BEAM IN GAP MEASUREMENTS AT THE SNS FRONT-END *

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Abstract

The pulsed beam in the SNS accelerator has a fine time structure which consists of 695ns long mini-pulses separated by 250ns gaps in order to minimize transient beam losses in the accumulator ring which could arise during the ring extraction kicker rise time. This time structure is provided by a two stage Front End chopping system which must reduce the beam current in the gap to a level of 10^{-4} of the nominal current in order to satisfy requirements on the ring extraction losses. A Beam-in-Gap measuring system based on H^- stripping using Nd-YAG laser was developed and tested during the SNS Front-End commissioning period. This paper describes the Beam-in-Gap measurement system design and measured performance.

INTRODUCTION

The SNS accelerator systems are described in details elsewhere [1]. They have to deliver proton beam with average power of 1.44MW to the spallation target. The 1ms long H^- macro pulses are accelerated by the linac to 1GeV energy and injected into accumulator ring. After 1ms accumulation cycle, beam is extracted from the ring in one turn using fast kicker with about 200ns rise time. In order to minimize losses of the partially kicked particles during kicker rise time beam is chopped at the revolution frequency of about 1MHz into 'min-pulses' of 645ns duration with 300ns gaps. The required extinction ratio of about 10^{-4} is provided by two separate chopper systems located in the low energy beam transport section (LEBT) and medium beam transport section (MEBT), respectively. The LEBT chopper with design extinction ratio of about 1% and rise time of 25ns removes most of the beam power during the mini-pulse gaps. The MEBT chopper further reduces extinction ratio to 10^{-4} and sharpens gap's rise/fall edges to 10ns. In order to measure extinction ratio of the chopped beam diagnostic system with dynamic range better than 10^4 is required. Moreover it should have large bandwidth to be capable to measure 10ns rise/fall time of the gap. Beam-in-gap (BIG) measuring system was included in the original base line suit of the SNS diagnostics. The idea was to detach electrons from H^- using pulsed laser beam and measure flux of created neutral H^0 downstream [2]. BIG diagnostics was to be installed in the high-energy beam transport line where dipoles could be used to separate neutral particles from the main beam. This system was rejected later due to budget constraints. Meanwhile decision was made to replace wire scanners in the superconducting part of the linac by laser-based beam profile diagnostics, which is based on the same principle as original BIG diagnostics. Prototype beam profile measuring equipment was installed at the MEBT exit and was successfully tested during front-end system commissioning [3,4]. The same equipment proved to provide BIG measurements with required dynamic range and time resolution as described below.

DESIGN OF THE LASER BASED BEAM-IN- GAP MEASURING SYSTEM

General layout

General layout of the beam-in-gap measuring system is shown in figure 1. The measured beam (1) is intercepted by the overlapping light beam (2) from a high power pulsed laser (3). The electrons removed from the H^-s in photo-detachment process are deflected by dipole magnetic field of a magnet (4) and arrive to the collector (5). Collected charge is measured by data acquisition system. Timing of the laser pulse can be adjusted using variable delay thus allowing scanning H^- density along the macro-pulse. Time resolution is limited by the laser pulse duration.

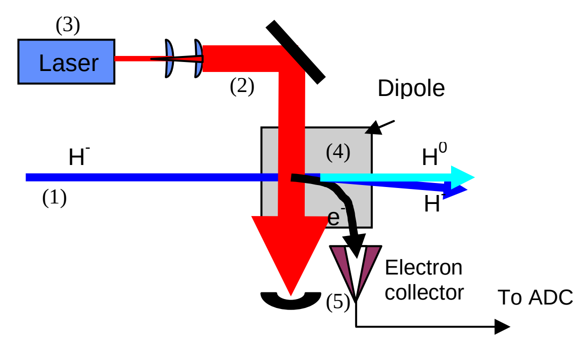

Figure 1. Schematic view of the beam-in-gap measuring system

Signal strength

Signal strength in the detector is defined by ratio of stripped ions in the beam or so called neutralization degree. Neutralization degree due to negative hydrogen ion stripping by overlapping laser beam crossing the ion beam at 90 degrees can be estimated as [5]:

$$\eta_0 \approx \frac{\lambda W_l}{2\pi hcv} \frac{\Sigma_0}{\tau_l \sigma_l},$$

where λ is laser wavelength, W_l is laser pulse energy, Σ_0 is invariant cross-section of photo-detachment, τ_l is laser pulse duration, σ_l is transverse laser beam size (assuming laser beam completely overlaps ion beam), v is ion beam velocity.

Expected neutralization degree in our experiment was close to 100%. Number of stripped electrons and therefore signal in the collector is

$$I_e = k \cdot I_b \cdot \eta_0 ,$$

where k is collection efficiency, I_b is ion beam current. Collection efficiency is close to 1 in our experiment due to large size of electron collector therefore electron current in the collector is close to the ion beam current. Note that absolute calibration is not required in the beam-in-gap measurements because we are interested in gap cleanness relative to the peak beam current.

Background signal

Two main sources produce a background charge in the collector: H^- stripping on the residual gas upstream of the detector and secondary electrons from beam particles lost in the collector vicinity. Both sources are correlated with the beam but not correlated with the laser pulse therefore time gating of the signal from the collector synchronized with the laser pulse helps to suppress background significantly. For this reason a Faraday cup with large frequency bandwidth was used to collect stripped electrons.

Hardware

We utilized hardware developed for the 'laser wire' profile monitor [5] for the beam-in-gap measurements. Commercial Nd-YAG laser has the following parameters:

Wavelength	1064nm
Max. pulse energy	600mJ
Pulse width	6-8ns
Max. rep. rate	30Hz

Light was transported through a transport line and injected into the vacuum chamber. Laser beam size at the interaction point was enlarged to ~ 2cm in diameter to ensure total overlap with the ion beam.

Stripped electrons were deflected by a 90° electromagnetic dipole and collected to a Faraday cup. The magnetic field required to deflect 1.25kV electrons is about 10Gs and its effect on the ion beam is negligible. The Faraday cup was designed with two important considerations in mind: good isolation from a 402.5 MHz electromagnetic interference from the beam; large frequency bandwidth to allow time gating synchronized with laser pulse for background suppression.

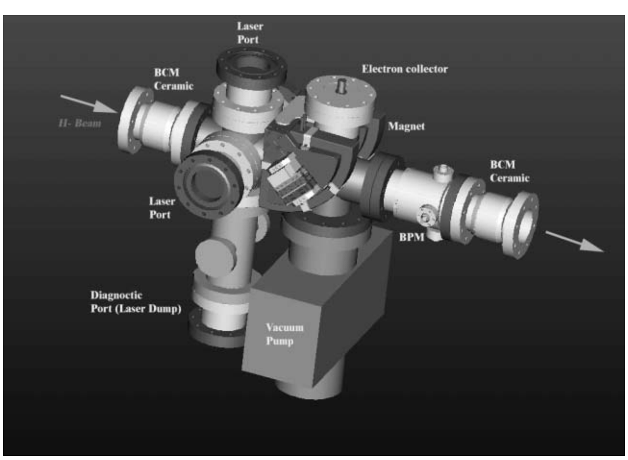

Figure 2. Vacuum chamber layout.

Signal from the Faraday cup was measured with a digital oscilloscope.

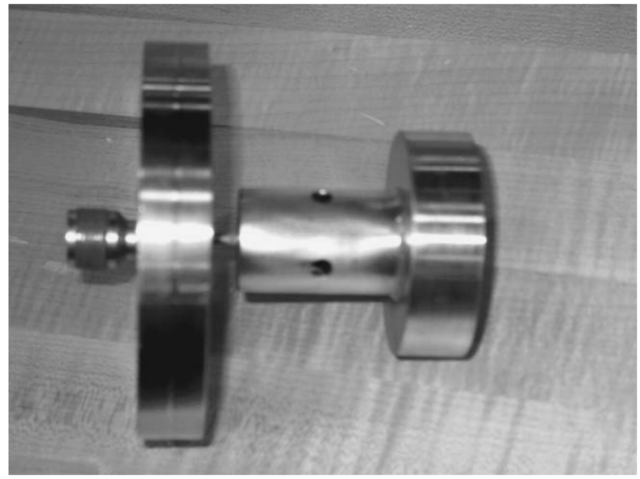

Figure 3. Faraday Cup design

EXPERIMENTAL RESULTS

Beam-in-gap measuring system was installed at the end of the MEBT and tested during the FES commissioning. The chopper system couldn't provide nominal chopping efficiency due to the failure of the high voltage chopper power supply switches. We simulated nominal operation of the chopper using DC deflection in the LEBT with specific goal to check capability of the measuring system itself.

Time resolution

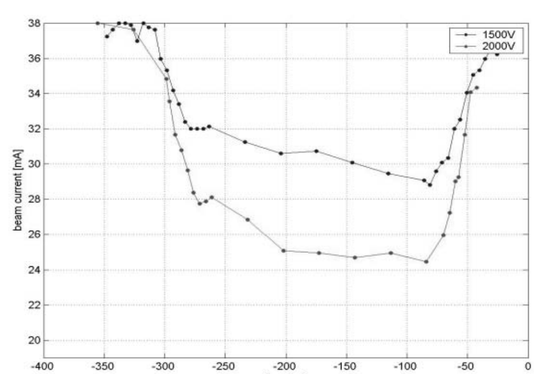

Figure 4. Time profile of a mini-pulse gap measured at different chopper voltage.

Gap of 250ns width was created in the stream of micro-pulses using one remaining operational switch. Nominally there are four switches. The efficiency of the deflector with only one channel operational is about ¼. Therefore depth of the gap couldn't reach design value of 1% but rise and fall edges of the gap were sharp enough to evaluate temporal resolution of the measuring system as shown in Fig.4. Ion beam density was sampled at various times along the mini-pulse by varying delay between ion beam and laser pulse. Observed temporal resolution of about 5ns is consistent with laser pulse duration.

Dynamic range

Beam-on phase of the mini-pulse was simulated by measurement at full beam current of 32mA. Signal from the electron collector in this case is shown in Fig 5.

In order to simulate full chopping efficiency, shifting beam closer to the edge of the chopper target by applying DC voltage on the deflector compensated lack of pulsed deflecting voltage on the chopper. As a result beam transmission was drastically reduced during both beam-on and beam-off phases. Minimum beam current of 70μA achieved in this configuration is a reasonable simulation of expected beam-in-gap residual current during normal operation of the chopper. Signal from the electron collector is shown in fig 6.

As seen from the Fig.6 beam current of 70μA produces signal in the collector, which is 10 times higher than the background. This represents dynamic range of about $5\cdot10^3$. In order to check that dynamic range was limited by the sensitivity of the oscilloscope and not by stripping on the residual gas, we increased residual pressure in the vacuum chamber by factor 2-3. It didn't result on corresponding increase of the background level proving that lack of amplifier gain was the factor limiting the dynamic range. There is no doubt that with additional amplification and filtering dynamic range could reach the required value of 10^4 or better.

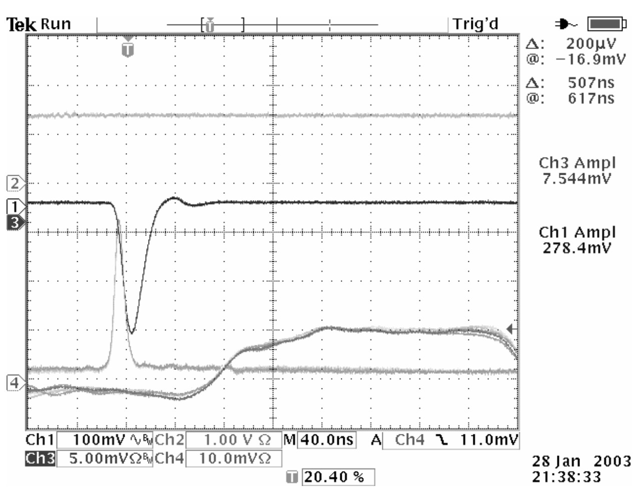

Figure 5. Oscilloscope trace of the signal for full beam current (blue trace). 0 dB amplifier gain. Green trace is laser pulse detected by a photodiode.

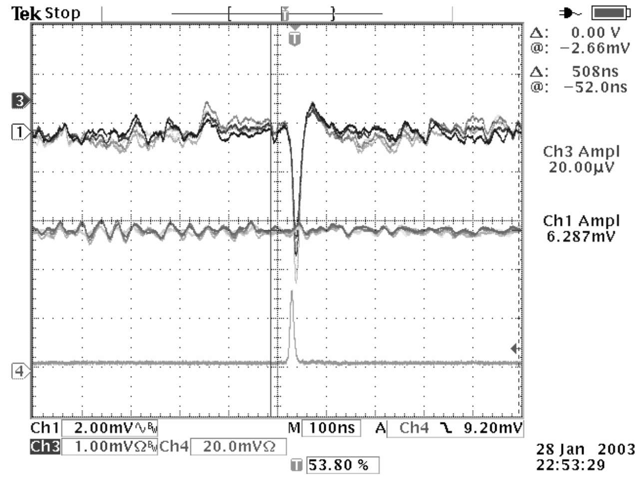

Figure 6. Oscilloscope trace of the signal for beam in the gap (upper blue trace). 20dB amplifier gain. Green trace is laser pulse detected by a photodiode.

CONCLUSION

We have developed a system for the beam-in-gap measurements in the SNS accelerator. Time resolution of 5ns and dynamic range of 10^4 has been achieved experimentally. Demonstrated parameters satisfy the SNS requirements. This system is based on the standard equipment of the 'laser wire' profile monitor therefore beam-in-gap can be measured at any location in the SCL.

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