HIGH ENERGY BEAM TRANSPORT LINE FOR THE IFMIF-EVEDA ACCELERATOR

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Abstract

The IFMIF-EVEDA accelerator [1] will be a 9 MeV, 125 mA cw deuteron accelerator which will verify the validity of the design of the future IFMIF accelerator [2]. A transport line is necessary to handle the high current beam from the DTL exit up to the beam dump. This line must produce the beam expansion to obtain an acceptable power density at the beam dump. Therefore the design of the transport line must consider the geometry and power handling capacity of the beam dump, the space requirements for diagnostics and the restrictions on the maximum length of the line. In addition, a bending magnet is required in order to avoid excessive irradiation of the diagnostics and line elements by neutrons and gammas produced at the beam dump and to perform energy spread measurements. In this contribution, the preliminary design of the high energy beam transport line will be presented. The results of a sensitivity study to the input beam and line elements errors will also be discussed.

INTRODUCTION

The mission of IFMIF (International Fusion Materials Irradiation Facility) is to provide an accelerator-based D-Li neutron source to produce high energy neutrons (40 MeV) at sufficient intensity (250 mA) and an irradiation volume to test samples of candidate materials in fusion energy reactors [2]. An Engineering Validation and Engineering Design Activities phase (EVEDA) of IFMIF is proposed to demonstrate the high current operation of the accelerator and the reliability of the different components. The EVEDA phase includes the construction, installation, commissioning and test beam of the low energy (up to 9 MeV) components (including ion source, the low energy beam transport system (LEBT), RFQ, the Medium Energy Beam Transport line (MEBT), a superconducting cavity HWR, the High Energy Beam Transport line (HEBT), the beam dump, control systems, diagnostics and RF power supplies) of the IFMIF accelerator. Further details can be found in [1].

REQUIREMENTS

The High Energy Beam Transport (HEBT) for IFMIF-EVEDA must meet the following requirements:

- Beam matching to the beam dump: the beam coming from the MEBT or from the HWR (depending on the commissioning phase) must be transported to the beam dump.
- Beam expansion. Due to the high beam power, the beam must be expanded to reduce the power density in the beam dump to acceptable levels [3]. For this purpose quadrupoles will be used.
- Space for diagnostics equipment. Some diagnostics [4] must be inserted in the line to characterize the beam coming from the accelerator.
- Reduction of the backscattering radiation coming from the beam dump to avoid damage in upstream accelerator components; for that purpose, the HEBT must be tilted, inserting a bending magnet
- Minimization of beam losses. We have to minimize beam halo generation to avoid the beam to be scraped off in the beam line. Additionally, enough space between the rms beam sizes and the beam pipe radius has to be required
- Robustness of transmission efficiency to beam or quadrupole errors. The beam parameters must be within the safe operating range of the beamstop.

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Input Parameters

The input parameters in the HEBT design are the beam parameters at the MEBT or HWR output, which are shown in Table 1. Further details can be found in [5]. In this paper only the commissioning of HWR with solenoids is analysed in detail.

Table 1: Beam Parameters

Parameter	MEBT output	HWR output
Energy	5 MeV	9 MeV
Current	127.9 mA	127.4 mA
ε_x (rms-norm.)	0.307 mm·mrad	0.319 mm·mrad
ε_y (rms-norm.)	0.300 mm·mrad	0.326 mm·mrad
ε_z (rms-norm.)	0.498 mm·mrad	0.504 mm·mrad
Xsize (rms)	2.56 mm	2.67 mm
Ysize (rms)	2.64 mm	2.76 mm
Wsize (rms)	56.7 keV	37.52keV

BEAM DYNAMICS DESIGN

To design the beamline, the code TraceWin/PARTRAN [6] has been used in order to perform particle simulations which can take into account details in the phase-space distributions and nonlinear space-charge forces.

To characterize the beam coming from upstream accelerator components, a 3 m long Diagnostic Plate (DP) [4] must be inserted in the line. A triplet of quadrupoles is located at the input of the HEBT (between the HWR output and the diagnostic plate) to match the beam in the entrance of the DP. A compromise between small beam size, which would lead to halo and therefore losses, and bigger size, which would requires larger vacuum chamber must be achieved. The positions of triplet quadrupoles are fixed, providing enough space for steerers and diagnostics

An important beam parameter to be measured in the DP is the transverse emittance. A non-interceptive quadrupole scan technique [7] is considered, which consists in varying the quadrupole gradients in order to produce and measure enough size variation in a given location of the line. By fitting these measurements to the solution of the envelope equations, the Twiss parameters and the transverse emittances are obtained. The space charge is not negligible and therefore the formalism of linear transformation matrix is no longer valid. However, the emittance and the Twiss parameters can be obtained by fitting the measurements to the results of a particle tracking code, which is able to handle the space charge. Other alternative could be to solve the envelope equations with the assumption that the space charge force can be linearized [8].

In the quadrupole scan technique, to obtain a good emittance resolution the measurement should be performed around a waist. However in our case the size of this waist can not be too small since they would produce some halo (due to the space charge) and therefore some losses downstream.

For the emittance measurement in the horizontal transverse direction the last quadrupole of the triplet is changed, keeping the rest of the triplet quadrupoles fixed. For the measurement of the vertical transverse emittance the first one is changed, keeping the other two fixed to the values needed to avoid losses. In Fig.1 the quadrupole scan is shown. The size should be measured at the end of the DP in order to obtain higher resolution.

The emittances are planned to be measured at nominal conditions (full current and duty cycle). That means that the variation of beam size produced during the quadrupole scan has to be corrected to be sure that the beam can be transmitted without losses up to the BD. For this purpose, a doublet of quadrupoles must be inserted just after the DP.

Bending Magnet

The backscattering radiation coming from the beam dump would damage the upstream diagnostics and accelerator components. To avoid this, a bending magnet will be inserted in the line after the quadrupole doublet. The bending angle must be chosen taking into account several factors:

- Reduction of the backscattering radiation [5].
- Energy spread measurement in the dispersive area.
- Building dimensions.

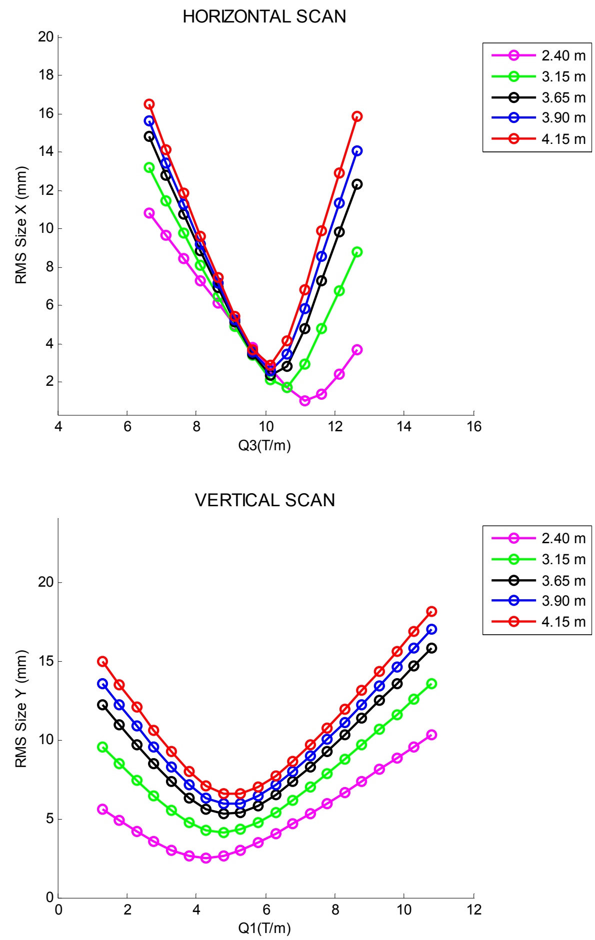

Figure 1: Quadrupole scan for transverse emittance measurement. RMS beam size as a function of the quadrupole gradients (first quadrupole for the horizontal direction and third for the vertical one). The different curves show the rms sizes at different locations from the input of the HEBT.

A 20º dipole was finally chosen. The curvature radius is 2 m and standard fringe-field estimation is used. The dipole length is about 700 mm and its radius aperture is 75 mm. A hard-edge approximation is used so far, but realistic simulations will be carried out hereafter.

Beam Conditions at the Beam Dump Input

Due to the high beam power (>1 MW), a careful design of the HEBT has to be performed in order to ensure that the beam dump will withstand the deposited beam power in all the working beam conditions. The main aspects to be taken into account are:

- A big beam size and a big BD aperture are required in the beam dump entrance in order to reduce the beam power density on it. However, the activation and the backscattering radiation from the BD impose a small aperture. Therefore a compromise must be achieved.

- The beam divergence at the input of the beam dump is also important, since the longitudinal position of the density power peak will depend on it [3]. It is desirable to have a large divergence to decrease the peak power density.
- The magnetic field of the quadrupoles is limited to 0.85 T to avoid the use of superconducting magnets.
- Symmetry in both transverse directions is very important to avoid thermal stress in the material of the beam dump. That means that an equal size and equal divergence in both directions are required.

Taking into account all these requirements, the final choice for the beam conditions in the beam dump entrance has been 40 mm for the beam rms size and 16 mrad for the rms beam divergence. A beam dump with conical geometry, 150 mm radius and 2.5 m length is considered in our studies. Further details about the beam dump design can be found in [3].

The final HEBT line is shown in Fig. 2. The particle density probability, Fig. 3, shows enough space between the beam and the vacuum chamber. The emittance and the halo are shown in Fig. 4

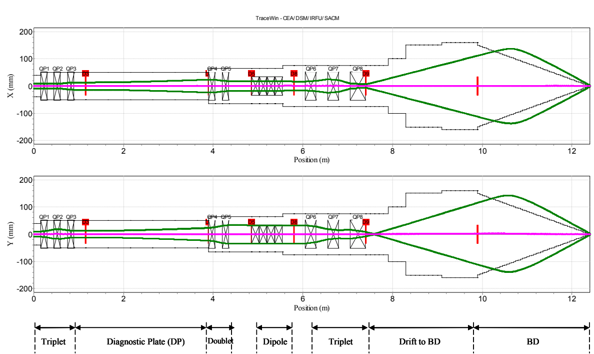

Figure 2: 3 RMS envelope for HEBT line.

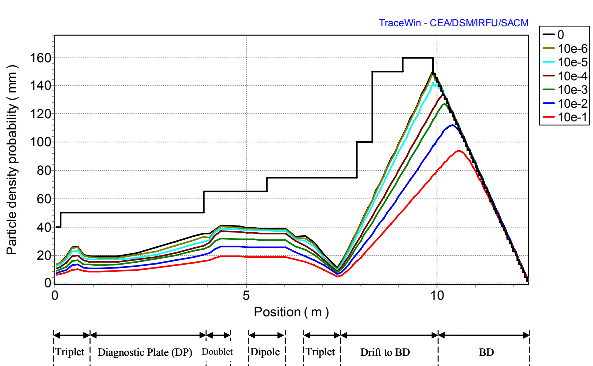

Figure 3: Particle density probability as a function of the accelerator axis.

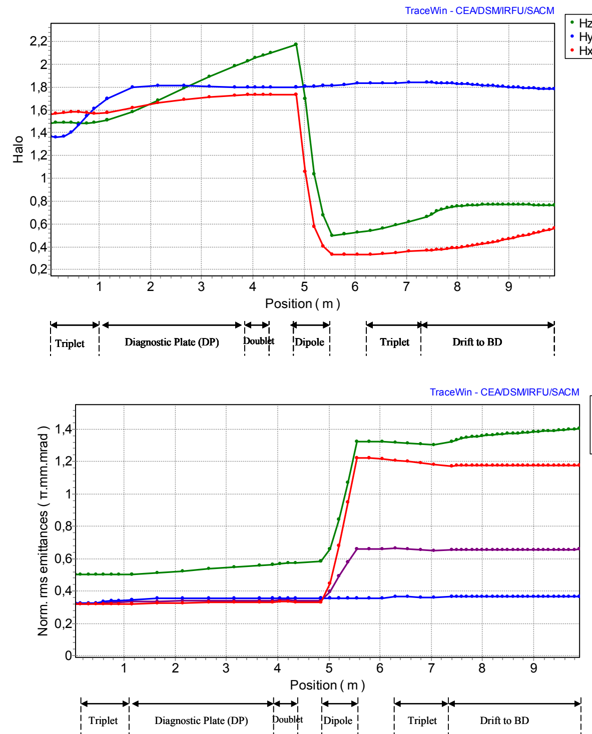

Figure 4: Halo (up) and normalized rms emittance (bottom) in the HEBT. X and y are the transverse coordinates whereas z is the longitudinal one.

CONCLUSION

The High Energy Beam Transport line of the IFMIF-EVEDA plays a key role for the characterization of the upstream beam and for the correct power deposition on the beam dump. A preliminary design of the HEBT has been shown in this paper taking into account the more important aspects. Further studies must be performed to optimize the design for the RFQ/MEBT commissioning and to include errors.

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