CONSTRUCTION AND BEAM COMMISSIONING OF CSNS ACCELERATORS

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Abstract

CSNS (China Spallation Neutron Source) is a proton accelerator based facility for delivering spallation neutrons to users. The main components are 80-MeV linac, 1.6-GeV RCS and neutron production target. The construction began in 2011, and now construction of the building and accelerator components is well in progress. Most of the components have been tested and installed into the tunnel. The ion source and RFQ have been successfully commissioned. The first DTL tank has successfully completed the beam commissioning, and the beam commissioning for the other three DTL tank will be performed before the end of 2016. The RCS commissioning will start in the beginning of 2017. This presentation provides a complete overview of the status of construction and beam commissioning.

INTRODUCTION

The China Spallation Neutron Source (CSNS) is a high intensity proton accelerators based facility [1]. Its accelerator consists of an 80MeV H- linac, an 1.6 GeV Rapid Cycling Synchrotron (RCS) and related beam transport line. The 50keV H- beam is accelerated to 3MeV by RFQ, and the 3MeV beam is matched into Drift Tube Linac (DTL) through Medium Energy Beam Transport (MEBT). The beam is accelerated to 80 MeV by 4 DTL tanks. The 81MeV H- beam is transported to the injection point of RCS through Linac to Ring Beam Transport (LRBT) line. By using stripping painting, 80 MeV H- beam is stripped into proton and accumulated in the RCS. The proton beam is accelerated to 1.6GeV with a repetition rate of 25Hz. The 1.6GeV beam is extracted by single-turn extraction. The 1.6GeV proton beam is transported through Ring to Target Beam Transport (RTBT) line onto the neutron target. The designed average beam power is 100kW, but for future upgrade, 85m space is reserved after the DTL tank for upgrading the linac energy to 250MeV, and then with the higher injection beam energy, much more beam can be accumulated in the RCS, as well as much higher extraction beam power. The upgrading goal of beam power is 500kW. Figure 1 gives the schematic layout of CSNS, and the Table 1 shows the beam power is primary parameters of CSNS.

The construction of the project started in September in 2011, and now construction of the building and accelerator components is well in progress. Most of the components have been tested and installed into the tunnel. The ion source and RFQ have been successfully commissioned. The first DTL tank has successfully completed the beam commissioning, and the beam commissioning for the other three DTL tank will be performed before the end of 2016. The RCS commissioning will start in the beginning of 2017. This presentation provides a complete overview of the status of construction and beam commissioning.

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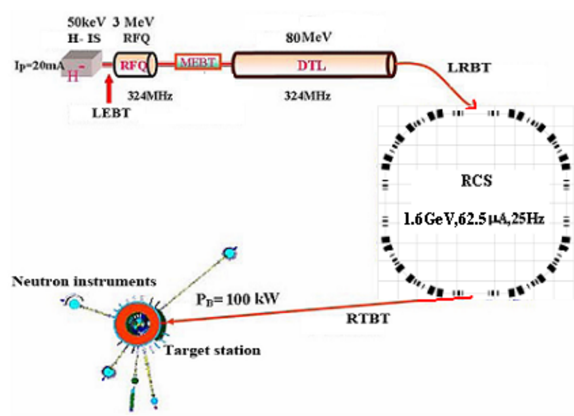

Figure 1: The schematic layout of CSNS.

Table 1: The Main Parameters of CSNS RCS

	CSNS	Upgrade
Beam power (kW)	100	500
Repetition rate (Hz)	25	25
Target number	1	1
Average current (μA)	62.5	312
Proton energy (GeV)	1.6	1.6
Linac energy (MeV)	80	250

CONSTRUCTION AND COMMISSIONING

The R&D for the key technologies of the linac and RCS have been started from 2006, and based on the key technologies developed in the R&D, the mass production has been started from 2012. Up to now, most of the accelerator components have been constructed and tested, and have been installing in the accelerator tunnel. The construction and test of some key components are presented.

Front End

After test and tuning in the test hall, the installation of ion source and LEBT in tunnel was started On Oct. 15, 2014. On Dec. 1st, 2014, beam commissioning of ion source and LEBT was started. Ion source can provide maximum 40mA H- beam, but with large emittance. Within the design emittance of 0.2πmm.mrad, the beam

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current is about 15mA, which can meet the requirement of 100 kW beam power of CSNS. In order to raise further the RFQ beam transmission efficiency, a collimator at LEBT to scrape the beam beyond the acceptance of RFQ was installed. Figure 2 shows the ion source and LEBT installed in the tunnel.

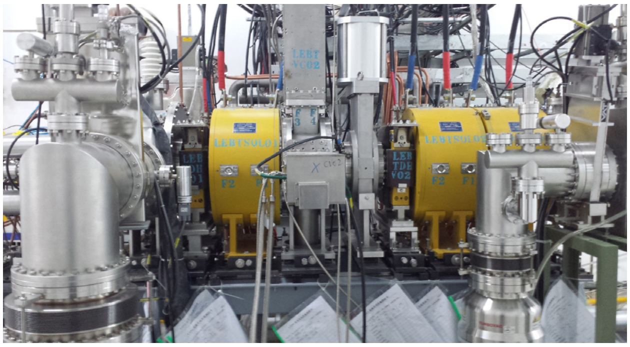

Figure 2: Ion source and LEBT in the tunnel.

High power RF conditioning for RFQ has been done before installing into the tunnel, with a duty of 700us and 25Hz, input RF power 450kW. In total, 240 hours RF conditioning have been done, and finally the spark number was reduced to 1~2 times a day. Figure 3 shows the installed RFQ in the tunnel.

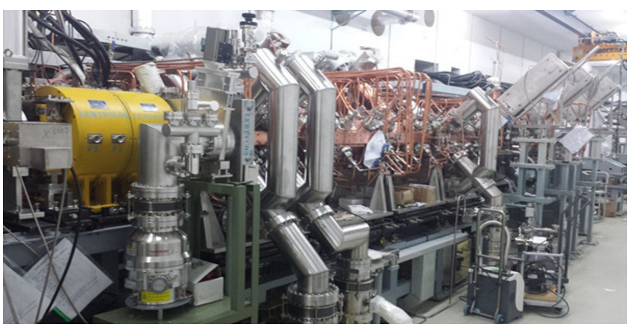

Figure 3: RFQ in the tunnel.

The beam commissioning of RFQ was done together with MEBT. Many measurements have been done, including BPM offset measurement, Response matrix measurement, orbit measurement and correction, emittance measurement and beam chopping test. A 72 hours test run for high power operation has also been performed.

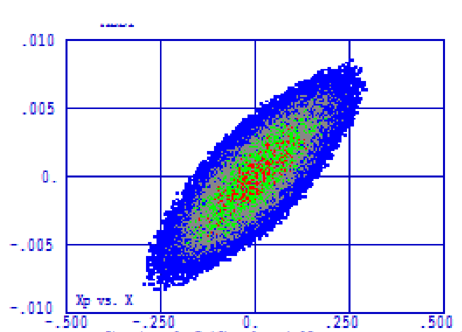

Figure 4a: Emittance measured by using WS, α x=-1.39 β x=0.61 ε x= 0.152 π mm mrad.

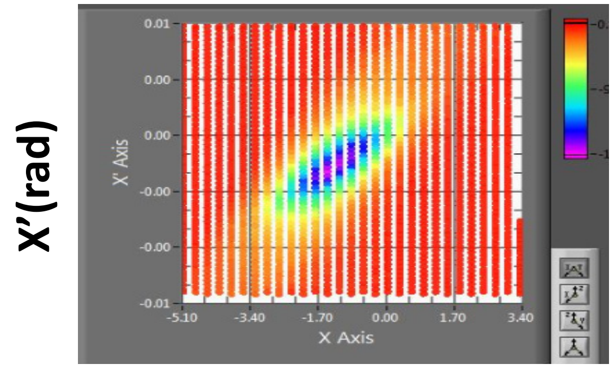

Figure 4b: Emittance measured by EM, α x=-1.2 β x=0.75 ε x= 0.16 π mm mrad.

Beam emittance in MEBT was measured by both Wire Scanner (WS) and Emittance Monitor (EM), as shown in the Figure 4. The measurement results are consistent with each other.

A electrostatic chopper is adopted in the LEBT, instead of a fast kicker in MEBT. The waveform measured in the MEBT shows the rise time is about 15ns(5 RF periods), as shown in the Figure 5. The rise time is comparable to the fast chopper that always used in MEBT.

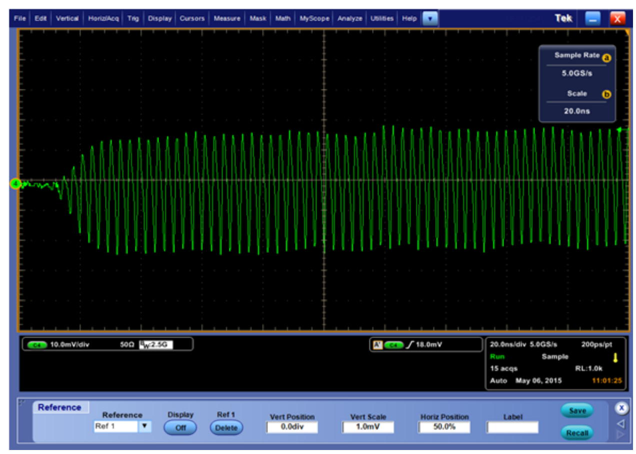

Figure 5: The waveform of beam, in which the rise time of chopper can be investigated.

DTL Linac

DTL linac consists of 4 DTL tanks (DTL-1~4). Drift tube assembly was started from Oct. 2014, and up to now, the assembly nearly complete. The required accuracy for the DTL1 alignment has been achieved. The DTL-1 has been installed into the tunnel, and the beam commissioning has been successfully completed. The low power RF tuning for the other 3 tanks are in progress. Among the four tanks, the assembly, tuning and beam commissioning experience is of important for the performance of whole linac. The DTL-1 has 63 full drift tubes and 2 half-drift tubes to provide longitudinal acceleration, 31 post-couplers to stabilize the accelerating field, 12 fixed tuners and 2 movable tuners to adjust the resonant frequency. Figure 6 shows alignment error of the drift tube assembly. Tolerable alignment error for drift tubes is 0.05mm in transverse plane, 0.1mm along the beam line

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take into account the effect of thermal expansion and contraction. The required alignment accuracy has been achieved.

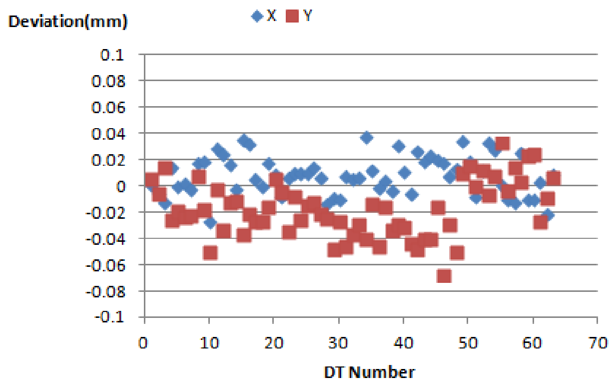

Figure 6: Alignment error of DTL-1 drift tubes.

The field are within ±2% of design after RF tuning. Figure 7 shows the field stability against the insertion of movable tuner. The cavity shows a good stability against perturbation. Figure 8 shows the installed DTL-1 in tunnel, which was ready for beam commissioning.

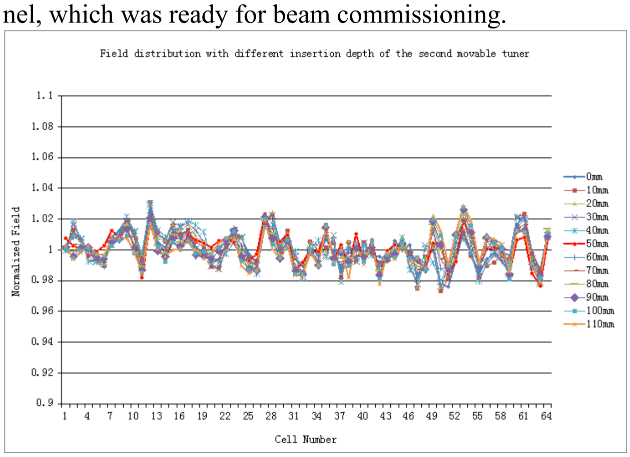

Figure 7: Field distribution vs. insertion of movable tuner.

Figure 8: DTL-1 installed in the tunnel.

The beam commissioning for DTL-1 was done before the installation of other three DTL tanks, with a temporary test beam line, called D-plate, which is consisted of BPM, BCM, FCT, EM(emittance measurement), wire scanner and a beam dump. D-plate was installed just after DTL-1. After the commissioning of DTL-1, the D-plate was removed, and DTL2-4 will be installed together. The beam instruments in the LRBT will be used for the commissioning of three DTL tanks. The three tanks will be commissioned one by one. When the upstream tank is commissioned, the downstream tank will be set as transport line. The tuning procedure for each tank is similar to the DTL-1

The commissioning started from the low peak beam current, low repetition rate and short pulse length, and then increase the average beam current to the designed peak current and pulse length in the commissioning of first stage.

For DTL beam commissioning, the most important thing is the longitudinal tuning[2,3]. The RF set point of DTL-1 was searched with phase scan method. The tuning goal of the RF set point is 1deg in phase and 1% in amplitude. The phase scan curve obtained with a numerical model for the design RF set-point is adopted as the reference curve, and the reference curves is shifted to fit the measured phase scan curves under various RF amplitude settings. Figure 9 gives the results of phase scan of DTL-1. It shows that the measured beam energy is 21.72MeV at the exit of DTL-1, while the design value is 21.67MeV. The suggested phase from phase scan is 155.17°, and corresponding field amplitude is 2.86MV/m.

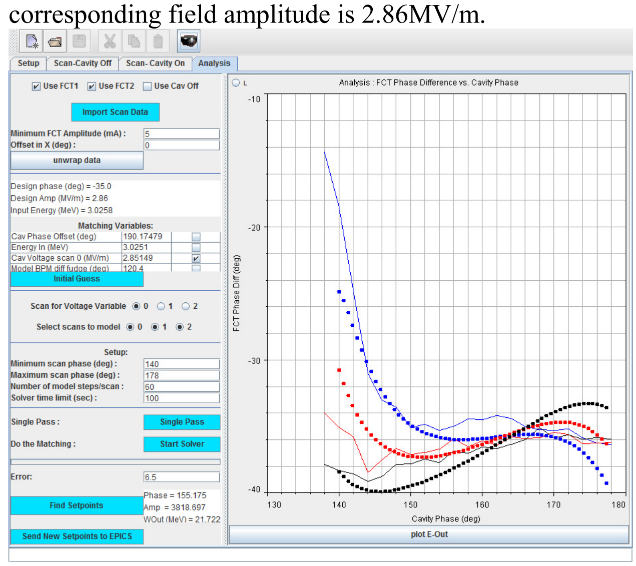

Figure 9: Phase scan of DTL-1.

In Jan. 9, 2016, the beam reached the end of DTL-1 without acceleration. In Jan. 11, the first beam is accelerated to the end of DTL-1, with 4mA at 21.6MeV. To Jan. 18, 2016, 18mA/21.67MeV/50us/1Hz beam was obtained, which exceeds the design goal of beam current of 15mA. the beam reached the end of the first DTL tank with peak current of 18mA at 21.67 MeV, with transmission rate of 100% within the error of Current Transformer.

Rapid Cycling Synchrotron

Almost all the RCS components have been fabricated and tested. Now these components have been installing in to the RCS tunnel or local station.

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AC dipoles and quadrupoles are the key components of RCS. Totally 24 dipole, 48 quadrupole, have been installed in to the tunnel. For these dipoles and quadrupoles operate in AC mode, powered by WHITE power supply, the field measurement, including the study of time harmonic injection become very important, and took long time to perform the measurement. Figure 10 shows the dipoles and quadrupoles installed in the tunnel.

Figure 10: The dipoles and quadrupoles installed in the tunnel.

24 ring dipole magnets are all measured with a field quality better than requirement. The uniformity is nice with integral field difference among them better than ±0.1%. With harmonic injection, the time-harmonic error is reduced to about 0.02% for single dipole.

48 quadrupoles have been measured in both DC and AC mode. Family uniformity is better than ±0.2%. Space-harmonic error is less than 0.06% and time-harmonic error is suppressed to less than 0.1% for single quadrupole.

A new method was developed to perform harmonic injection, which is based on the transfer function in AC mode. New method has many merits: the transfer function can be quickly measured; For several magnets powered by one family of power supply, one can use the average harmonic current to decrease the non-uniformity error; and also, by using the new method, one can "arbitrarily" charge the tune during a RCS cycle. The new method can be used on any existing RCS.

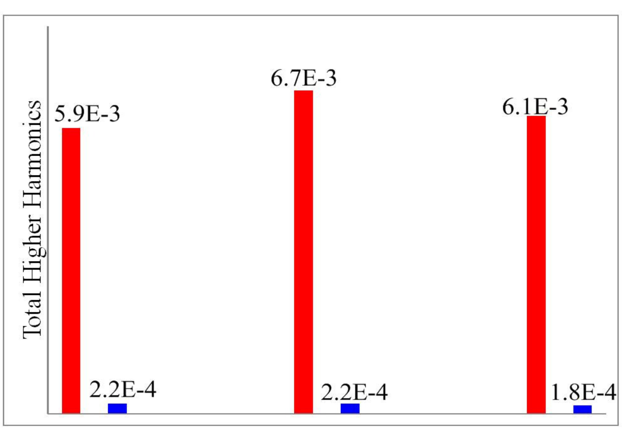

Figure 11: The effect of harmonic injection.

The harmonic injection is based on the individual measurement. The red column indicates the field harmonic without harmonic injection, and the blue column is with harmonic injection.

The fringe field interference and interaction between main dipole/quadrupole and nearby sextupole/corrector was studied by both measurement and simulation. The study shows that the interference effect is not negligible, and was considered in the I-B curve and magnet sorting. A small flip-flop coil measurement system has been set up for the AC fringe field measurement of RCS main Quadrupoles and dipoles.

Magnets Sorting was done not only for dipoles, but also for quadrupoles in one family. Due to the inconsistency between the DC field and AC field, the sorting also need to consider both DC and AC field, and some time, we need to balance between DC and AC mode and DC. Figure 12 gives a example of quadupole sorting, and it shows that the beta beating is significently depressed with and quadrupole sorting.

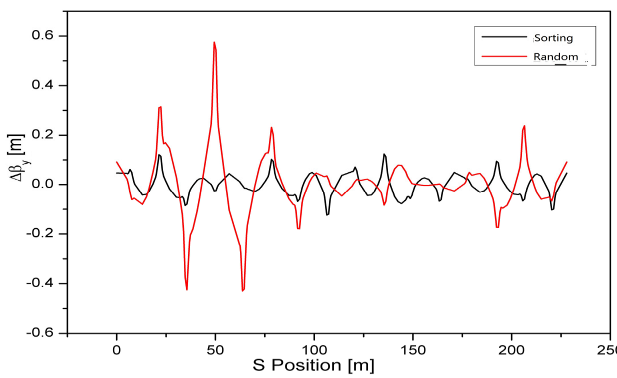

Figure 12: The beta beating with and without quadrupole sorting.

1 set WHITE power supply for dipoles and 5 sets WHITE power supply for quadrupoles have been manufactured and delivered to CSNS site. Figure 13 shows the choke and capacity bank for WHITE power supply First WHITE power supply has been tuned and tested with real load of 8 quadrupoles, and the test results well meet the design specifications.

Figure 13: The choke and capacity bank for WHITE power supply.

All 8 ferrite-loaded RF cavities and their tetrode RF power sources with biased power supplies have been delivered to CSNS site, and the cavity assembly have

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been completed. The system integral test have been done. 7 of 8 cavities have been done the 7 days high power test. The amplitude error is better than ±0.5%, and the phase error is better than ±0.5° during the long time high power test. Figure 14 shows the ferrite-loaded cavity under test.

Figure 14: The ferrite-loaded cavity under test.

Totally 86 pieces ceramic chamber have been delivered to CSNS site. The TiN coating have been doing in the test hall, and all the RF shielding wrapping have been done. Figure 15 shows the ceramic chamber for dipole, in which coating and RF shielding have been done.

Figure 15: The ceramic chamber for dipole.

All the injection components, 8 painting magnets, 4 bump magnets, 2 septums and two stripping foil assemblies have been installed, and alignment have been completed.

For the other components in the RCS, 8 Extraction kickers and their pulsed power supplies and a Lambertson magnet have been tested; 1 primary collimator and 4 secondary collimators have been put into the tunnel; beam diagnostics are now available for installation; most of the control system have been installing.

COMMISSIONING PLAN

To the end of July of 2016, the installation of DTL2-4 and their power sources will be completed. To the end of August of 2016, the RF aging will be completed and ready for beam commissioning. To the end of 2016, the beam commissioning of DTL will be completed. The installation of RCS will be completed in the end of August of 2016, and the tuning of RCS devices will be completed in the end of November of 2016. In the beginning of 2017, RCS beam commissioning will start, and it is planned to have first beam on the neutron target in June of 2017. The time for officially acceptance is March of 2018.

CONCLUSION

The construction of CSNS is in good progress. Almost all the components have been tested and installed into the accelerator tunnel. The beam commissioning of the front end and first DTL tank have been successfully performed. It is planned the first beam will bombard the neutron target in the June of 2017.

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