
Magnetic field asymmetry studies of the PITZ gun main solenoid

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Abstract

Asymmetry of magnetic fields in a focusing structure leads to changing the form of the beam, an increase of the beam emittance and can even lead to a beam loss. The magnetostatic simulations for the PITZ solenoid were performed using CST Studio. Research on the influence of different parts solenoid for the asymmetry of the field was performed.



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1 Introduction

1.1 PITZ overview

The Photo Injector Test Facility (PITZ) at the DESY, Zeuthen was created to test and develop photoelectron sources for Free Electron Lasers (FEL) [1] and other linear accelerators.

In the beginning, synchrotron radiation was considered as a negative result of synchrotron accelerator operation. However now it is an essential tool for analysis of molecular structures in biology and chemistry. New tasks make new requirements for radiation. FEL radiation is analog of synchrotron light, but also has advantages, like ultrashort pulses (fs scale), transverse spatial coherence and extremely high peak brilliance [2].

To satisfy the European XFEL (European X-Ray Free-Electron Laser Facility) [3] project requirements, an electron injector should provide bunches with small emittance value, small energy spread, short longitudinal length, and high charge. Small transverse and longitudinal emittance are required by high-gain FELs. In this way, the main task of the PITZ is a photoinjector optimization to obtain as small as possible beam emittance.

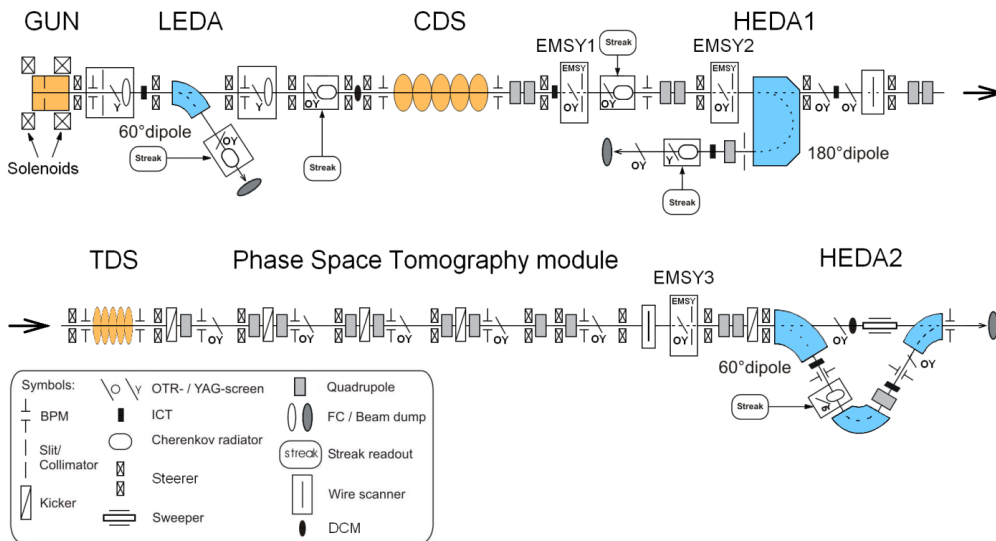


Figure 1: PITZ facility layout

The PITZ facility is a linear accelerator which consists of an RF photoelectron gun cavity with a pair of focusing solenoids, a booster cavity, multiple diagnostic components for beam investigation. A layout of the facility is shown in Figure 1.

1.2 RF photoelectron gun

The heart of the PITZ facility is a photoelectron gun (Figure 2). The gun consists of RF normal conducting (OFHC copper) 1.6 cell L-band cavity, supplied by RF power via a

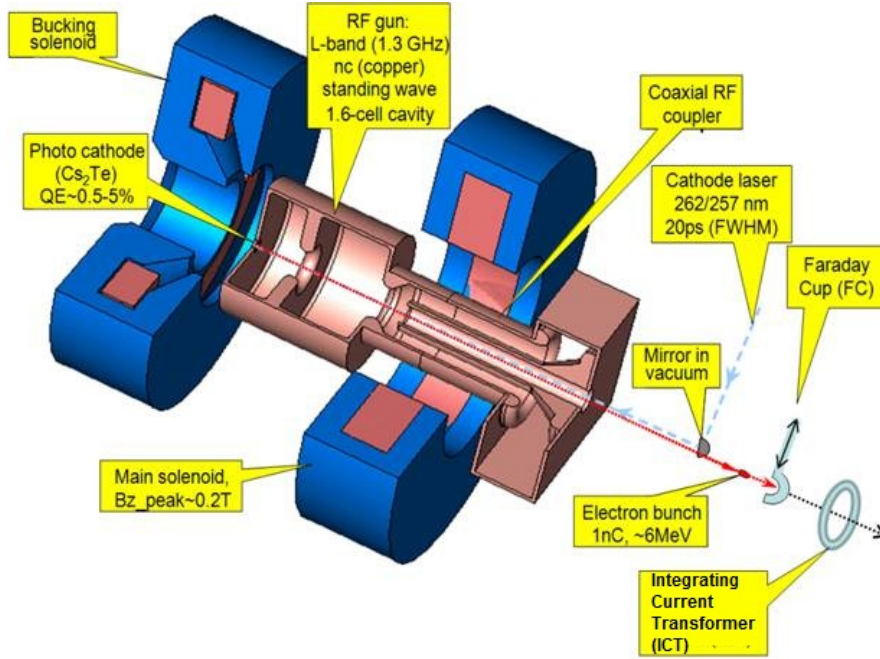


Figure 2: PITZ photoelectron gun setup

coaxial coupler, main and bucking solenoids and cathode plug with Cs_2Te coating, located at the back wall of the half cell.

Light from cathode laser with wavelength 257 (nm) is bounced off vacuum mirror and reach the photocathode Cs_2Te , which causes electron emission. The gun is able to produce up to 6 nC charge bunches acceptable them to 7 MeV energy.

1.3 Solenoid

The main gun solenoid is installed around the coaxial RF coupler position. It is dedicated for beam focusing and emittance growth compensation [4]. The bucking solenoids is installed upstream the cathode surface and dedicated for main solenoid field cancellation on the cathode surface to avoid X and Y emittances coupling, which increases emittance of the beam.

The maximum main solenoid current is 500 A, at which the solenoid produces 0,3 T at the solenoid center. The bucking solenoid current is set so, that the parameter magnetic field at the cathode is 0 T. But the bucking solenoid can work up to 300 A, and produce maximum magnetic field 0,16 T (Figure 2, and Figure 4).

The main solenoid consists of 108 turns of copper wire that surrounded by an iron jacket, transitions, connectors and a hole in the iron jacket.

2 Motivation

During the PITZ operation, there was always observed the asymmetrical shape of the beam. It was decided to perform experiments to find a region, where asymmetry is located. Investigation of the beam asymmetry source showed that it is located in the gun region [5]. The Larmour angle experiment showed that the source is located in the region of the coaxial coupler to the full cell transition. This place is also located inside the main solenoid. That is why two reasons of the asymmetry are considered: asymmetrical RF wave in the transition from coaxial RF coupler to the full cell of the gun and field asymmetries from the main solenoid.

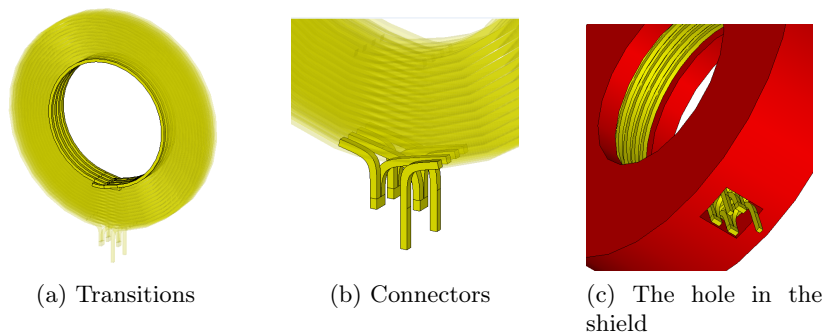


Figure 3: Asymmetrical parts of the main solenoid (see detailed description in the text)

The symmetrical magnetic field inside the solenoid is needed for the symmetrical shape of the beam. The magnetic field asymmetry may come from asymmetrical parts of the main solenoid geometry. The magnetic field might be decomposed to symmetrical and asymmetrical parts. There are following asymmetrical parts (Figure 3): transitions between winding layers, connectors and the hole in the shield.

The main goal of this project is an investigation of field asymmetry contribution that comes from different solenoid parts.

3 Simulations

3.1 CST

CST (Computer Simulation Technology) [6] is a tool for 3D electromagnetic simulations. It consists of a few packages for different problem types, for example, the Eigenmode solver is dedicated to the simulation of closed resonant structures, the Magneto-Static solver (MS) is suitable for the solution of linear and non-linear magnetic problems. For the current project, MS-solver is suitable, because of study magnetic field in the solenoid.

The simulation process consists of a few steps. The first is a geometry modeling of a structure. The second is a choice solver setup for simulation. The third step is setting boundary conditions. The fourth is using symmetry planes for faster simulation (if symmetry exists in the geometry).

It is important to use the local mesh settings for each model part to better set up a simulation (problems with a choice right mesh will be discussed further). In the end, there should be a solution for a system in initial points. In our case, it should be magnet field distribution inside the structure. Postprocessing tools are used for values analysis and distribution of a field inside the structure with different types of plots.

3.2 Modeling of the solenoid geometry

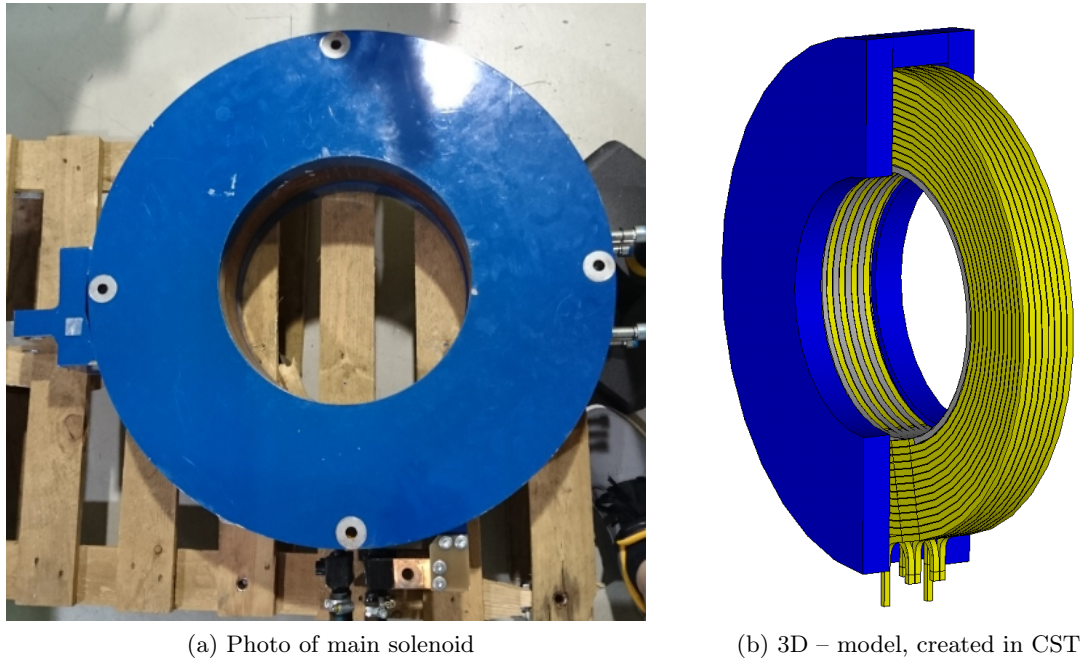


Figure 4: Main solenoid

The investigation of the solenoid asymmetrical parts (Figure 4 b) on field structure was done utilizing magnetic field simulations for each part separately. In the beginning, there is created symmetrical in all directions model and afterwards model that contains only one type of asymmetry. The first model is with connectors and the second is with transitions.

In order to study field asymmetry structure, it is necessary to use field projections to curves. Since the field should have axial-symmetrical structure, there were created a few circular curves for field projections (Figure 5 a). The first and the third positions are on equal distance from the center of the structure. The second position is in the center of the solenoid.

There are three circular curves with different radii at each position (1, 2, 3 in Figure 5 b). The smallest radius is for study magnetic field close to the axis. The biggest radius is for study magnetic field close to coils or spirals. The intermediate radius is used for study magnetic field in a region between two previous circles.

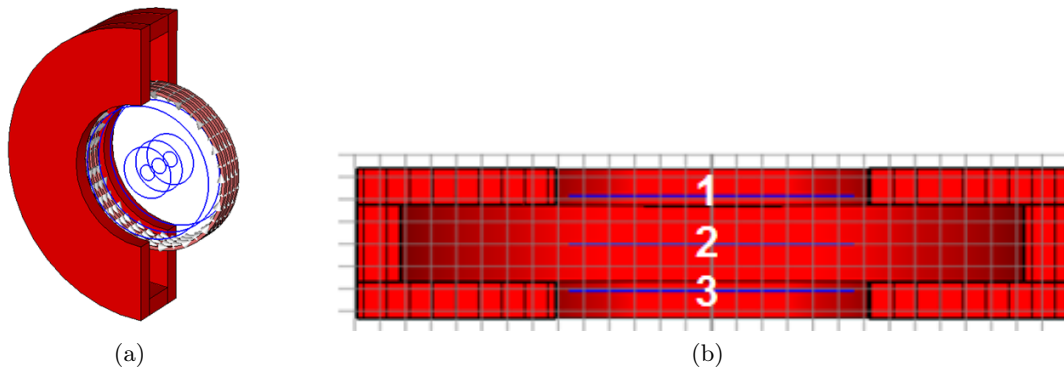


Figure 5: Nine auxiliary curves is used in the solenoid (three curves with different radius in three positions)

The same result is in the first and the third points in symmetrical structure, but values and plots are different on these points in the asymmetrical structure. In case of better mesh, more points on curves are received (more accurate result).

3.3 Studies of mesh parameters

Before a simulation, it is necessary to define the mesh. A polygon mesh is a collection of vertices, edges, faces and nodes that define the shape of a polyhedral object for 3D computer simulation. If a mesh has a higher number of cells, result is more precisely. On the other hand, bigger number of cells leads special requirements for computing resources. That is why, it is important to find right balance between computing capabilities and accuracy in an experiment.

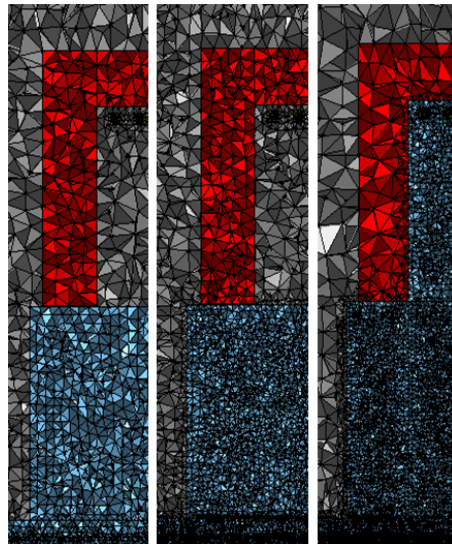


Figure 6: Mesh of a structure with different numbers of cells (from left to right): bad, medium and good mesh (see detailed description in the text)

Three different meshes are shown in Figure 6. The number of cells for good mesh is in

two times more than for medium mesh and in four times more than for bad mesh. The yoke has a red color, the background has a grey color and the vacuum has a blue color. The difference between meshes is in the number of cells for different parts of the model. The quality of the mesh was increased inside the structure around places, that considered for plots. The mesh was increased in the blue region of the solenoid (vacuum), how it is shown in Figure 6.

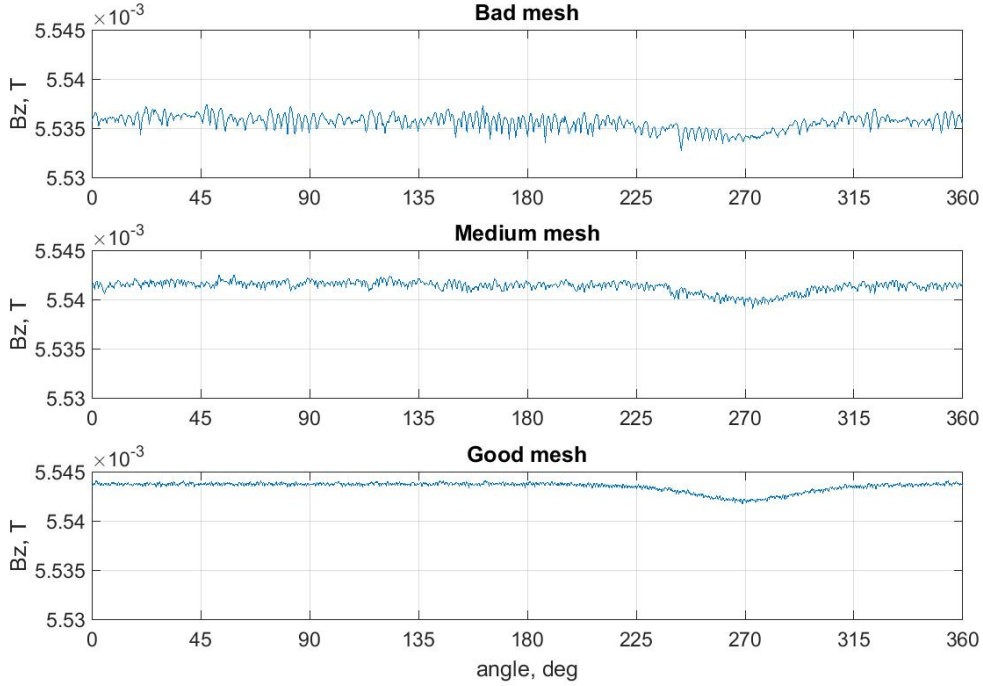


Figure 7: Z-component of magnetic field inside the structure with different mesh (different number of points) for the same model, the same curve, and the same position

Three different plots of z-component of magnetic field inside one structure with different mesh are presented in Figure 7. Magnetic field decrease in the sector (from 200 to 350 degree) is shown better on the plot of the model with bigger numbers of cells.

3.4 Simulations of symmetrical part of the solenoid

The idea of the splitting model for three parts gives an opportunity to see a contribution to the magnetic field from each part. In the beginning, how it was written before, there was created a symmetrical model for obtaining symmetrical magnetic field. The same mesh settings were used for each model. This was done for better comparison of the results of 3 simulations.

The model of the symmetrical part of the solenoid was obtained by creating separate coils (108) instead of copper windings of a full solenoid model. There was used 100 A

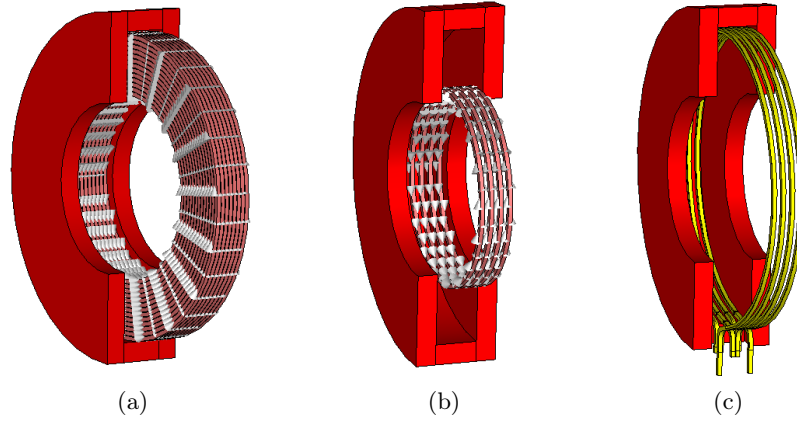


Figure 8: Models with (a) round coils, (b) transitions, (c) connectors

current. Additionally, the hole in the iron jacket (used for connectors) was not taken into account. So the model consist of only symmetrical parts (see Figure 8 a).

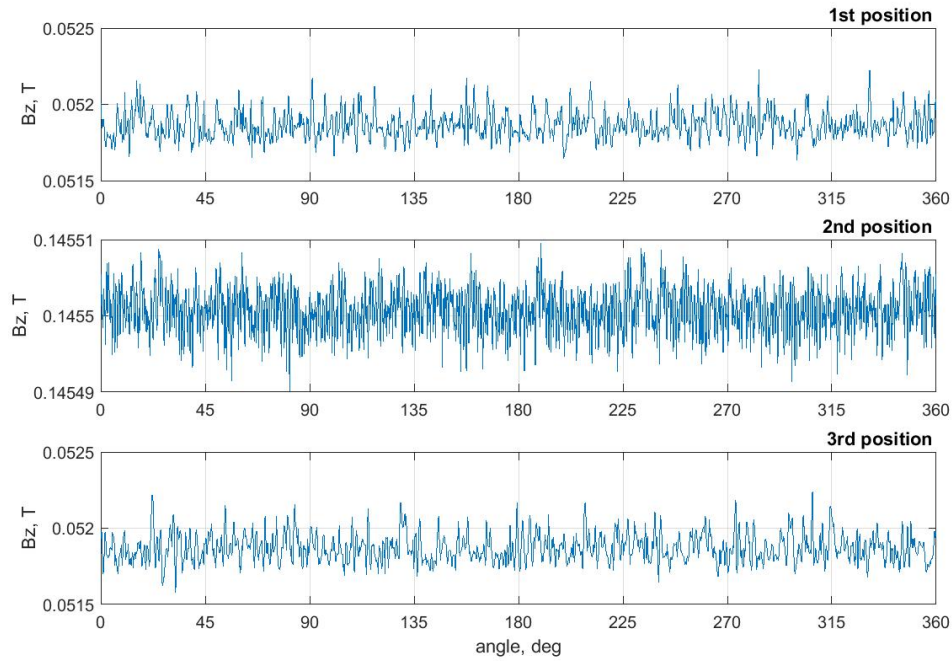


Figure 9: Z-component of magnetic fields of symmetrical structure projected to the circle with the biggest radius at three different positions (1, 2, 3 on Figure 5 b)

There are 3 plots in Figure 9 that describe magnetic field, projected on the curves. The curves with the biggest radius were chosen, because in this case, one can see the biggest difference in magnetic field values of structures. All three plots show constant values of the field vs. angle (with noise). The conclusion (based on plots) is that the magnetic field

inside the structure is homogeneous symmetrical (all points on the same distance from the center have the same values).

3.5 Simulations of asymmetries of the solenoid

Eight rows of spiral exist in the solenoid. Transitions are used in the central part in order to connect them. To connect the layers at the outer part and with power supply, there used connectors. These asymmetrical parts are considered separately in two models. Transitions of the central part are changed to rotated coils. Connectors of the external part are similar to full the model of the solenoid.

3.5.1 Simulations of connectors

There was created a model with connectors (Figure 8 c) with the same current and position, but another shape (Figure 3 b).

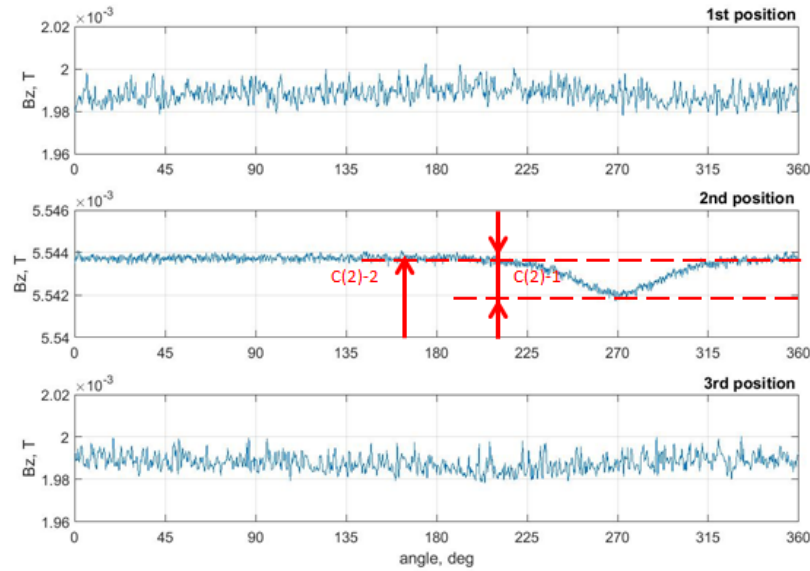


Figure 10: Z-component of magnetic fields of connectors projected to the circle with the biggest radius at three different positions (1, 2, 3 on Figure 5 b)

There are three plots in Figure 10. In the first and in the third plots the symmetrical magnetic field is shown. On the second plot decrease of the value of the magnetic field exists in the place, there is asymmetry (hole) in the structure. This data does not indicate about any asymmetries field mode, but show, that connectors in combination with hole produce field distortions exactly at this angle.

The relative difference between C(2)-1 and C(2)-2 values (Figure 10) equals 0,04%. The relative difference between C(2)-2 value and mean value of symmetrical model at the second position is 0,0013%.

3.5.2 Simulations of modified transitions

There were used 4 rotated coils (Figure 8 b) instead of transitions. The coils have the same radius, current, and position, but another shape (Figure 3 a).

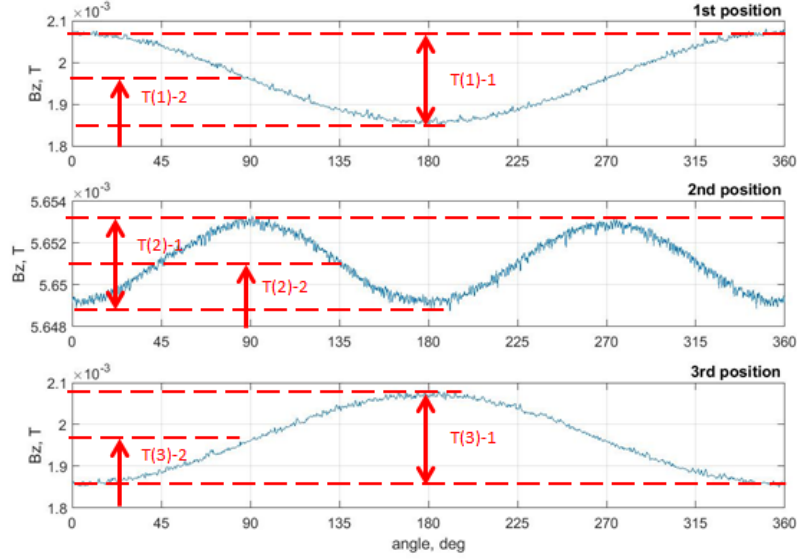


Figure 11: Z-component of magnetic fields of transitions projected to the circle with the biggest radius at three different positions (1, 2, 3 on Figure 5 b). T(1)-2, T(2)-2, T(3)-2 are average values.

Clear dipole components of the magnetic field are in the first and the third plots (Figure 11). The second plot shows clear quadrupole component.

The relative difference between T(1)-1 and T(1)-2 values (T(3)-1 and T(3)-2) equals 10,3%. The relative difference between T(1)-2 T(3)-2 value and mean value of symmetrical model at the first (third) position is 0,4%.

The relative difference between T(2)-1 and T(2)-2 values equals 0,08%. The relative difference between T(2)-2 value and mean value of symmetrical model at the second position is 0,003%.

Comparison of magnetic fields for one spiral turn and one rotated coil

In order to find the difference between a turn of spiral and rotated coil, there were performed simulations for test models. For the model was chosen equal boundaries and equal current (10 A) for the coil and the spiral. The coil rotation was adjusted so, that coil copies spiral shape as close as possible (upper half of the model coincide).

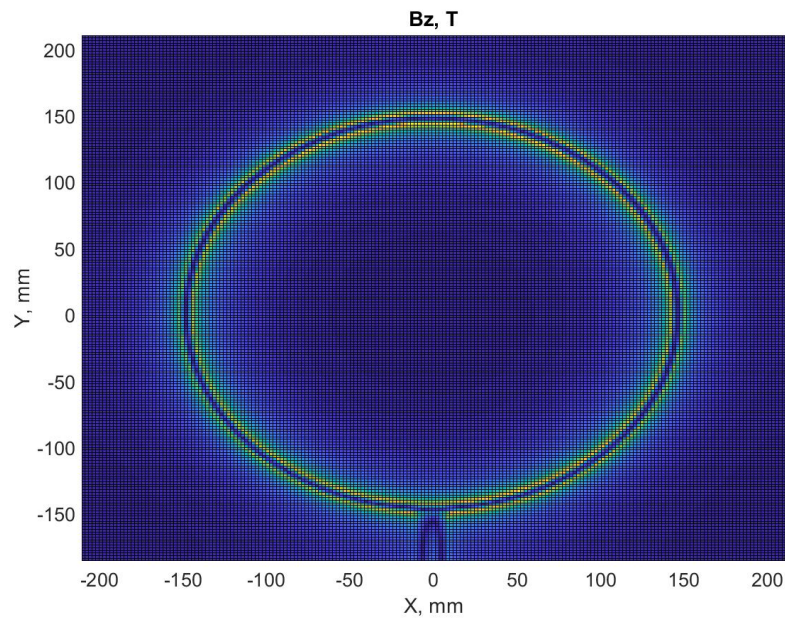


Figure 12: The difference between Z-component of magnetic field of coil and spiral in surface perpendicular the Z-axis in the point equals 0

MATLAB [7] application was used to find the difference between magnetic fields of a spiral and a rotated coil models. The script in MatLab takes data from CST in ASCII format and give 2D-plot (Figure 12). The results are not completely the same due to shape difference, but in the upper part of geometry (angles from 12,5 to 347,5 degrees), the results might be considered as reasonably correct.

4 Conclusions

Solenoid for the PITZ RF gun was considered and simulated. The simulated model has different asymmetries inside the structure. They are connected with transitions in the middle, connectors on an outer level and the hole in the shield. These asymmetries influence on the asymmetry of the magnetic field. The complicated structure was split into three models: 4 transitions, connectors and symmetrical part with coils instead of wires.

Success in simulations is connected with the right choice of the mesh. After many attempts mesh was chosen and there were received 1D – plots with distribution magnetic field inside the structure. It was chosen three different positions with three circles with different radius.

All three plots for the symmetrical model show constant values of the field vs. angle (with noise). This result says that the magnetic field inside structure is symmetrical and homogenous .

There is the symmetrical magnetic field for connectors in the first and the third plots. On the second plot decrease of the value of the magnetic field exists in the place, where asymmetry (hole) is in the structure. This data does not indicate about any asymmetries field mode, but the fact, that connectors in combination with hole produce field distortions exactly at this angle.

Clear dipole components of the magnetic field for transitions are on the first and the third plots on Figure 11. Clear quadrupole component is visible on the second plot.

Outlook

The results of this work are dedicated to a better understanding of the PITZ RF gun operation. The conclusion of the performed investigations will be taken as an input for further more detailed studies of the electron beam asymmetry at PITZ.

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