DESIGN AND OPTIMISATION OF THE ELENA ELECTRON COOLER GUN AND COLLECTOR

G. Tranquille, J. Cenede, CERN, Geneva, Switzerland

Abstract

Phase space compression of the antiproton beam in ELENA will be performed by a new electron cooler. The performance of the cooler is greatly influenced by the properties of the electron beam. Careful design of the electron gun electrodes, the quality of the guiding magnetic field and the efficient recuperation of the electrons in the collector ensure that the cooler performance is optimal. We have used COMSOL Multiphysics® to design and optimise the complete electron cooler with particular attention to the gun and collector. This software suite uses physics interfaces for modelling common applications and then allows the user to combine the different interfaces in one multi-physics simulation.

INTRODUCTION

The Extra Low ENergy Antiproton ring (ELENA) [1] is a small ring at CERN which is being built to increase substantially the number of usable (or trappable) antiprotons delivered to experiments for studies with antihydrogen and antiprotonic nuclei.

The electron cooler [2] plays a key role in ELENA both for efficient deceleration as well as for preparing extracted beam with parameters defined by the experiments.

COMSOL Multiphysics® has been used to complement traditional programs such as EGUN and OPERA to completely model the electron cooling device in 3D. We have taken advantage of the different physics-based modules of COMSOL Multiphysics® to optimise the various components of the cooler (magnetic transport system, electron beam generation, recuperation of the electrons in the collector etc.) and then to integrate the different studies into one model of the complete system.

In addition, COMSOL Multiphysics® has enabled us to make detailed tracking simulations of the passage of the antiproton beam in the highly non-linear magnetic field of the toroid section of our setup [3].

MODELLING THE MAGNETIC FIELD

Three identical standard solenoids are used to guide the electrons from the gun to the collector. The operational field in these magnets is 100 Gauss with a maximum field of 250 Gauss. Each of the standard solenoids consists of the solenoid winding itself as well as a set of "saddle" coils at each end, "circular" coils in the central region and two sets of Helmholtz steering coils running the length of the solenoid; one for each transverse direction. The role of the "saddle" and "circular" coils is to improve the good field ($B_\perp/B_\parallel < 5\times10^{-4}$) region in the drift solenoid and to compensate any B field that may leak into the drift solenoid from the toroids and vertical solenoids. In addition, 24 fine-tune coils will be used to further reduce the transverse component of the magnetic field to below 50 mT.

An expansion solenoid, having a magnetic field ten times stronger than the standard solenoid, is placed around the electron gun for the adiabatic expansion of the electron beam. The resulting effect is a reduction by a factor of three of the electron beam transverse temperature and an increase in the beam radius from 8 mm to 25 mm.

The toroid sections, which bend the electron beam in and out of the drift solenoid, are made up of 9 racetrack coils and come in 3 different sizes; two medium sized coils near the drift solenoid, 3 large coils to allow access by the antiproton beam as well as access for pumps etc. and finally 4 small coils near the gun and collector solenoids, respectively.

Each section was simulated individually using COMSOL and then combined to give a full model of the magnetic field of the cooler (fig. 1). By combining the models of the expansion solenoid and a standard solenoid we could make a linear setup for a more efficient study of the gun and collector.

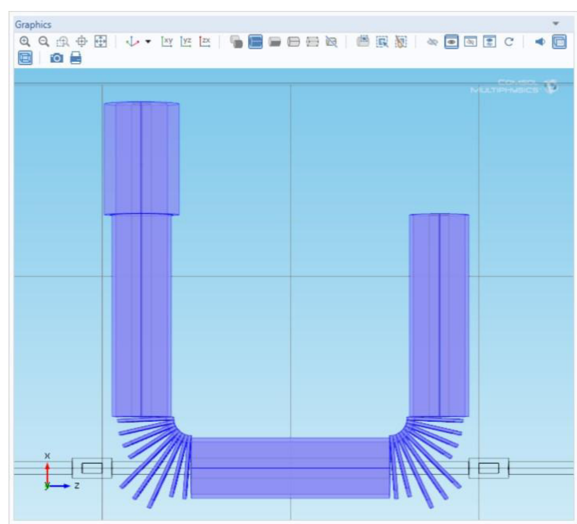

Figure 1: Magnetic model of the cooler.

ELECTRON GUN DESIGN

The electron gun will produce a cold ($T_\perp < 0.1$eV, $T_\parallel <$ 1meV) and relatively intense electron beam ($n_e \approx 1.5\times10^{12}$ m^{-3}) at energies below 350 eV. Electrons are emitted from a thermionic cathode heated to 1200 °C and are accelerated to the desired energy by a series of electrodes designed to minimize the transverse temperature. As explained in the previous section, an adiabatic expansion is used to further reduce the transverse temperature and to adjust the beam size with that of the ion beam to be cooled.

The initial design of the gun was made with the EGUN code [4]. Particular attention was paid to the position of the "grid" electrode with respect to the cathode as this determines the gun perveance. Generating a few mA of current at such low energies is non-trivial and one must avoid using a positive "grid" potential with respect to ground as this can result in the trapping of electrons in the gun. EGUN was also used to determine the required grid potentials for the different currents. At the time we started the design of the gun, the COMSOL version did not offer the possibility to simulate thermionic emission from surfaces. An example of an EGUN simulation is shown in figure 2.

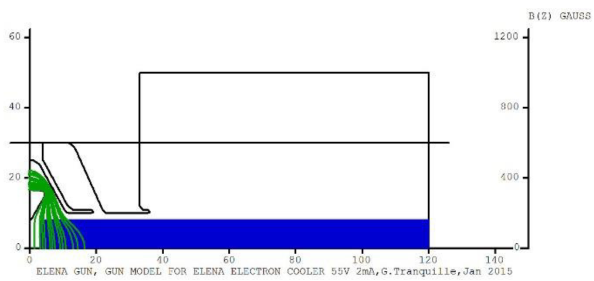

Figure 2: EGUN simulation of the electron gun.

COMSOL was then used to reproduce the EGUN results using the possibility to extend the study to 3D. A fairly simple geometry was created by combining various predefined shapes to represent as accurately as possible the EGUN model (fig. 3). A study of the angle of the Pierce electrode surrounding the cathode was performed to ensure that the equipotential lines at the cathode exit were as parallel as possible hence minimising any transverse kicks on the electron beam.

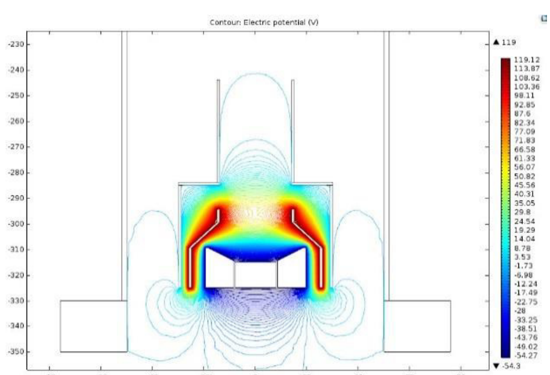

Figure 3: Equipotential contours in the simple COMSOL gun model.

Once the shape and dimensions of the various electrodes had been fixed, the production model and drawings were made in CATIA. This file was then imported into COMSOL for the final optimisation giving us the possibility to verify the influence of the different material properties on the electric potential and subsequently make any modifications to the electrodes.

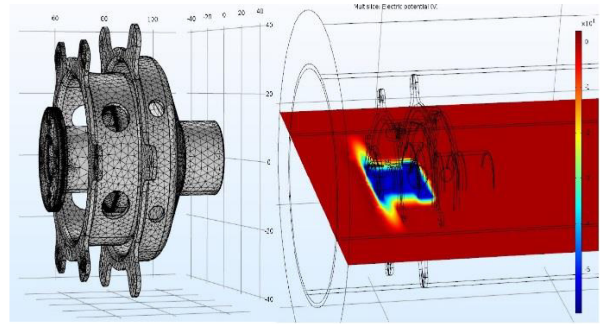

Figure 4: The meshed gun (left) and electric potential (right) for the final gun geometry (E_e = 55 eV).

The results of the simulations showed a smooth accelerating gradient in the gun with almost perfectly parallel equipotential contours at the cathode exit. A further optimisation showed that by increasing the Pierce angle from 67.2° to 70.9° we could also improve the parallelism of the equipotential lines close to the cathode surface. A second Pierce electrode is being made and will be tried at the same time as the gun measurements on the test stand.

THE COLLECTOR

After the cooling section the electron beam is bent by 90° and is dumped on the collector. Even though the beam power is low (<2W) this energy needs to be spread out over a large a surface as possible to avoid any excessive outgassing. As the electrons enter the collector they are decelerated by the "repeller" electrode and at the same time the longitudinal magnetic field falls off. This allows the electrons to be spread out over the collector surface where they finally come to rest.

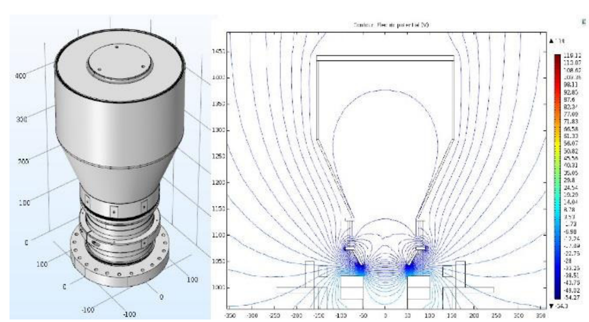

Figure 5: The collector: imported CATIA model (left), equipotential plot (right).

At the same time the ExB field at the collector entrance creates a barrier that prevents secondary electrons from being re-accelerated back into the cooling section where they can oscillate back and forth between the gun and collector before being lost on the vacuum chamber and causing a pressure rise.

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BEAM TRANSPORT

To investigate the transport of the electron beam from the gun to the collector we built a magnetic field model comprising of the expansion solenoid, a standard solenoid and the squeeze coil (fig. 6). The gun, vacuum chamber and collector elements were inserted into the model and a time dependent simulation was made to determine the properties and trajectories of the electrons from the gun to the collector.

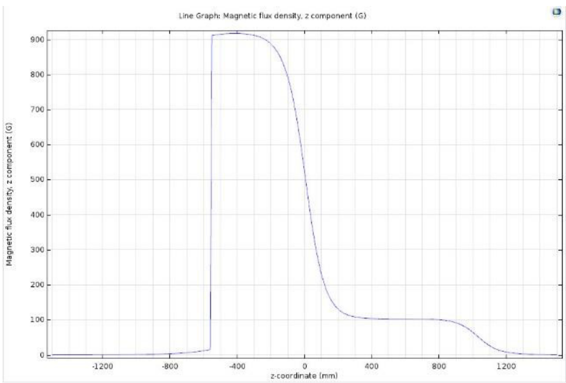

Figure 6: Magnetic field on axis in the linear setup.

As the electrons leave the cathode they are accelerated to the desired velocity and intensity by the different potentials that are applied to the gun electrodes. One also clearly sees the expected increase in electron beam size in the transition between the expansion and standard solenoids (fig. 7). The factor of ten difference in the magnetic field increases the electron beam radius from 8 mm to 25 mm.

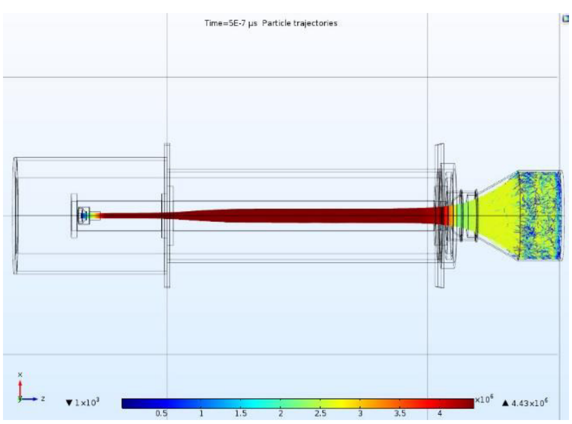

Figure 7: Electron trajectories from the gun to the collector in the linear model of the cooler.

The beam flows along the 1 m long standard solenoid and as the longitudinal field drops at the collector entrance, the electrons begin to disperse. The squeeze coil is used to push back the zero field point so that the electrons can be efficiently spread out over the collector surface. The repeller and collector potentials are adjusted such that the power dissipated on the collector is reduced and also stop any secondary electrons returning into the solenoid.

OUTLOOK

The latest release of COMSOL Multiphysics incorporates a number of new features [5] that are of great interest to us for our simulations:

- Thermionic emission from surfaces will give an indication of the maximum currents that we can expect our gun to deliver and will serve as a cross-check to the EGUN calculations
- Particle-particle interactions will allow us to compute how the electron beam trajectories are affected by the electric field of the space charge of the beam as they travel from the gun to the collector
- The introduction of collisional forces and secondary emission can give us information on how we expect the pressure to increase in the presence of the electron beam and also how secondary electrons behave in the collector.

We are in the process of applying the above features to our linear model before extending them to the full model of the electron cooler. This should give us a better understanding of the electron beam dynamics at low energies and in particular how the electrostatic plates in the toroid sections influence the electron beam trajectories.

Before installation on the ELENA ring, the gun will be validated on our test bench and the results obtained will be compared to our simulations made with the two software packages.

REFERENCES

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