Modeling of the PXIE Solenoid Correctors with 3D Fields

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Abstract

This document presents the modeling of the PXIE solenoid correctors with the beam dynamics codes TRACK and TRACEWIN using 3D fields from Microwave Studio. Measurements of beam positions and angles taken during the conditioning of the PXIE LEBT are also presented in this document and compared with the predictions from the codes.

1 Microwave Studio model of the correctors

A 3D model of the PXIE solenoid and correctors have been implemented in Microwave Studio (MWS) [1]. The purpose of such modelling was to extract the 3D fields of the solenoids and correctors from MWS for implementation in the simulation codes TRACK [2] and TRACEWIN [3]. Together with the use of 3D space charge routines, implementation of 3D fields in the codes lead to full 3D simulations of the LEBT.

Figure 1 shows the solenoid and correctors as implemented in MWS. A detail description of these devices is presented in Ref. [4]. We report on this document only their main characteristics. The solenoid has an inner diameter of 80 mm and an outer diameter of 400 mm for a total physical length (coil and yoke) of 140 mm. At a maximum current of 300 A the measured solenoid field integral $\int B_z^2 dz$ is 0.03445 T^2m for a peak field B_z of 6.2 kG. Each solenoid includes a pair of correctors within its bore as shown in Figure 1. The correctors are dipole magnets with a racetrack shape of about 2 mm tick covering the total length of the solenoid. The horizontal correctors are installed in the top and bottom of the solenoid core at about 1 mm from its inner diameter. The vertical correctors are positioned on the right and left, flushing the inner diameter of the horizontal correctors by 1 mm. At a maximum current of 12 A, the measured field integral $\int B\, dl$ for the horizontal and vertical correctors is 4.845×10^{-4} T m.

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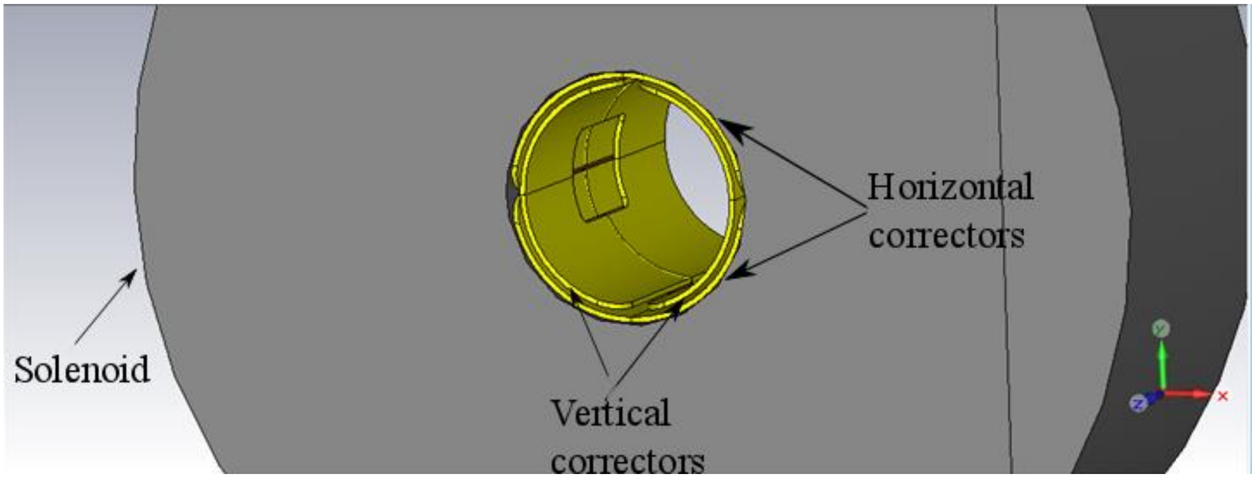

Figure 1: PXIE solenoid as implemented in MWS with the Horizontal correctors (two outer racetracks) and Vertical correctors (two inner racetracks).

2 Implementation of the 3D fields into TRACK and TRACEWIN

The MWS fields from the solenoid and correctors were generated on a grid of 40 cm longitudinally (+/- 20 cm from the solenoid middle) and 8 cm transversely (+/- 4 cm horizontally and vertically). The field was output at a step of 1 mm longitudinally and 3.3 mm transversely, leading to a field grid from MWS of 201×25×25 points. The TRACK input fields were generated using an executable provided by ANL, which reads MWS 3D output fields and converts them into TRACK 3D inputs fields. The 3D fields for TRACEWIN were created using a simple Matlab macro, which reads TRACK 3D fields and converts them into TRACEWIN format. The input field in the codes have been normalized to match the measured solenoid and corrector field integrals mentioned in the previous section. Figure 2 shows the measured normalized field profile along one of the PXIE solenoid and the overall good agreement with the simulated field from MWS. We made polarity measurement on each corrector and solenoid and found that with a positive current on the horizontal corrector the field is oriented down and with a positive current on the vertical corrector the field is oriented left. The solenoid field points in the direction of the beam. The fields have also been implement in the codes to match the measured field polarity. A detailed field profile measurement has not been recorded for the corrector fields, as a consequence Figure 2 simply shows the MWS vertical field produced by the horizontal correctors as implemented in the codes.

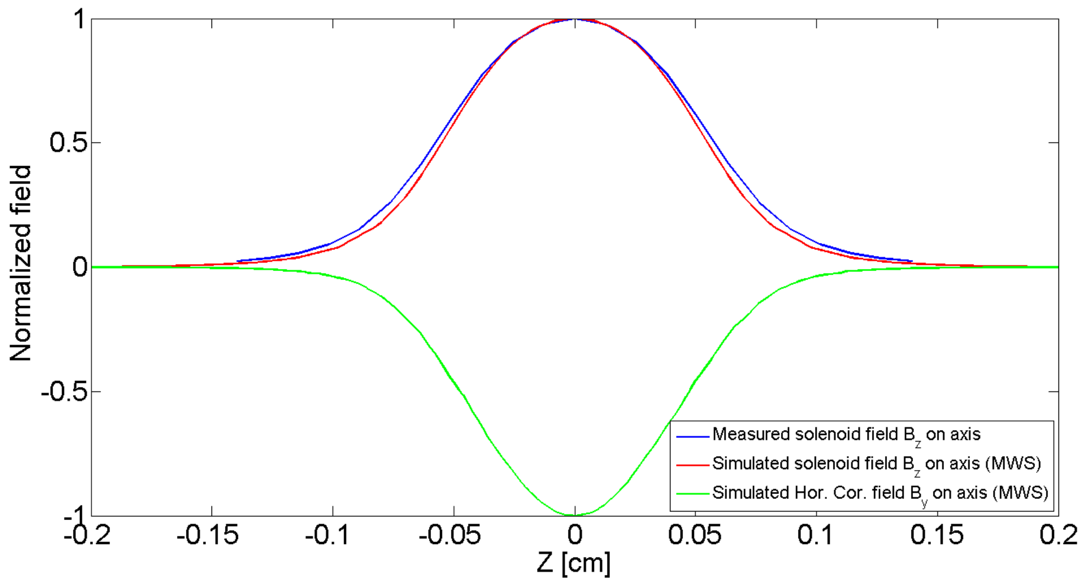

Figure 2: Measured and simulated field on axis for the solenoid and Simulated vertical field on axis for the horizontal corrector. Fields are normalized and simulations are from MWS.

3 Beam position correction: A simple model Vs a 3D model

Figure 3 shows the predicted beam horizontal and vertical displacement from TRACK at 70.7 cm from the solenoid middle for a field on the horizontal corrector of +10 A and no current on the vertical corrector. We can see in this figure that, for a given corrector strength, the vertical displacement gets larger with the solenoid field while the horizontal displacement gets smaller. When the solenoid field is set at zero current and the horizontal corrector at +10 A, TRACK predicts a pure horizontal displacement of 11.43 cm, in excellent agreement with the prediction from a simple model.

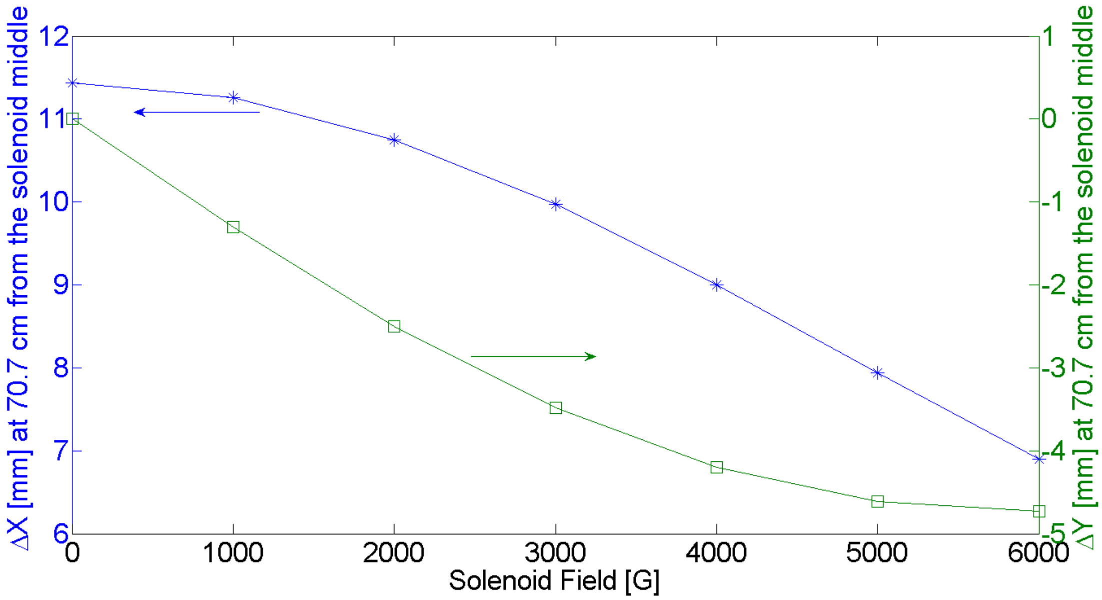

Figure 3: Horizontal and Vertical displacement as a function of the solenoid field at 70.7 cm from the solenoid middle and for a current in the horizontal corrector of +10A. The vertical corrector has no current. From TRACK.

In fact, the deflection angle of a corrector magnet is related to the magnetic field by the equation

$$\theta[mrad] = \frac{0.3 \cdot B[Gauss] \cdot L_{eff}[cm]}{p[\frac{MeV}{c}]}$$

which for a field integral of 403.75 G.cm (corresponding to +10A in the corrector) lead to an horizontal displacement of $\Delta x = 11.42$ mm at 70.7 cm for a 30 keV H- beam. When the solenoid field is increased between 3000 to 5000 Gauss (typical operation of the solenoids between 150A to 250A) then Figure 3 predicts a corresponding horizontal motion of about 10 mm to 8 mm, which is about 10% to 30% lower than predicted by the simple model. As a consequence, the simple model abovementioned was found to be inappropriate for precise beam positioning in the PXIE LEBT. Following the TRACK simulations presented in Figure 3, a tool has been developed allowing, for every current in the solenoid, a pure horizontal or vertical motion of the beam by the proper adjustment of the current in both the horizontal and vertical correctors. Figure 4 shows the excellent agreement between the measured horizontal beam displacement at the Allison Scanner (located 41.51 cm downstream from the middle of solenoid 3) and the predictions from TRACK for a current in solenoid 3 of 300 A. The results presented in Figure 4 allow us to conclude that the tool we have developed using TRACK and 3D fields for the solenoid and correctors enables the positioning of the beam with an estimated accuracy of about 1%.

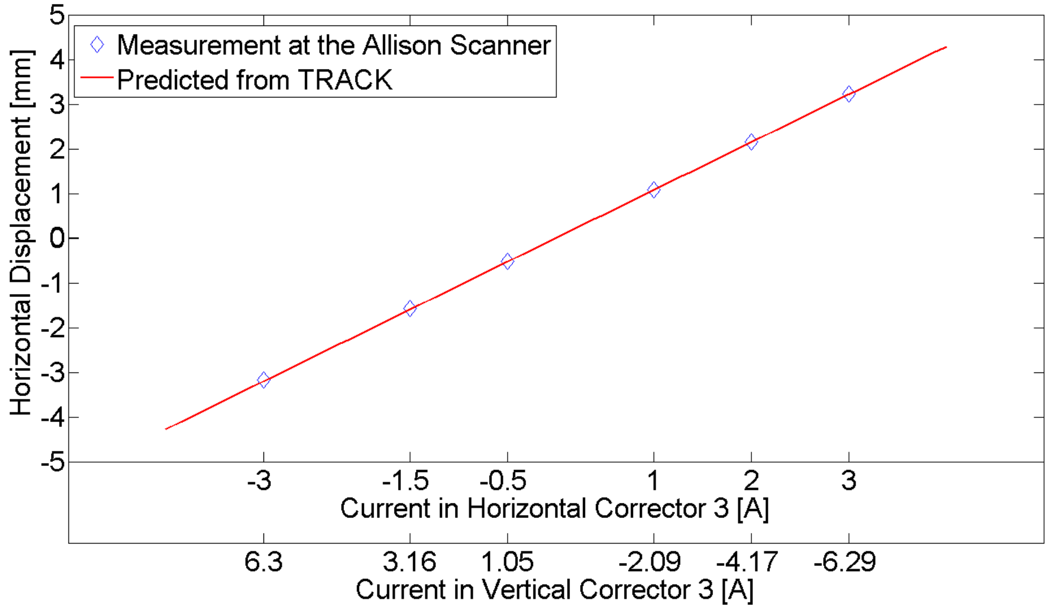

Figure 4: Measured (on 01292015) and predicted (from TRACK) horizontal beam displacement at the Allison Scanner for a current of 200 A in solenoid 3.

4 Beam angle correction

In preparation for the operation of the RFQ, we tested a tool on June 2nd, 2015 that uses the correctors of solenoid 2 and 3 to adjust at a desired value the beam deflection angle on the Allison Scanner (located 52.54 cm downstream of the middle of solenoid 3) while keeping its position at the LEBT scrapers (located just downstream of solenoid 3) unchanged. This tool has been developed using the matching procedure of TRACEWIN to find the correct values to set on the 4 correctors to allow for a beam deflection angle of +20 mrad at the Allison Scanner with a constraint to not move the beam at the LEBT scrapers. Once the corrector values for +20 mrad found, we checked this tool for beam angles of +10 mrad, -10 mrad and -20 mrad. Results for the measured and predicted beam angle at the Allison Scanner are reported on Figure 5 for a current on solenoid 2 of 158 A and on solenoid 3 of 253 A. During these measurement, we did measure the beam position using LEBT scraper scans and we found that the beam was standing still at the LEBT scrapers, as expected. Concerning the beam angle at the Allison Scanner and based on the results reported on Figure 5, we conclude that the measured beam angles agree within 10% with the predictions from TRACEWIN.

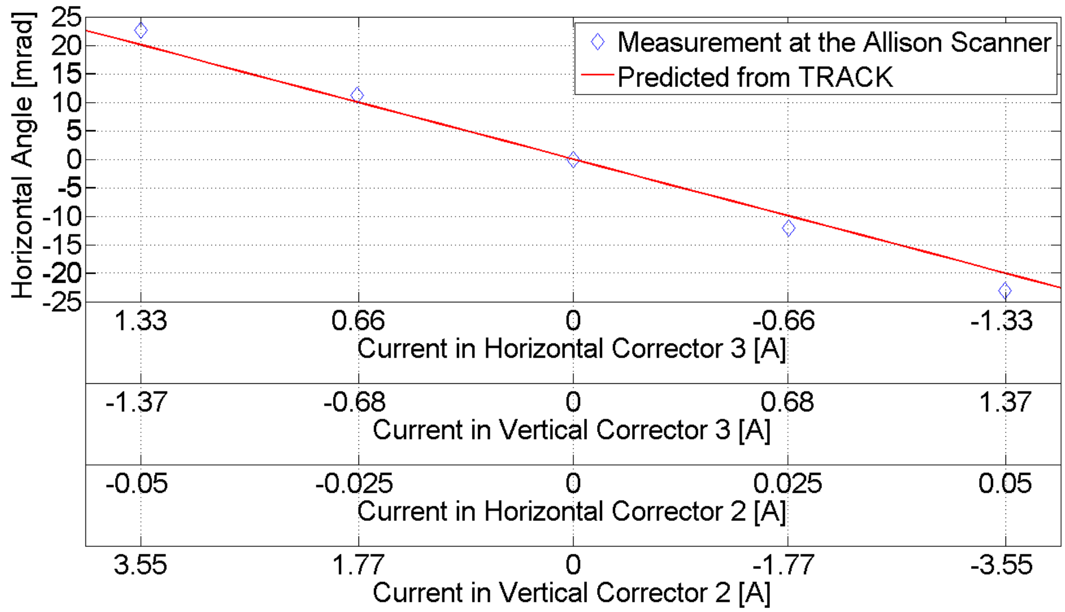

Figure 5: Measured (on 0602015) and predicted (from TRACK) horizontal beam angle at the Allison Scanner for a current of 158 A in solenoid 2 and 253 A in solenoid 3.

5 Conclusion

The solenoid and corrector fields are now implemented into the beam dynamics codes TRACK and TRACEWIN using 3D fields from MWS. We found this tool to be particularly efficient for the correction of the beam position and angle. We have measured the correction in the beam position to be in the order of 1% compared to the predicted one from the codes. Concerning the correction in the beam angle, we measured beam angles to be within 10% of the codes predictions.

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