BEAM DYNAMICS STUDIES OF THE HIE-ISOLDE TRANSFER LINES IN THE PRESENCE OF MAGNETIC STRAY FIELDS

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Abstract

The ISOLDE facility at CERN produces radioactive isotopes far from stability for fundamental nuclear physics research. The radioactive beams are accelerated to high-energy using a post-accelerator before being transferred for study in different experiments at the end of a network of High Energy Beam Transfer (HEBT) lines. In the framework of the HIE-ISOLDE project, the energy of post-accelerated beams is to be increased to over 10 MeV/u and new experimental detectors are being proposed for installation to exploit the new energy regime. The stray magnetic fields associated with many of the new detectors will distort the beam trajectories in the HEBT, potentially affecting the transmission of the low intensity beams delivered to the experiments. In this contribution, the influence on the HEBT of the stray field of the proposed ISOL Solenoidal Spectrometer (ISS) is discussed, correction schemes described and shielding options assessed.

INTRODUCTION

Since the completion of the first stage of the HIE-ISOLDE project, post-accelerated beams with energies of up to 5.5 MeV/u have been made available and delivered with an atomic mass-over-charge ratio of up to $A/q = 4.3$ to two experimental beam lines XT01 and XT02. In the next stage a third beam line is being installed and the XT02 line extended to accommodate the new ISOL Solenoid Spectrometer, see Fig. 1. In the scope of this paper, the influence of the stray field of the ISS magnet along the third HEBT line as a function of beam energy and A/q was investigated. Earlier approximate studies showed that the beam transfer can be ensured for stray magnetic fields of less than 5 G at the location of the beam lines [2]. Latest 3D simulations of the solenoid using the coil geometry provided by the manufacturer with its optimised magnetic shielding are shown in Fig. 2.

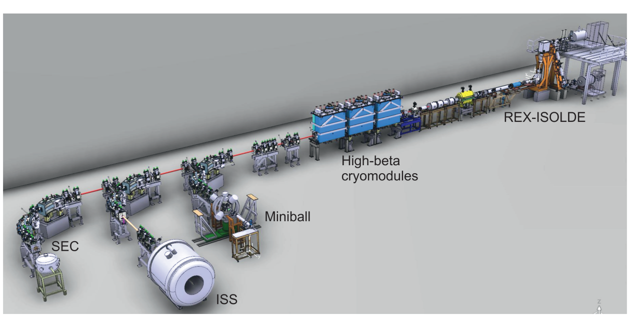

Figure 1: A 3D visual of the HIE-ISOLDE linac, composed of three cryomodules, and the three experimental stations in the HEBT. At the end of the first beam line, XT01, Miniball is located, at the second, XT02, the ISOL Solenoidal Spectrometer, ISS, and the third, XT03, is reserved for movable setups. In the drawing, XT03 is occupied by the scattering chamber, SEC, which is presently connected to XT02. [1]

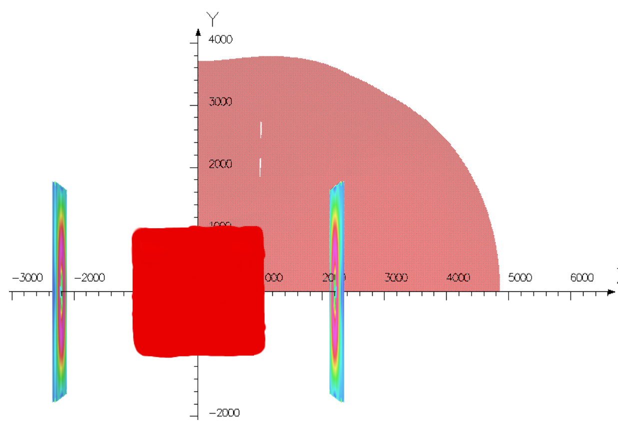

Figure 2: 3D simulations of the solenoid's magnetic field with the latest magnetic shielding design. In addition, the envelope of the 5 G limit around the ISS magnet is shown in light red.

The shielding design has been modified with two ferromagnetic plates separated by a gap, which makes it lighter and further attenuates the field along the beam axis, with the main objective being to contain a 100 G limit within the envelope for personnel safety. The envelope of the 5 G limit around the ISS magnet at XT02 extends to approximately 5 m longitudinally and 4 m transversely. XT01 and XT03 are at 5.24 m and 5.04 m distance from XT02, respectively. Hence, they are located outside the area, where the ISS stray magnetic field exceeds 5 G. The beam delivery to XT03 in the case of no magnetic shielding was investigated as a worst-case scenario and to understand the impact of the operation of the ISS on the adjacent beam line.

OPTICS AND MAGNETIC MODEL

The latest beam line design from the post-accelerator up to the end of XT03 was implemented in MADX [3]. The corresponding optical functions and the respective beam sizes based on the emittances given in [4] along XT03 are presented in Fig. 3, where the dashed lines indicate the minimum available aperture given by the quadrupoles.

The magnetic field was exported from the 3D field simulation every 10 cm throughout the HEBT lines. The integrated transverse field components (B_x, B_y) were translated into

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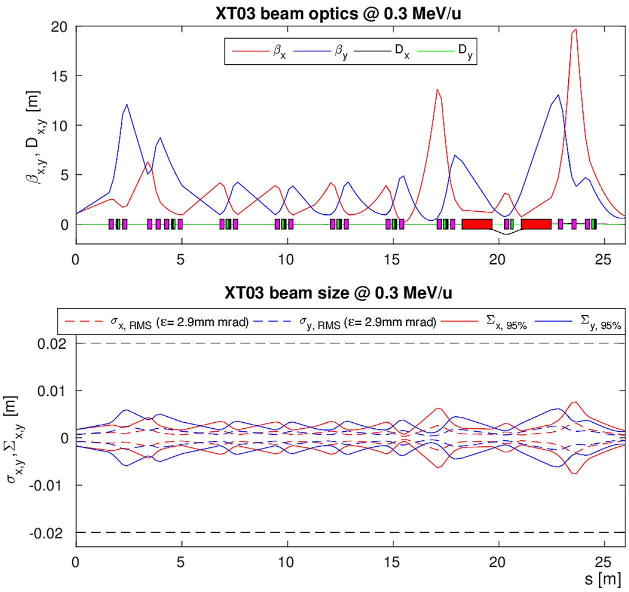

Figure 3: Optics and beam sizes along XT03.

thin lens dipole kicks ($\alpha_{x,y}$), where possible, in-between existing equipment such that an equivalent integrated kick was imparted to the beam:

$$\alpha_{x,y} = \int \frac{B_{y,x}}{(B\rho)}\, dl \tag{1}$$

with $B\rho$ denoting beam rigidity.

EFFECTS ON BEAM TRANSFER

Three different effects relevant to the operation of the accelerator were studied, each for various kinetic beam energies ranging from 0.3 MeV/u to 5.9 MeV/u:

- First, the nominal transfer throughout XT03 with and without the presence of the ISS stray magnetic field, e.g. if the ISS is turned off due to a quench or maintenance at the experiment, was investigated.
- The second study takes into account that the intensity of most radioactive isotope beams is so low that they are effectively invisible to the available instrumentation in the transfer line. Thus, the setting-up is done using a pilot beam of a nearby A/q, which is observable. Then the LINAC and HEBT are scaled linearly to the target A/q. However, changing the A/q also changes the beam rigidity, which then can be more susceptible to the stray magnetic field.
- Finally, a comparison of the required steering strengths for compensating the stray magnetic field to the steering induced by random misalignment of the HEBT quadrupoles was done.

Ramping the ISS Magnet

The effect on the beam trajectory along XT03 due to turning the ISS magnet on and off is shown in Fig. 4. The RMS of beam positions measured at the 10 Beam Diagnostic

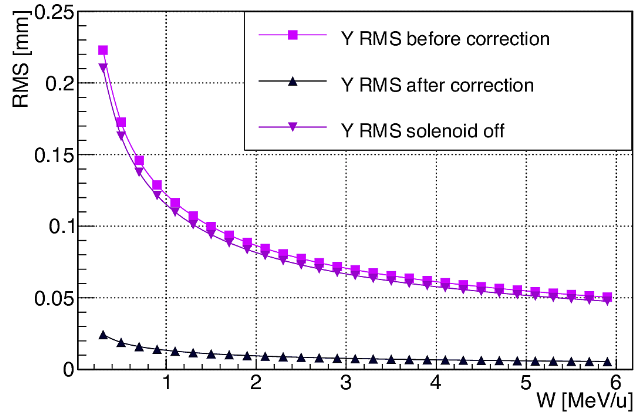

Figure 4: Energy dependent Y RMS measured on BPMs before and after correction as well as after turning the ISS magnet off.

Boxes (BDB) stays below 230 µm for all investigated beam energies for the case of the ISS magnet being on and no correction being applied. A maximum excursion of 1.1 mm is observed in the first quadrupole of the last triplet at an energy of 0.3 MeV/u, which corresponds to 0.18 σ, and the beam moves a maximum 110 µm at the location of the experiment (0.08 σ). At an energy of 5.5 MeV/u the maximum excursion is 0.08 σ and the offset at the target 0.03 σ. Correcting the trajectory using the MADX built-in MICADO and SVD techniques results in an RMS of below 30 µm along the line. The correction counteracts the stray field very well. Therefore, when the ISS magnet is ramped down and turned off the trajectory inverts in almost exactly the same amount as in the case with the solenoid on without correction.

A/q Scaling Study

To study the effect of scaling the HEBT the stray field was taken into account and the trajectory corrected for A/q = 4.5. Then the A/q of the beam was changed and the HEBT scaled accordingly, down to A/q = 2.0. The trajectory is perturbed because the stray field does not scale with the A/q of the beam, whereas the rigidity of the beam does. The results

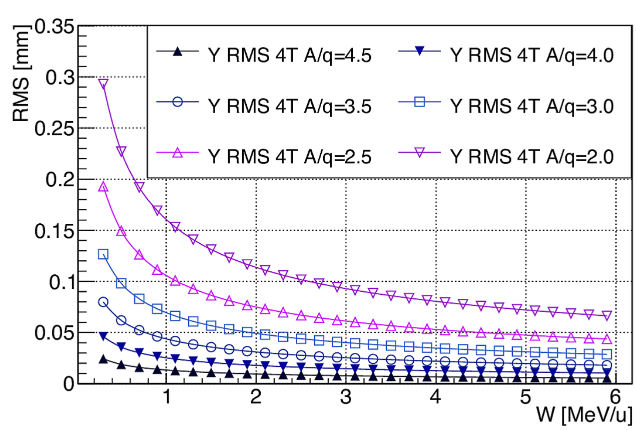

Figure 5: Energy dependent Y RMS measured on BPMs after correction for the ISS magnetic stray field at A/q = 4.5 and various scaling of A/q.

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are presented in Fig. 5. It was found that even for a very large scaling of $A/q = 2$, the trajectory RMS does not exceed 300 µm. A maximum excursion of 1.3 mm is observed in the first quadrupole of the last triplet for $A/q = 2$ at an energy of 0.3 MeV/u, which corresponds to 0.22 σ, and the beam moves at maximum 150 µm at the location of the experiment (0.11 σ). At an energy of 5.5 MeV/u the maximum excursion is 0.10 σ and the offset at the target 0.05 σ.

Misalignment Studies

Two cases were investigated, a gaussian distributed misalignment of $\sigma_y = 0.1$ mm and one of $\sigma_y = 0.2$ mm [5]. The distorted trajectories with and without the ISS magnetic stray field were corrected for 200 error seeds. Figure 6 shows the resulting corrector settings for seven correctors from the post-accelerator to the experimental station on XT03 for the case of $\sigma_y = 0.1$ mm misalignment at the lowest beam energy. The effect of the stray field manifests itself as a systematic shift in the corrector strengths required to correct for both the stray field and quadrupole misalignments. The required deflection angles in all cases are below 0.8 mrad at an energy of 0.3 MeV/u, which is well within the specifications of the correctors [6]. The effect is less pronounced for higher energies.

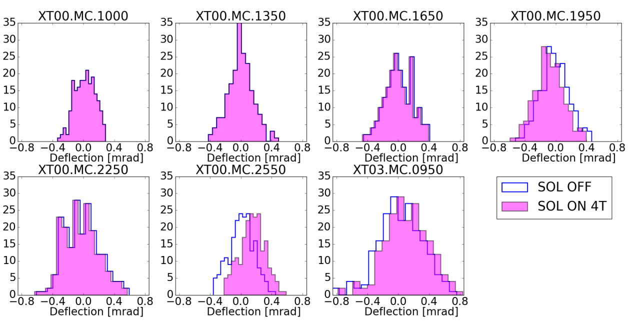


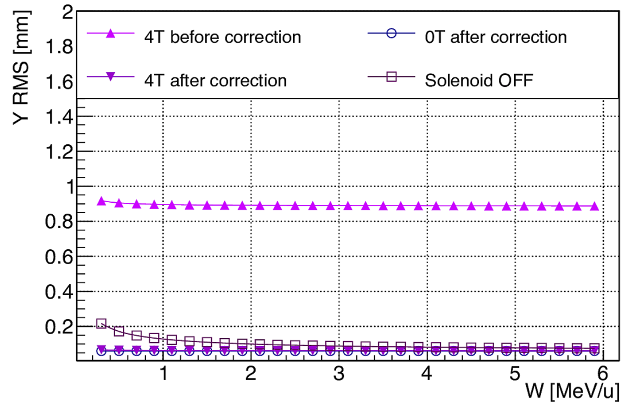
Figure 6: Corrector settings along XT00 and XT03 for $\sigma_y = 0.1$ mm misalignment of the quadrupoles with and without the presence of the ISS magnetic stray field for a beam energy of 0.3 MeV/u.

The contribution of the quadrupole misalignment to the trajectory distortion dominates the contribution of the magnetic stray field, as can be seen from Fig. 7. Nevertheless, misalignment is static, whereas the magnet status (on/off) can change during operation. As already shown in Fig. 4 the effect of ramping the ISS magnet on the trajectory RMS is at most around 230 µm, independent of misalignment.

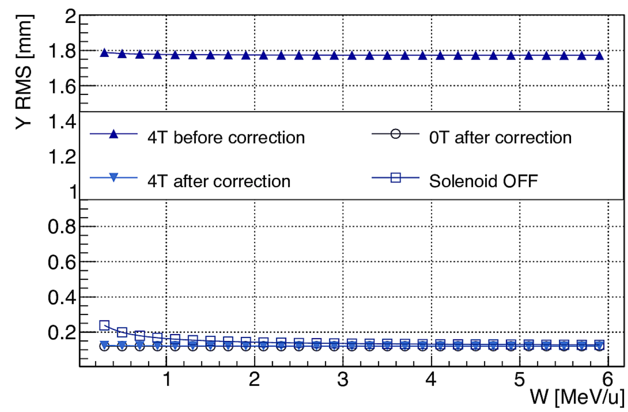
In addition, the influence of misalignment of the ISS magnet was investigated. The additional calculated trajectory excursion in X due to the off-axis field, however, would be still two orders of magnitude smaller than any excursion shown above.

CONCLUSION

In order to ensure stable operation of the HEBT lines the influence of the ISS magnetic stray field and quadrupole misalignment on the beam transport along the XT03 line has been investigated. It was found that the stray field does



(a)



(b)

Figure 7: Energy dependent Y RMS measured on BPMs over all seeds for (a) $\sigma_y = 0.1$ mm and (b) $\sigma_y = 0.2$ mm misalignment of the quadrupoles in XT00 and XT03.

influence the beam trajectory, but the maximum expected excursion as well as the offset at the experimental station are smaller than a quarter of the beam size at those locations. A move of 0.11 σ at the experiment is not negligible, but this is only an issue at low energy and can be controlled by procedures, e.g. ensuring no change of the ISS magnet status during low energy beam operation. The reduction of the stray field due to the latest shielding design still remains to be checked.

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