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COMMISSIONING OF THE BEAM INSTRUMENTATION SYSTEM OF CSNS

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Abstract

China Spallation Neutron Source (CSNS) accelerator complex consists of a front end, an 80MeV DTL LINAC, and a 1.6GeV Rapid Cycling Synchrotron (RCS). It is designed with a beam power of 100kW in the first phase and reserves upgrade capability to 500kW in the second phase. CSNS has started user operation at 20kW after the initial beam commissioning in 2018, the beam power is quickly up to 50kW and 80kW by two times beam commissioning in between the user beam time 2019, and finally reached 100kW, the design goal, in February 2020. The experiences and most recent status of beam instrumentation system of CSNS during the beam power ramping is introduced.

INTRODUCTION

The CSNS is designed to accelerate proton beam pulses to 1.6 GeV kinetic energy at 25 Hz repetition rate, striking a solid metal 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 500kW 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 Figure 1. In the phase one, an ion source produces a peak current of 25 mA H- beam. RFQ linac bunches and accelerates it to 3 MeV. DTL linac raises the beam energy to 80 MeV. After H- beam is 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].

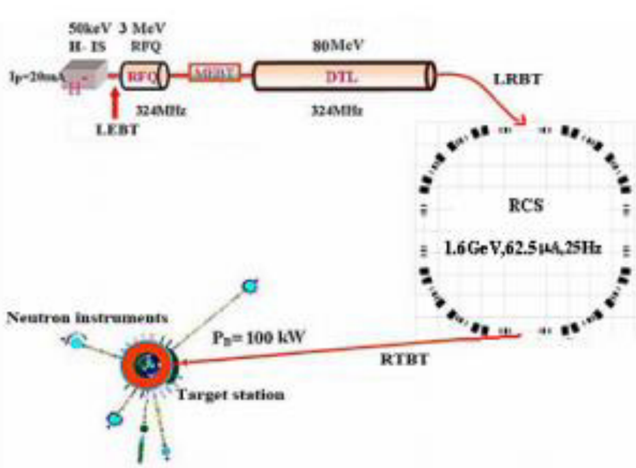

Figure 1: Schematics of the CSNS complex.

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BEAM MONITORS

For the entire beam instrumentation system of CSNS, amounts of beam monitors are installed along the beam line, including beam position monitor (BPM), beam current monitor, beam profile monitor, beam loss monitor (BLM) and so on. Layout of the beam instrumentation system as shown in Figure 2 [3].

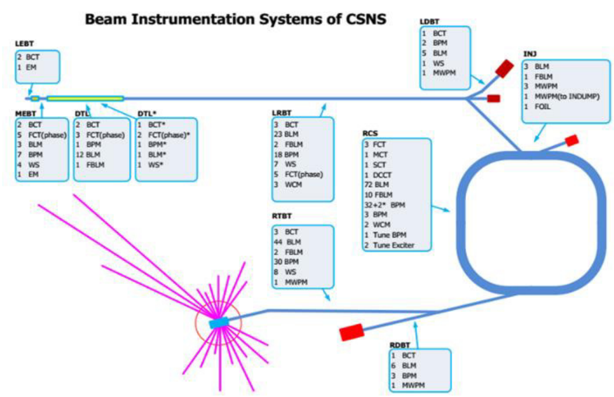

Figure 2: Layout of the beam instrumentation system of CSNS.

Beam Current Monitor

Many current transformer (CT) are used for the current measurement. Part of the magnetic rings of CT purchased from Bergoz and the other developed by our self together with a domestic company. The Cobalt-base alloys with magnetic conductivity around 20,000 to 25,000 at 25 Hz was used for the self-developing ring. Two methods used for the current calculation: 1) Take part of the flat waveform subtract background waveform then averaging; 2) Integrated waveform value as the particle number calculation.

There are two special requests for the current measurement at CSNS. One located at LINAC in front of a beam dump (LDCT), as shown in Figure 3, during normal operation the H- beam goes down to RCS but one of the BLMs along the goes up direction line has an expected high value, which induced by the residual gas stripped proton beam. A new type of electronics for low current measurement was designed for the LDCT and the residual gas stripped proton beam was measured successfully, the H- stripping percentage is ~4‰. The other special CT is located at the injection line for the strip foil efficiency measurement. Most of the H- lose two electrons when pass through the strip foil turn to proton beam and cycling in RCS, very tiny part loses only one electron turn to H0, after the second strip foil fully stripped goes to the beam dump, as Figure 4 up shows.

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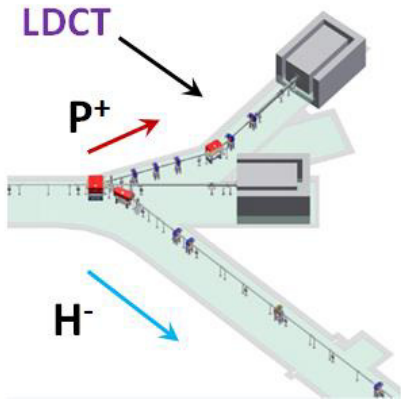

Figure 3: Layout of the LINAC beam dump.

A CT was designed in 2019 for the low current H0 detection and mounted on the beam line during summer shutdown. The history data of H0 CT can be seen in Figure 4 down, the output signal is around 20 µA (beam power 100 kW) when a new strip foil is applied, which corresponding the strip efficiency ~99.7%. The output is decreasing smoothly with the time goes on, mainly because the foil becomes wrinkling and make the H0 scattered, not all H0 passed through the CT. Together with the BLMs at the injection area, the strip foil life time is estimated around 5 weeks.

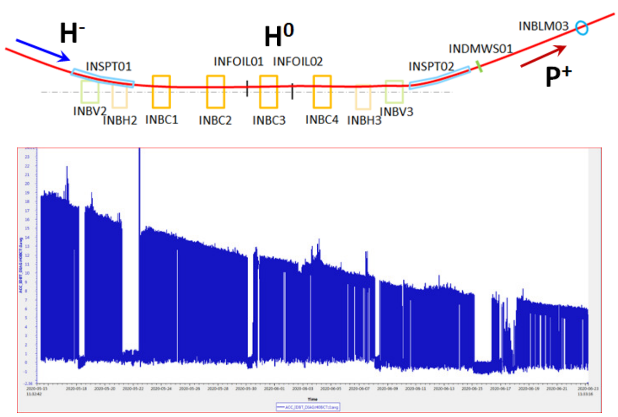

Figure 4: Schematic of the injection line of CSNS (up) and history data of the H0 CT at injection line (down).

Beam Position Monitor

Two type of BPM were designed for the accelerator, stripline for LINAC and shoe-box for the RCS ring and RTBT, as shown in Figure 5. 38 shoe-box BPM are installed in the RCS ring, 32 of them will be used to the orbit measurement, 3 of them will provide the beam position signal to the RF system, 1 for tune measurement, and the last 2 have lower capacitance will be used mainly during commissioning to measure lower signals.

Figure 5: Stripline BPM designed for LINAC (left) and shoe-box BPM for RTBT (right).

The cycling period of the beam bunches is changing from injection to extraction at RCS, two triggers were used for the BPM data acquisition, one from control system (Yellow) to indicate the beam (Pink) is coming soon and the other one from RF system (Green) to tell the electronics to start the data acquisition for each bunch, see Figure 6.

Figure 6: Two triggers of the RCS BPM electronics.

Beam Profile Monitor

Stepper motor driven type wire scanner is used for the beam profile measurement at CSNS-LINAC, mechanical schematic as shown in Figure 7, 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.

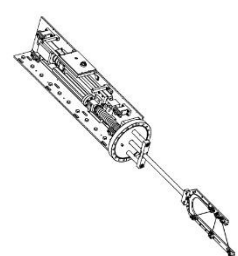

Figure 7: Mechanical schematic of CSNS wire scanner.

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

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30 µm diameter is applied at LRBT and RTBT, here the energy deposition is not a fatal issue any more since the beam energy has been increased to 80 MeV and 1.6 GeV.

In order to restrain the neutralization, a positive bias is normally applied on the wire to enhance the signal to noise ratio. 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.

Figure 8 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.

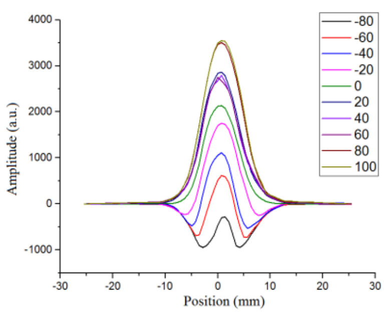

Figure 8: Horizontal profile measurement results under different bias voltage at CSNS-MEBT.

Same experiment as MEBT was performed at LRBT, here the H- beam energy is 80 MeV, which is much higher than MEBT. Figure 9 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.

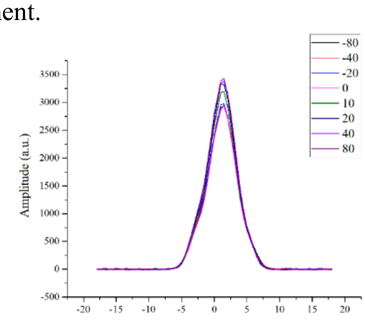

Figure 9: Horizontal profile measurement results under different bias voltage at CSNS-LRBT.

From Figure 9, 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 satisfying the profile measurement also at LRBT, same as MEBT.

Beam Emittance Measurement System

Double slits system was set up for the low energy section beam emittance measurement, mainly for LEBT@50 keV, MEBT@3 MeV and DTL1@20 MeV. Graphite plate is welded in front of the copper plate for the one mounted after RFQ and DTL1 in order to protect the copper from the thermal deposition. The first slit of all 3 sets are with water cooling to protect the copper plate from the beam damage. One of the measurement results as shown in Figure 10 of the beam after RFQ, left figure shows the simulated result ε_x=0.152 π mm·mrad and the right figure shows the measured result ε_x=0.160 π mm·mrad, which show good agreement with each other.

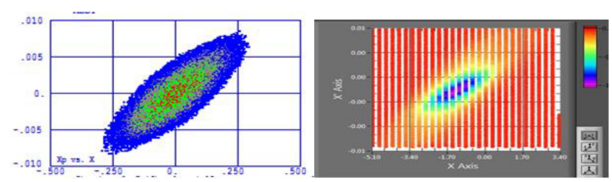

Figure 10: Emittance measurement result of the beam after RFQ (X plane).

Beam Loss Monitor

Ionization chamber filled with Argon and Nitrogen plus self-developed electronics is the main solution at CSNS for beam loss measurement for gamma ray detection. The schematic of the BLM as shown in Figure 11. All ion chambers were calibrated through a Cobalt-60 plus Keithley-6517 system after manufacturing, 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.

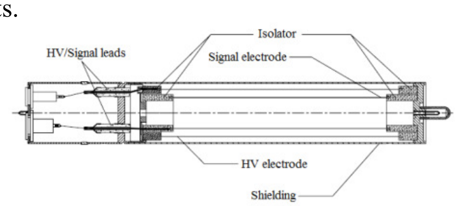

Figure 11: Schematic of the BLM at CSNS.

Beside the gamma ray ion chamber, neutron ion chamber was also developed mainly for low energy section beam loss detection since 2016. The ion chamber is filled with BF3 and with 7.5 cm thick PE covered as the fast neutrons' moderator. One neutron detector and a gamma detector were mounted in the same location at DTL1 for cross comparison, as shown in Figure 12. Through beam test the BF3 signal is ~1757 times higher than Ar+N2, agrees well with theoretical calculation

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(~1600). Optimization of the thickness of the moderator is now on going to increase the response time of the neutron detector.

Figure 12: Beam test layout of the neutron detector and gamma detector.

SUMMARY

CSNS has achieved its design goal of 100 kW, in February 2020, 18 months ahead of schedule, and running at 100 kW stably since then. For beam instrumentation system all subsystems perform well, we are keep developing, improving and updating.

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