ACCURACY DETERMINATION OF THE ESS MEBT EMITTANCE MEASUREMENTS

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Abstract

The European Spallation Source MEBT will be equipped with a full set of diagnostics in order to characterize the bean properties before the injection in the DTL. The 6D phase space of the beam shall be characterize during the commissioning of the normal conducting as well as on regular basis during retuning phase of the machine.

In this paper we will discuss the accuracy of the transverse emittance measurement that will be performed with the slit-grid method. The slit geometric parameters have been determined in order to achieve the required resolution and sensitivity. Scattering effects at the slit have been considered to determine the emittance measurement accuracy.

INTRODUCTION

The European Spallation Source (ESS) [1] is a neutron source based on a 5 MW proton linac, build in Lund, Sweden. The normal conducting front end will accelerate the beam coming for the ion source up to 90 MeV, it consists in an ECR ion source, a Low Energy Beam Transport line (LEBT), a radio frequency quadrupole (RFQ), a Medium Energy Beam Transport line (MEBT) and a drift tube linac. At the exit of the RFQ, the beam has an energy of 3.63 MeV, with a current of 62.5 mA and nominal pulse length and repetition rate of 2.86 ms and 14 Hz respectively.

One of the function of the MEBT is to fully characterize the beam at the exit of the RFQ [2], the lattice and the beam envelopes are shown in Fig. 1, a preliminary layout of the beam diagnostics has been proposed (see Fig. 2). The slit and grid system will installed in reserved drift space for beam diagnostic downstream the second triplet.

The space available for the beam diagnostics after the second triplet is less than 350 mm (flange to flange) and might not be sufficient to meet the performance requirement for emittance measurement with the slit and grid system. The distance between the slit and grid has to be increased to provide enough angular resolution, therefore the slit has to be positioned between 2 quadrupoles, in this case the distance between the slit and the grid is increased to 400 mm. A bipolar power supply might be requested for the quadrupole positioned between the slit and the grid, primarily to suppress any remanent magnetic field which can lead to perturbation in the emittance measurement., in addition bipolar power supply might be useful for emittance measurement by increasing the rotation of the beamlet in the phase space.

For the studies presented in this paper, the nominal Twiss parameters at the slit location have been used, they are summarized in Tab. 1.

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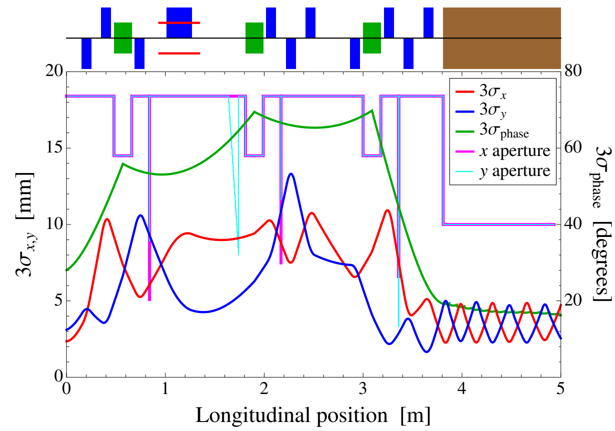

Figure 1: Schematics layout of the MEBT lattice (top), beam envelopes (3 σ), and apertures. In the schematic, blue boxes are quadrupoles, green boxes are buncher cavities, red lines are chopper plates. (courtesy of R. Myamoto).

Table 1: Nominal Courant-Snyder parameters 70 mm upstream the slit location .

Parameter	H plane	V plane
$\varepsilon_{norm.}$ $[\pi.mm.mrad]$	0.282	0.256
β [m/rad]	2.25	5.76
α	-5.37	13.62

GENERAL ARCHITECTURE OF THE SLIT AND GRID SYSTEM

The mechanical design of the slit is constraint by the space available between 2 quads and the necessity to absorb the beam power. The slit is not able to absorb the nominal beam power, during emittance scan the pulse length as well as the repetition rate has to be reduced to 50 μs and 1 Hz respectively. From the studies done for the LINAC4 emittance meter [3], graphite seems to be the best candidate for the slit material.

The slit has to be inclined w.r.t the beam axis in order to spread the energy deposition on a larger surface, the angle can not be less than 45 degrees due to space limitation.

The SEM grids will be equipped with 50 μm tungsten wires. The pitch of the grid is 500 μm, despite this small distance between the wire, the resolution is not sufficient for the beam parameters considered. The resolution can be increased to 100 μm by moving the grids by small step for a given slit position. A metallic foil will be positioned downstream and will be polarized in order to reduce the cross talk between wires.

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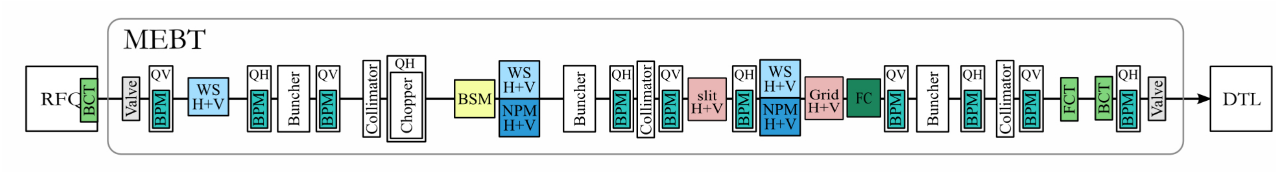

Figure 2: Beam instrumentation layout in the ESS MEBT.

EFFECT OF MULTIPLE SCATTERING ON EMITTANCE RECONSTRUCTION

Multiple scattering on the slit edges can affect the measurement accuracy and lead to over estimated the beam transverse emittance, the Monte Carlo simulation package FLUKA [4] has been used to study this effect.

A Gaussian source has been generated with the parameters presented in Tab. 1, the beam is considered as mono energetic, the discrimination of scattered and non scattered particles on the SEM grid plane is based on energy difference of the particles. The geometry of the slit has been simplified, the aperture and the thickness of the slit (see Fig. 3 for definition) are free parameters, the SEM grid is simulates as a screen. For these studies, a simulated pitch of 100 μm has been assumed for the SEM grids, in this case the the error on emittance reconstruction due to the sampling of the beamlet profile is less than 0.1 % and is neglected for the simulations done with the Monte Carlo code.

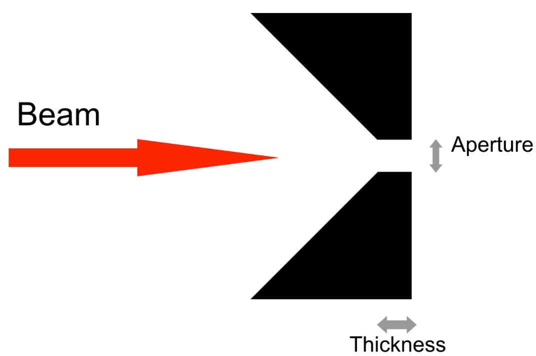

Figure 3: Schematic diagram of the slit used in the simulations (dimensions are not on scale).

A first set of simulations have been performed to estimate the ratio between scattered and non scattered particles for a given slit position (x=0 mm). Several slit thicknesses (0, 20,50, 200 and 500 μm) have been simulated for two values of apertures (100 and 200 μm).

As shown in Fig. 4 and Fig. 5 for an aperture of 100 μm, the thickness of the slit has a strong influence on the scattering, below the range of proton in graphite ($\approx$ 150 μm at 3.63 MeV), the number of scattered particles can not be neglected, in the worst case, the ratio between scattered and non scattered particles is around 6 % and decrease to 1 % for a slit thick thickness equal to two third of the proton range.

For thicknesses above the proton range in graphite, the ratio is almost reduce to 10^{-4}. For all the cases considered,

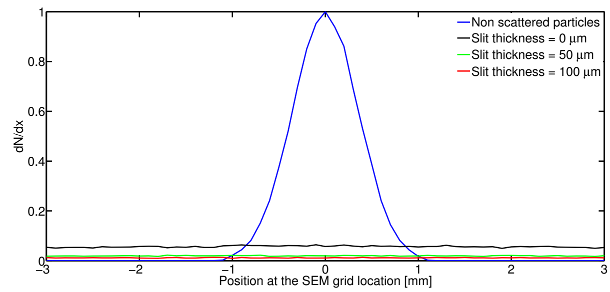

Figure 4: Particle distribution at the SEM grid location, for the slit in position x=0. In blue, the non scattered particles, in black the profile of scattered particles for a slit thickness of 0 mm, in green for 50 μm and in red for a thickness of 100 μm.

it is interesting to note that the distribution of scattered particles is almost flat.

Increasing the slit aperture by a factor 2 will decrease the contribution of the scattered particles on the emittance measurement, the number of scattered particles is more or less constant while, the number of non scattered particles is increased by almost a factor 2.

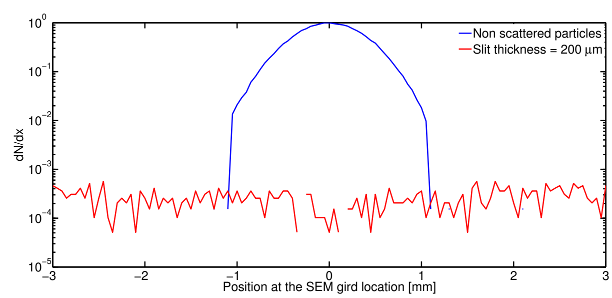

Figure 5: Particle distribution at the SEM grid location, for the slit in position x=0. In blue, the non scattered particles,, in blue the profile without scattering effect, in black the profile of scattered particles for a slit thickness of 200 μm.

In a second step, full emittance scans in both transverse plane have been simulated in FLUKA, assuming and aperture of 100 μm, since this case is mores sensitive to multiple scattering, and a thicknesses of 50 and 200 μm, the output file have used to reconstruct the full phase space (Fig. 6 and Fig. 7 for two slit thicknesses considered) and calculate the RMS emittance. A weight of 1 has been assigned to the non scattered protons, due to their lower energy, the scattered particles are producing more secondaries electrons, their weight has been increase by 10 % to reflect this difference.

Other estimation of the RMS emittance have been done with a weight of scattered particles set to 0, in order to suppress in post processing the multiple scattering.

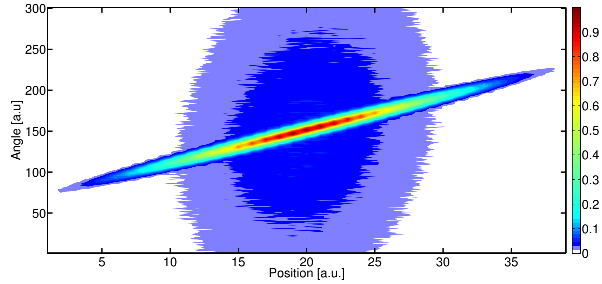

Figure 6: Horizontal phase space reconstruction with a slit thickness equal to 50 μm and a slit aperture equal to 100 μm.

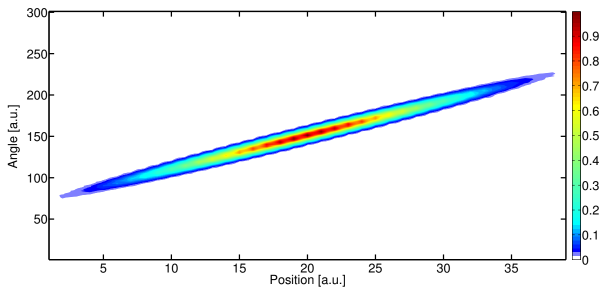

Figure 7: Horizontal phase space reconstruction with a slit thickness equal to 200 μm and a slit aperture equal to 100 μm.

Table 2: Error on the reconstructed emittance for different slit thickness with or without scattering effect, threshold is set to 0.3 % of the maximum data value for reconstructed emittance with scattering effect.

Thickness $[\mu m]$	H plane scattering	H plane no scatt.	V plane scattering	V plane no scatt.
	$\frac{\Delta\varepsilon}{\varepsilon_{ref}}$ [%]		$\frac{\Delta\varepsilon}{\varepsilon_{ref}}$ [%]	
200	0.5	0.5	-0.7	-0.8
500	-0.22	-0.3	-1.72	-2

The background induced by the scattered particles can be clearly see in Fig. 6, while increasing the slit thickness reduced this background to the expected noise level of the electronic.

With multiple scattering effect activated, the scattered particles are spread all over the phase space covered by the system, even small contribution far from the beam core has a strong influence on the the statistical evaluation of the emittance. In order to have a proper estimation of the RMS emittance, the introduction of a threshold, with which signals that are lower than it are neglected, is needed. With a threshold set at 0.3 % of the maximum value , the emittance is well reconstruct for a 200 μm slit thickness (Tab. 2), to reach the same value with a thinner slit, a threshold of 5 % has to be applied on the data.

Without multiple scattering effect, a threshold value is not needed, the results presented in Tab. 2 are calculated without this threshold,

In the vertical plane, due to the high beam divergence, the reconstructed emittance is smaller than the reference if the slit thickness is above 200 μm. When the slit is positioned on the beam edges, the beamlet sizes are well reconstruct, but transmission thought the slit is less compare to an ideal slit (thickness =0) and compare to the transmission when the slit is in center of the beam. The weight of these slit positions in the estimation of the RMS emittance is less and leads to an underestimation of the emittance, in the worst case, the a slit thickness equal to 2 mm, the emittance is underestimated by 10 %. To reach the same error with a slit thickness of 500 μm, the aperture has to be increased to 200 μm.

CONCLUSION AND OUTLOOK

In order to preserve a good accuracy for the measurement the slit has to fulfill these specifications:

- An aperture of 100 μm
- A thickness of 200 μm

The fabrication of these slits in graphite might be difficult, a larger aperture will relax the tolerance of the machining, nevertheless this might be also increase the error due to space charge, further studies will be performed in the next months to estimate the effect for different slit apertures.

In parallel, in order to ease the machining procedures, alternative materials for the slit will be studied with finite element codes. TZM or Albemet might be good alternatives to graphite.

REFERENCES

[1] "European Spallation Source Technical Design Report".

[2] R.Miyamoto et al., "beam physics design of the ESS Medium Energy Beam Transport" THPME045, IPAC2014, Dresden Germany.

[3] B. Cheymol et al., "Design of the Emittance Meter for the 3 and 12 MeV LINAC4 H^- Beam", CERN-BE-2010-013.

[4] A. Ferrari, P.R. Sala, A. Fasso, and J. Ranft, "FLUKA: a multi-particle transport code" CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773.

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