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THE OPERATION STATUS OF CSNS FRONT END*

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Abstract

China spallation neutron source (CSNS), as the China's first 100 kW beam power pulsed neutron source, its operation target beam power is now larger than 50 kW. During the beam power upgrading process of CSNS to 50 kW from 2018 to 2019, many improvements have been made for the front end of CSNS. The improvements mainly focus on solving the problems of ion source instability and the radio frequncy quadrupole (RFQ) sparking caused by the pre-chopped beam into RFQ.

INTROUCTION

The China Spallation Neutron Source (CSNS) is an accelerator-based high power project with multipurpose currently under operation with a 50 kW target beam power. The accelerator complex consists of an 81 MeV H- linear accelerator as the injector and a 1.6 GeV rapid cycling proton synchrotron (RCS). The linear accelerator consists of a 50 keV H- Penning surface plasma ion source (IS), a low energy beam transport line (LEBT), a 3.0 MeV RFQ accelerator, a medium energy beam transport line (MEBT), a 81 MeV drift tube linear accelerator (DTL) and a high energy beam transport line (HEBT).

The front end means the front part of linac that includes IS, LEBT, RFQ and MEBT. As the start point of CSNS, the condition of front end is one of key factors which influence the stable operation of CSNS. Based on the beam requirement of CSNS phase I, the front end should provide a stable H- beam with energy of 3.0 MeV, a maximum pulsed peak current up to 15 mA, a beam duty factor 1.0% at a repetition of 25 Hz and beam pulse width of 400 us before chopping. The installation of CSNS front end was completed in 2015. Although the front end meets the beam requirement of CSNS phase I, the stability of the front end is not satisfactory during beam commissioning. The instability mainly comes from the ion source and RFQ sparking. Through the past 4 years commissioning and improvements, now the stability and availability of CSNS front end at routine operation was highly improved.

PENNING IS

The main design parameters of Penning IS for CSNS phase I are listed in Table 1.

During the last 4 years commissioning and operation of CSNS, there are in total used about 26 sets of ion source discharge chamber. In general, for each set of discharge chamber, the ion source can produce up to 50mA H- ion beam with a beam duty factor about 1.25% (500 us & 25 Hz) and a normalized rms. emittance about 0.8π mm·mrad. Although the emittance is much larger than the acceptance of RFQ (0.2π mm·mrad), the H- ion beam current is still larger than 20 mA within the acceptance of RFQ, which satisfies the current requirement of CSNS phase I. For present 50 kW beam power operation, a routine beam current from ion source of about 30 mA is enough. The average expected lifetime of CSNS IS, mainly limited by the discharge chamber, is about 1 month, which satisfies the requirement of CSNS phase I. The longest operation time for one of the 26 discharge chambers is near to 50 days.

Table 1: Main Design Parameters of IS for CSNS Phase I

Parameter	Value
Ion source	H-
Output Energy (keV)	50
Output Current (mA)	>20
Emittance $\varepsilon_{n,rms}$ (π mm · mrad)	<0.20
Repetition Rate (Hz)	25
Beam Duty Factor (%)	1.3
Lifetime (month)	>1

Since the ion source was installed in Oct. 2014, many improvements have been made for the ion source. Firstly, the electric Penning magnet, which is integrated with the bending magnet before, was replaced by an independent permanent magnet. Since it has the same electric potential as the discharge chamber, the sparking between Penning magnet and discharge chamber is avoided; Secondly, the extraction power supply was moved into tunnel where is much closer to the source to decrease the induced voltage by the cable; Thirdly, the post acceleration ceramic insulator was replaced by a new insulator with an additive 45 mm high collar to increase the creep-age distance; Lastly, the post acceleration power supply with 55 kV and 10 mA was replaced by the one with 65 kV and 80 mA. After these improvements, the stability and reliability of the ion source is highly enhanced [1]. A control closed loop between the bending magnet exciting current and the extracted beam current is also developed to ensure the beam orbit from IS unchanged. Now, the only factor leading to the instability of ion source comes from the extraction sparking at very low beam duty factor due to the cesium deposited on the extractor.

This instability could be also well controlled through strictly limiting the consumption of cesium. In addition, a new extraction power supply with double voltage-output pulses is also developed to solve the extraction sparking. As shown in Fig. 1, with this new power supply, the extracting beam by one pulse with lower voltage output

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(<8 kV) is used to clean out the cesium deposited on the extractor. The beam functioning as cleaning out cesium on extractor is lost in LEBT, and only the beam extracted by another pulse with normal voltage output (15 kV-18 kV) can transport through LEBT and into RFQ. Now the new extraction power supply is being used and works well as expected at very low beam duty factor for machine study.

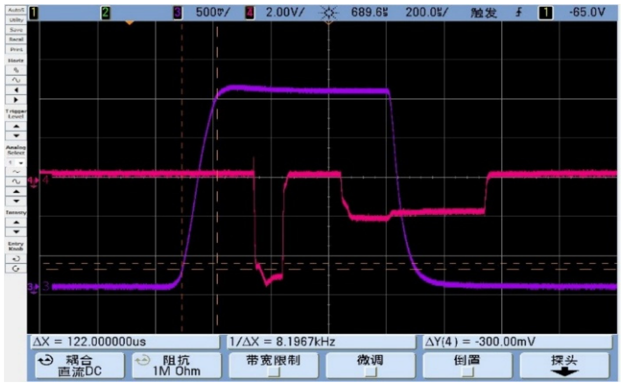

Figure 1: Two beams (red curve) are extracted with the new extraction power supply. One for the normal operation (left), another for the cesium cleaning (right).

LEBT

Mainly three solenoids, a double slit type emittance monitor (EM), a pre-chopper and a beam collimator are adopted in LEBT. The EM is installed downstream the first solenoid. Results of emittance and beam current measurement are shown in Fig. 2. At the beam current of 53 mA, the rms. emittance is 0.892π mm·mrad in x-x' phase plane and 0.742π mm·mrad in y-y' phase plane, respectively. Within the beam rms. emittance of 0.2π mm·mrad, the beam current is 15mA in x-x' phase plane and 25 mA in y-y' phase plane, respectively.

It is proved theoretically and experimentally that, with three solenoids, the asymmetrical emittance can switch to symmetrical emittance and match the acceptance of RFQ.

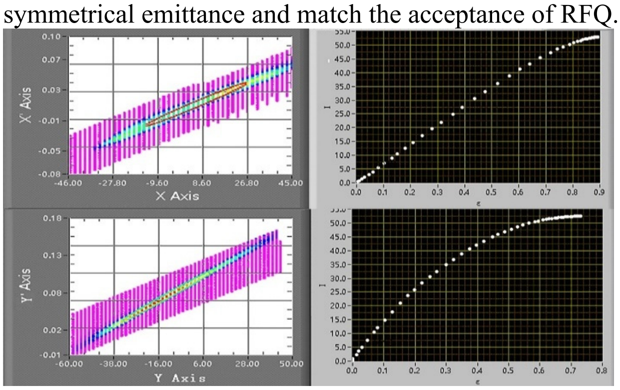

Figure 2: Results of emittance and current measurement: The left two plots show the emittance in x-x' and y-y' phase plane at the beam current of 53 mA. In the right two plots the beam current is shown as a function of the emittance in x-x' and y-y' phase plane, respectively.

Because the normalized rms. emittance of the beam from ion source is about 0.8π mm·mrad, larger than the acceptance of RFQ (rms. 0.2π mm·mrad), the beam transmission efficiency of RFQ in the beam commissioning of front end is often among 75-88.5%, but the maximum current at exit of RFQ could be larger than 30 mA. Considering this beam current is much larger than the requirement current of CSNS phase I, in order to raise the beam transmission efficiency of RFQ and reduce the risk of damage on RFQ done by the beam losses, a collimator (in the third vacuum chamber of LEBT) are designed and installed in LEBT. With the collimator, the RFQ transmission now ranges from 96% to 92% in the light of the beam current from 10 mA to 18 mA at the exit of RFQ.

For CSNS, only one electrostatic pre-chopper, which is installed at entrance of RFQ, is employed in LEBT to chop beam to the required beam structure asked for RCS. In the chopping experiment shown as in Fig. 3, the macro pulse beam with a width of 100μs and a repetition rate of 1 Hz is chopped to the micro pulse beam with a width of 500 ns and a repetition rate of 1 MHz. The chopping ratio shown here is 50%, but it is adjustable from 50% to 75% in beam commissioning.

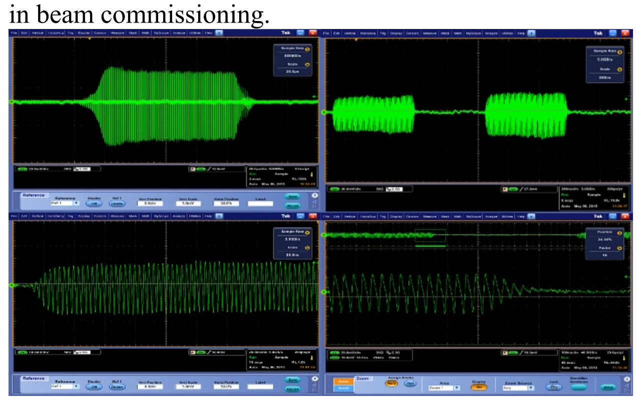

Figure 3: Beam signal of BPM after chopping. The upper plots: (left) the macro pulse of beam: 20 μs/div; (right) the micro pulse of beam: 200 ns/div. The lower plots: (left) the rising edge of beam signal; (right) the falling edge of beam signal.

The results shown in Fig. 3 are got from the beam position monitor (BPM) at the exit of RFQ. It can be seen that, at a applied chopping voltage of 4.5 kV, both the rise and fall time for the chopped beam are about 3 to 4 periods of the working RF (1 period time= 3.086 ns), i.e. both the rise and fall time are less than 15 ns. With a higher applied chopping voltage, the minimum rise/fall time is down to 10 ns.

RFQ

A four-vane type RFQ with energy 3.0 MeV is the first accelerating structure of CSNS accelerator complex. The design current of 40 mA for RFQ is aimed to meet the future upgrading of CSNS [2].

As mentioned above, the chopped beam is designed to lose in RFQ for a small load capacitance of pre-chopper and thus a fast rise/fall time of the chopped beam. For this chopping design, RFQ sparking problem is not sharp in the initial beam commissioning when the beam duty factor is low. However, when the proton beam power on the

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target is near to 20 kW, RFQ sparking problem becomes very seriously. At last, the operation of CSNS has even to be suspended to wait for the RF conditioning of RFQ due to the sparking from May to June, 2018. After a series of analyses and experiments, the sparking reason is focused on the chopped beam.

Based on the injection beam parameters of RFQ, thermal analysis shows the chopped beam cannot melt the vane. The main damage of the lost beam on the vane top of RFQ is due to sputtering, which will cause the increase of surface roughness of vane. For the initial installation angle of the pre-chopper, most of the chopped beam lost in RFQ will hit on the same vane-top area. In order to solve the sparking problem caused by sputtering, the pre-chopper is rotated clockwise 45 degrees about the beam center. In addition, the envelope size of the beam into RFQ is also limited by the smaller beam bore on the entrance plate of RFQ. The beam bore on the entrance plate now has the same size as the beam envelope got by RFQ acceptance. After these improvements taken, the chopped beam almost does not bombard on the vanes but goes through the gap between vanes and then hits on the wall of RFQ.

Another important improvement of RFQ to reduce everyday sparking times is the feeding mode of RF power. In normal case without sparking, the RF power is fed into RFQ with a pulse width of 500 us and repitition of 25 Hz. When a sparking is detected via the standing wave ratio (SWR) protection signal, the RF pulse for the sparking is immediately interrupted in about 5 microseconds and the next 24 consecutive pulses are also stopped by the low level digital control system of RF.

After above improvements have been done, now the everyday sparking times for RFQ is about 100 to 150, so the failure time of RFQ is dramatically reduced to about 2 minutes due to RFQ sparking.

MEBT

All diagnostics instruments, the two bunchers and the 10 quadrupole magnets in MEBT work normally since the beam commissioning started in 2015. The normalized rms beam emittance measured at MEBT is about 0.27π mm·mrad for both horizontal and vertical plane while the beam transmission keeps near to 100% during all the operation time.

FRONT END

As a whole including IS, LEBT, RFQ and MEBT, the history of CSNS front end beam availability from January 17 to March 17, 2019 is shown in Fig. 4. From the figure, one can see that the availability of the front end is about 99.9% except at February13, 14 ,15 and 20. The breakdown all comes from ion source. For February 13, 14 and 15, the breakdown is led by the cracking of the hydrogen gas transport pipe, while the breakdown at February 20 is caused by undue usage of cesium. Due to the slow and small variation of the beam current extracted from ion source, it is also variable for the target beam power. To keep a stable beam power, we set a control closed loop between the target beam power and the exciting current of the first solenoid in LEBT. By via of adjusting the focus intensity, the target beam power could be kept stable.

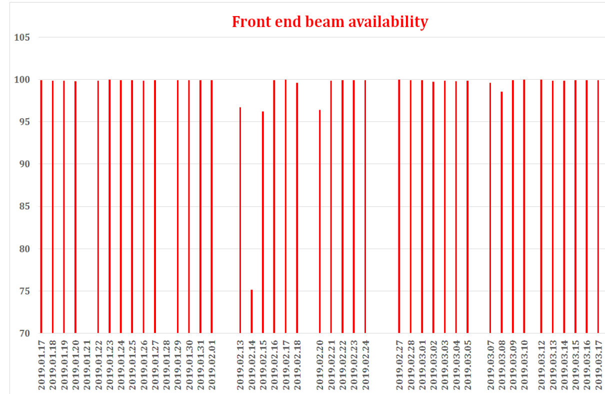

Figure 4: History of front end beam availability from January 17 to Mach 17, 2019.

THE LABORATORY OF ION SOURCE

There are three sets of ion source test stands in lab. The first one is the hot spare stand which aims to check the discharge chamber, create plasma discharge and produce pulsed arc (without beam extraction). This stand makes the time needed for exchanging the discharge chamber and putting ion source into operation again reduce to 3-4 hours. The second one, named on-line test stand of IS, consists of an ion source and a LEBT which are both the same with these in tunnel of CSNS. It is used to make IS improvements and beam diagnosis. The last one is RF ion source R&D stand [3]. Its purpose is to provide an RF ion source for the future upgrading of CSNS.

SUMMARY

The performance of CSNS front end was stable until May 2019. As to the asymmetrical and large emittance beam characteristics of Penning IS, three solenoids and one beam collimator are used in LEBT to produce an matched beam and to raise the beam transmission of RFQ. The beam damage to RFQ by the chopped beam is also avoided through changing the installation angle of pre-chopper and reducing the beam bore on the entrance plate of RFQ. The suitable RF power feeding mode is also beneficial to RFQ stability.

REFERENCES

[1] S. Liu *et al.*, "The modification at CSNS ion source", in *Fifth International Symposium on Negative Ions, Beams and Sources*, vol. 1869, Oxford, United Kingdom, Sept. 2016, pp. 030056. doi:10.1063/1.4995776

[2] Y. Xiao *et al.*, "Development of CSNS RFQ", *Nuclear Techniques*, vol. 38, pp. 120201-1-120201-7, 2015.

[3] W. Chen *et al.*, "RF H-Minus Ion Source Development in China Spallation Neutron Source", in *Fifth International Symposium on Negative Ions, Beams and Sources*, Oxford, United Kingdom, vol. 1869, Sept. 2016, pp. 030013. doi:org/10.1063/1.4995733