ESS LINAC BEAM MODES

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INTRODUCTION

The ESS Linac will ultimately deliver 5 MW of beam power to the target with a long-pulse structure of 2.86 ms and 14 Hz repetition rate, which are essential for the production of long-wavelength neutrons [1]. Ten different beam power levels are requested for the operation. In order to preserve the required time structure of the beam, different beam power levels will be produced by reducing the beam current in ten regular steps using an iris with an adjustable aperture in the Low Energy Beam Transport (LEBT). Low current and low emittance beams may as well be useful for the beam commissioning of the Linac. This paper describes the generation and the beam dynamics of different beam modes in the ESS Linac.

GENERATION OF BEAM MODES

The different beam currents are generated in the LEBT by adjusting the aperture of the iris placed between the solenoids, collimating the required beam fraction. The beam is matched to the Radio Frequency Quadrupole (RFQ) with two solenoids. All simulations are done using TraceWin and Toutatis codes [2].

LEBT

Beam modes with a beam current from 6.3 mA up to the nominal 62.5 mA at the target will be produced in ten regular steps. Table 1 lists the relevant design parameters of the ESS Linac without considering eventual errors. The schematic layout of the LEBT is presented in Fig. 1.

Table 1: Design Nominal Parameters of the ESS Linac

Parameter	Value	Unit
Source output beam current	65	mA
Source output norm. RMS emittance	0.2	π.mm.mrad
Space charge compensation in the LEBT	≥95	%
LEBT beam transmission	100	%
RFQ input norm. RMS emittance	0.25	π.mm.mrad
RFQ beam transmission	≥97	%
MEBT-to-target beam transmission	100	%
Beam current at the target	62.5	mA

The field strength of the solenoids and the iris aperture radius for each beam mode are calculated through an iterative process, while matching the beam to the corresponding RFQ input beam parameters in each step. To simplify the calculations, a fixed RFQ transmission of 97% has been assumed for all beam currents. For beam currents below the nominal this will introduce only a small error of up to 3% in the beam current at the target. Taking into account the overall efficiency of the Linac, beam currents from 6.5 mA to 65 mA shall be produced at the RFQ input. We will be referring to the beam currents at the RFQ input in the rest of the document.

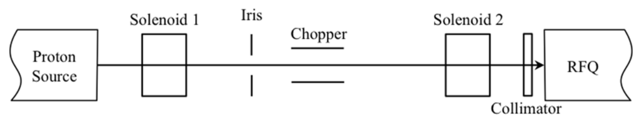

Figure 1: LEBT schematic layout.

A uniform space charge compensation of 95% along the LEBT has been assumed in the simulations, except in the collimator with the repelling electric field at the RFQ entrance. Field strength of solenoids for different beam modes is presented in Fig. 2. The beam current and the RMS emittance at the RFQ input as a function of the iris aperture radius are presented in Fig. 3. The beam size for different beam modes in the LEBT is presented in Fig. 4.

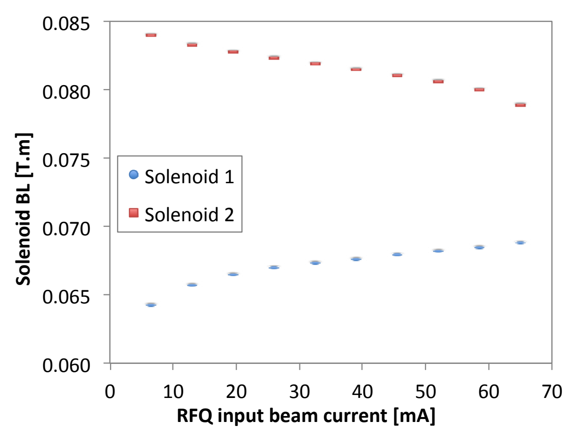

Figure 2: Field strength of the LEBT solenoids.

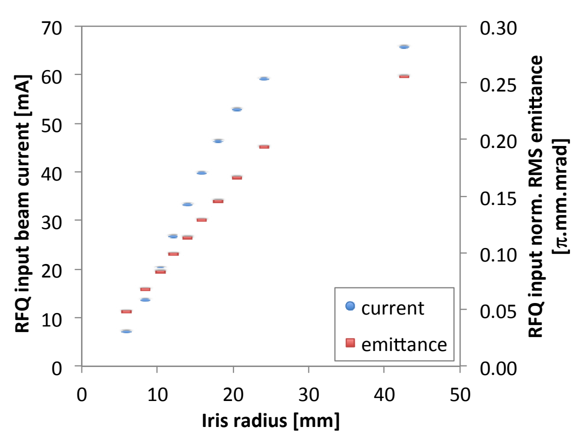

Figure 3: RFQ input beam current and RMS emittance.

 ISBN 978-3-95450-142-7

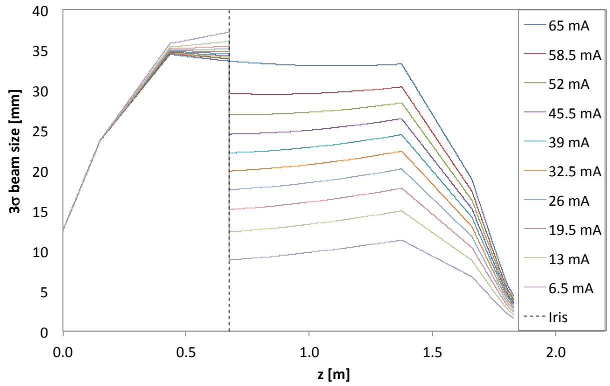

Figure 4: LEBT beam size (3 standard deviations).

The process of obtaining the settings for different beam modes could be rather complex and time consuming during the commissioning. The solenoid strength and the iris aperture variation is rather linear with the beam current. Presumably, the process could be simplified by obtaining the settings for the highest and lowest beam modes and then interpolating linearly between them.

RFQ

Matched RFQ input beam parameters are not linear functions of the input beam current and emittance (see Fig. 5) due to a non-linear variation of the space charge forces (ratio of the beam current to the RMS emittance).

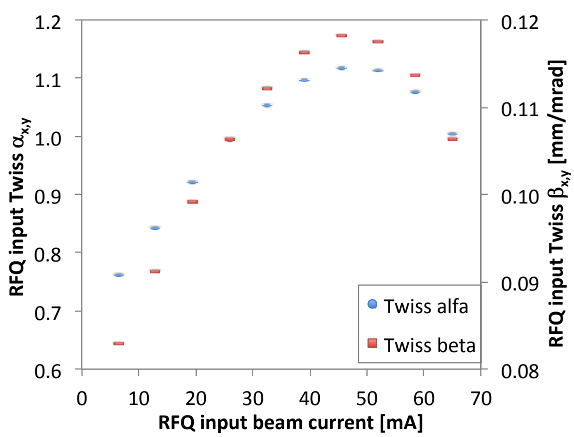

Figure 5: Matched RFQ input beam Twiss parameters.

The RFQ output transverse RMS emittances vary linearly with the input beam current, whereas the longitudinal emittance does not. However, both transverse and longitudinal RMS beam sizes at the RFQ output vary linearly with the input beam current. The RFQ beam transmission improves for the beam currents and consequently emittances below the nominal one.

DYNAMICS OF BEAM MODES

Once the different beam modes are generated in the LEBT and accelerated through the RFQ, the Medium Energy Beam Transport (MEBT) transports and matches the beam to the downstream Drift Tube Linac (DTL). To simplify the matching, the settings of the first bunching cavity and all quadrupoles except the last four are fixed at their values for the nominal beam current. The last two bunching cavities and last four quadrupoles are used then to match the beam to the DTL for each beam mode. The DTL contains permanent magnet quadrupoles and therefore no adjustment can be done. The cavity RF and quadrupole gradients in the Superconducting Linac (SCL) are set for the nominal beam current for all beam modes. Sections requiring different settings for different beam modes are then limited to the LEBT and the MEBT.

MEBT and DTL

In the simulations the matching to the DTL for each beam mode is done using two bunching cavities and four quadrupole magnets at the end of the MEBT by smoothing the beam phase advances over several focusing periods. The matching parameters for different beam modes are rather different and their evolution with the beam current is not linear (see Fig. 6). However, the variation of the integrated gradient of the last four MEBT quadrupoles for different beam modes is rather small (see Fig. 7). The same is true for the effective voltage of the last two bunching cavities of the MEBT (see Fig. 8), except for the lowest beam current.

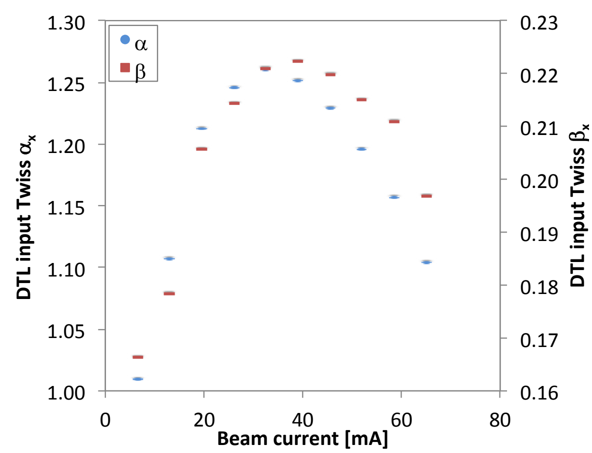

Figure 6: DTL input beam Twiss parameters.

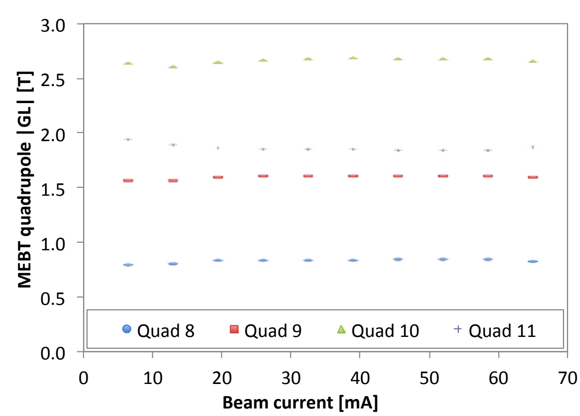

Figure 7: Integrated gradient of the last four MEBT quadrupoles.

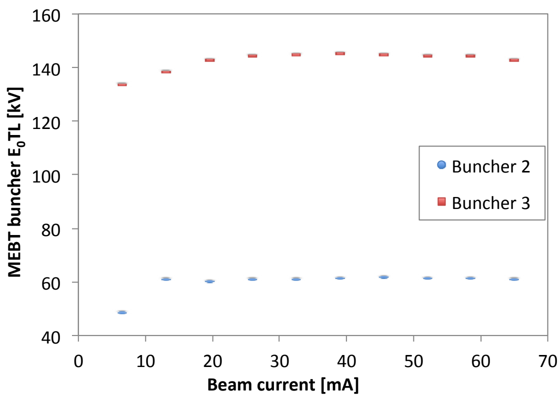

Figure 8: E_0TL in the last two bunchers in the MEBT.

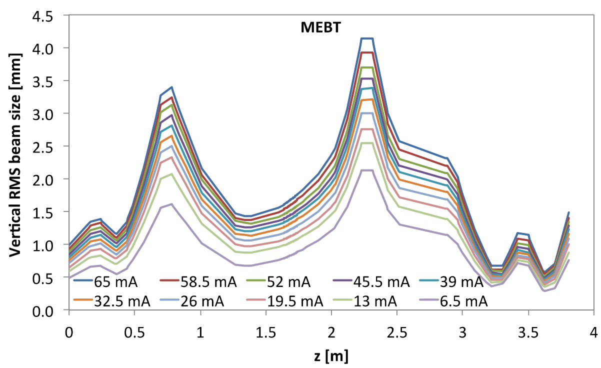

Figure 9: Vertical RMS beam envelopes in MEBT.

The beam size and the divergence at the DTL input reduce linearly with the reducing beam current. The vertical RMS beam envelopes along the MEBT are presented in Fig. 9. Presumably, once the quadrupole and bunching cavity settings are found for the matching of the nominal beam parameters, the settings for the lower beam currents could be obtained by small variations of those settings around their nominal values and by optimizing the beam size in all three planes, first at the MEBT exit and later at the exit of the first DTL tank.

SCL, HEBT and A2T

Once the beam is matched to the DTL, no further matching is done in the SCL and High Energy Beam Transport (HEBT), which are set for the nominal beam current. In reality, small adjustments may be required to optimize the beam performance. The transverse RMS emittance growth is larger for smaller beam currents. Nevertheless, due to a smaller emittance for smaller beam currents, the beam size is reducing with a reducing beam current. The quadrupole gradients in the Accelerator-to-Target line (A2T) could be adjusted to obtain the same beam size on the target for all beam modes.

BEAM CHOPPING

As shown in Fig. 9, the vertical beam size is getting smaller for smaller beam currents in the MEBT and at the dump position in particular. Therefore, the chopping efficiency for lower beam currents is improving with respect to the nominal case at a fixed chopper voltage. Assuming no errors, for a chopper voltage of 4 kV the chopping efficiency is >99.999% for the nominal beam and it improves for lower currents. Since the beam size is the smallest for the 6.5 mA beam current, that beam mode could be used to test directly the chopper deflection angle versus the applied voltage, while the quadrupole housing the chopper, which amplifies the deflection, is turned off.

DYNAMICS WITH ERRORS

End-to-end combined error studies of the ESS Linac [3] showed some beam power losses along the Linac for the nominal beam parameters. Based on the results discussed above, beam power losses in the case of the lowest beam (current) mode are expected to be significantly lower due to the combination of small beam current and emittance. The same statistical error study as in [3] for the 6.5 mA case showed no beam losses along the Linac. The beam power levels from that study are shown in Fig. 10. This beam mode could be useful for the beam commissioning of the Linac with the nominal pulse length and repetition rate, when the beam power losses are a matter of great concern, especially during the phase scan procedure.

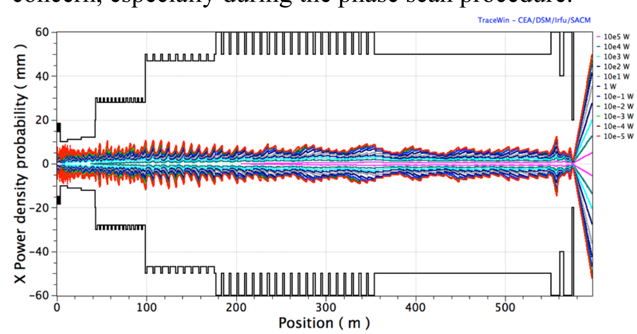

Figure 10: Beam power levels for the 6.5 mA beam mode with errors (black line delimits the beam pipe aperture).

CONCLUSION

Different beam modes can be generated in the LEBT with an adjustable iris, while setting the solenoids to match the beam to the corresponding RFQ input beam parameters. Once the different beam modes are matched to the DTL, no further adjustments are necessary in the downstream structures, which are set for the nominal beam current. The lowest beam current mode can be useful during the commissioning, for the chopper and lattice set-up and when the beam power losses are critical.

REFERENCES

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[2] R. Duperrier, N. Pichoff and D. Uriot, “CEA Saclay Codes Review for High Intensity Linac”, ICCS conference, Amsterdam, 2002.

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ISBN 978-3-95450-142-7