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COMMISSIONING OF THE NEW EXPERIMENTAL FODO LINE AT THE SNS BEAM TEST FACILITY*

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Abstract

The Spallation Neutron Source Beam Test Facility (SNS BTF) consists of a 2.5 MeV proton accelerator and a beam line with various diagnostics for high intensity beam dynamics study. A beam line consisting of 19 identical quadrupole magnets arranged in FODO configuration, and a large dynamic range emittance monitor has been added recently. The new setup is designed for experimental study of mechanisms of halo formation in mismatched high intensity beams. We present results of the new beam line commissioning with beam.

INTRODUCTION

The SNS Beam Test Facility functionally replicates the SNS Front End systems to ensure relevance of beam measurements at the BTF for SNS operation. It can produce pulsed 2.5 MeV beam of negative hydrogen ions (H-) with maximum peak current of 50mA, maximum pulse width of 1ms, and maximum pulse repetition rate of 60 Hz. A detailed description of the BTF systems can be found in [1]. One of the BTF goals of commissioning the new SNS RFQ was accomplished by the end of 2017 [2]. The new RFQ was moved to the SNS Front End to replace the old RFQ, and the old RFQ was moved to the BTF. A short BTF run in August of 2018 confirmed successful relocation and integration of the old RFQ with the BTF infrastructure. The BTF expansion to add the new FODO line took place in the period from August to December of 2018. A layout of the reconfigured BTF is shown in Fig. 1. This paper presents results of the new BTF beam line commissioning.

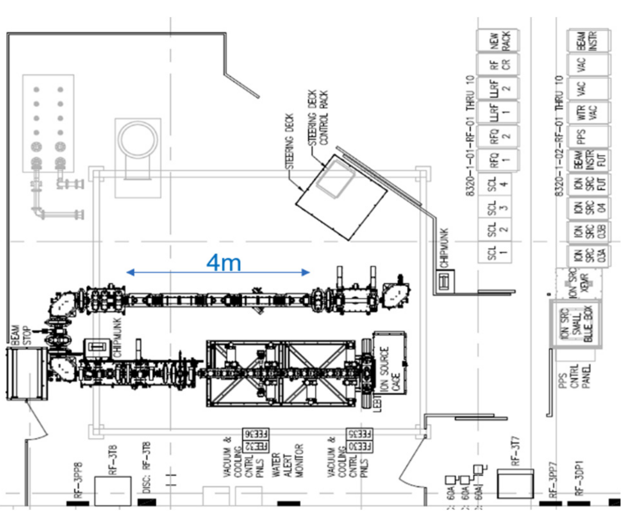

Figure 1: A general layout of the SNS BTF.

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THE BTF BEAM LINE

The main purpose of the latest beam line extension is to provide tools for experimental investigation of halo formation in high intensity hadron beam and beam dynamics simulation codes benchmarking. A layout of the beam line is shown in Fig. 2, and a photograph in Fig. 3. The H- beam is produced by the ion source (1), accelerated to 2.5 MeV by the RFQ (2), the six-dimensional phase space distribution is measured by the 6D scanner (3) [3], the beam is turned in the achromatic bend (4), and injected into the FODO line (6) with the Twiss parameters adjusted in the matching section (5). The output transverse phase space is measured by the high dynamic range scanner (7). The need to turn the beam by 180° is dictated by the available space in the building.

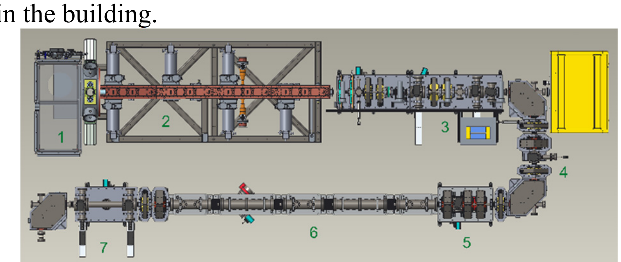

Figure 2: A general layout of the BTF beam line with the Ion Source (1), the RFQ (2), the 6D phase space scanner (3), the achromatic 180° bend (4), the matching section (5), the FODO line (6), and the emittance scanner (7).

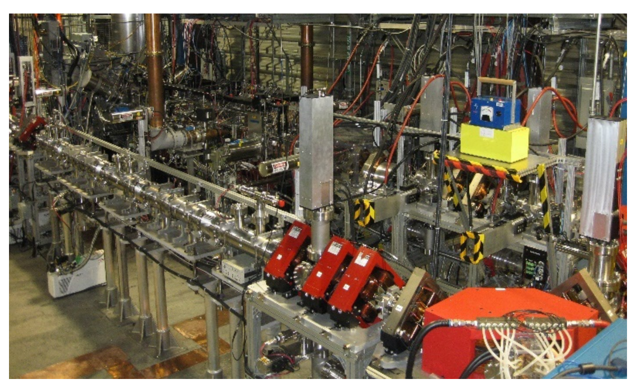

Figure 3: A photograph of the SNS BTF beam line.

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The FODO Line Design

The FODO arrangement of quadrupole magnets was chosen as a benchmark beamline because of its simplicity and widely accepted proposition that halo can develop in a beam propagating through a FODO line if the input conditions are not matched [4]. The optics design is described in detail in [5]. The FODO line consists of 19 identical permanent magnet quadrupoles, shown in Fig. 4, with integrated gradient of 1.8 T. The maximum number of magnets is limited by the available space. The magnets are mounted on rails as shown in Fig. 5 and can be moved to adjust the phase advance in the FODO line. The initial assembly for commissioning is done with 90 degrees per cell phase advance. The whole beam line was assembled and aligned in the lab before moving to the BTF, Fig. 6. The design beam size is shown in Fig. 7 for the matched (a) and mismatched (b) conditions. Multi-particle PIC simulation predicts the halo development in the mismatched case as shown in Fig. 8.

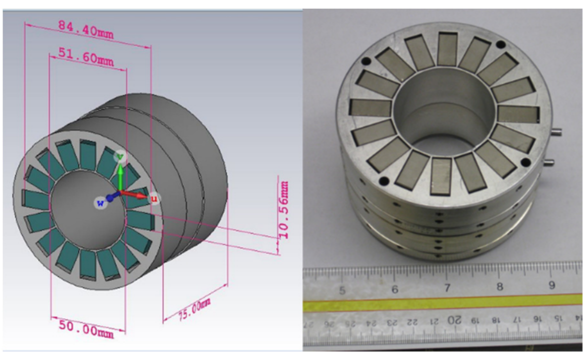

Figure 4: Permanent magnet quadrupole used in the BTF FODO line.

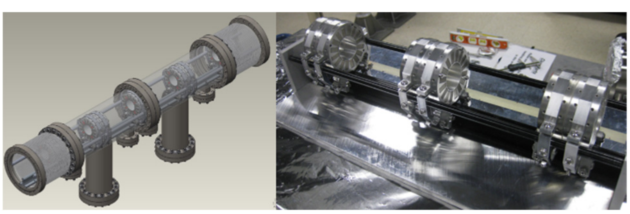

Figure 5: The PMQs assembly on a rail inside the vacuum pipe.

Figure 6: The FODO line assembled in the lab.

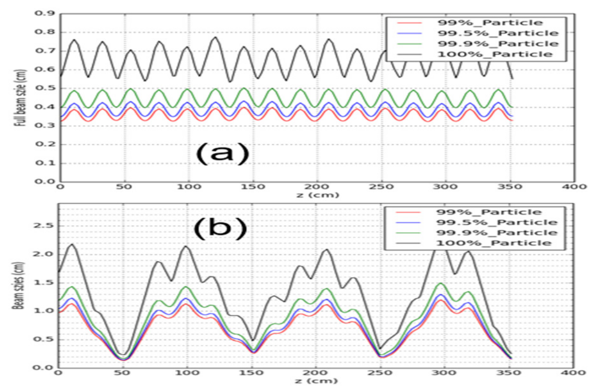

Figure 7: The expected beam size in the FODO line for matched (a) and mismatched m=3 (b) input conditions.

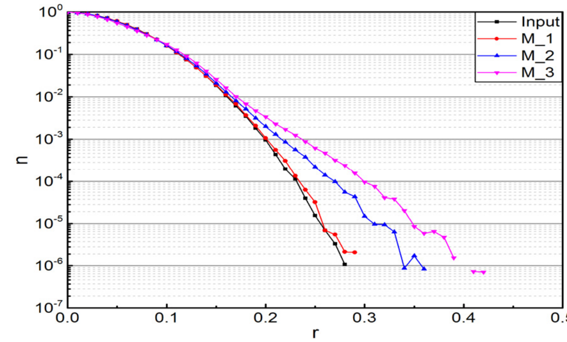

Figure 8: The phase space particle density at the end of the FODO line from multi-particle simulations for various mismatch parameters.

The High Dynamic Range Emittance Scanner

The minimum dimensionality of the phase space projections useful for simulation benchmarking is 2, therefore slit-slit emittance scanners ar placed at the beginning of the BTF beam line and the FODO line exit to measure the horizontal and vertical emittances. For unambiguous characterization of the halo, a dynamic range of 10^6 or higher is required [6], which is beyond the demonstrated state-of-the-art of today. The key features of the scanners that allow achieving the highest dynamic range are the slit-slit design and addition of a dipole magnet after the second slit. The purpose of the magnet is to eliminate the ions that are scattered by the first slit and, typically, are the major limitation to the dynamic range in slit-based emittance measurement systems. The ions are collected by a Faraday Cup after passing through the two slits and the magnet. The charge is measured by a combination of a transimpedance amplifier and a high-resolution ADC.

THE NEW BEAM LINE COMMISSIONING RESULTS

The goals of the first commissioning run were to verify beam transport to the end of the beam line, to ensure good alignment and correct polarity of the magnets, and to check correct operation of the diagnostics.

A relatively good transmission of 97% was quickly achieved by manual tuning of the magnetic elements. The beam current was measured at three locations: close to the

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RFQ exit, close to the FODO line entrance, and at the end of the beam line. A typical result is shown in Fig. 9. There are only two pairs of dipole correctors located right after the RFQ exit, therefore a good alignment of the focusing elements is required for good beam transport, which was confirmed to be the case. Good transmission is also an indicator of the correct assembly of the permanent magnets in the FODO line.

A typical high dynamic range emittance scan result is shown in Fig. 10. The up to date demonstrated dynamic range of 10^5 is believed to be limited by the readout electronics dynamic range. The phase space particle density, calculated from the data in Fig. 10 using the algorithm described in [6], is shown in Fig. 11.

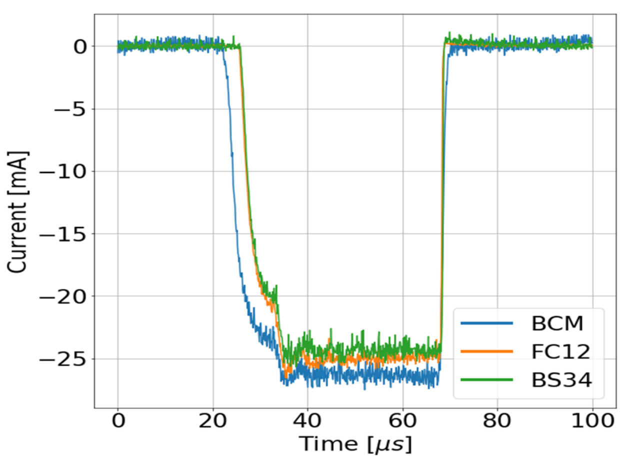

Figure 9: The measured beam current at the RFQ exit (blue), FODO entrance (orange), and end of the beam line (green).

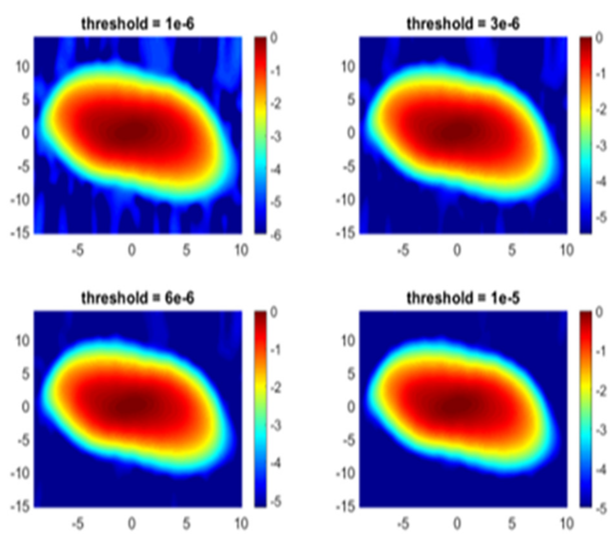

Figure 10: The measured vertical emittance at the beginning of the BTF beam line with different noise cut off threshold. The color scale is logarithmic.

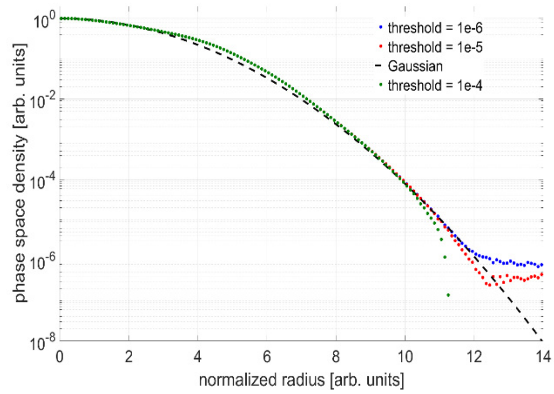

Figure 11: The phase space particle density calculated using the data shown in the Fig. 10 using the algorithm described in [6].

CONCLUSION AND FUTURE PLANS

The next step will be to develop good understanding and control of the beam optics; to improve the dynamic range of the emittance measurements; to identify need for more optics control elements and, possibly, need for halo scrapers to prepare clean initial distribution at the FODO entrance.

ACKNOWLEDGMENTS

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REFERENCES

[1] A. V. Aleksandrov *et al.*, "Commissioning of the New SNS RFQ and 2.5MeV Beam Test Facility", in *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, pp. 2438-2440. doi:10.18429/JACoW-IPAC2017-TUPVA145

[2] Y. W. Kang *et al.*, "Construction, Test, and Operation of a new RFQ at the Spallation Neutron Source (SNS)", in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, Canada, Apr.-May 2018, pp. 1113-1116. doi:10.18429/JA-CoW-IPAC2018-TUPAL046

[3] B. Cathey, S. Cousineau, A. Aleksandrov, A. Zhukov., *Phys. Rev. Lett*. vol. 121, p. 064804, 2018.

[4] A.V. Fedotov, "Mechanisms of Halo Formation", *HALO'03 Workshop*, Montauk, New York, 2003.

[5] Z. L. Zhang, A. V. Aleksandrov, and S. M. Cousineau, "FODO Lattice Design for Beam Halo Research at SNS", in *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copen-hagen, Denmark, May 2017, pp. 2449-2451. doi:10.18429/JACoW-IPAC2017-TUPVA148

[6] A. V. Aleksandrov, "Beam Halo Characterization and Mitigation", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, pp. 4248-4252. doi:10.18429/JACoW-IPAC2016-FRXBA01