponential with an average electron energy of 30 eV [2]. The electron current emitted from an EGP is claimed to be more or less parallel with the channels of the EGP [12]. The spatial distribution of the electrons from the EGP is therefore assumed to be equal to the inclinement of the channels of the EGP, which is specified to be $8^\circ \pm 1^\circ$.

The limiting factor for the resolution of the electron path simulations, is the recording of the initial and final position of the electrons. 100 by 100 bins are used, resulting in a bin size of 508 by 508 μm, when the entire area of the EGP or MCP is imaged. In the simulations 10^5 electron paths were computed for each case, resulting in an average of 10 electrons per bin. If the electron distribution is plotted along either the z or x-axis only, an average of 1000 electrons per bin is obtained in one dimension.

RESULTS AND CONCLUSION

The resulting electron distribution on the MCP from Garfield simulations of electrons emitted from the EGP are shown in Fig. 2 (a) and (b) for B=1 Gauss and B=1000 Gauss, respectively. In Fig. 2 (c) and (d) a projection onto the z-axis of these distributions are shown. The figures show that at low magnetic fields the emittace angle of the electrons play an important role, and the electron distribution is distored by both edge effects and shadows from the cathode wire grid. At high magnetic fields, these effects are however negligible. Experiments conducted with no external magnetic field applied, confirm the results. However, experiments with an applied magnetic field is required to confirm the results for B=1000 Gauss and determine the accuracy of the system.

Simulations of the electrical field of the IPM during operation mode, with the EGP implemented, were conducted to confirm that the modification would not decrease the systems performance during actual beam profile measurements.



(a) B=1 Gauss.

(b) B=1000 Gauss.

(c) B=1 Gauss.

(d) B=1000 Gauss.

Figure 2: The resulting electron distribution on the MCP, and the projection onto the z-axis.

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