BEAMS DYNAMICS END TO END SIMULATIONS WITH ERRORS STUDIES THROUGH THE ESS SC LINAC

N. Pichoff[1], D. Uriot, R. Duperrier, R. Ferdinand,

CEA/DSM/DAPNIA/SACM, 91191 Gif-sur-Yvette cedex, France

Abstract

The ESS project (European Spallation Source) aims to deliver high power beams for matter studies. Both H^+ and H^- beams have to be accelerated and guided to the different spallation targets. Two 50 mA H^- branches are funnelled with one 100 mA H^+ beam at around 20 MeV. The H^- front end is constituted by a chopper lines between two RFQs and DTLs. The H^+ front end is composed by one RFQ and one DTL. The two species are transported through the same linac up to 1.334 GeV. This common part is composed by a SDTL and a CCL from 20 to 185 MeV and followed by a SCL (SuperConducting Linac) to reach the final energy. This paper presents the results of beams dynamics studies through the ESS linac including end-to-end simulations and errors studies.

1 INTRODUCTION

ESS is a European project of spallation neutrons source aiming to distribute to its users 50 neutron short pulses (1.4µs) and 50/3 neutron long pulses (2.5ms) per second. The neutrons are created in two targets from a spallation reaction between protons and heavy elements.

The 5MW short proton pulse is obtained by compressing two 470µs, 114mA-peak H^- pulses in two 600ns, 62.5A-peak proton pulses in two rings. Both short pulses are extracted from the rings and guided to the target one after the other with 200 ns in between. H^- ions are used rather than protons for injection efficiency reasons. Because H^- sources are for the moment not able to produce 100mA within all the other requirements (emittance, repetition rate, life-time…), two 50mA sources are used and both beams are funnelled at upper energy (~20 MeV). Moreover, in order to extract the beam from the ring with minimum losses using a fast kicker, a ~200ns hole in the beam is needed in the accumulated. This hole is obtained by chopping 30% of the beam at low energy (2MeV) with a 1.2416 MHz repetition rate (revolution frequency of the beam in the ring).

The 2.5ms-100mA long pulse is directly injected in the target. Both H^- ions and protons can be used. The simpler solution consists in using H^- because the short pulse is already H^-. Nevertheless, the source capability of producing the long pulse is doubtful. A fallback solution consists in using protons for the long pulse. The main advantage is the already existing ECR proton sources (SILHI, LEDA) fulfilling all the requirements. The main difficulty is to demonstrate that it is possible to transport two beams with different charges and current in the same linac. Both solutions have to be studied.

This paper presents the results of beams dynamics studies made for ESS including end-to-end simulations and errors studies with H^- and protons. Most of the work presented here can be found in [1].

2 END-TO-END SIMULATIONS WITHOUT ERRORS

The first step of the beam dynamics studies consists in showing that the beam will fulfil the ESS requirements. They are:

- Beam losses lower than 1W/m (short and long pulses),
- Beam normalised rms transverse emittance lower than 0.5 π.mm.mrad (short pulse only).
- Beam normalised rms longitudinal emittance lower than 2.3 π.mm.mrad (short pulse only).

Linac has been matched and multi-particle simulations were done from the first RFQ input to the linac exit with the Saclay code package TOUTATIS-TRACEWIN-PARTRAN.

The input distribution is a 4D water-bag with a rms transverse emittance of 0.3 π.mm.mrad to relax H^- sources.

2.1 H^- beam

For beam dynamic reasons at low energy, both short pulse and long pulse (if done with H^-) should have the same bunch current: 114 mA. The linac has been matched for this H^- beam because the requirements for ring injection are more stringent than for the long pulse. The H^- rms emittances evolutions along the linac are plotted on figure 1.

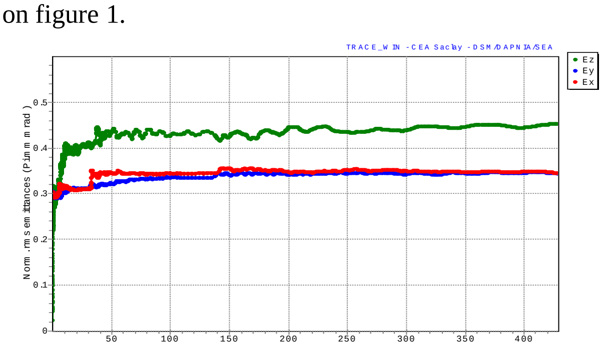

Figure 1: H^- beam rms emittances growth.

Most of the emittance growth is visible in the funnel line. This is due to the non-perfectly smooth line and the deviation, which depend on the particle phase. Nevertheless, the final emittances are much smaller than the required ones.

The main source of losses is H^- stripping in the residual gas. The SNS estimation of the residual gas pressure and composition [2] was used to obtain the estimation of 0.9 W/m, equivalent to an activity of 170 µSv/h at 1 foot after 4 hours [3] (in the CCL at 185 MeV). Fortunately, at this energy, the linac becomes superconducting with much lower pressure, decreasing drastically the stripping losses.

2.2 H^+ beam

The long pulse can also be done with protons. In this case, a proton beam is injected in between the two H^- beams in the funnel section. To achieve the 5 MW requirement in 2.5ms with a 50/3 Hz repetition rate, a 90 mA beam is needed. Since the H^+ bunch repetition is 352.2 MHz and the H^- beam bunch repetition is 704.4 MHz, the proton beam charge per bunch is 1.58 bigger than the H^- beam. The part of the linac common to both beams is matched for H^-. However, because the phase advance per meter and the focusing lattice have been kept continuous along the linac, the proton beam is almost matched in the linac. The emittances evolution of the proton beam is plotted on figure 2.

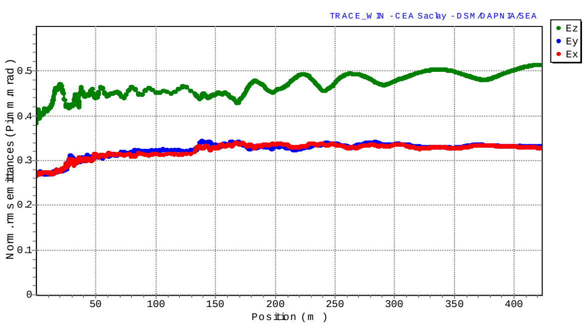

Figure 2: H^+ beam rms emittances growth.

Of course, in this case, no losses by stripping are expected in the linac.

3 END-TO-END SIMULATIONS WITH ERRORS

In order to evaluate the beam losses arising from the beam dynamics in space charge in a real linac, typical errors on linac element have been defined and simulated. Errors are of two kinds:

- The *static errors* are the ones whose effects can be corrected by appropriate diagnostics and correctors. In order to evaluate the effect of these errors, a correction scheme has been defined and applied.
- The *dynamic errors* are the errors whose effects cannot be corrected. These are vibrations, microphonics,… for example.

The amplitudes of the errors used in the calculation are represented on table 1. The errors are different from one section to the other, taking into account the element specification. The first figure (the biggest one) is the static error; the second is the dynamic error.

section	*Quad*	*dx-dy (µm)*	*θ_x/θ_y (°)*	*θ_z (°)*	*dG/G (%)*
	Cav.	**dx-dy (µm)**	**θ_x/θ_y (°)**	**dφ (°)**	**dE (%)**
rfq-dtl match.	*Quad*	*125/2*	*.2/.004*	*.2/.004*	*.5/.05*
	Cav.	125/2	.2/.004	0/.5	0/.5
DTL	*Quad*	*125/5*	*.2/.01*	*.2/.01*	*.5/.05*
	Cav.	125/5	.2/.01	0/.5	0/.5
Funnel	*Quad*	*125/2*	*.1/.002*	*.1/.002*	*.5/.05*
	Cav.	125/2	.1/.002	0/.5	0/.5
Deflection	*Quad*	*125/2*	*.05/.001*	*.05/.001*	*.5/.05*
	Cav.	125/2	.05/.002	0/.5	0/.5
SDTL	*Quad*	*125/2*	*.2/.004*	*.2/.004*	*.5/.05*
	Cav.	125/2	.1/.002	0/.5	0/.5
CCL	*Quad*	*125/2*	*.1/.004*	*.1/.004*	*.5/.05*
	Cav.	300/2	.2/.002	0/.5	0/.5
SCL	*Quad*	*125/2*	*.03/.0005*	*.03/.0005*	*.5/.05*
	Cav.	2000/2	.2/.0002	0/.5	0/.5

Table 1: Error amplitude for each element.

3.1 Correction scheme

The correction scheme is different whether one uses the H^- or H^+ for the long pulse. If H^- is used, the scheme is easy and one uses one two-plans BPM and one two-plans steerers per lattice (except for the DTL). The problem consists in solving a system of two equations with two unknowns. If H^+ is used, the scheme is a little more complex with one two-plans BPM (able to measure the position of both beams) coupled with two two-plans steerers per lattice (except for the DTL). The point is to solve a system of four equations with four unknowns.

3.2 H^- beams only

Static errors

A set of 1 000 linacs has been simulated with static errors and correction scheme ON. No errors have been assumed on the BPM measurement. The rms value of the residual transverse orbit is plotted on figure 3. After 20 MeV (where the activation becomes high), the residual rms orbit is lower than 100 µm. Errors on BPM measurement add quadratically with this orbit. This orbit is smaller than the beam size and much smaller than the bore radius of the linac. A residual orbit of only 1.5 mm is obtained at low energy in the DTL. This is due to the low number of diagnostics in the tanks.

Dynamic errors

A set of 230 linacs has been simulated with dynamics errors assuming no static error. The beam contains 100 000 particles. The evolution of the beam size containing 90%, 99%, … 1-10^{-7} of the beam is plotted on figure 4. It can be compared with the bore radius. Margins are big especially in the superconducting section. The big jump around element 180 is due to the funnel deviation.

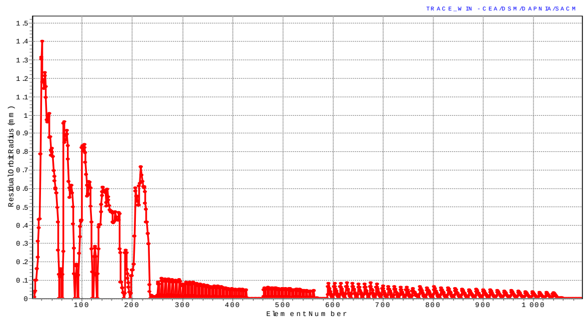

Figure 3: rms residual orbit with only H-

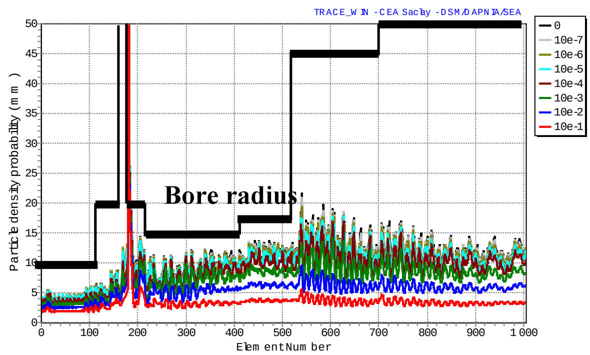

Figure 4: Radii including a certain beam fraction.

The main effect on these dynamic errors is observed in the longitudinal phase-space. It is due to the 0.5°, 0.5% field errors in the cavities. The position of the beam centre of gravity in longitudinal phase-space at linac exit for the 230 linacs is plotted on figure 5. A study of the bunch compressor line before injection into the rings has shown that field errors up to 0.65°, 0.65% were acceptable for a proper injection. This level of error should be achievable.

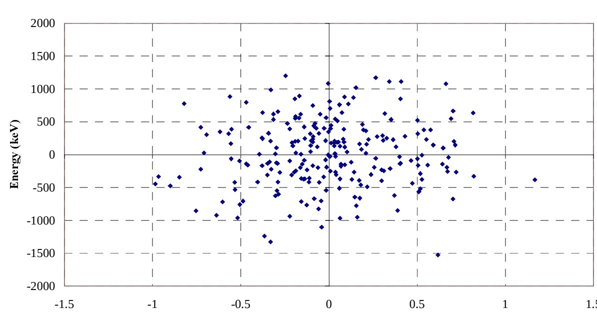

Figure 5: Position of the beam c.o.g. in longitudinal phase-space at linac exit for 230 different set of errors.

3.3 Both H^- and H^+ beams in the same linac

When the long pulse is made of H^+, the errors and the correction field have a different influence on both beams. The scheme is a little bit more complicated. The rms value of the residual transverse orbit is plotted in the linac part common to both the short and the long pulses on figure 6. The residual rms orbit is **twice** the one with only H^-. However, it is lower than 200 µm (beam size is lower than 15 mm).

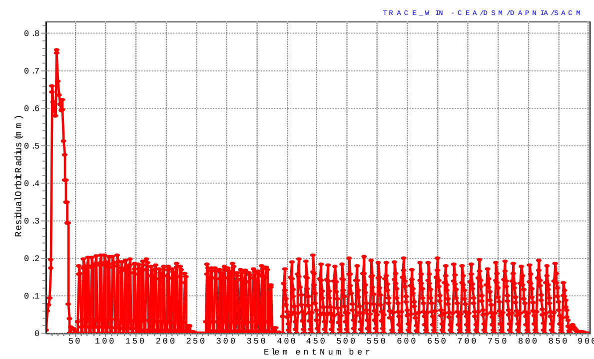

Figure 6: rms residual orbit with both H^- and H^+ and linac errors.

It is clear that both beams can be transported through the same linac with this simple correction scheme. The effect of dynamic error is the same as with only H^-.

4 CONCLUSION

ESS linac fulfils its requirements. Estimated beam losses are lower than 1 W/m, especially at high energy. Most of the losses are coming from the H^- stripping in the residual gas. An interesting option consists in using a H^+ beam for the long pulse. It reduces the requirements on the H^- sources, increase the linac availability and probably reduce the level of activation of the linac.

5 REFERENCES

[1] The ESS project, Vol III, Technical report, May 2002.

[2] J. Stovall et al., *Final design and expected beam performances of the SNS linac*, SNS ASAC Review, September 19, 2001.

[3] N. Pichoff et al., *Beam Losses in ESS from H-stripping on residual gas*, ESS Linac Technical note ESSLIN-TN-0202-01, February, 2002.