BEAM COMMISSIONING OF C-ADS LINAC INSTRUMENTATION*

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Abstract

The China Accelerator Driven Subcritical system (C-ADS) linac, which is composed of an ECR ion source, a low energy beam transport line (LEBT), a radio frequency quadrupole accelerator (RFQ), a medium energy beam transport line (MEBT) and cryomodules with SRF cavities to boost the energy up to 10 MeV. The injector linac will be equipped with beam diagnostics to measure the beam position, the transverse profile and emittance, the beam phase as well as beam current and beam losses. Though many are conventional design, they can provide efficient operation of drive linac. This paper gives an overview and detail in beam commissioning of C-ADS linac beam instrumentation.

INTRODUCTION

The Chinese ADS project is aimed to solve the nuclear waste problem and the resource problem for nuclear power plants in China. With its long-term plan lasting until 2030th, the project will be carried out in 3 phases: Phase I of R&D facility, Phase II of experiment facility and Phase III of industry demonstration facility. The driver linac of the CADS consists of two injectors to ensure its high reliability. Each of the two injectors will be a hot-spare of the other. Although the two injectors that are installed in the final tunnel will be identical, two different design schemes, named injector I and II respectively are being pursued in parallel by the Institute of High Energy of Physics (IHEP) and the Institute of Modern Physics (IMP) [1]. This paper aims to introduce the instrumentation beam commissioning of the injector I. The Injector I ion source is based on ECR technology. The beam will be extracted with an energy of 35 keV. The ion source will be followed by a Low Energy Beam Transportline (LEBT), which consists of 2 solenoids, a fast chopper system and a set of beam diagnostics including CTs and faraday cup. A Radio Frequency Quadrupole (RFQ) will accelerate the beam up to 3.2 MeV and will be followed by the first Medium Energy Beam Transport line (MEBT1), fully instrumented and also equipped. The next section is two cryogenic modules named CM1 and CM2 with seven cold beam position monitors in each, which accelerate beam up to about 10 MeV. The last section is the second Medium Energy Beam Transport line (MEBT2). The drift tubes between magnets provide the gap for diagnostics.

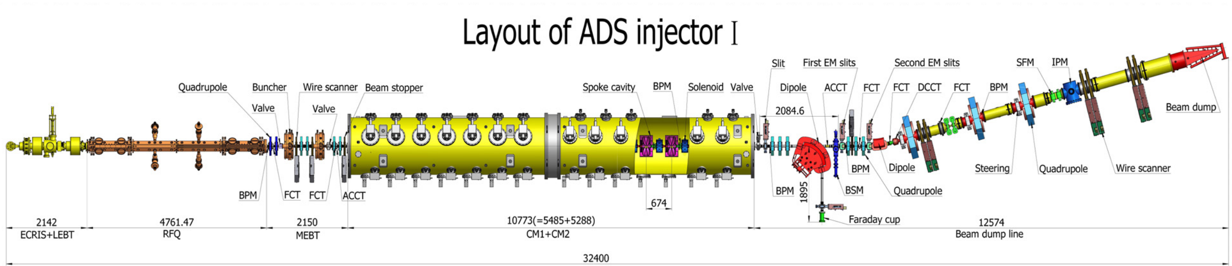

Figure 1: Beam instrumentation layout in C-ADS linac.

INSTRUMENTATION OF INJECTOR I

The injector I linac is equipped with beam diagnostics to measure the beam position, the transverse profile, the beam emittace, the beam energy as well as beam current and beam losses. This will provide efficient operation of drive linac and ensure the beam loss at a low level. A list of the different type of monitors using in the injector I linac is presented in Table 1.

According the geometry of pick-ups, three type of BPMs are hired to measure the beam position in the injector I linac. There are 25 BPMs of which 14 is cold BPM installed in two cryostats. Measurement of the particle beam position of CADS injector I proton linac is an essential part of beam diagnostics. The BPMs could provide information about both the center of mass position and the beam phase that can be used to detect energy on line by using the time-of-flight (TOF) method [2]. The sum signal of BPM could be used for beam loss measurement which can be detected by a Differential Beam Current Monitor (DBCM) measuring beam current difference at two locations along the accelerator, especially for the beam energy is lower than 10MeV [3].

For the beam profile monitor in injector I, four wire scanners using solid material as a probe inside the beam to sample the charge at different location is installed in MEBT1 and the start of MEBT2. Three pairs of wire scanner is installed downstream of the first SFM (step-like field magnet). For the beam profile is expanded quickly, one wire scanner can only measure one direction beam dimension. Although the double slits is for emittace

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measuring specially, the wire scanners are also used for check the result with Q-magnet scan method for checking the result of double slits. Two non-invasive beam profile measurement methods were developed for the CADS main Linac in which beam is very intensive. One is an IPM (ionization beam profile monitor), and the other is electron scanner.

Table 1: List of Beam Instrumentation in C-ADS Linac

Device	Accuracy	Resolution	Quantity
Beam position monitor	±100um	30 um	25
Wire scanner	±0.5mm	50 um	4+3
Beam emittace unit	10%	-	2
Beam current monitor	1.5%	0.01mA	5
Beam loss monitor	1%	-	8
Beam energy monitor	±1deg	0.5deg	3
IPM	1mm	200 um	1
Electron scanner	1mm	300um	1

Kinds of Current transformers (CTs) are used measure the beam current. Three different kinds of CTs are used in the linac for different purpose. FCTs are for checking bunch shape with fast rise time and measuring the beam phase by using the time-of-flight (TOF) method. ACCTs are used for beam transmission monitor and beam pulse current. NPCT measures beam current in CW mode.

A double-slits emittance mertre is equipped to measure beam emittance in both horizontal and vertical. The first slits are made of tungsten with a cooling system. To ensure the slits safety, the heat analysis is carried out and the result is shown in Fig.2

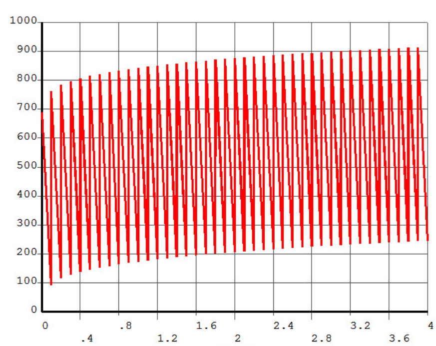

Figure 2: The time (x-axis in unit second) versus temperature(y-axis in unit degree) of first slit in beam, with the beam duty factor 0.1% and 10Hz pulse repetition rate.

The beam loss monitor is the most important diagnostic system for proton linac. The purpose of the beam loss monitor is to avoid the accelerator damage and excessive machine activation by beam loss. Ionization chambers will be the main beam loss detector. However, at low energies, ionization chambers are not effective to detect beam loss due to the self-shielding from the copper cavities and the low energy particle can't penetrate the shielding. The differential current measurement between two beam position monitor will be the primary input to the fast machine interlock system. Also the ports signal of beam position pick-ups are used for the fast machine interlock system if the voltage exceeds some thresholds [4].

BEAM COMMISSIONING

The injector I beam commissioning is including five stages. The first stage is ion source and LEBT. RFQ and MEBT1 tuning is the second stage, the third stage is test cryomodule commissioning. Each formal cryomodule beam test is one stage. This paper presents the RFQ and CM1 beam test result and the beam parameters of the RFQ.

RFQ and MEBT1 Tuning

In MEBTI, there are three wire scanners, two FCTs, six BPMs, and an ACCT, the location of beam instrumentations in MEBT1 are shown in Fig.1 .The RFQ commissioning starts from May 15th, 2014. After about two 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 [5]. In the period of RFQ commissioning, the emittance of RFQ is obtained by double slits shown in Fig.3. Three wire scanners installed in MEBT1 with two Q-magnets between each other. The quad-scan and the multi wire scanners emittance measurement method are also used to check the result of double slits. Also the beam energy measured with the FCTs is reported. The transmission is based on the proportion of ACCT at entrance to the ACCT at the exit. The transmission reached 90% with beam shooting through the RFQ with 90% duty factor. The beam position is monitored, and finished the beam based alignment(BBA) to determine the offset of BPM pick-ups.

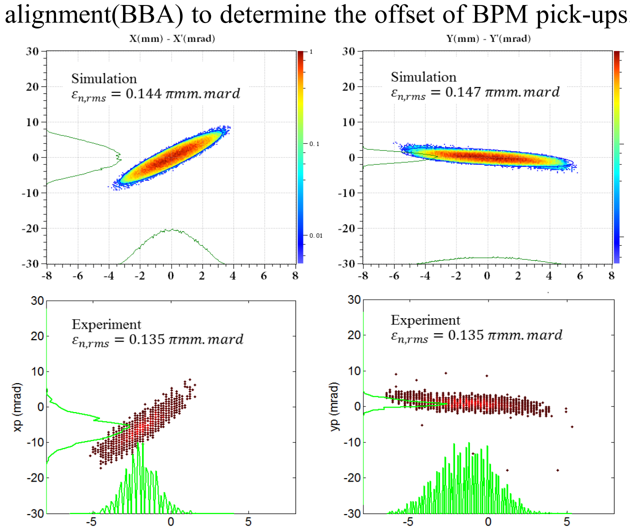

Figure 3: The measured beam emittance of RFQ (bottom) with double slits versus the simulation result (upper).

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CM1 Beam Commissioning

The SC (Super Conduct) section including two cryomodules, named CM1 and CM2, which boost the proton from 3.2MeV to 10Mev.The first CM was installed in the tunnel after the Test cryomodule was commissioned. The fisrt CM houses 7 spoke cavities, 7 solenoids and 7 cold BPM. The cold BPMs are used to scan beam phase and determine cavity phase in CM1 tuning. Beam based phase scan is the most simple and effective method for measuring cavity phase and amplitude. For the first cavity phase measurement, we detuned the second cavity and use the two following BPMs to measure energy after calibrating the offset between the BPMs [6]. The phase scan result is listed in Fig.4. The beam energy is checked by energy analysis station including a dipole magnet, two slits and an end-type faraday cup. Also the beam emittance of CM1 is shown in Fig.5 measured by double slits emittance meter.

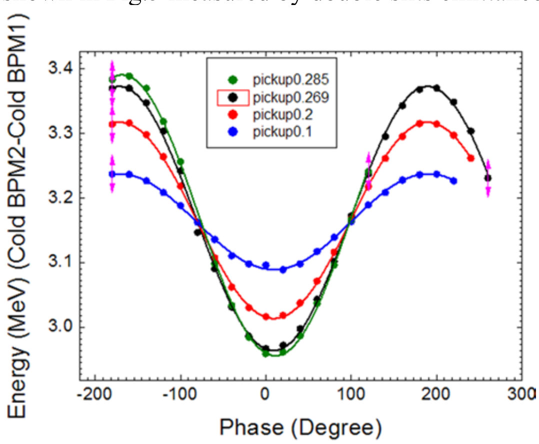

Figure 4: The beam energy versus SRF cavity phase with different amplitude (in different color) in NO.1 cavity of CM1.

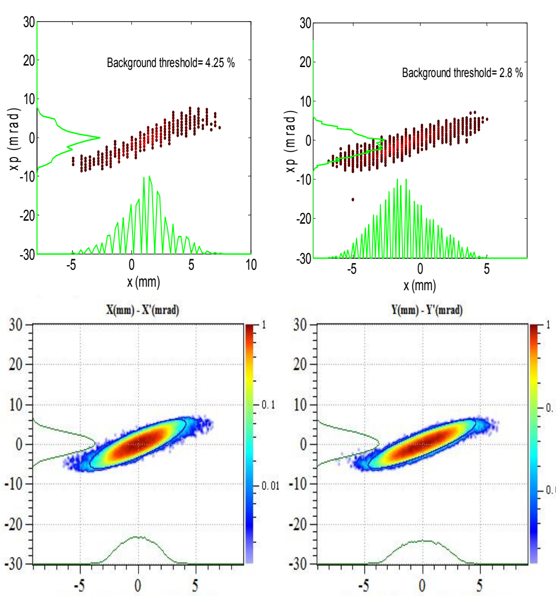

Figure 5: The measured beam emittance of CM1 (upper) with double slits versus the simulation result (bottom).

CONCLUSION

The beam instrumentation system works well in beam commissioning of injector and is very helpful in beam tuning. The required parameters of beam are all acquired for the injector tuning. For the important beam parameters, such as beam energy, beam emittance, beam current, the result are checked with at least two methods. Cold BPMs are carefully test and works well in cryostat. In the SRF cavities tuning, the cold BPMs play important roles in determining the phase of cavities. As an intensity accelerator, Fast Protection System (FPS) should be developed to prevent permanent damage to the machine. For the beam diagnostics, the beam position signal and the beam loss signal are feed to FPS as the inputs. In the future the BPM sum signal will be used as the Differential Beam Current Monitor and set as an input to FPS.

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