COMPARATIVE STUDY OF BEAM DYNAMICS IN LINAC4 USING CERN AND RAL MEBT (MEDIUM ENERGY BEAM TRANSPORT) LINES*

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Abstract

CERN (European Organization for Nuclear Research) and RAL (Rutherford Appleton Laboratory) are working in parallel to develop Front Ends for future particle accelerators. At CERN the Front End will be part of LINAC4 [1], a potential replacement for the LINAC2 accelerator, whilst at RAL the Front End is intended to demonstrate that a high current, high quality chopped beam is achievable [2] and that the design could be used as part of a Proton Driver for a future Neutrino Factory. The two Front End designs have many similarities and basically consist of four main components: an H^- ion source, a Low Energy Beam Transport (LEBT) matching into a Radio-Frequency Quadrupole (RFQ) and a Medium Energy Beam Transport (MEBT) line with a fast beam chopper. The beam choppers are different in the two designs and it is important to compare the effectiveness of the two methods of operation. This paper describes a simulation study of high intensity beam dynamics and beam transport when the RAL and CERN MEBT designs are each fed into the same CERN structure for LINAC4.

CERN AND RAL MEBT LINES

The MEBT chopper line is one of the key parts of these two Front End designs and it consists of a series of quadrupoles, RF re-bunching cavities, and a beam chopper system (Table 1). While at CERN the MEBT optical design is final, at RAL three proposed designs are still under consideration: the compact scheme derived from the ESS (European Spallation Source) chopper line, the tandem scheme and the symmetric scheme which was used for this simulation study [3]. A schematic drawing of the RAL symmetric scheme and the CERN MEBT design can be seen in Figure 1.

Table 1: CERN and RAL MEBT parameters

Element type	CERN		
	No.	**Length**	**Obs.**
Quadrupoles	11	56 - 255 mm	G = 0.6-38 T/m
Buncher cavities	3	200 mm	V = 100-140 kV
Chopper	1	400 mm	V = +/- 0.5 kV
	RAL		
Quadrupoles	11	70 mm	G = 9-33 T/m
Buncher cavities	4	200 mm	V = 75-160 kV
Fast Chopper	1	450 mm	V = +/- 1.3 kV
Slow Chopper	1	450 mm	V = +/- 1.5 kV

Choppers Description

CERN and RAL have adopted different approaches for their chopping schemes. The CERN designs consists of a 1 meter long chopper (2 sets of plates each 40 cm long) housed inside two quadrupoles that are meant to keep the beam focused in the chopping plane and to provide a 90 degrees phase advance between the centre of the chopper and the dump. In order to obtain nanosecond range rise times, the CERN deflecting plates are made using travelling-wave stripline structures that are meander-folded to match the speed of the travelling wave to the

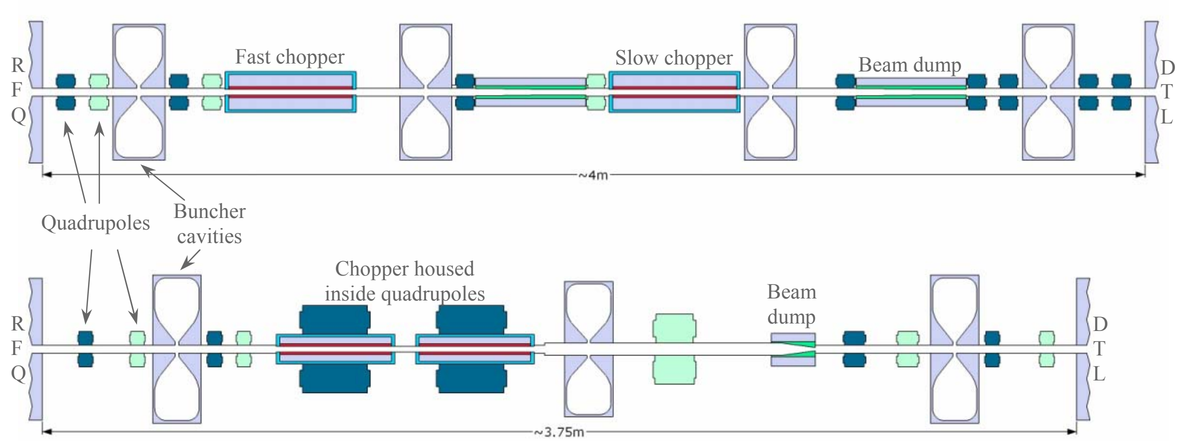

Figure 1: Schematic drawing of the RAL Scheme A (top) and the CERN MEBT Line (bottom).

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beam velocity [4]. The RAL chopper uses a configuration first developed for the ESS, and consists of a tandem combination of fast transition time, short duration and slower transition time, longer duration choppers (the 'fast-slow' beam choppers). The "fast-chopper" removes 3 adjacent bunches at the beginning and at the end of the chopping interval creating 2 gaps in the bunch train. These gaps will then be used by the second chopper field as a transition interval. This prevents bunches being partially chopped during the transition time of the second chopper [5].

SIMULATION RESULTS

We have performed a comparative simulation study of the two different chopping aproaches when both the RAL and CERN MEBT designs are fed into the same CERN LINAC4 structure that consists of a Drift Tube Linac (DTL) followed by a Cell-Coupled Drift Tube Linac (CCDTL) and a Side-Coupled Linac (SCL) [6]. Since the two Front Ends have been designed for different frequencies (324 MHz for RAL and 352.2 MHz for CERN), the RAL design had to be scaled to the new frequency to enable a better comparison, by considering a higher frequency for the buncher cavities. All the simulations have been performed with TraceWin/Partran [7] with 3D space-charge routines, using a uniform beam distribution tracked through the IPHI (High Intensity Proton Injector) RFQ. The MEBT input beam parameters for this distribution can be seen in Table 2.

Table 2: MEBT input beam parameters

Beam current	70 mA
Bunch frequency	352.2 MHz
Kinetic Energy	3 MeV
No. of particles	50000
Normalized RMS Emittance	ε_x=0.2733 π.mm.mrad ε_y=0.2710 π.mm.mrad ε_z=0.1357 π.deg.MeV

As described above, the choppers are quite long objects and by placing them in the MEBT beam lines, the phase advance per meter is considerably modified; for this reason the quadrupoles in the MEBT line are arranged so that in both designs they form FODO focusing periods. In this way the continuity of the phase advance is modified as little as possible. Some of the MEBT quadrupoles are also used to amplify the deflection given by the choppers, thus reducing the required voltage on the chopper plates. The MEBT line RMS beam envelopes in the chopping plane can be seen in Figure 2.

The matching to the DTL was made using the last 5 quadrupoles (4 in the CERN case) and the last rebunching cavity. The Linac itself accelerates the beam from 3 MeV to 160 MeV using 3 different accelerating structures: DTL up to 40 MeV where a more efficient CCDTL structure is used to accelerate the beam to 90 MeV where the frequency is doubled and the accelerating structure is changed to a SCL.

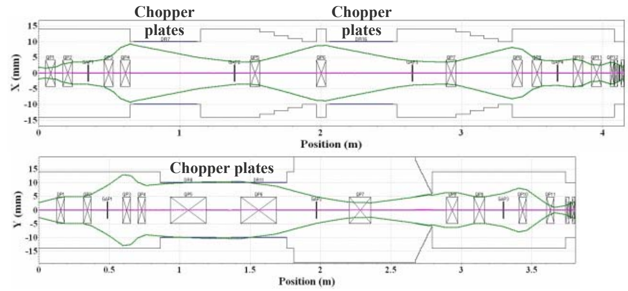

Figure 2: MEBT Beam Envelopes (from Partran, 5 RMS) in the chopping plane for RAL (top) and CERN (bottom) with the beam chopper switched off.

RMS Emittance Growth

The RMS emittance evolution in LINAC4 and the emittance increase when using the RAL and CERN schemes are shown in Figure 3 and Table 3 respectively. For the RAL case the growth in emittance is lower than in the CERN case. As it can be seen, emittances at the output of the CERN MEBT are already bigger than in the RAL case due to the fact that the CERN design has more constraints regarding the beam optics. Consequently, this difference is more or less preserved in the linac, hence the difference in the total emittance growth.

It is important to avoid emittance growth in the transverse plane since the bore radius in the LINAC4 is quite small and emittance growth can cause beam loss. An important source of emittance growth is the emittance exchange between the longitudinal and the transverse planes. However, simulations indicate that the linac has been designed to avoid the unstable area of the Hofmann's instability chart [8], and resonances are avoided in both cases.

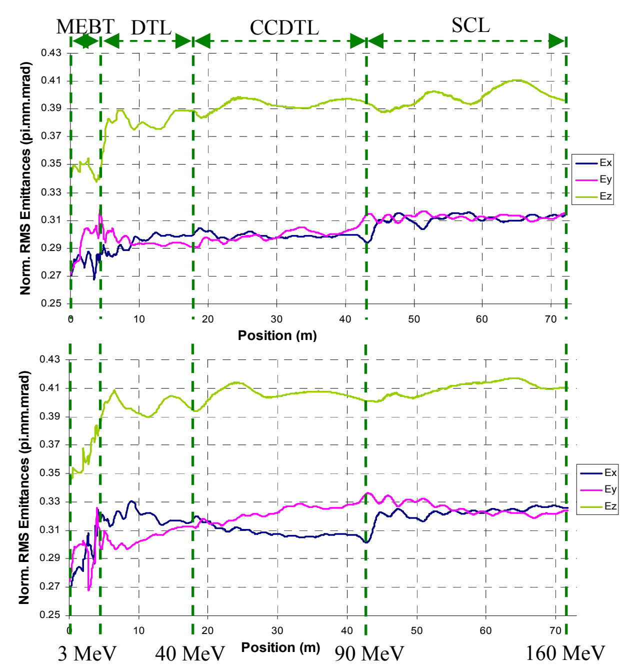

Figure 3: Longitudinal and Transverse Emittances evolution (Normalized RMS) in LINAC4 using RAL (top) and CERN (bottom) MEBT.

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Table 3: RMS Emittance growth and beam transmission in LINAC4 using the RAL and CERN MEBT lines

	MEBT	LINAC4	Total
	RAL		
ε_x growth (%)	2.85	11.45	14.63
ε_y growth (%)	9.92	5.80	16.30
ε_z growth (%)	0.05	15.97	16.05
Transmission (%)	98.31	100	98.31
	CERN		
ε_x growth (%)	12.18	6.30	19.25
ε_y growth (%)	6.05	12.73	19.55
ε_z growth (%)	9.63	9.66	20.25
Transmission (%)	94.55	100	94.55

Halo formation is an important source of emittance growth that can lead to beam loss and radio activation of the linac, a process that has to be avoided in high intensity linacs. To reduce the halo, scrapers have been included at the transition between the accelerating structures in the LINAC4 design but not in these simulations where a ~50% increase in the halo parameter [9] in each phase plane has been observed.

Losses

Figure 4 presents the losses at each position in the MEBT and linac. While almost no losses occur on the accelerating structures, the MEBT line is quite lossy for both designs. For the RAL design some particles are lost on the beam dumps. These losses can be reduced by increasing the aperture at the dump, but for this, one would need a stronger deflection from the chopper plates, and hence a higher voltage. For the CERN design, losses are higher and occur mainly on the chopper plates and on the beam dump/scraper, where quite a considerable amount of power is dissipated on a small volume, making the dump one of the “hottest points” in the linac. The aperture of the CERN MEBT beam dump is made intentionally smaller so that it can be used as a scraper. Designs with higher aperture can be considered, provided a higher voltage on the chopper plates is achievable, but they could be used only for dumping the beam and the beneficial effect of reducing the halo would be lost

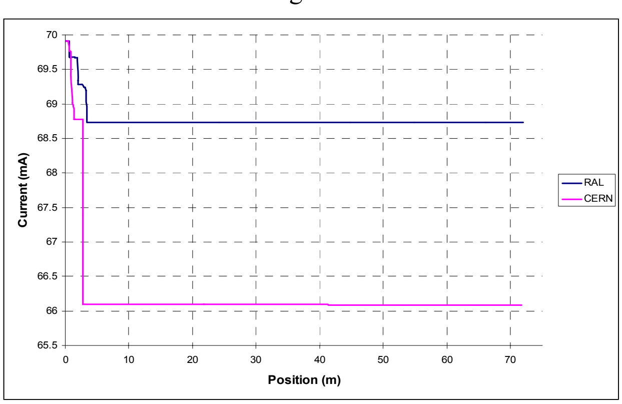

Figure 4: Beam current variation in LINAC4 using RAL and CERN MEBT lines.

Residual Chopped Beam

The computed chopping efficiency for both designs is higher than 99.7%, the main limit being the voltage that can be applied on the chopper plates. However, a small fraction of the beam will survive and will continue in the downstream linac. This can be quite problematic especially if the unchopped particles are accelerated to higher energies. To avoid this, scrapers have to be placed at key positions in the linac design. Simulations indicate that for the LINAC4 0.1 duty cycle the residual chopped beam power after the SCL is less than 10W and the power dissipated by the unchopped particles is between 1 and 1.5W in each different accelerating structure (DTL, CCDTL and SCL) for both CERN and RAL designs.

CONCLUSION

Although CERN and RAL have adopted different chopping schemes, end-to-end simulations indicate that they are similar in many respects. Slightly better results have been obtained when using the RAL chopper line, mainly due to the different MEBT optics in the two cases. The CERN MEBT line is already in a more advanced design stage, whereas for the RAL case more realistic engineering considerations have yet to be added in with expected influence on the beam dynamics. Simulations show that LINAC4 machine has been designed to be a stable and reliable machine, and that the differences in the beam dynamics in the linac are mainly caused by the differences in the MEBT line optics.

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