ALIGNMENT AND MAGNET ERROR TOLERANCES FOR THE HIGH ENERGY BEAM TRANSPORT LINE OF THE IFMIF-EVEDA ACCELERATOR*

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Abstract

A High Energy Beam Transport line (HEBT) has been designed for the IFMIF-EVEDA accelerator to drive the beam toward a beam dump with the required expansion, under the hands-on maintenance constraint. It consists of eight quadrupoles and one dipole. Given the very high space charge regime and the very high power (1.1 MW), any small deviation from the nominal conditions could seriously compromise the HEBT objective. That is why possible misalignments and rotations of the magnets as well as power supply errors have been thoroughly studied. The error budget is fairly distributed among the tolerances for the different components, and effects of those errors on loss distribution and beam profile at the beam dump entrance carefully analysed.

INTRODUCTION

The mission of IFMIF (International Fusion Materials Irradiation Facility) is to provide an accelerator-based D-Li neutron source producing high energy neutrons to test samples of candidate materials in fusion energy reactors [1]. To demonstrate the high current operation of the accelerator and validate the design of its components, a 9 MeV, 125 mA cw deuteron accelerator (IFMIF-EVEDA) is being designed [2]. It consists of an injection section, a RFQ, a matching section and a superconducting linac based on half wave resonator cavities. The so called High Energy Beam Transport (HEBT) line, which is the subject of the present document, drives the beam from the linac exit to the beam dump.

HEBT LAYOUT

In order to satisfy the different requirements of the HEBT of IFMIF-EVEDA [3], the following elements have been considered (see Figure 1) :

- A quadrupole triplet at the beginning of the line, in order to control the beam at the output of the superconducting linac and to obtain optimum conditions for the beam transport along the diagnostic plate
- A 2.5 m diagnostic plate for the complete characterization of the beam.
- A quadrupole doublet, located after the diagnostic plate, to provide additional focusing, specially during the quadrupole scan emittance measurements
- A 20º bending magnet to reduce the neutron radiation backward from the beam dump onto the accelerator elements, allowing in this way beam energy spread measurements
- A last quadrupole triplet in a combination with a 2.6 m long drift to obtain the required beam conditions at the end of the HEBT for the safe operation of the beam dump (maximum power density around 200W/cm^2 and symmetric beam [4]).
- Horizontal and vertical dipolar correctors, located inside all the quadrupoles (except in the middle quadrupole of each triplet) to correct any beam centre deviations that could lead to losses along the HEBT as well as an increase of thermal stress at the beam dump. Two Beam Position Monitors (BPMs) located in each drift after the quad triplet or doublet are used for the beam alignment.

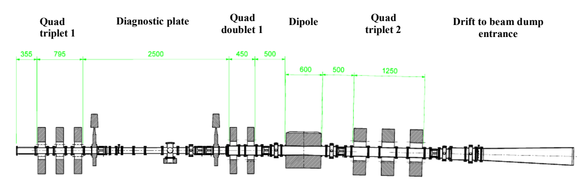

Figure 1:HEBT line projection on yz plane

BEAM DYNAMICS FOR NOMINAL CONDITIONS

In order to verify the overall architecture and matching, detailed beam dynamics calculations have been carried out with the code packages TraceWin/Partran [5]. A 3D space-charge routine with an optimum mesh has been used.

The HEBT input beam used in these simulations has been obtained from the transport of a Gaussian beam from the entrance of the RFQ to the exit of the superconducting linac. To be able to simulate losses of the order of 1W (that is 10^{-6} of the nominal power) per meter the simulation tools have to track a number of particle exceeding 10^6.

A matching has been performed along the HEBT to fulfil the different requirements. The resultant required magnetic fields at the pole for the different quadrupoles are lower than 0.6 T/m.

The rms envelopes along the HEBT for horizontal and vertical directions are shown in Fig. 2. Fig. 3 shows the transverse density and extension of the beam, and the radial space reserved for it (beam stay clear radius).

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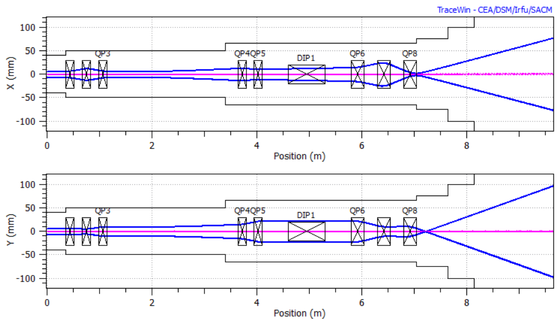

Figure 2: 3 RMS envelope along the HEBT line.

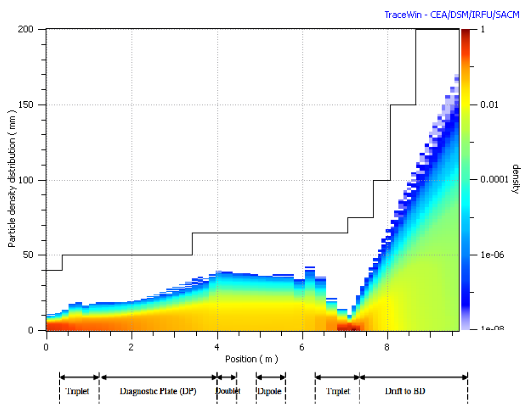

Figure 3: Particle density probability along the accelerator axis.

Studies with different input beams have shown the robustness of the HEBT line design, being able to transport properly the different beams, fulfilling the beam dump requirements in any case.

ERROR SIMULATIONS

Previous studies have been performed for an ideal situation in which all magnetic elements are perfectly aligned and power supplies do not have any random current variation. However errors will be present in the accelerator. In this section simulations of the following errors are presented:

- magnet displacements (mm) (x and y)
- magnet rotations along the x, y and z axis
- quadrupole gradient and bending magnet field errors

The goal of the error studies is two-fold:

- To define the manufacturing tolerances of the magnets
- To evaluate the robustness of the HEBT line design as a whole with respect to manufacturing errors, quadrupole rotation or displacement. The most important goal is to obtain the proper beam conditions for the beam dump power deposition without any losses along the line. Special attention must be paid to the maximum corrector strength.

More details about the error simulations can be found elsewhere [6].

Static errors

By static errors we understand time-independent (slow) errors. Some effects of these errors can be corrected, as for example those related to trajectory deviation using steerers.

In a first step of the study of static errors, the sensitivity of the HEBT to each type of error has been analyzed separately to evaluate its individual contribution. For each element of the line, the amplitude of the error is randomly generated in a uniform distribution within a given range. Afterwards, once the effect of each error type has been studied, an acceptable limit on each error is chosen, so that the effects on the trajectory deviations are about the same for all the error types. Finally, all errors within the given tolerances are combined simultaneously to verify the set of tolerances determined previously and to study the maximum beam size and overall degradation of the beam properties. In the case of beam losses or unacceptable trajectory deviations or steerer strengths, a global reduction factor would be allocated to all the errors.

After the different simulations and studies, the resulting tolerances for magnets are the following:

- Power supply tolerances for quadrupoles (dipole): ±2% (±0.1 %)
- Quadrupole (dipole) transverse displacement:±0.2 mm (3 mm)
- X-Y quadrupole (dipole) rotation: ±0.9º (±0.6º)
- Z quadrupole (dipole) rotation: ±0.3º (±0.6º)

Reasonable values are needed for steerers when all magnet errors are considered together. Small effects are observed on beam parameters. The rms and maximum values for steerer strengths and for beam position along the line are shown in Table 1. It has been found that the maximum values occur at the last triplet position.

Table 1: Summary of the effect of all combined quadrupole and dipole errors on beam position and on corrector strength

	x	**y**
RMS orbit (mm)	0.26	0.15
Max orbit (mm)	0.77	0.30
RMS steerer strength (G.m)	1.75	3.96
Max steerer strength (G.m)	6.84	18.39

Figure 4 represents the particle density probability in the presence of combined quadrupole and dipole errors, along with appropriate steerers. The whole beam remains inside the beam stay clear limit.

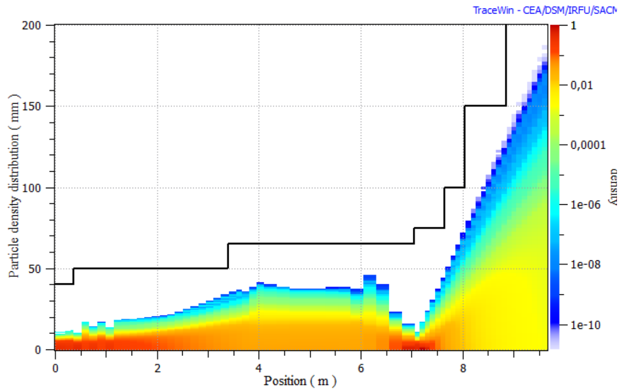

Figure 4: Particle density probability for combined quadrupole and dipole errors

BPM accuracy

In addition to the errors associated to magnets, an extra source of error comes from the BPM accuracy. Its effect on the beam correction along the HEBT line has been analyzed. Dipole and quadrupole static errors have been combined with BPM accuracy errors. The main effect of the finite BPM accuracy is the increase of the orbit position deviation in both transverse directions. The rms and maximum values of the required integrated magnetic field of steerers increase linearly with the BPM accuracy.

From the results and taking into account steerer strength and trajectory position, a value of 0.1 mm has been set as a reasonable accuracy requirement for the BPMs. However, there is some uncertainty about the accuracy that can be achieved on the BPMs located in the last drift of the HEBT, due to the beam debunching and the big vacuum chamber in that region. In addition, the reduced available space there, makes it impossible to locate the BPMS in the optimum position (as far as possible from each other and the last BPM close to the beam dump entrance). Therefore, the accuracy and position of the BPMs will have a big impact on the trajectory correction, imposing stronger steerers and higher beam deviations at the beam dump entrance. Studies on this matter are ongoing.

Dynamic errors

The study of dynamic errors (time-dependent, fast errors) has been performed assuming its magnitude to be a fraction of the values chosen in the static errors studied. Since dynamic errors cannot be corrected, no steerers are included in these simulations and trajectory deviation increases as the beam goes through the line, leading to maximum deviation at the input of the beam dump. Since the beam dump is quite sensitive to beam center deviations, it will be the limitative factor for dynamic errors. It has been found that dynamic errors must not exceed 2.5% of static errors. The comparison of the effect on beam trajectory of static and dynamic errors is shown in Figure 5.

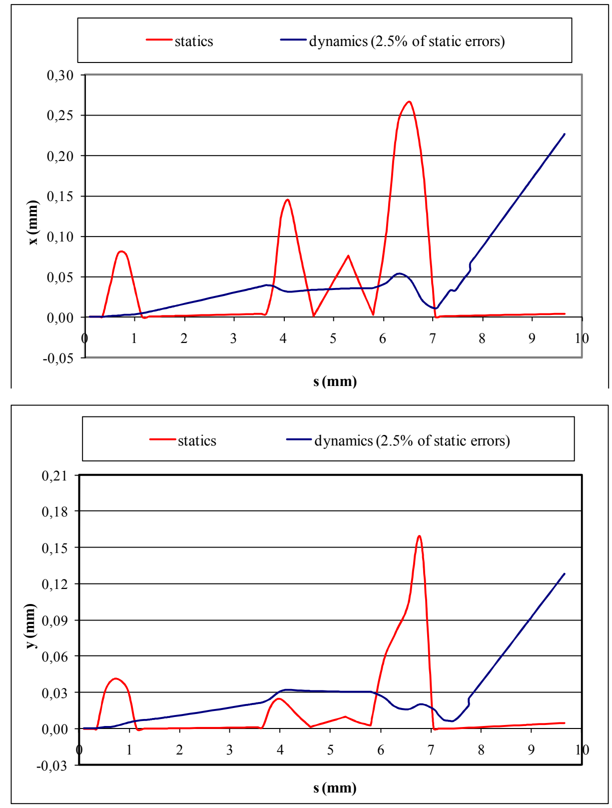

Figure 5: Comparison of the effect of static and dynamic errors on trajectory deviation

CONCLUSION

The strong requirements imposed by the minimization of losses along the HEBT and by the beam parameters at the beam dump entrance imposes a detailed study of possible errors along the HEBT. An analysis of static and dynamic errors has been performed for the HEBT of IFMIF-EVEDA accelerator. As a result, tolerances on magnet alignment and power supply requirements have been specified. Ongoing studies include the effect of BPM accuracy and position on beam correction, the start-to-end simulations for the whole IFMIF-EVEDA accelerator and the effect of realistic magnet field maps.

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