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FUTURE ESS UPGRADE TO MEDIUM PULSE LENGTH: WHAT ARE THE TECHNICAL CHALLENGES FOR THE ACCELERATOR AND TARGET?

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Abstract

A compression of the ESS proton pulse from the present 2.86 milliseconds to a medium pulse length of a few tenth of microseconds which is better matched to the moderator time-constant of thermal neutrons would considerably boost the performance for many instruments at ESS. Generating such a proton pulse with preserved instantaneous beam power requires a storage ring to be added to the ESS accelerator. Such a ring has been studied within the ESS-nuSB neutrino super-beam study. The proton pulse length extracted in single turn extraction from this ring would be approximately 1 microsecond long which could be destructive for the present ESS target and is very short compared to the moderator time constant. The more desirable medium length pulse could possibly be generated by multi-turn extraction and a new concept using a cyclotron like extraction scheme in a synchrotron or a FFA. Another way to generate the longer pulses is to extract a bunch train using fast strip line kickers but this would require a larger storage ring. Using a "bunch train" has been successfully applied at the CERN ISOLDE facility to avoid destruction of sensitive liquid metal targets used for Nuclear Physics experiments. Other challenges are linked to the injection into the storage rings and the understanding of the target, moderator and neutron extraction systems with short and medium pulse length.

INTRODUCTION

A medium proton pulse length of a few tenth of microseconds with an average power of 5 MW at the European spallation Source (ESS) [1] is a very attractive upgrade path for ESS and would assure that ESS remains the brightest peak and average Neutron Spallation source in the world for the foreseeable future. First studies for the instruments being built for the end of the ESS construction project in 2027 shows a performance enhancement of many instruments with a factor 10-15. New loss free extraction schemes from a 5 MW beam accumulated in a ring seems feasible and target and moderator aspects possible to handle. A workshop was held at ESS in February 2023 [2] to discuss the gain for the present instrument suite and the technical challenges. Much of the content in this contribution is taken from this workshop with the author list reflecting the contributors at this workshop.

INSTRUMENTS

The performance of the ESS instrument suite including prospects for future instruments for a medium pulse was discussed at the quoted workshop by M. Arai , P. Deen and W. Schweika [2] and by W. Schweika et al. [3]. The gain in the instrument suite for ESS at the end of construction in 2027 is described in [3] with a full description of the ESS instruments available in [4]. The goal of a medium pulse of 50 microseconds duration can result in a high gain, ~5 to 30, for the wavelength spectrum used at ESS instruments down to the minimum of 0.5 Å at the instruments DREAM, HEIMDAL, TREX and VESPA. It would be difficult to make use of shorter pulses in the order of microseconds for the current instruments and it will very likely not be acceptable for the target.

Figure 1 shows a comparison of peak brightness at neutron facilities world-wide illustrating that the perspectives for the ESS with a medium pulse will have a superior performance compared to other proposed and existing facilities. Our claim is that this is a new paradigm in pulsed neutron performance that opens the path towards a new generation of (upgraded) spallation sources with very high brightness.

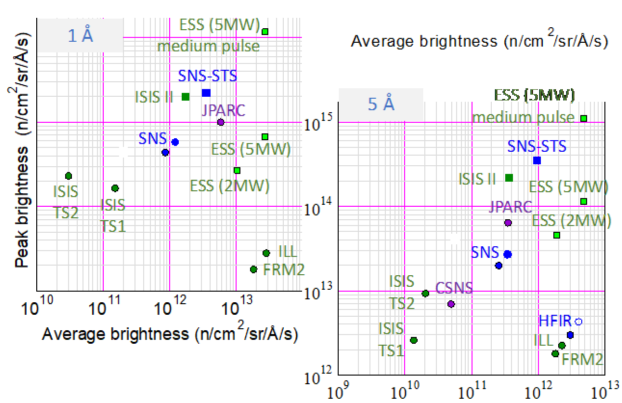

Figure 1: Brightness of present and future neutron facilities showing that an upgrade of ESS with a medium pulse length would make it brighter than all present and proposed spallation facilities, W. Schweika [3].

TARGET AND MODERATOR

The change of peak brightness of the butterfly moderator has been discussed by L. Zanini [2] for various pulse

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lengths and wavelengths. The gain in peak brightness is larger than ~10 for thermal neutron with less than ~2 Å wavelength for 50 microsecond pulse.

Changing the pulse length has no impact on the total power and target cooling requirements, since heat transfer is slow compared to the proton pulse, U. Odén and W. Schweika [2]. Thermo-mechanical shock waves are crucial and scale with the peak power, which will increase upon shortening the proton pulse at constant average power. The peak power of existing and planned short pulse spallation targets are in the order of ~40-50 GW, which would be reached by shortening the ESS pulse to ~8.5 microsecond. Therefore, a short pulse of ~1 microsecond, which would be simpler to make by a accelerator/storage ring, is probably not acceptable. For the present ESS rotating target design [5], thermo-mechanical stress is shown to appear in simulations particularly near sharp edges of the tungsten blocks. These edges are desirable for turbulent He-flow. It is possible to do modifications in future target wheels as the ESS target will have to be replaced at regular intervals. An alternative target design has been proposed for ESSnuSB [6] using a granular gas cooled target, it will be further studied for application to the ESS target station.

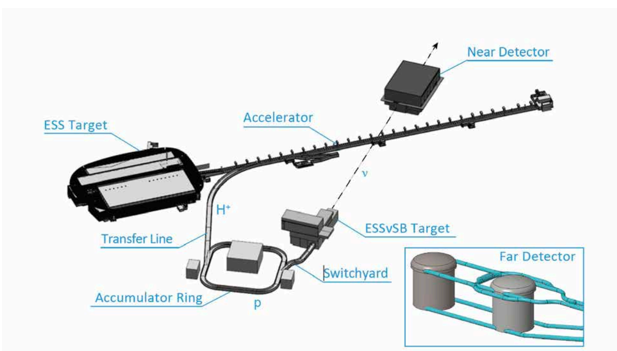

Figure 2: The ESSnuSB study [6] has looked at possible locations of an accumulation ring on the ESS site. For a medium pulse source, we would strive to find a ring design which is compatible with ESSnuSB. The switchyard in the ESSnuSB design is needed to distribute the beam on four different targets.

ACCELERATOR

Spallation sources using an accumulation ring or an RCS typically will have a proton pulse length in the order of a microsecond, while ESS with the LINAC pulse being sent directly to the target will have a pulse length of 3 milliseconds. The range of 50-100 microseconds with preserved total pulse power cannot be achieved at ESS as that would require a very high peak proton current which cannot be produced nor accelerated with the existing LINAC structures. Producing a medium pulse of a few tenth of microseconds from an accumulation ring or and RCS has long been considered impossible for high power beams as traditional methods of slow extraction are limited in beam power by inherent losses in slow extraction systems.

Challenging the validity of the statement that medium high beam power pulses cannot be generated with a ring, D. McGinnis et al. [7] has proposed a loss free extraction scheme generating a bunch train of 50-100 microseconds for a 5 MW average beam power source. This scheme requires a large stacked (4 rings) storage ring with a circumference of 1100 m and the use of fast strip line kickers to enable loss free bunch-by-bunch extraction.

A few more alternatives to this scheme have been explored, see e.g. presentations at [2]. A very interesting proposal was made by S. Machida [2] for a loss free cyclotron like extraction scheme. Back-of-the-envelope calculations indicates that the scheme and proposed extraction mechanism is feasible. Finally, slow extraction from the ESSnuSB accumulation ring (Fig. 2) using a fast integer resonance scheme has also been proposed by M. Olvegaard [2].

Injection into a ring usually requires using an H^- beam. H- and H+ bunches can be accelerated in different bunches with e.g. a repletion rate of 28 Hz in the ESS LINAC which is the baseline for ESSnuSB neutrino beam proposal [6]. Separate RF buckets are used for the H- and H+ bunches so beam loading is not an issue.

C. Prior has proposed [2, 8] an injection scheme with a tilted injection septum using an H+ beam and traditional Betatron stacking. In his simulations, a sufficient number of turns can be accumulated to satisfy the needs for the proposed ring at ESS (both for ESSnuSB and for a 5 MW Medium Pulse source). Regarding the need of collimation for a Medium Pulse length source, using accumulation rings the extracted beam is probably sufficiently flat to annul the need for different beam expansion schemes before the target. Collimation to get rid of e.g. a beam halo can be done in the ring or in the transfer line from the ring.

CONCLUSIONS

A medium pulse source length source with a 50-microsecond proton pulse length using the existing ESS target station would enhance the performance of many instruments with a factor of 10-15. The average and peak neutron flux would be superior to any other proposed facility, see Fig. 1. The proposed extraction schemes to generate such a pulse at high-power should be further explored and studied to better understand the performance and possible limitations of the different extraction schemes. Target and moderator aspects also need to be further studied with the main option being to use a design compatible with the existing target station.

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