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STUDY WITH WIRE SCANNER AND BEAM LOSS MONITOR AT CSNS-LINAC

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Abstract

The China Spallation Neutron Source (CSNS) has been passed the national acceptance in 2018 and opening for users for several months. Some beam study experiments with wire scanner and beam loss monitor were performed at the CSNS-LINAC during the machine study time. Quite amount of positive ions were found by wire scanner at the Middle Energy Beam Transport line (MEBT), but no more exist at LINAC to Ring Beam Transport line (LRBT). Meantime, the sensitivity of the Beam Loss Monitor (BLM) was verified by the wire scanner through these experiments.

INTRODUCTION

The CSNS accelerates proton beam pulses to 1.6 GeV kinetic energy at 25 Hz repetition rate, striking a Tungsten target to produce spallation neutrons. The accelerator provides a beam power of 100 kW on the target in the first phase. It will be upgraded to 500 kW beam power at the same repetition rate and same output energy in the second phase. A schematic layout of CSNS phase-1 complex is shown in Fig. 1. LINAC consist of an ion source, RFQ, DTL and beam transport lines. The ion source produces a peak current of 25 mA H- beam. RFQ bunches and accelerates it to 3 MeV and DTL raises the beam energy to 80 MeV. Then H- beam is injected into RCS and converted to proton beam via a stripping foil, RCS accumulates and accelerates the proton beam to 1.6 GeV before extracting it to the target [1, 2].

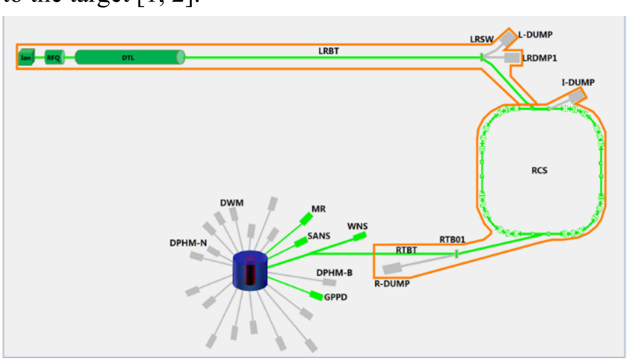

Figure 1: Schematics of the CSNS complex.

For the beam instrumentation system of CSNS, plenty of key monitors are distributed along the beam line, including beam position monitor (BPM), beam current monitor, beam profile monitor, beam loss monitor and so on [3]. Layout of the beam instrumentation system as shown in Fig. 2.

Profile Measurement

Stepper motor driven type wire scanner is used for the beam profile measurement at CSNS-LINAC, mechanical

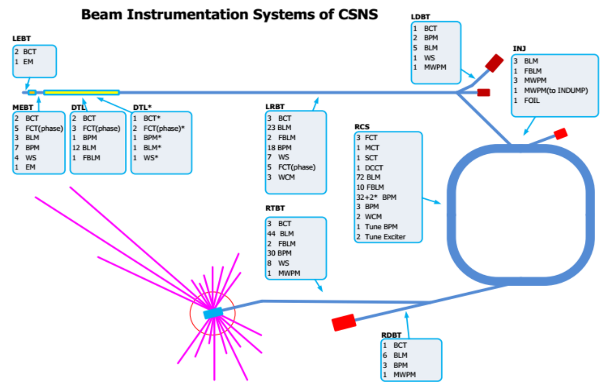

Figure 2: Layout of the beam instrumentation system of CSNS.

schematic as shown in Fig. 3, during the measurement a frame with three wires mounted is driven by a stepper motor scanning through the beam. H- loses 2 electrons on the wire during the interception and the beam profile can be obtained by measure the amount of these electrons during scanning.

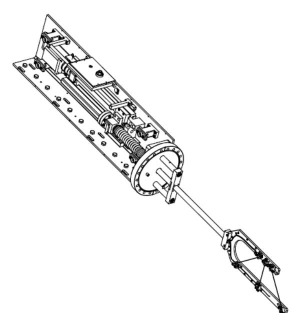

Figure 3: Mechanical schematic of CSNS wire scanner.

Carbon wire with 50 µm diameter is applied at MEBT, as carbon wire has lower energy deposition thus has longer life time than the metal wire. Tungsten wire with 30 µm diameter is applied at LRBT, here the energy deposition is not a fatal issue any more since the beam energy has been increased to 80 MeV.

Beam Loss Measurement

Ionization chamber filled with Argon and Nitrogen plus self-developed electronics is the main solution at CSNS for beam loss measurement. The schematic of the BLM as shown in Fig. 4. All ion chambers were calibrated through a Cobalt-60 plus Keithley-6517 system after manufactur-

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ing, the sensitivity of the ion chamber is ~19 pA/rad/h. Beside the ion chamber, plastic scintillator together with photomultiplier is used for fast beam loss detection at some key positions, e.g. injection area and downstream of the bending magnets.

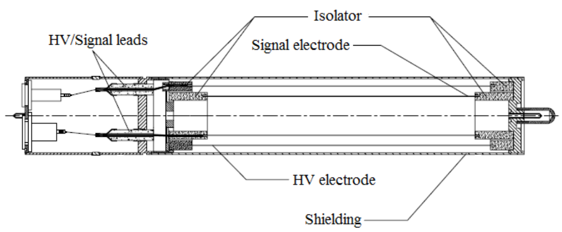

Figure 4: Schematic of the BLM at CSNS.

STUDY WITH WIRE SCANNER

The total signal on the wire actually consist of two parts: two electrons stripped from H-, which is dominated; secondary emission electrons induced by the interception. The secondary emission electrons always fly away from the wire and neutralize the stripped electrons, weaken the total signal in some extent.

In order to restrain the neutralization, a positive bias is normally applied on the wire to pull the secondary emission electrons back and stay, through which the signal to noise ratio can be improved. On the contrary, if negative bias applied the total signal will be further weakened.

An experiment aim to find out how much positive bias should be enough for the profile measurement at CSNS-LINAC was carried out at both MEBT and LRBT. Mean time negative bias was applied also, to see how it will influence the measurement.

MEBT

Figure 5 shows the MEBT horizontal profile measurement results under different bias voltage (varying from -80 V to 100 V) of the 3 MeV H- beam running at 1Hz, 100 µs pulse width, ~5 mA beam current. The total signal on the wire indeed enhanced when positive bias applied, and the bias voltage beyond 20 V, the total signal reaches a plateau, no more enhancement gained even further increase the bias. The beam current goes higher when measuring at 80/100 V bias, that is why the profile curves are higher than the curves at 20~60 V.

An interesting phenomenon in Fig. 5 is that the total signal on the wire slowly goes reverse, from margin to center, while changing the bias from positive to negative. Theoretically the negative bias should only reject more secondary emission electrons away from the wire, strengthen the neutralization of the stripped electrons, and weaken the total signal approaching, never should reverse it.

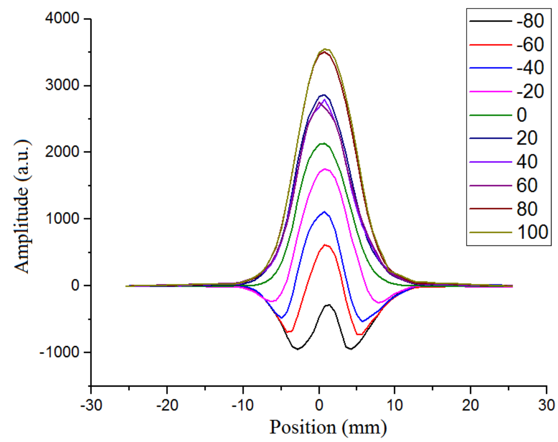

Figure 5: Horizontal profile measurement results under different bias voltage at CSNS-MEBT.

A proper explanation of the signal reverse is there are some positive ions exist in the beam pipe. These ions were attracted onto the wire by the negative bias and reverse the total signal along with the negative voltage increasing. The positive ions may generated from the residual gas ionization, and its potential distribution can be obtained by subtract the 0 V curve from the -80 V curve, as shown in Fig. 6.

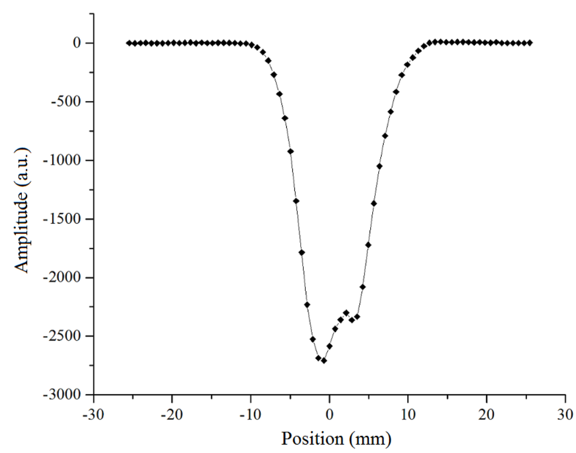

Figure 6: Positive ions distribution at MEBT.

The beam parameter, sigma and FWHM, can be calculated out by Gaussian fitting from the data in Fig. 5. As shown in Fig. 7, the calculating beam size is increasing with the bias goes from negative to positive and come to a plateau at 20 V, which means a 20 V positive bias will satisfy the H- beam profile measurement at CSNS-MEBT.

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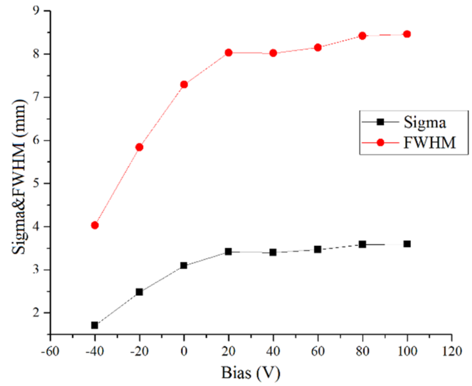

Figure 7: Calculating beam size varying with the bias.

LRBT

Same experiment as MEBT was performed at LRBT, here the H- beam energy is 80 MeV, which is much higher than MEBT. Fig. 8 shows the horizontal beam profile measured by a specific wire scanner while different bias was applied, and beam current was stable at 9 mA during the experiment.

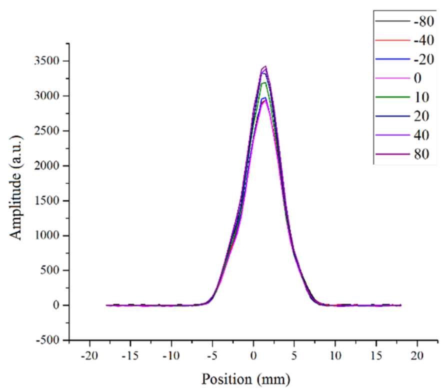

Figure 8: Horizontal profile measurement results under different bias voltage at CSNS-LRBT.

From Figure 8, there was no signal reverse at LRBT even a negative bias was applied. The measurement results are almost the same when negative bias and no bias applied, the main reason is the reaction cross section between residual gas and H- beam at 80 MeV is much lower than 3 MeV [4], the amount of the positive ions induced by the ionization become negligible. For the positive bias, it does improve the signal to noise ratio, and 20 V bias should be satisfy the profile measurement also at LRBT, just like at MEBT.

VERIFICATION OF THE BLM SENSITIVITY

The BLMs play a significant role in the beam commissioning and normal operation of CSNS, they are the key component in the fast machine protection system, as the BLM has quite higher sensitivity than any other beam diagnostic sensors. But the sensitivity of the BLM to the beam is still uncertain even with Cobalt-60 calibrated, since the ion chamber is a type of indirect monitor, secondary rays caused by the beam loss is what ion chamber detecting rather than the beam loss itself, and the parameters of the secondary rays are highly relevant to the beam condition.

During the bias experiments of the wire scanners, the output of the BLM located downstream of the wire scanner, was found having the same varying trend as the signal on the wire. Two curves in Fig. 9 is the horizontal profile of 1.7 mA H- beam plots with wire signal and beam loss signal, normalized. Two signals show good agreement with each other, thus the BLM can be used as the backup readout of the profile measurement system. Also, the sensitivity of the BLM to the beam can be verified in some extent by the wire scanner. Assuming the beam have Gaussian distribution in transverse plane, and a vertical wire place in the beam, the current intercepted by the wire can be calculated by the following function:

$$i(x_0) = \int_{-\infty}^{+\infty} J_0 \delta e^{-\frac{1}{2}\left(\frac{x_0}{\sigma}\right)^2} e^{-\frac{1}{2}\left(\frac{y}{\sigma}\right)^2} dy = \frac{I\delta}{\sqrt{2\pi}\sigma} e^{-\frac{1}{2}\left(\frac{x_0}{\sigma}\right)^2} \quad (1)$$

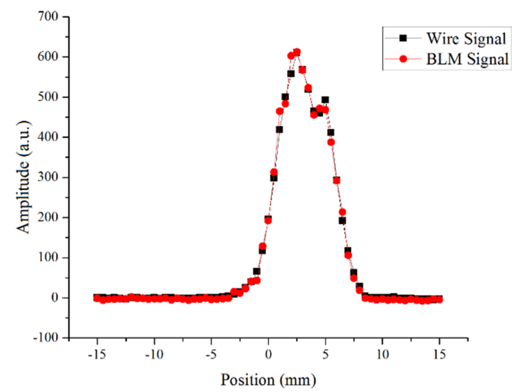

Figure 9: Beam profile plotted by wire signal and downstream BLM signal.

Where I is the total beam current, δ is the diameter of the wire, σ is the beam size and x_0 is the wire's location respect to the beam center, which can be measured by the wire scanner. In Fig. 9, it is around 100 nA beam intercepted when the wire located at the $\pm 3\sigma$ position, and the beam loss signal can be detected clearly. It is sure to say that the sensitivity of the BLM to the beam is better than 100 nA, as not all lost beam detected by a single BLM.

Unfortunately, it is difficult for the ion source to reach lower current and operate stably, otherwise the sensitivity of the BLM can be further verified.

CONCLUSION

Bias on wire scanner experiment was performed at CSNS-LINAC, positive ions induced by the residual gas ionization were detected at MEBT, while no more found at LRBT, since the ionization yield become much lower when beam energy up to 80 MeV. The BLM sensitivity to the beam was verified in the same experiment, it was found that beam loss signal can be detected clearly even around 100 nA beam distrubed.

How the positive ions influence the H- beam transportation at MEBT should be further studied.

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