Summer student project - Olav Willumsen Haugå

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The LINAC4 ion source

Introduction

My summer student project has been split in three parts. During the first 4-5 weeks I was involved in the design of the filtermagnets for the IS02 with the simulation tool Opera. After this, I have performed data analysis of the plasma light emission in the IS01 source with the software Matlab and I took part in the development of a Fortran code for plasma simulations. In all projects, understanding plasma physics has been essential and the learning outcome related to this field has been very high.

Project 1 - Designing filter magnets for the Ion Source

In the LINAC4 ion source the goal is the production and extraction of H^- ions. The H^- production mechanism takes place in two steps. First H_2 molecules need to be excited vibrationally by hot electrons, and secondly, the interaction of these molecules with slow electrons allows its dissociation into an H atom and an H^- ion:

$$e(fast) + H_2(v) \quad -> \quad e(slow) + H_2(v') \qquad v' > v \tag{1}$$

$$e(slow) + H_2(v') \quad -> \quad H + H^- \tag{2}$$

Therefore the plasma parameters require to split the plasma in a vold and a hot part. This is achieved by introducing filtermagnets. The magnetic field that is shown necessary from previous work is 25 mT. Due to long waiting time from Vacuumschmelze (magnet manufacturer), it was decided that I would make a design of the filtermagnets with the magnets we already had. The magnets would then be cut accordingly. This process involved a lot of theory related to electromagnetism, especially the use of Maxwells equations and boundary conditions for B-fields and H-fields was essential when understanding the outcomes of different design scenarios.

To allow the tuning of the magnetic field, a soft iron ring surrounds the plasma chamber and the filtermagnets. In my simulations the magnets are put as close as possible to this ring, see Fig. 1. They have space enough to be moved further towards the center if an increase in magnetic field is desirable. We cut the magnets from our VacoDym 633 HR magnets with dimensions $71x13.5x10.0$ mm. After the cut the magnets have circular arcs. The inner arc has a length of 31.76 mm and the outer arc has a length of 40.02 mm. Finishing the arcs 360 degrees will result in rings with radius 46 mm and 40.2 mm, respectively. The thickness of the magnet is reduced to 10.0 mm to fit in the Ion Source geometry. It follows that the distance between the magnets is 5.8 mm.

The inner radius of the soft iron ring is 46.0 mm and the outer radius is 54.1 mm. As it is made of soft iron, its' material properties are set by a standard tenten BH curve. In accordance with Maxwells equations the ring stops the magnetic field lines from getting too far away and hence interfere with other parts of the Ion Source. For the NdFeB (Vacodym 633 HR) magnets, the coercivity is set to be $1040\frac{\mathbf{kA}}{\mathbf{m}}$ and the relative permeability is calculated to be $\mu_r = 1.03$. As one can see from the simulations in Opera the Z-component of the B-field is 26.6 mT. This agrees very well with the required magnetic field! It decreases along the X-axis and increases along the Z-direction away from the center of the magnets. The plasma chamber has a radius of 24 mm and at the edge of the plasma chamber, the magnetic field has fallen to approximately 15mT. See plots. This field is not as uniform as in the DESY design, a consequence of the fact that the distance between the magnets is now much bigger and that the magnets are not cubic anymore.

Model symmetri in Opera is a block scaled with factors 2-5-2 in x-y-z directions, respectively. Maximum element size is set to 5, and maximum angle between elements is set to 7. We also prefer tetrahedral elements.
The magnets have been cut and the resulting magnetic field is now to be analyzed experimentally with a hall probe. As my time at CERN is going to coming to an end, someone else will take over my work in this field. During this project it has been interesting to learn the simulation tool Opera, which I know quite well now, but the main outcome of the first week has certainly been the understanding of core concepts in electromagnetism.

Results from filtermagnet project

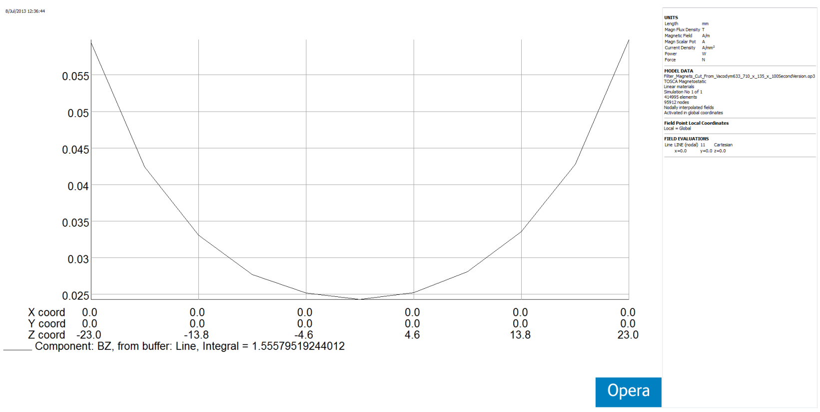

Figure 1: Z component of B-field along z axis

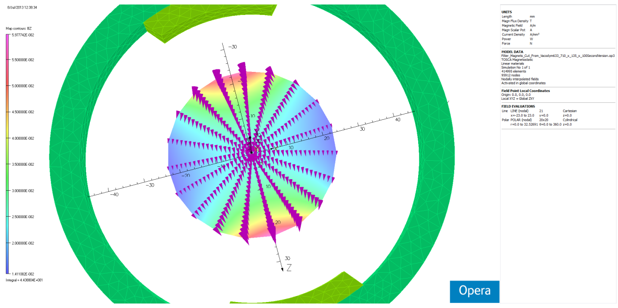

Figure 2: Field plot of the B-field including vectors

Project 2 - Analyzing Lightmeasurements from the Ion Source plasma with Matlab

Plasma light emission is a powerful tool to understand the plasma properties. With the use of Matlab we have analyzed the light emission from the Ion Source plasma, where we wanted to increase our understanding of the phase difference between the antenna current and the light emission. The RF current is a perfect sinusoidal wave with frequency 2 MHz. The light emitted from the hydrogenplasma should consist mostly of a 4 MHz signal (Balmer lines). We have analysed the plasma ignition and the steady state regime. We made 60 measurements from the plasma and used Matlab to study the phase difference by means of the fourier transform. We took the original signals and mapped them to their frequency spectrum. To do this discrete foruier we used the already matlab implemented function *fft* . With the use of the *fft* one also gets the phase of the signal as well as the magnitude of the different frequencies. We see clearly the expected maxima at 4 MHz. The phase analysis proved to be more difficult and only preliminary results have been obtained with the direct fft phase results and the convolution method. In this analysis I got quite familiar with the Fourier transform.

Results - Analysis with Matlab

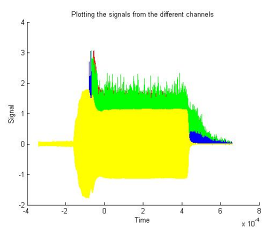

Figure 3: Original signal as a function of time

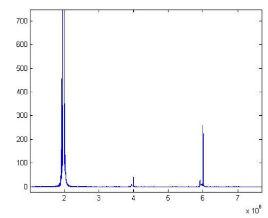

Figure 4: Signal mapped to frequency spectrum

Project 3 - Implementing the simulation of proton collisions inside the Ion Source with the use of Fortran

The last weeks have been spent learning the Fortran language and implementing proton collisions in the ion source plasma. The code is implemented in cooperation with the Keio University in Japan. As they have implemented parts of the code that is relevant to my work, I also spent my time on fully understanding the code, and writing down the functionality of the different variables that was unaccounted for. In the plasma simulations, only electron collisions are implemented, but different collisions for the protons are not included. This is important for energy balance as the proton heating by the RF coil is not compensated by a cooling process, so the simulated energies are too high. So my task became to implement some reactions for the protons as well. When dealing with this problem, one are specially interested in the *cross section* of different reactions which is directly connected to the probability that a certain reaction will take place. I used reliable theoretical expressions to obtain the cross section for the reactions and then afterwards implemented the dynamics related to these reactions. During my time I implemented the following collisions for the protons, which will be directly inserted into the plasma simulation code.

Excitation of hydrogen molecule from v=0 to v=1,2,3....14

$$H^+ + H_2(v=0) \dashrightarrow H^+ + H_2(v) \tag{3}$$

Dissociation of hydrogen molecule into two hydrogen atoms in ground state (1s)

$$H + + H_2(X^1\Sigma_g^+; v) \dashrightarrow H^+ + H(1s) + H(1s) \tag{4}$$

Excitation of hydrogen atom from ground state (n=1) to n=2

$$H^+ + H(n=1) \dashrightarrow H^+ + H(n=2) \tag{5}$$

Excitation of hydrogen atom from ground state (n=1) to v=2,3...14

$$H^+ + H(n=1) \dashrightarrow H^+ + H(n=2) \tag{6}$$