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Upgrade possibility of the ESS linac for the ESSnuSB project

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The European Spallation Source (ESS), currently under construction in Lund, Sweden, is the world's most powerful neutron spallation source, with an average power of 5 MW at 2.0 GeV. The linac accelerates a proton beam of 62.5 mA peak current at 4 % duty cycle (2.86 ms at 14 Hz). The ESS neutrino Super Beam Project (ESSnuSB) proposes to utilise this powerful accelerator as a proton driver for a neutrino beam that will be sent to a large underground Cherenkov detector in Garpenberg, mid-Sweden. By adding a second H^- beam, interleaved with the proton beam, the duty cycle will be increased to 8 % and the average power to 10 MW. In this paper we discuss the modifications of the ESS linac required to reach an additional 5 MW beam power for neutrino production in parallel to spallation neutron production.

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1.Introduction

In the ESS baseline design, the linac will accelerate protons to the energy of 2 GeV in 2.86 ms long 62.5 mA pulses at 14 Hz repetition rate, for spallation neutron production. [1, 2] The low duty cycle of 4% of the ESS linac makes it possible to accelerate additional pulses of H^- ions, interleaved with the proton pulses. In the ESS neutrino Super Beam Project (ESSnuSB) it is proposed to utilise this powerful accelerator as a proton driver for a neutrino beam to be sent to a large underground Cherenkov detector in Garpenberg, mid-Sweden [3]. The pion focusing horns at the neutrino target provide focusing during only 1.5 µs, requiring the proton pulses to be of the order of microseconds. These short pulses can be achieved by injecting the H^- beam into an accumulator ring by charge exchange injection before they are sent to the neutrino target. As the average power and the duty cycle of the linac will be doubled from 5 MW to 10 MW, a corresponding increase of the output power from the RF sources and of the capacity of the different cooling systems will be required. The layout of the beam line for neutrino production including accumulator ring, production target and near detector are shown in Figure 1.

The baseline upgrade plan of the linac is to provide the additional 5 MW for the neutrino beam at higher energy of 2.5 GeV, Figure 2, which allows a lower average beam current of 50 mA. This will decrease the demands for the RF power in each module, results in lower space charge tune shift in the ring and reduces the strain on the accumulator ring design. Also stripping of H^- ions due to intra-beam scattering will be reduced, leading to lower beam loss, which has been a problem at SNS [4].

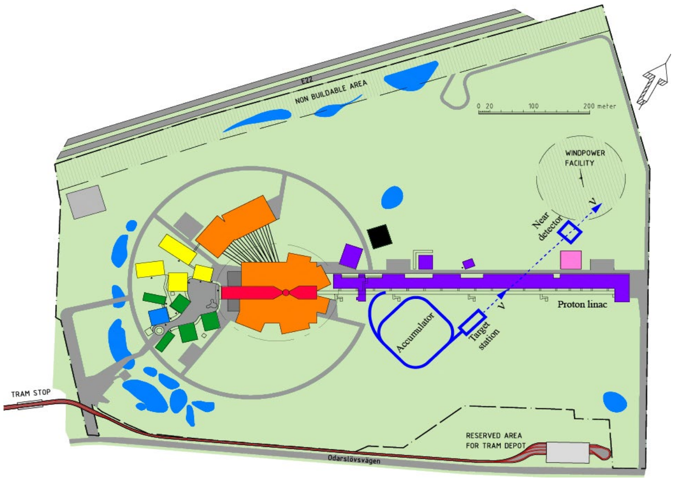

Figure 1. Layout of the ESS neutrino Super Beam facility added to the ESS neutron spallation facility. In blue are shown the new accumulator ring, the target station and near detector.

The layout of the accelerator is shown in Figure 2 with different sections of the accelerator indicated, including an upgrade section in the high energy section to 2.5 GeV.

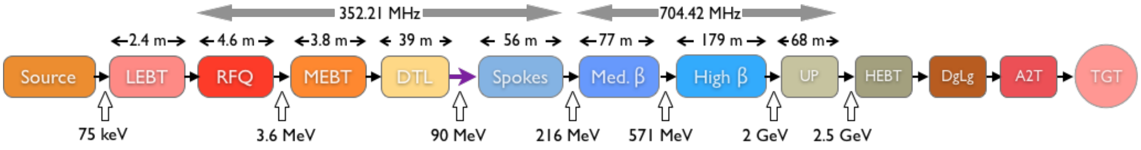

Figure 2. The accelerator layout, with normal conducting and superconducting sections. Indicated is the energy upgrade to 2.5 GeV.

2.Pulsing structure

The extraction of the beam from the accumulator ring to the target requires extraction gaps in the accumulated beam in the order of 100 ns, corresponding to the rise time of the extraction kickers, in order to avoid beam loss and unnecessary activation during this time. One option is to create the gap in the accumulator ring itself with RF barrier bucket cavities. However, simulations show that instabilities are likely to develop in the ring during the time needed to create the gaps [5]. Another option is to create the gap already in the linac, with chopping of the beam in the Medium Energy Beam Transport (MEBT) section. However, the pulsing of the beam will generate frequencies that can drive higher order oscillation modes in the acceleration cavities. The consequences are discussed further in next section.

A pulsing scheme with an overall 28 Hz macro-pulse structure is selected as the baseline design, see Figure 3. Other pulsing schemes have been considered, such as higher pulse frequencies, 56 Hz or 70 Hz. This would however result in a higher load of the RF system, since the filling time of the SC cavities is in the order of 0.3 ms, and would require a major modification of the ESS RF modulator system. Each macro-pulse of $8.9 \cdot 10^{14}$ particles will be divided into four batches of $2.2 \cdot 10^{14}$ particles. Each batch will be used for one filling of the accumulator ring. Each pulse is compressed to about 1.2 µs, which is subsequently extracted to the target. Each batch will be separated by a gap of approximately 100 µs. This is the time needed for the current in the extraction kickers in the accumulator ring to fall back, so that the ring is ready for the next injection. Each batch will be chopped up in a pulse train of about 540 pulses, each with an extraction gap of 100 ns in between.

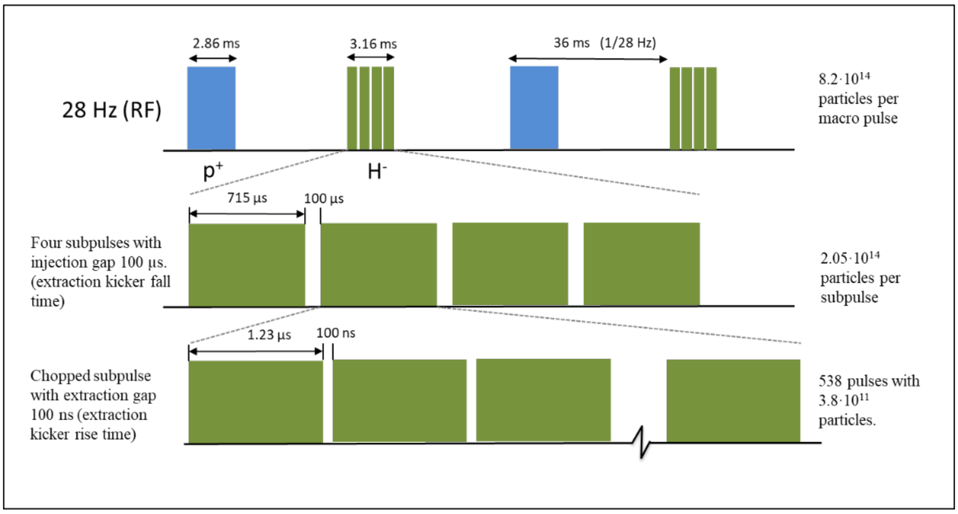

Figure 3. Each macro-pulse will be divided into four batches with 100 µs gap. Each of these batches will be chopped into about 540 pulses with extraction gaps of about 100 ns.

3. Higher order modes

The impact of higher/same order modes (HOMs/SOMs) is a general concern in high power superconducting linacs [5]. The HOMs can cause heating of the cavity walls, extra cryogenic heat load, and beam instabilities. The effect of HOMs has been studied for ESS in standard mode [1, 6, 7] and, together with the problems of HOM couplers experienced at SNS [8], the choice was to design ESS without HOM couplers. However, for the future operation with a chopped pulse scheme, the effects of HOMs need further attention, since the chopped beam can drive HOM excitation in the acceleration cavities.

Preliminary results from simulations of SOM effects in the superconducting cavities are shown in Figure 4. This is the result of the power spectrum in the medium beta cavities with a chopped beam pulse with the extraction gap in the pulse structure. The beam power spectrum generated will have main bunching frequency at 352 MHz (center frequency in the plot) with sidebands at frequencies that are multiples of the chopping frequency 752 kHz (1/1.33 μs). As can be seen, the first sideband is close to the 5π/6 mode in the accelerator passband of the medium beta cavities (the dashed red line). Different ways to mitigate possible problems with HOMs, e.g. different pulsing schemes will be studied to conclude whether chopping of the beam in the linac is feasible, or if the extraction gap needs to be created in the accumulator ring.

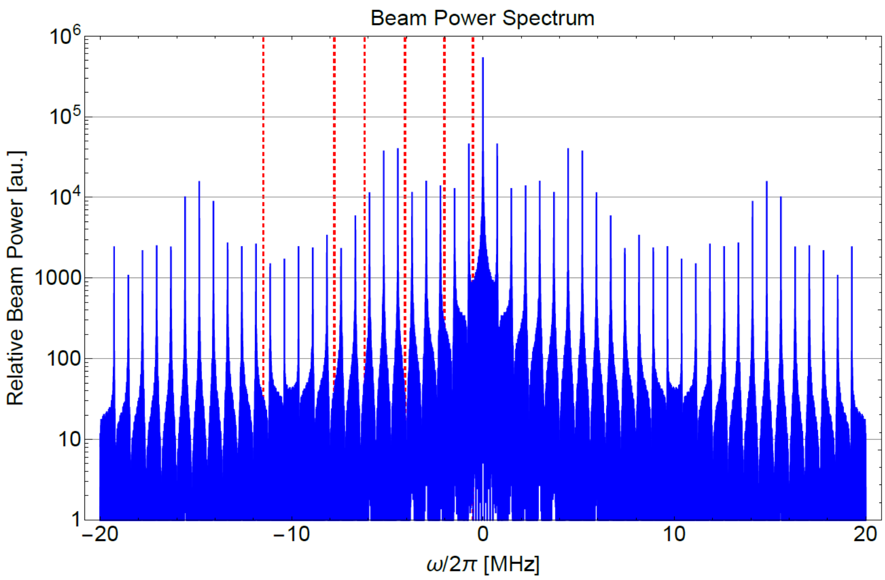

Figure 4. Beam Power Spectrum in medium beta cavities with a chopped beam. Monopole modes of the cavities are indicated with red dashed lines, with the 5π/6 mode close to the first sideband.

4. Summary

For the ESSnuSB project, the accelerator needs to be upgraded to add a 5 MW H^- beam for neutrino production in addition to the 5 MW proton beam for spallation neutron production. As the baseline design, the energy will be upgraded to 2.5 GeV, by adding high-beta cavities at the end of the linac. At this stage of the project it is most important to identify the critical issues that may cause problems accelerating the H^- ions and to identify if there are any modifications that have to be made early in the design. So far, no showstoppers have been identified for this future upgrade. We have identified issues that need to be further studied such as the effect of chopping of the beam in the linac leading to possible HOM problems and beam loss related to stripping of H^- ions.

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References

[1] S. Peggs et al. Technical Design Report ESS, 2013; http://esss.se

[2] R. Garoby et al., Physica Scripta **93** 014001, 2018.

[3] M. Dracos, these proceedings; http://essnusb.eu

[4] M. Schuh et al., Phys Rev ST, **14,** 051001, 2011.

[5] A. Shishlo, et al, PRL **108**, 11480, 2012.

[6] A. Farricker. Thesis, University of Manchester, 2017.

[7] R. Ainsworth and S. Molloy. Nucl. Instr. Meth. A, **734**, 95 2014.

[8] S. Kim, Proc. of LINAC 2008, Victoria, BC, Canada, 2008.