MEASUREMENTS ON THE H- ION SOURCE AND LOW ENERGY BEAM TRANSPORT SECTION FOR THE SNS FRONT-END SYSTEM*

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Abstract

Berkeley Lab is engaged in the construction of the front end of the Spallation Neutron Source (SNS) [1] being built in Oak Ridge, Tennessee. Parts of the front end are the ion source and the Low Energy Beam Transport (LEBT) section. The startup ion source, enabling SNS to achieve 1-MW average beam power, has to provide 35 mA of H^- beam current at 6% duty factor (1 ms pulses at 60 Hz) with a normalized rms emittance of 0.15 π-mm-mrad. The H^- beam will be accelerated to 65 keV and matched into a 2.5 MeV RFQ. Ultimately an upgraded ion source is required to produce 65 mA of H^- at 6% duty factor with 0.2 pi-mm-mrad emittance, consistent with the nominal SNS beam power of 2 MW. To generate the H^- beam, a radio-frequency driven, magnetically-filtered multicusp ion source is being developed at Berkeley Lab. Extracted electrons are separated from the negative ion beam by a strong dipole magnet located in the outlet electrode and are then deposited on a dumping electrode inside the extraction gap. To compensate for the associated bending of the H^- beam, the source is tilted by a few degrees. The design of this ion source is directed towards operation at the required high duty factor. The LEBT section incorporates two electrostatic einzel lenses and has a total length of only 10 cm. With an all-electrostatic system, space charge neutralization is prevented. Experimental results (including emittance measurements) with the ion source and the LEBT section will be presented.

1 EXPERIMENTAL SETUP

The SNS integrated test stand consists of the ion source [2], the vacuum chamber with the all electrostatic LEBT section [3], and the tank for the diagnostics. A matching network within a cylindrical shell is located between the high voltage enclosure and the source. The ion source and LEBT electrodes are shown schematically in figure 1. The source is mounted inside a reentrant-cylinder within the LEBT vacuum vessel. This arrangement provides good vacuum pumping speed near the extraction gap. The cylindrical source plasma chamber (10 cm long by 10 cm diameter) is made out of stainless steel with a back plate at one end and an outlet electrode at the other. The plasma is confined by line-cusp fields produced by 20 rows of water-cooled, samarium-cobalt magnets that surround the source chamber and by the cusp fields of additional rows of magnets on the back flange. The hydrogen plasma is sustained by up to 35 kW of pulsed 2 MHz RF power. The inductive RF power coupling to the plasma is accomplished via a 2 1/2-turn, porcelain-coated copper antenna. A pair of water-cooled permanent magnet rods placed near the outlet electrode creates a narrow region of transverse magnetic filter field (200 G peak) that

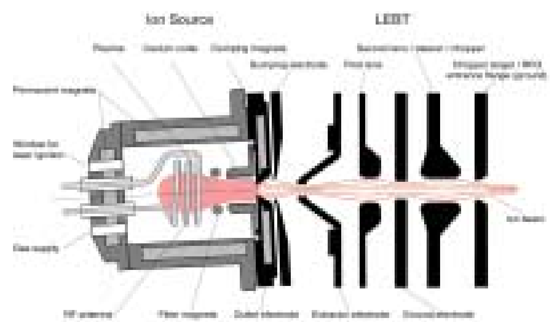

Figure 1: Schematic of the ion source and Low Energy Beam Transport section. The ion source with outlet and dumping electrodes is tilted by 3^0 with respect to the LEBT axis. Note that the actual filter and electron-dumping magnetics field are oriented orthogonally to the illustration plane. The shape of the beam envelope is exaggerated for emphasis.

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divides the source chamber into the "hot-plasma" discharge region and the "cold-plasma" H^- generation region. Installing a collar around the outlet aperture reduces the amount of electrons extracted together with the H^- ions. The collar, a double-walled cylinder (15-mm diameter, 15-mm long) is mounted on the outlet electrode, facing the plasma side. This stainless steel collar is also being used to accommodate tiny cesium getter containers inside vertical cuts. It is thermally insulated from the rest of the ion source. Active cooling or heating - depending on the discharge duty factor - is possible by adjusting a temperature-regulated airflow through the collar jacket. The collar is sufficiently massive to maintain a uniform temperature distribution along its inner surface. Cesium coverage of the collar surface lowers its work function, thereby increasing the H^- ion density in the cold-plasma region by surface production. The lowest work function can be achieved at a surface temperature of around 200 ^oC [2].

The outlet electrode consists of a copper plate, a soft iron plate for magnetic field shaping, a number of permanent magnets in the so-called Halbach configuration and a stainless steel plate with the aperture [4]. In front of this aperture the magnets generate a transversely homogeneous dipole field. The dumping field of 1700 Gauss peak strength not only deflects the electrons to the plasma chamber or to the dumping electrode, but slightly steers the H^- beam as well. Therefore provision is made to adjust the source angle with respect to the beam axis between 1^0 and 6.5^0, to compensate the deflection. The RF-driven source is operated with a continuous hydrogen gas flow of 20-30 sccm. All measurements have been carried out with a collar temperature of 150 - 200 ^0C, to ensure cesium coverage. Beam is formed at 35-65 kV and then injected into the LEBT section.

The LEBT is used to transport and match the extracted beam from the source to the entrance of the RFQ accelerator and consists essentially of four electrodes: the extractor, first lens, ground, and second lens. The geometry and position of the different electrodes have been designed using the computer simulation program IGUN [5]. The lens potentials are typically 50 to 70 % of the outlet potential. The second lens electrode consists of four isolated segments, which can be biased independently. This allows for beam steering and will be later used to generate the beam pulse mini structure (beam chopping). The beam enters the diagnostic chamber through a grounded aperture which also acts as chopper target. In the diagnostic chamber the beam is collected by a water-cooled Faraday cup in which secondary electrons are suppressed by means of a magnetic dipole field. To determine the beam quality, two Allison emittance scanners are used.

2 EXPERIMENTAL RESULTS

A typical result of a beam current measurement is shown in figure 2. In this scope picture channel 1 gives the signal measured at the end plate of the Faraday cup into 25 Ω, i.e. the 920 mV corresponding to 38 mA H^-. Channel 2 was connected to the body of the Faraday cup. This signal is most probably due to electrons generated at the end plate. Channel 3 is the measured voltage drop of the extraction power supply. In this measurement, the voltage decreases during the pulse

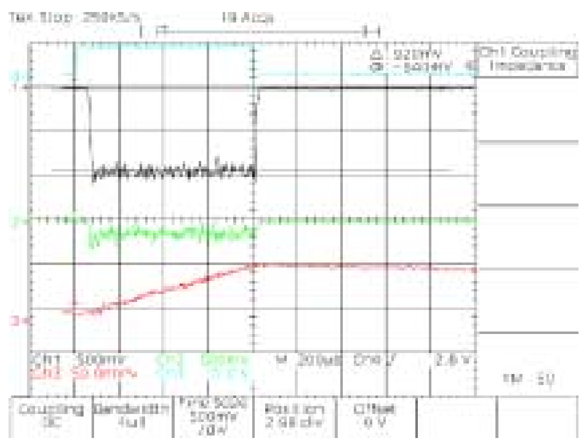

Figure 2: Scope picture of a 38mA H^- pulse current. The 750 µs H^- pulse is constant within 5 %. The repetition frequency was 10 Hz

from 41 to 40 kV. The repetition frequency was varied between 5 and 60 Hz and no influence on pulse shape or current was found. For optimized output current, the potentials were: -45 kV source potential, 13 kV extractor potential (gap voltage 58 kV), -40 kV lens 1 potential, -35 kV lens 2 potential. The H_2 gas flow was set to 30 sccm. To verify that no electrons were being extracted and transported, the experiment was repeated with helium as working gas. Helium does not form negative ions in a discharge and only electrons can be extracted from the source. For a similar parameter setting as discussed before, no current was measured on the electrodes or in the Faraday cup, but 200 mA on the electron dump electrode. This result demonstrated that no electrons enter the LEBT section. The ion source and LEBT now repeatedly produce and transport H^- beam currents larger than the required 35 mA for which the system was designed. Typical operating parameters are: RF power 30-35 kW, gas flow 20-30 sccm, beam energy 50-60 keV (presently limited by the HV power supply), electron dumping voltage 3-6 kV, cesium collar temperature 150-250 ^{0}C. To determine the beam losses in the Low Energy Beam Transport (LEBT) section, the currents on the extractor and ground electrode have been measured. By adjusting the ion source tilt angle, the losses on the extractor electrode are smaller than 5 % of the transported beam current. The current on the ground electrode is zero when the potential of the first lens electrode is optimized and a stable 40 mA H^- beam with 1 ms pulse length at a repetition frequency of 60 Hz has been measured in the Faraday cup. After running the source/LEBT system for two weeks, it has been inspected, and no damage was found.

The beam emittance has been measured 25 mm behind the LEBT chopper target in the diagnostic chamber. The emittance diagram for a low energy beam of 31 keV with 28 mA beam current are shown for the vertical plane in figure 3. The beam is seen to be convergent and deflected by several mrad with respect to the LEBT axis. The values for the normalized RMS emittance are 0.28 π mm mrad for the vertical and 0.6 π mm mrad for the horizontal plane. The larger value for the horizontal plane is caused by the strong dipole field in the

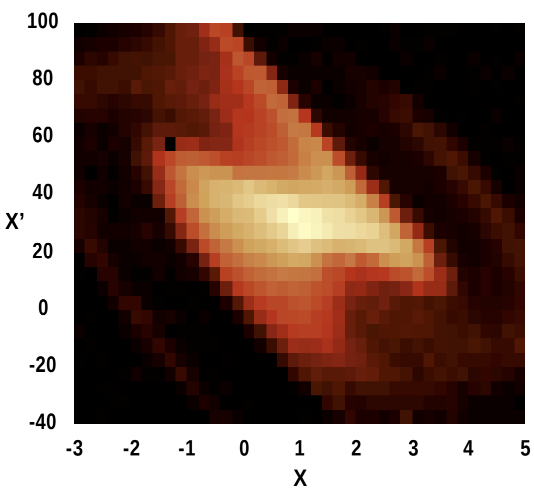

Figure 3: Vertical emittance diagram for a beam of 31 keV energy with 28 mA beam current. The normalized RMS emittance is 0.28 π mm mrad. The beam is convergent and deflected by several mrad with respect to the LEBT axis.

outlet aperture, which acts on the beam in this plane beyond the extractor. In both planes the diagrams show strong aberrations which are caused by the nonlinear fields of the lenses. Smaller emittance value at higher energies indicates that even at higher current the beam is better matched to the transport section. This is also shown in figure 4 where the emittance plot for a 40 mA-55 keV beam is shown. The emittance value is 0.26 π mm mrad, the diagram shows less aberrations. Due to limitations in the extraction power supply, no measurements at the required 65 keV have been performed yet.

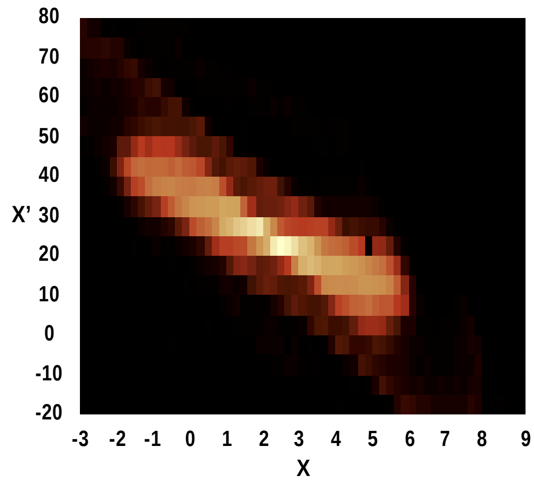

Figure 4: Vertical emittance diagram for a beam of 55 keV energy with 40 mA beam current. The normalized RMS emittance is 0.26 π mm mrad. The beam is convergent and deflected by several mrad with respect to the LEBT axis.

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