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5 MW BEAM POWER IN THE ESSnuSB ACCUMULATOR: A WAY TO MANAGE FOIL STRIPPING INJECTION AT 14 Hz LINAC PULSE RATE*

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Abstract

The ESSnuSB is aiming to measure the leptonic charge-parity violation using a 5 MW H$^-$ beam in 2.86 ms long pulses from the ESS. For the millisecond long pulses, foil-based stripping must be used before laser stripping is common practice. In the past, the scenario consisted of splitting a linac pulse into 4 rings, or 3 or 4 intermediate pulses, and one ring. At present, the scenario, in view of ultimate laser stripping, consists of one ring, one pulse, split into four batches. Conventional stripping geometry would lead to foil evaporation under this beam load. On the other hand, the final emittances at extraction increased. This suggests replacing the standard corner foil with a single-edge foil, rotated to about 45 deg. The tilted foil allows moving the injection point together with the painting bumps along the foil edge, distributing the deposited beam power over a larger foil area. We present simulation results obtained with the same tools as in the past scenarios. They show peak foil temperatures, which compare with the best results obtained from the past scenarios with intermediate pulses.

INTRODUCTION

The ESSnuSB project [1, 2] extends the 5MW, 14 Hz ESS proton linac for neutron production by inserting H$^-$ pulses between the proton pulses for neutrino production.

The H$^-$ pulses are injected into an accumulator ring [3-6]; after accumulation they are sent to four target horns. Each H$^-$ pulse is split in four consecutive batches, cf. Fig. 1. Charge exchange injection by foil stripping as used in the SNS would leave to evaporation of the foil [7]. For this reason, laser stripping was foreseen, still many years ahead [8]. Here we sketch a possible way to use foil stripping, allowing to bridge the gap until laser stripping is fully developed.

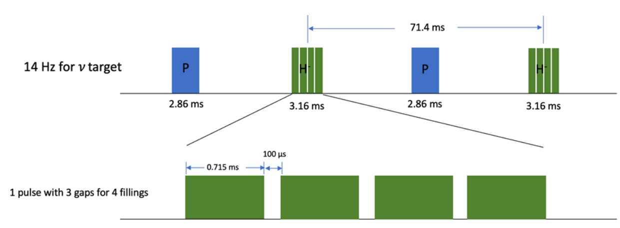

Figure 1: The 14 Hz Cycle of the ESSnuSB.

For some years the solution consisted in distributing the batches over 3 or 4 intermediate H$^-$ pulses of reduced intensity. Final painted emittances of the extracted beam were tight: 95% within 33 π mm mrad geom. In the last years these were relaxed successively to 99% within 90 π and 120 π (100%).

Ways out of the Foil-Heating Dilemma

Different ideas were proposed how to distribute the load of the four consecutive batches:

i. Move the injection point on the foil with simultaneous following of the painting orbit bump
ii. Use a different area of the foil for each batch
iii. A row of several thinner foils

Ideas (i) and (ii) combined were studied for a final painted geometric emittance of 120 π mm mrad.

Idea (iii) was studied for a final painted emittance of 60 π mm mrad (geom.) and is described in [9].

HANDLING FOUR BATCHES OF 120 π

Optimisation without Space Charge

With the present linac parameters [4], 480 H$^-$ spots of 0.35 π rms normalized emittance, corresponding to 1 π (10 σ) geom., must be placed within 120 π final emittance.

Fortunately, with this final emittance the space charge tune shifts become very small, suggesting the use of no-space-charge algorithms. Only these allow the necessary speed by using analytic expressions for multi-particle tracking. In our case we used MISHIF [10], a multiturn injection programme developed for heavy ion storage rings for inertial fusion. The final transverse distribution of the painted beam as plotted by MISHIF is shown in Fig. 2.

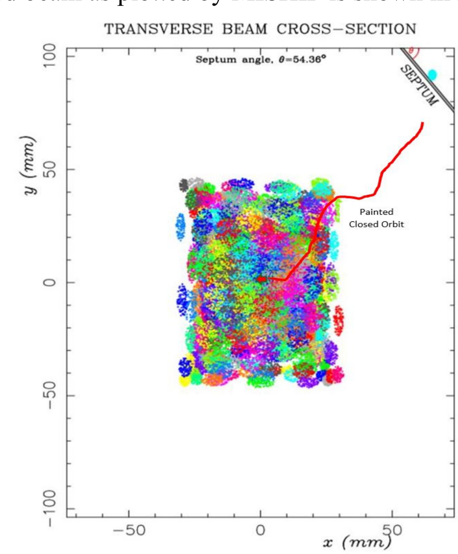

Figure 2: The final x-y distribution of 480 injected turns. It shows the painting orbit bump, coming down to zero.

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Mentioned idea (i) seems possible only with a tilted foil, which is a priori hit more frequently, hence inferior to a corner foil. This is compensated by moving the injection point along the foil edge, distributing the linac spot over a larger area. The whole painting setup is displaced for every batch, again along the foil edge (ii), as is shown in Fig. 3.

This is achieved by a 'base bump' which displaces the single-batch geometry along the foil edge between consecutive batches.

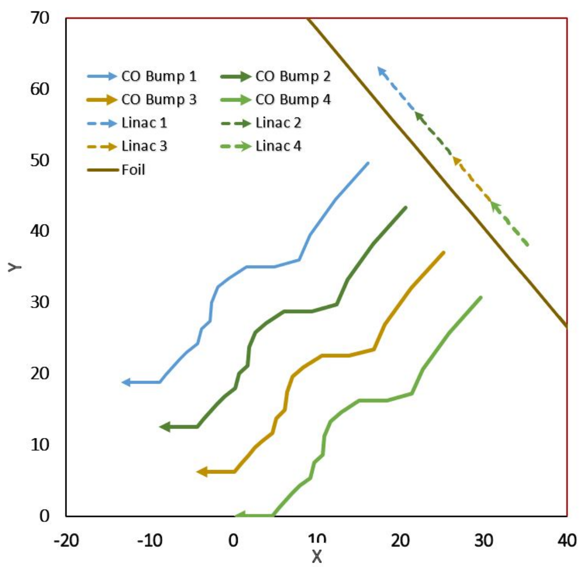

Figure 3: Geometry of the combined strategies (i) and (ii).

Introducing Space Charge

The painting orbits found with MISHIF were transferred to the ACCSIM code [11]. This program allows inclined foils, moving injection points, includes space charge and provides the final particle distributions. It counts in the number of foil hits by H$^-$ and proton beams on a grid of 1 mm bin size. Note that ORBIT [12] was conceived on the base of ACCSIM.

Four runs were effectuated for the four different batch positions. They produced nearly identical results as expected. Figure 4 shows the distributions of the circulating beam for one and all four batches. Figure 5 shows the final x-y distribution, to be compared with Fig. 2. The foil hit distributions were ported in a Mathematica program to compute the temperature distributions with the method used in the SNS [7].

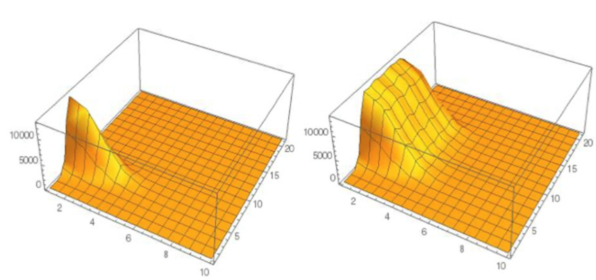

Figure 4: Distributions of foil hits.

In the temperature calculations, the energy deposed is calculated from the local foil hit density of H$^-$ ions and protons, as shown in Fig. 6.

The fact that the peak temperature of the combined effect of linac and circulating beams is only slightly higher than of the linac alone suggests that our strategy can be applied to beams of smaller final emittance, handled by multiple foils in [9].

Another point worth to be considered is the requirements for the power converters of the closed orbit bumps and the base bumps. These can at best be inferred from their amplitudes as a function of time, as shown in Fig. 7.

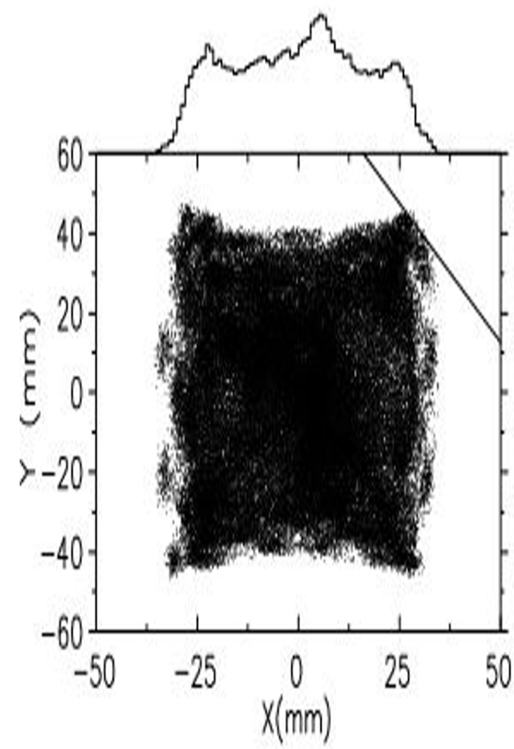

Figure 5: Final x-y distribution as in Fig. 2, calculated with ACCSIM including space charge.

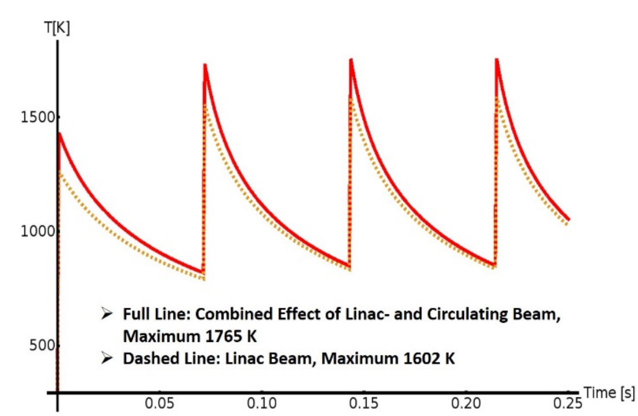

Figure 6: Foil temperatures for 4 batches.

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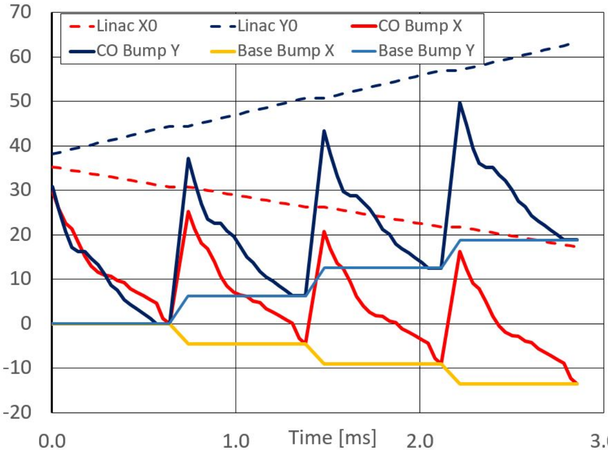

Figure 7: The different bump amplitudes as a function of time.

CONCLUSION

The design of the accumulator ring for the ESSnuSB is progressing. The ring will accumulate 2.2×10^{14} particles per fill to an unnormalized 100% emittance that can be less than 120 π mm mrad and a tune shift of 0.05. The extraction gap can be preserved efficiently using a barrier RF cavity [4]. Detailed studies of the beam loss, collimation, and chromaticity correction, are ongoing.

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REFERENCES

[1] E. Wildner *et al.*, "The opportunity offered by the ESSnuSB project to exploit the larger leptonic cp violation signal at the second oscillation maximum and the requirements of this project on the ESS accelerator complex", *Advances in High Energy Physics*, vol. 20, pp. 1-16, Jan. 2016. doi:10.1155/2016/8640493

[2] E. Baussan *et al.*, "Neutrino super beam based on a superconducting proton linac", *Phys. Rev. Accel. Beams*, vol. 17, p. 031001, Mar. 2014. doi:10.1103/PhysRevSTAB.17.031001

[3] M. Olvegård *et al.*, "Overview of the ESSnuSB accumulator ring", in *Proc. HB2016*, Malmö, Sweden, Jul. 2016, pp. 105-109. doi:10.18429/JACoW-HB2016-MOPR021

[4] Y. Zou *et al.*, "Status of the ESSnuSB Accumulator Design", in *Proc. 10th Int. Particle Accelerator Conf. (IPAC'19)*, Melbourne, Australia, May 2019, pp. 666-668. doi:10.18429/JACoW-IPAC2019-MOPRB046

[5] Y. Zou, "The accumulator ring for the ESSnuSB project", in *Proc. 21st Int. Workshop on Neutrinos from Accelerators (NuFact2019)*, Daegu, Korea, Jun. 2020, p. 061. doi:10.22323/1.369.0061

[6] Y. Zou, "Challenges and status of the ESSnuSB accumulator design", in *Proc. 20th Int. Workshop on Neutrinos from Accelerators (NuFact2018)*, Virginia, USA, Dec. 2019, p. 117. doi:10.22323/1.341.0117

[7] R. W. Shaw *et al.*, "Spallation neutron source (SNS) diamond stripper foil development", in *Proc. PAC07*, Albuquerque, New Mexico, USA, Jan. 2008. pp. 620-622. doi:10.1109/PAC.2007.4440298

[8] S. Cousineau *et al.*, "First demonstration of laser-assisted charge exchange for microsecond duration H^- beams", *Phys. Rev. Lett.*, vol. 118, no. 7, p. 074801, Feb. 2017. doi:10.1103/PhysRevLett.118.074801

[9] Y. Zou, "The ESSnuSB accumulator design", presented at the ESSnuSB Workshop UHH - Barenfeld – DESY, Online, Oct. 2020, unpublished. https://www.conferences.uni-hamburg.de/event/129/

[10] C. R. Prior, "MISHIF: A code to optimise multiturn injection", STFC Rutherford Appleton laboratory, Harwell Didcot, UK, internal communication.

[11] F. W. Jones, G. H. Mackenzie, and H. Schönauer, "ACCSIM – A Program to Simulate the Accumulation of Intense Proton Beams", in *Proc.14th International Conference on High Energy Accelerators*, Tsukuba, Japan, Aug. 1989, paper CERN-PS-89-55-HI, pp. 1407-1412.

[12] A. Shishlo *et al.*, "The particle accelerator simulation code PyORBIT", *ICCS 2015 International Conference on Computational Science*, vol. 51, pp. 1272-1281, Dec. 2015. doi:10.1016/j.procs.2015.05.312