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THE STATUS OF CSNS FRONT END*

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Abstract

The commissioning and improvement of front end as well as the laboratory construction are summarized. The improvement as well as its effects mainly focuses on a low energy beam transport line (LEBT) and a 3.0MeV four-vane type radio frequency quadrupole (RFQ). In addition, the constitution, significance and construction of laboratory are mentioned.

INTRODUCTION

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

As shown in Figure 1, 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 3.0MeV, a maximum pulsed peak current up to 15mA, a beam duty factor 1.0% at a repetition of 25Hz and beam pulse width of 400us before chopping. The installation of CSNS front end was completed in 2015. Although the front end satisfies 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. After last 3 years commissioning and improvements, now the stability of CSNS front end was improved a lot.

PENNING IS

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

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

During the last 3 years commissioning and operation of CSNS, there are in total used about 20 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% (500us & 25Hz) 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 20mA within the acceptance of RFQ, which satisfies the current requirement of CSNS phase I. 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 20 discharge chambers is near to 50 days.

Since the ion source was installed in CSNS tunnel in Oct. 2014, many improvements have been made for the ion source. Firstly, the electric penning magnet, which was integrated with the bending magnet before, was replaced by an independent permanent magnet that has the same electric potential as the discharge chamber; Sec ondly, the extraction power supply was moved into tunnel where was much closer to the source to decrease the induced voltage by the cable; Thirdly, the post acceleration

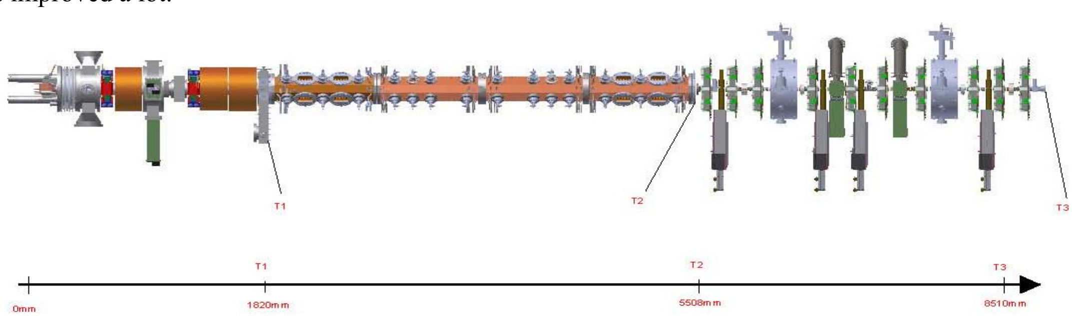

Figure 1: The beam line of CSNS Front End.

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ceramic insulator was replaced by a new insulator with an additive 45mm high collar to increase the creepage distance; Lastly, the post acceleration power supply with 55kV and 10mA is replaced by the one with 65kV and 80mA. After these improvements, the stability and reliability of the ion source is highly enhanced [1]. Now, the only factor leading to the instability of ion source comes from the extraction sparking at very low beam duty factor.

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. With this new power supply, the extracting beam by one pulse with lower voltage output (<8kV) 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 (15kV-18kV) can transport through LEBT and into RFQ. The new extraction power supply is now commissioning in ion source laboratory and works well as expected.

LEBT

As shown in Figure 1, a double slit type emittance monitor (EM) is installed downstream the first solenoid. Results of emittance and beam current measurement are shown in Figure 2. At the beam current of 53mA, 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 25mA in y-y' phase plane, respectively.

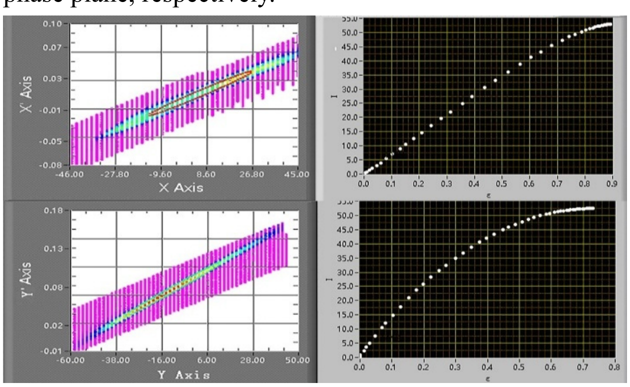

Figure 2: Results of emittance and current measurement: The left two plots show the emittance in x-x' and y-y' phase plane at the beam current of 53 mA. In the right two plots the beam current is shown as a function of the emittance in x-x' and y-y' phase plane, respectively.

To deal with the asymmetrical emittance of the beam from ion source, three solenoids are adopted in LEBT. It is proved theoretically and experimentally that, with three solenoids, the asymmetrical emittance can switch to symmetrical emittance and match the acceptance of RFQ.

As shown in Figure 3 (left), 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% (86.5% here), but the maximum current at exit of RFQ could be largeur than 30mA. 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 moveable aperture plate (in the second vacuum chamber) and a collimator (in the third vacuum chamber) are designed and installed in LEBT.

Figure 3: The beam transmission efficiency of RFQ without a beam collimator in LEBT (left) and with a beam collimator in LEBT (right).

With both of the aperture and the collimator, the RFQ transmission could be high up to 98.5% while the current is usually 4 to 5 mA at the exit of RFQ, and this beam intensity just satisfies the requirement for the DTL beam commissioning. With the collimator but without the aperture, the RFQ transmission ranges from 90% to 96% in the light of the beam current from 10mA to 18mA at the exit of RFQ. As shown in Figure 3 (right), the beam transmission of RFQ is about 92.1% when the beam current is 16.726mA at the exit of RFQ.

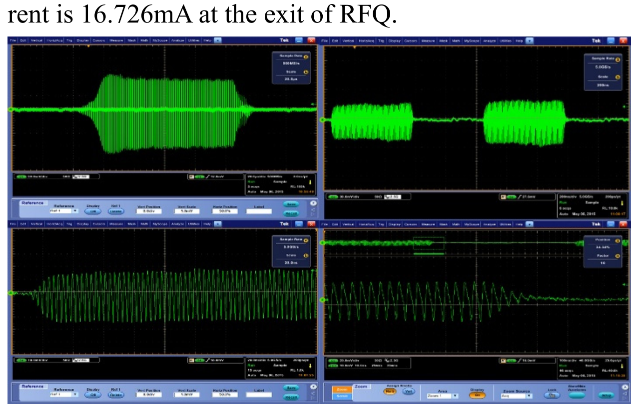

Figure 4: Beam signal of BPM after chopping. The upper plots: (left) the macro pulse of beam: 20μs/div; (right) the micro pulse of beam: 200 ns/div. The lower plots: (left) the rising edge of beam signal; (right) the falling edge of beam signal.

For CSNS, only one electrostatic pre-chopper is employed in LEBT to chop beam to the required beam structure asked for RCS, which is installed at entrance of RFQ. In the chopping experiment shown as in Figure 4, the macro pulse beam with a width 100μs and a repetition rate 1Hz is chopped to the micro pulse beam with a width of 500 ns and a repetition rate 1MHz. The chopping ratio shown here is 50%, but it is adjustable from 50% to 75% in beam commissioning. The results shown in Figure 4

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

RFQ

A four-vane type RFQ with energy 3.0MeV is the first accelerating structure of CSNS accelerator complex. The design current of 40mA for RFQ is aimed to satisfy 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. 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 target is near to 20kW, 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 restricted 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. After improvements, 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.

Other improvements of RFQ include the development of a RF auto-conditioning program and the renovation of RF conditioning strategy. The program can automatically and quickly reduce the RF power feeding into the cavity to interrupt the sparking when sparking occurs, and then restore and increase the RF power feeding according to the settings after a period without sparking.

Two RF conditioning strategies are adopted in taking use of the RF auto-conditioning program. The main difference of the two strategies is the step value of power reduction when sparking occurs. Comparing to the second strategy, the first strategy limits the sparking number to a very small value by setting a larger step of power reduction. In this case, for most of the time, the power keeps on a lower value when sparking occurs. To reach the same operating power and duty factor, the time taken for RF conditioning of RFQ was 14 days from May 10 to May 23, 2018 by using the first strategy, while the taken time was only 9 days from Jun 12 to Jun 20 by using the second strategy. In addition, the RF conditioning of RFQ from May 31 to Jun 11 had no effect by using the first strategy.

After all above improvements have been done, the failure time of RFQ is dramatically reduced. For example, the total failure time of RFQ was about 477mins during subsequent operation period of CSNS from June 21, 2018 to July 13, 2018, the average failure time is about 22mins a day.

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 0.22 π mm·mrad for both horizontal and vertical plane which is the same as the simulation result while the beam transmission keeps near to 100% during all the operation time.

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 new developed extraction power supply with double voltage-output pulses is now experimented on this stand. 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 2018. As to the beam characteristics of Penning IS, three solenoids and one beam collimator are used in LEBT to produce an appropriate beam and raise the beam transmission of RFQ. The beam damage to RFQ is also avoided through changing the installation angle of pre-chopper and reducing the beam bore on the entrance plate of RFQ. The conditioning strategy with higher efficiency is chosen for RFQ conditioning but needs to verify in the following operation of front end.

REFERENCES

[1] S. Liu *et al.*, "The modification at CSNS ion source," in *Fifth International Symposium on Negative Ions, Beams and Sources*, vol. 1869, D. Faircloth, Ed. AIP Conference Proceedings, 2017.

[2] Y. Xiao *et al.*, "Development of CSNS RFQ," *Nuclear Techniques,* vol. 38, no. 12, pp. 120201-1-120201-7, 2015 2015, Art. no. 0253-3219(2015)38:12<120201:zgslzz>2.0.tx;2-4.

[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*, vol. 1869, D. Faircloth, Ed. (AIP Conference Proceedings, 2017.