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OVERVIEW OF BEAM INSTRUMENTATION FOR THE CADS INJECTOR I PROTON LINAC*

Y.F. Sui#, J.S. Cao, H.Z. Ma, L.D.Yu, Y. Zhao, Q.Y. Deng, J. He, X.Y. Zhao, Q. Ye, J.H. Yue, L. Wang, IHEP, 100049, China
Key Laboratory of Particle Acceleration Physics and Technology, IHEP, Chinese Academy of Sciences

Abstract

The injector I of China Accelerator Driven Subcritical system (C-ADS), 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 beam 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 energy as well as beam current and beam losses. Though many of that are conventional design, they can provide efficient operation of injector linac. This paper gives an overview 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] 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.

The injector I linac is equipped with beam diagnostics to measure the beam position, the transverse profile, the beam emittance, 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.

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
Beam emittance 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

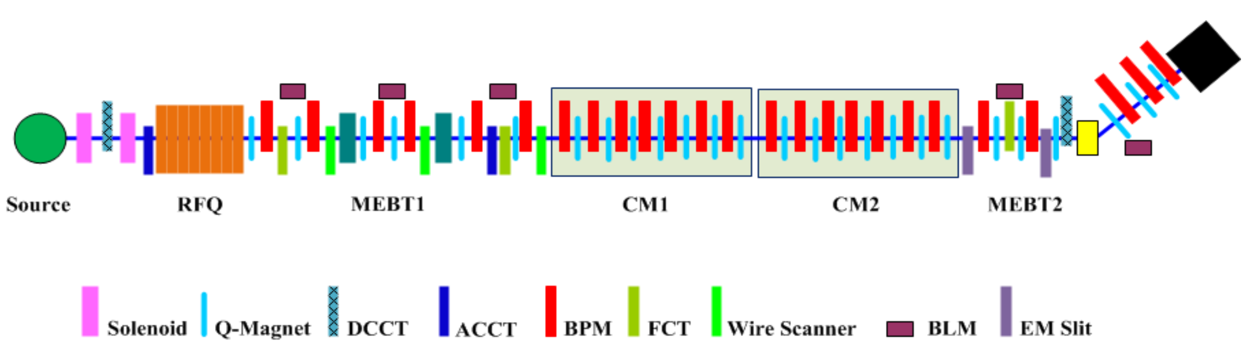

Figure 1: Beam instrumentation layout in C-ADS linac.

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BEAM POSITION MEASUREMENT

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 in CADS injector I proton linac is an essential part of beam diagnostics, and the Beam Position Monitors (BPMs) provide the basic diagnostics tool for commissioning and operation of accelerators. 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] This part will be described in the beam loss part. The signal of pick-ups will also be used for machine protection, if one of them output is much bigger than some thresholds, the electronics will provide signal to the fast interlock protection system.

BEAM PROFILE MEASUREMENT

Three different types of transverse beam profile monitors are adopted to monitor the beam profile. The wire scanner is a typical profile measuring system using solid material as a probe inside the beam to sample the charge at different location. It is an intercepting diagnostics cannot survive in a high beam power density such as ADS injector I linac with CW mode, so they are only employed to measure beam profile during the period of machine tuning. There are three wire scanners in MEBT1 separated by two Q-magnets from each other, and also one wire scanner is positioned in MEBT2. Fig. 2 shows the MEBT1 beam profile measured with wire scanner. Two non-invasive beam profile measurement methods were developed for the CADS Injector I Proton Linac. One is an IPM (ionization beam profile monitor) system which detects the ionized products from a collision of the beam particle with residual gas atoms or molecules present in the vacuum pipe, the other is an electron beam scanner as figure 3 shown which using a low energy electron beam instead of a metal wire to sweep through the beam. The deflection of electron beam by the collective field of the high intensity beam is measured.[4] The two systems will be installed in MEBT2.

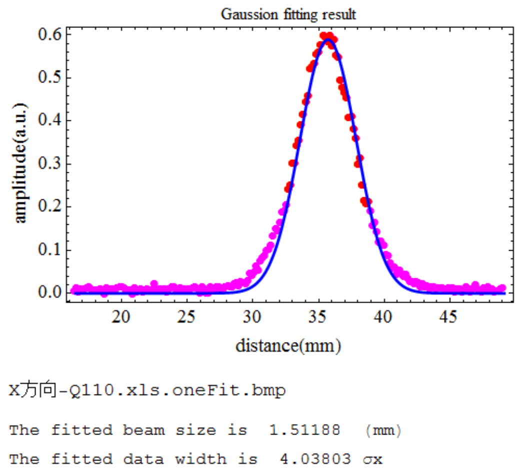

Figure 2: The MEBT1 beam profile measured with wire scanner.

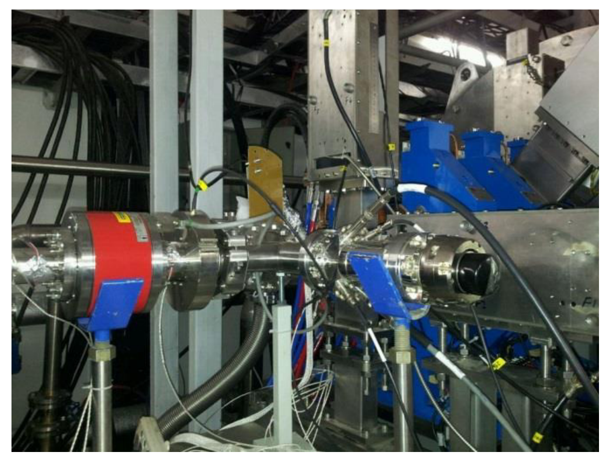

Figure 3: The electron beam scanner installed on the beam line for transverse beam profile measurement.

BEAM CURRENT MEASUREMENT

Beam Current Monitors system is composed of AC Current Transformers (ACCT), Fast Current Transformers (FCT) and DC Current Transformers (DCCT). ACCT is used to measure the average current over the beam pulse, the pulse charge and the longitudinal pulse profile. FCT is for checking bunch shape with fast rise time and measuring the beam phase.

One ACCT, one DCCT and one movable faraday cup are installed in the LEBT. The DCCT is positioned before the second solenoid, for LEBT beam current monitoring. The ACCT is located at the end of LEBT and before RFQ. It measures the beam transmission in the RFQ with another ACCT installed at the MEBT1. Two FCTs are located in the MEBT1 with the distance is about 1 meter. They are used to measure the beam energy of the MEBT1 by using the time-of-flight (TOF) method. In the MEBT2, there also are two FCT to measure the beam energy acquired from the SRF. Also there is an NPCT for measuring the beam current when the linac in CW mode.

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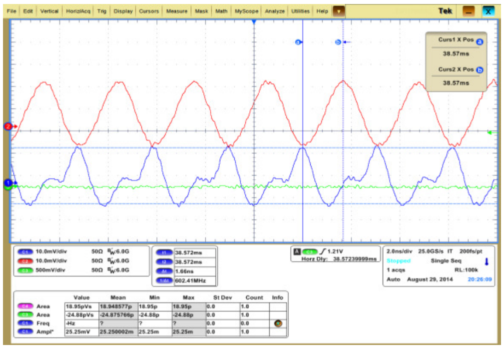

Figure 4: The beam energy of RFQ is 3.199MeV measured with two FCT with TOF.

EMITTANCE MEASUREMENT

An Emittance Measure Unit (EMU) is installed after the LEBT, this device is based on Allison scanner [5] and can measure the emittance when ion source is tuning. This device is removed when the RFQ and LEBT join together. Transverse emittance measurement is also required in the MEBT and is equipped with a double-slits system. The first slit could not be able to stand the high beam power of the CADS Injector I Proton Linac, therefore, the beam pulse frequency is reduced to 10Hz and the beam pulse length has to be reduced to 100us or less, even though the first slit is made of tungsten with high melting point. A cooling system is also requested. Studies are done for the first slit. The Special beam modes are applied to the first slit to ensure the first slit can survive in the beam. The emittance of the RFQ is measured and shown as below in Fig. 5 and Fig. 6 when RFQ commissioning. To verify the results using the double slits, the measurement base on changing Q-magnet strength is also used, the wire scanner near the RFQ exit is selected.

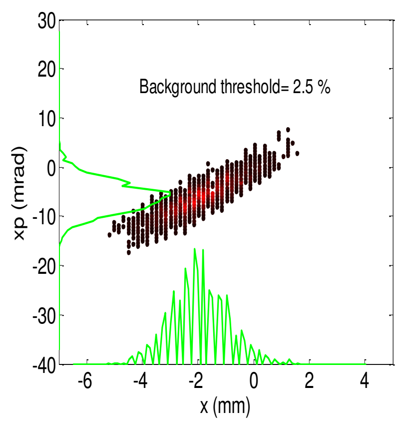

Figure 5: The horizontal emittance of RFQ is 0.1203πmm.mrad measured with double slits system.

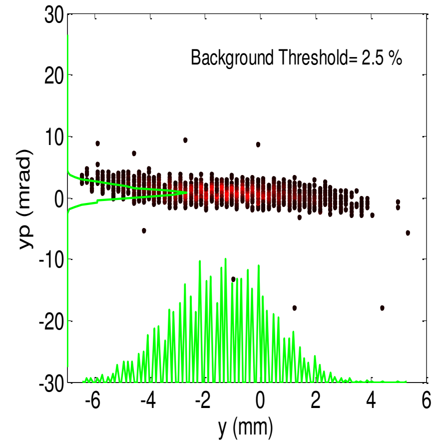

Figure 6: The vertical emittance of RFQ is 0.1347πmm.mrad measured with double slits system.

BEAM LOSS MONITORING

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.

CONCLUSION

The beam instrumentation system works well and the characteristic of beam is measured. The RFQ and test cryomodule (TCM) tuning are finished. To establish more stable and safety operation, more improvement should be done to the interlock system. To measure the longitudinal bunch profile in high power beam, some longitudinal diagnostic should be developed such as non-intercepting bunch shape monitor based on the IPM principle and so on.

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