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Nonintrusive emittance measurement of 1 GeV H^- beam

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ABSTRACT

A laser wire based transverse phase space measurement system has been developed at the Spallation Neutron Source (SNS). The system enables a direct measurement of the transverse emittance in both directions on a 1 GeV hydrogen ion (H^-) beam at the high energy beam transport (HEBT) beam line. The measurement is non-destructive and has been conducted on a neutron production H^- beam. This paper describes the design, implementation, and measurement performance of the system. The experience on the installation and commissioning of the laser emittance measurement system will also be discussed.

1. Introduction

The knowledge of transverse phase space such as beam emittance is of essential importance for beam matching and beam loss or residual activation control in high-brightness particle accelerators. Conventional emittance measurement techniques are generally classified into the slit-and-collector method and the pepper-pot method [1–3]. Both techniques are usually intrusive and cannot be applied to full spec high-brightness particle beams. Laser based nonintrusive emittance measurement approach was proposed and a proof-of-principle demonstration was conducted in Ref. [4]. While the laser based nonintrusive emittance measurement systems have been installed in electron beam accelerators [5,6], neither of them directly yielded the full information of the transverse emittance. For example, in the measurement of electron beam emittance in the damping ring of the Accelerator Test Facility of KEK, the beta function of the beam at the measurement location was used to calculate the beam emittance [6].

In this paper, we describe a laser wire based phase space measurement system at the high energy beam transport (HEBT) of the Spallation Neutron Source (SNS) accelerator complex. The system enables a direct measurement of the transverse emittance in both directions and the measurement is non-destructive and therefore can be conducted on operational particle beam parameters, i.e., particle beams with high beam current, long pulse duration and/or high repetition rates. Measurement of transverse emittances at the SNS HEBT is very important for both the evaluation of the existing 1 GeV/1 MW neutron production H^- beam and the planning for the upgrade project which aims at a beam energy/power of 1.3 GeV/3 MW.

2. Experimental setup

2.1. Measurement principle

Fig. 1 shows a diagram of the laser wire based emittance measurement system. It is in principle a slit-detector style emittance scanner except the conventional mechanical slit is replaced by a narrow laser beam (laser wire). When the H^- beam interacts with the laser light, a certain number of the ions illuminated by the laser pulse are neutralized and separated from the beam path. These hydrogen (H^0) atoms preserve the angular distribution of the original H^- beam. Therefore, the measurement of the divergence of the narrow H^0 beam leads to the determination of the H^- beam divergence.

The measurement of the H^0 beam angular distribution is conducted through the measurement of its transverse profile after its propagation over a certain distance. The measurement is performed again through the electron detachment process, this time with a metal wire interacting with the particle beam. By measuring the profiles of the detached electron density, the wire scanner reveals the distribution of the H^0 beam which corresponds to the divergence of the narrow H^0/H^- beam released from the laser slit. Finally, the emittance of the ion beam along

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the correspondent axis can be obtained by scanning the incident laser beam. The measurement can be conducted on horizontal and vertical directions with a proper optics scheme.

2.2. System layout

The SNS accelerator complex consists of an H^- injector, a 1 GeV linear accelerator, an accumulator ring, and associated transport lines [7]. The linear accelerator produces a 1 ms long, 38 mA peak, chopped beam pulse at 60 Hz. This beam is transported through the HEBT line to the injection point of the accumulator ring, where the 1 ms long pulse is compressed to less than 1 μs by charge-exchange multi-turn injection. The current operational beam power is 1 MW in 1-ms pulsed mode at a repetition rate of 60 Hz. In the SNS upgrade plan, additional nine cryomodules will be added to the linear accelerator to boost the H^- beam energy to 1.3 GeV with a beam power reaching 3 MW.

The emittance measurement setup is located about 40 m away from the beginning of the HEBT beamline. The expected beam emittance at this location is about 0.5 mm mrad. As shown in Fig. 2, the setup consists of two parts: a laser wire scanner (laser slit) and a conventional metallic wire scanner. The laser wire scanner is installed right before the first of eight 11.25° C-type dipoles which turn the H^- beam to the accumulator ring. These dipoles also separate the neutralized hydrogen beam (H^0) from the main beam trajectory and direct the H^0 beam to the linac dump beam line. A metallic wire scanner is installed in the linac dump beam line, about 11.6 m downstream of the laser wire station. The wire scanner measures the distribution of the H^0 beam released from the laser slit. Since the laser wire only interacts with a very tiny portion ($\sim 10^{-7}$) of the ion beam and the wire scanner is interacting with an off-line H^0 beam, the entire measurement is effectively nonintrusive and can be conducted parasitically on a neutron production H^- beam.

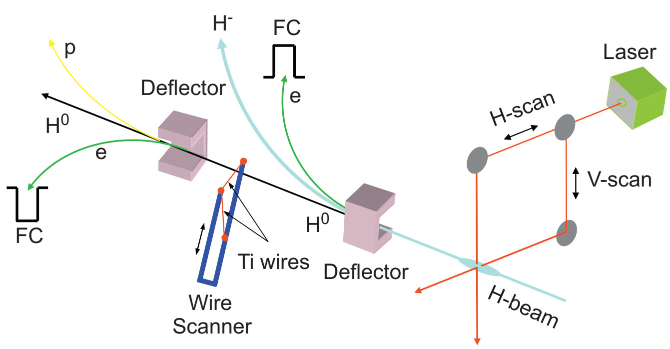

Fig. 1. Outline of laser wire based H^- beam emittance measurement system. FC: Faraday cup.

2.3. Laser slit setup

The laser wire scanner installed in the HEBT beamline serves as a slit for the H^- beam for emittance measurement. It uses the same light source of the SNS laser wire system [8,9]. The laser source is a Q-switched Nd:YAG laser (Spectra Physics PRO-290-30) with a pulse energy of up to 1 J over a pulse width of $\sim$7 ns. The actual pulse energy is remotely tunable. The distance between the laser source and the HEBT laser wire scanner is about 60 m. The laser beam is delivered to the measurement station through an enclosed free-space transport pipe. To control the spatial beam drift caused by mechanical and thermal uncertainties of the transport line, an active beam position stabilization scheme based on feedback control has been implemented [10]. Using the stabilization scheme, the achieved beam stability at low frequencies is better than 5 μrad, which corresponds to only ± 0.3 mm at the HEBT laser wire station. The spatial beam position stability ensures the measurement accuracy and repeatability.

The optics setup of the measurement station is shown in the inset of Fig. 2A. The laser beam is switched between horizontal and vertical beam paths by a flipper mirror (FM). Two paths have

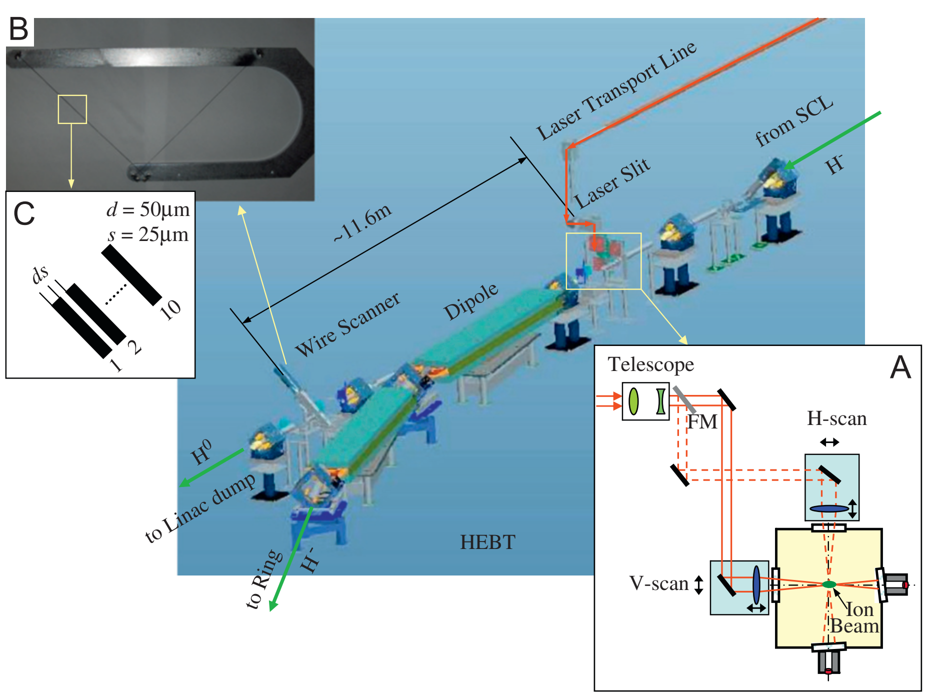

Fig. 2. Schematic diagram of the laser wire based emittance measurement system installed in the high energy beam transport (HEBT) at SNS. Inset A shows the configuration of the laser slit (wire) setup. FM: flipper mirror. Insets B and C show the picture and dimension drawing of the 10-wire titanium wire scanner, respectively. *d* and *s* are the individual wire thickness and the separation between wires, respectively.