COMMISSIONING OF THE CHINA-ADS INJECTOR-I TESTING FACILITY*

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Abstract

The 10 MeV accelerator-driven subcritical system (ADS) Injector I test stand at Institute of High Energy Physics (IHEP) is a testing facility dedicated to demonstrate one of the two injector design schemes [Injector Scheme-I, which works at 325 MHz], for the ADS project in China. The ion source was installed since April of 2014, periods of commissioning are regularly scheduled between installation phases of the rest of the injector. Proton energy of 6.05 MeV has been achieved with beam peak current of 10 mA with seven superconducting (SC) spoke cavities at present. This contribution reports the details of the commissioning results together with the challenges of the CW machine commissioning.

INTRODUCTION

The China ADS (C-ADS) project proposes to build a 1000 MW Accelerator Driven sub-critical System around 2032. The accelerator will work in CW mode with 10 mA in beam current and 1.5 GeV in final beam energy [1]. The linac is composed of two major parts: the injector and the main linac. There are two different schemes for the injector section. The Injector-I scheme is based on a 325 MHz RFQ and SC spoke cavities of the same RF frequency and the Injector-II scheme is based on a 162.5 MHz RFQ and SC HWR cavities of the same frequency. The two injector schemes have been studied independently in two different institutes of China: IMP and IHEP. Finally one scheme will be chosen and two identical injectors will be built and operated as a hot spare stand by.

The paper focuses on the experimental results obtained during the different stage beam commissioning of ADS injector-I test facility since April of 2014. The specifications of the injector-I are listed in table 1.

COMMISSIONING RESULTS

As shown in figure 1, the Injector-I testing facility is composed of an electron cyclotron resonance (ECR) ion source, a low energy beam transport (LEBT) line, a four-vane type copper structure radio frequency quadrupole (RFQ), a medium energy beam transport (MEBT) line, a SC section, an Energy Divergence Analysis System (EDA) and a beam dump line. The designed output energy of the RFQ is 3.2MeV. The SC section includes two cryomodules (CM) with 14 β=0.12 SC spoke cavities, 14 solenoids and 14 cold BPMs, for boosting the proton beam energy up to 10 MeV. At present, the first CM with specification energy of 5MeV has been commissioned through the beam dump line, and finally into a beam stop. Energy of 6.05MeV has been achieved at the exit of this CM. At this point, all the components of the Injector-I test stand including the other CM has been installed in the tunnel and ready to be commissioned.

Table 1: ADS Injector-I Test Facility Specifications

Particle	Proton
Output Energy (MeV)	10
Average Current (mA)	10
Beam power (kW)	100
Duty factor (%)	100
RF frequency (MHz)	325

Ion Source and LEBT Performance

Details of the ion source and LEBT design can be found in [2-3]. The ion source provides with 35keV CW or pulsed proton beam. The LEBT chopper provided pulsed beam with width started from 30μs with repetition frequency of 1Hz up to 50Hz. The rise and down time of the chopper, as shown in figure 2, is smaller than 20ns as measured at the LEBT ACCT, which is located right after the chopping system. Maximum peak current of 13 mA could be delivered at the entrance of RFQ. Alison detector is used for the LEBT emittance measurement. Twiss parameters close to the designed values at the entrance of RFQ were achieved by adjusting the LEBT solenoid set

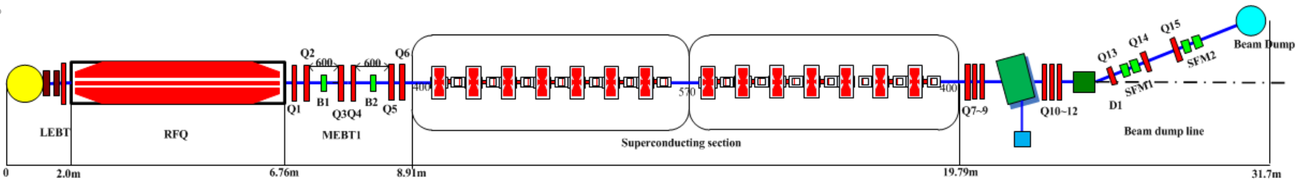

Figure 1: Layout of the ADS injector-I testing facility.

* Work supported by CAS Strategic Priority Research Program-Future Advanced Nuclear Fission Energy (Accelerator-Driven Sub-critical System).

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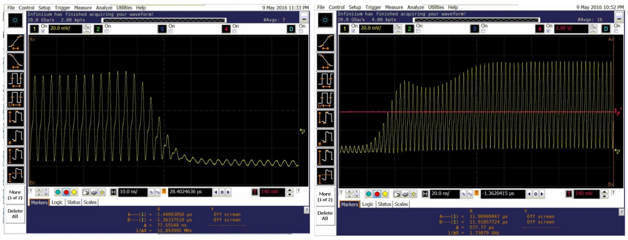

Figure 2: LEBT chopper rise time (left trace) and fall time (right trace) measured at the MEBT FCT.

tings. 5% background was assumed. The simulation and measurement results reported in reference [3].

RFQ Performance

The design of the 4.7m long 4-vane type copper stucture RFQ with π mode stabilizers is described in detail elsewhere [4]. It operates on frequency of 325MHz and accelerates H^+ beam from 35keV to 3.2MeV.

The RFQ RF commissioning starts from May. 15th of year 2014, beginning with short pulse of 100us and 1% RF duty factor, gradually ramping the power to designed values. Then the pulse width was progressively expended up to 1ms after 50% duty factor being achieved with short pulse while keeping the full designed power in the RFQ. After reaching over 10ms, the pulse width was fixed, while the RF duty factor was gradually ramping up by increasing the repetition frequency. In the meanwhile CW conditioning was processed alternately. After about 2 months conditioning, 99.97% RF duty factor was reached with pulse width of 12.5ms, repetition frequency of 79.975Hz and 250kW in cavity power. In the meanwhile, while switching to CW mode, the maximum in cavity power reached 194kW.

Beam conditioning was started afterwards with beam duty factor starts from 50% to 90%. The transmission reached 90% with beam shooting through the RFQ with 90% duty factor in Sep. 25th of 2014, which is stopped after few minutes to save the dump target. However beam with 60% duty factor lasted for one hour after passing through the RFQ, before being stopped artificially.

3.2MeV output energy from RFQ was detected by two downstream FCTs. The RFQ transmission have also been measured for different in cavity power with short pulse beam and small duty factor, the maximum transmission dropped from 97% [5] to 90% as shown in figure 3 after a period of CW conditioning last year. Large area of surface damage observed from the power coupler port of the RFQ could be the reason. Figure 4 shows the surface damage status pictured from #1 power coupler port at April of last year after the CW conditioning. Although the damage had already caused, the transmission does not drop so much fortunately. The RFQ performance is still in good status. New conditioning method will be trying afterwards.

MEBT Performance

The detailed MEBT design is described elsewhere [6]. The MEBT is composed of 6 Quadruples, 6 pair of Steering magnets and 2 Bunchers. Beam diagnostic devices including 6 Beam Position Monitors, 2 Fast Current

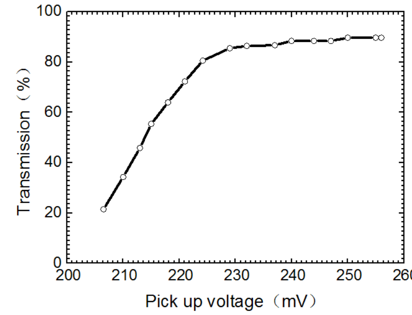

Figure 3: Verification of tank level with transmission scan.

Figure 4: RFQ surface damage status pictured from the #1 power coupler port.

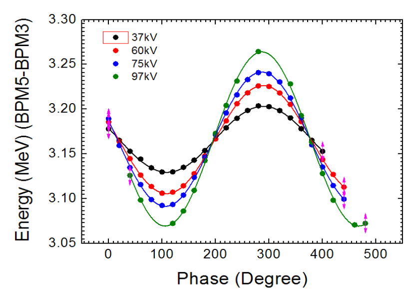

Figure 5: The Buncher 1 phase scan results.

Transformers (FCTs), one AC current transformer (ACCT) and 3 Wire Scanners. The two FCT are used for the energy measurement. The space between the two FCTs is 1.67m. Two downstream BPMs were used for the phase scanning determining of the buncher settings. Figure 5 shows the buncher 1 phase scanning results.

Different emittance measurement methods using double slits, wire scan and Quadruple scan had been tried for the RFQ exit emittance measurement at different stages. The difficulty for the double slit method is the determination of the background signals. Multi-wires located at three different locations were used for the emittance measurement also, however a self-consistent solution could not been worked out with the existing experimental data because of space charge effect. More wires could be a solution for this method. For the Quadruple scan, the first problem is the beam size fitting during the data processing. Usually Gaussian curve fitting is used for the RMS beam size calculation. However, beam is usually not Gaussian shape in most of the cases especially when the Quadruple setting deviated a lot from the normal design during the gradient scans. Direct Root Mean Square formula was used in our case for the RMS beam size calculation to eliminate the calculate method error caused by

ISBN 978-3-95450-147-2

unsuitable fitting formula. Detail descriptions please see reference [7]. Another problem of Quadruple scan is the traditional transfer map emittanc deducing method from the measurement position to the RFQ exit in which space charge effect is not considered. The problem was solved in our case using evolutionary algorithm for finding the optimal solution for multiple objective by calling the multiparticle tracking code TraceWin [8]. Detail descriptions please see reference [9]. Table 2 listed the emittance measurement results using Quadruple scan considering space charge effect, together with the simulation results.

Table 2: Twiss Parameters Comparation Between Simlation and Measurement Results for the RFQ and CM1 Exit

Parameters	α_x/α_y	β_x/β_y (mm/mrad)	$E_{n,rms,x/y}$ (π mm.mrad)
RFQ exit			
Simulation	-1.3/1.46	0.12/0.13	0.21/0.2
Quad. scan	-1.8/0.72	0.17/0.09	0.16/0.21
CM1 exit			
Simulation*	-1.44/-1.75	1.18/1.53	0.22/0.21
Double Slits	-2.12/-1.97	1.56/1.81	0.29/0.27

*Simulation results according to the Quad. Scan measurement results at RFQ exit with 30% longitudinal mismatch.

SC Section Performance

The periodical structure of the injector-I SC section includes one SC cavity, one solenoid and one BPM. During the design, different transverse and longitudinal phase advance ratios started from 0.4 up to 0.75 were studied for totally 14 periods without breaking. The maximum emittance growth percentages versus different phase advance ratios are shown in figure 6. More than 20% RMS normalized emittance growth were observed for the phase advance ratio of 0.4~0.6 with ideal input Gaussian distribution with no errors included. Beam losses observed for phase advance ratio of 0.4 because of weak transverse focusing with zero current periodical phase advance smaller than 30 degree. Finally a moderate phase advance ratio of 0.75 was chosen to avoid the envelope resonance and emittance growths. Transverse beam emittances at the exit of CM1 were measured for different phase advance ratios at Injector-I aiming to verify the conclusion obtained from the above mentioned research, the detail measurement results are presented in reference [10] in the same proceedings.

The SC section of Injector-I include two CMs, accelerate the proton beam from 5MeV up to 10MeV. The first CM was installed in the tunnel after the Test cryomodule was commissioned. The TCM houses two periodical periods, housing 7 SC cavities, 2 solenoids and 2BPM. The maximum cavity gradient achieved was 3.1MV/m (the specification is 7MV/m) because of field emission caused by cavity contamination preventing the accelerating gradient increasing further up. Improved technologies and methods were used for the succeeding cryomodule of CM1 and CM2, maximum gradient of over 7MV/m was achieved during the commissioning. The output energy at the exit of CM1 reached 6.05MeV with 7 SC cavities.

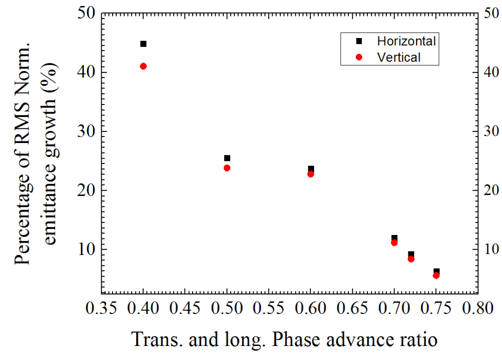

Figure 6: Maximum emittance growth percentages versus different phase advance ratios.

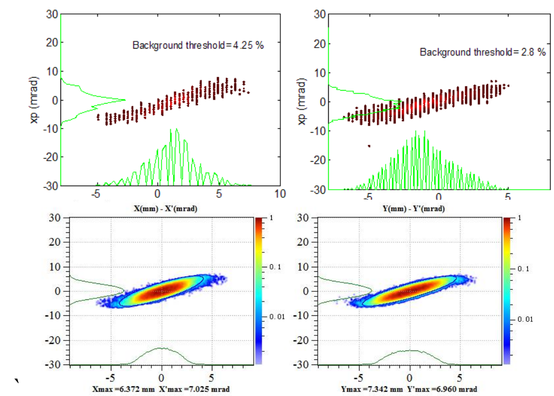

Figure 7: Measurement emittance results by two slits at the exit of CM1 (upper graph) comparing with the simulation results (below figure).

Figure 7 shows the twiss parameters measurement results obtained by two slits located at the exit of CM1. As a comparation, the simulation results at the same position were listed in table 2 (below) also. The RFQ exit parameters used for the simulations are obtained from the Quad. Scan at the MEBT section with 30% longitudinal mismatch assumed. The phase spaces are quite similar, but the twiss parameters are still not consistent with each other. More research will be done to investigate the emittance and twiss parameters deviation between the simulation and measurement.

CONCLUSION

The China ADS injector-I testing facility has been commissioned up to the first SC CM. The energy achieved at the exit of the CM1 is 6.05MeV. Experimental results obtained during 5MeV test stand commissioning meet the specifications at low duty cycle. The RFQ commissioned with high duty factor of 90% with 90% transmission achievement from the entrance of the RFQ to the exit of the MEBT. The injector recommissioning with 2CM will be soon started. The target energy is 10MeV with average beam current of 10mA. More experiments as well as some improvements are foreseen. Preliminary experiment results that have been obtained are encouraging but further work is still needed to achieve a better understanding of the phenomena that occur in high duty cycle operation of the linac.

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ISBN 978-3-95450-147-2