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THE COLD BEAM POSITION MONITORS FOR THE C-ADS INJECTOR I PROTON LINAC*

Y.F. Sui, J.S. Cao, H.Z.Ma, Q. Ye, L.D. Yu, J.H. Yue
Institute of High Energy Physics, Beijing, China
also at Key Laboratory of Particle Acceleration Physics and Technology, IHEP, Beijing, China

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 is equipped with beam diagnostics. Cold beam position monitor (BPM) is one of instrumentations of the injector. This paper describes the design and fabrication of the cold BPM pick-ups, and also the application of the BPM in commissioning of SRF cavities. Discussion of the promotion and other aspect will also be presented.

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 Transport line (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.

Table 1: The Beam Characteristics of CADS Injector I

Parameters	Value
Beam energy	3.5Mev~10MeV
Bunch frequency	325MHz
Beam pulse length	30us-CW
Peak current	10mA

To monitor the parameters of injector I, Several beam diagnostic and monitoring instruments are used. BPM as an essential part of beam diagnostics was designed and manufactured to measure the displacement of the beam. The BPMs provide the basic diagnostics tool for commissioning and operation of accelerators. The BPMs will provide information about both the transverse position of the beam and the beam phase that can be used to detect energy on line using the time-of-flight (TOF) method [2]. 27 BPMs including 14 cold BPMs are installed on the injector I. There are 7 cold BPMs, 7 superconducting quadruple magnet (SCQ) and 7 superconducting RF (SRF) cavities in each cryostat. The cold BPM is installed between SCQ and SRF cavity. So the SRF or SCQ is adjusted one to one based on BPM. The cold BPM is shown in Fig.1.

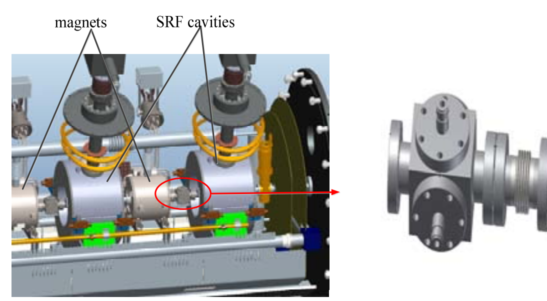

Figure 1: The position of the BPM in the cryostat and the structure of BPM.

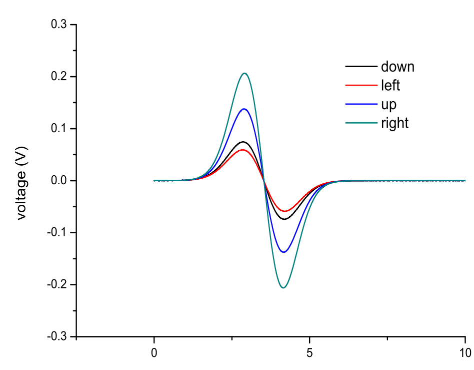

Figure 2: Voltages versus time during one period on four BPM electrodes from a passing transversely displaced (x = 2r/7; y =r/7) bunch.

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THE COLD BPM DESIGN

As mentioned above, there are seven BPMs for each cryostat. The button pickups are selected for cryogenic BPMs. Removable feedthroughs are used in the cold BPMs for maintenance and replacement. The button diameter is 10mm and the beam pipe is 35 in diameter. The cryogenic BPM is modelled and simulated in CST PS. Though the beam energy varies from the entrance to the exit of the cryomodule, we adopted the unique beam energy 3.5 MeV to compute the model. The signal induced by the beam is shown in the Fig.2. [3]

Figure 3: The liquid nitrogen test of the BPM pick-ups.

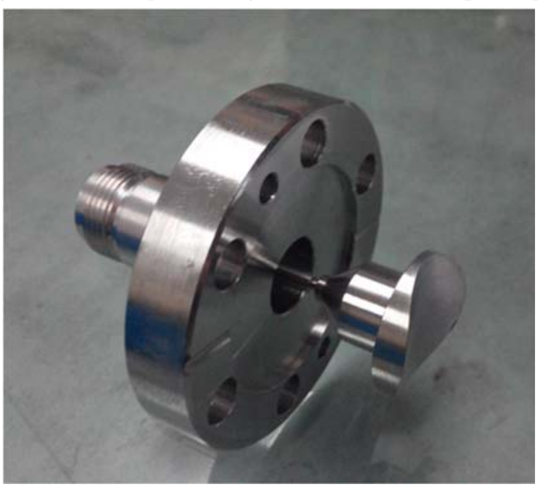

Figure 4: Removable feed through of cold BPM.

The stability of the cold BPM must be considered first. So the pick-ups and the cables in the cryostat are carefully design to satisfy the demands. The prototype of cold BPM pick-up is carefully designed and fabricated. Liquid nitrogen test is carried to verify the stability of the prototype. In the test, the pick-up is soaked in liquid nitrogen for long time， so that the temperature of pick up is as low as liquid nitrogen. Then the pick-up is transferred to a high temperature furnace and forced the temperature to rise quickly. This is one cycle of the test. After several cycles, the vacuum leakage of wielding part is checked carefully. Another vulnerable part is feed through for the ceramic seal suffered to drastic change in temperature. And also need to check for safety.

For the cold bpm pick-ups are all installed in cryostat, totally 28 cables used to feed the signal out of the cryostat for all pick-ups. The heat transferring by the cable should be considered to reduce heat load of cryogenic system. The conduction heat is calculated with different parameter cable. The main difference is inner conductor. The result is shown in Table 2.

Table 2: The Thermal Load of Two Type Cable at 2K

No.	Inner Conductor	Outer Conductor	Dielectric	Thermal Load @2K (W)
1	1. Silver Coating, 99.9% pure 2. Copper center conductor, 99.9% pure	OFHC Copper outer conductor	PTFE Dielectric	0.343
2	1. Silver Coating, 99.9% pure 2. Copper cladding, 99.9% pure 3. ASTM Class 40HS steel center conductor			0.486

Measurement of the particle beam position in injector I proton linac is an essential part of cold beam position monitor. Based on this, operator can steer the beam to reduce beam loss which is critical for high intensity proton accelerators. The beam positions in cryomodule section are listed as Fig. 5. Beam based phase scan is the most simple and effective method for measuring cavity phase and amplitude. For the first cavity phase measurement, the second cavity is detuned and the two following BPMs is used to measure energy after calibrating the offset between the BPMs. Because the significant velocity changes in superconducting cavity at low energy section, the effective voltage is changing with cavity phase, meanwhile the synchronous phase is non-linear with LLRF phase. [4] The phase and amplitude setting of superconducting cavity are very important at the operation of accelerator, so beam based measurement of cavity phase and amplitude is necessary. In ADS injector I, the method is used to determine the phase and amplitude of all SRF cavities. The Fig. 6 shows the beam phase scan result using cold BPMs. The line in different colour indicates different cavity amplitude. The cold bpm system plays important role in the commissioning of superconducting cavities. The last function of BPM system is interlock. The signal of pick-ups are 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. In this way, the accelerator is prevented from serious damage.

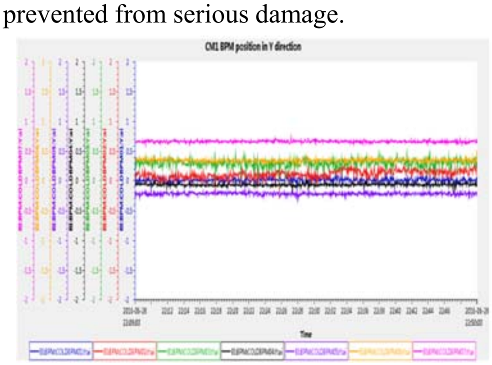

Figure 5: Beam position in cryostat by cold BPMs.

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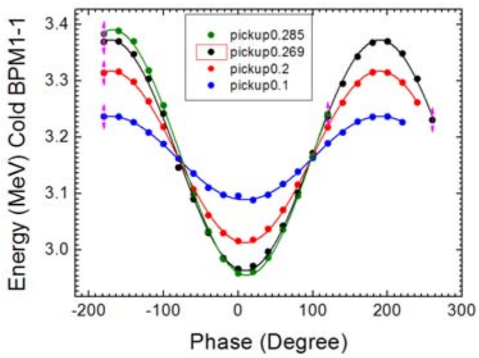

Figure 6: Phase scan with the cold BPM system

CONCLUSION & ACKNOWLEDGEMENT

The cold BPM system is carefully designed and fabricated. After that strict testing is carried out on the BPM pick-ups to ensure the system stability. The cold BPM system is set up and play important role in SRF cavities commissioning. After a long run, The system is still stable operation. We acknowledge Bian Lin for the help in thermal load calculation. The authors are grateful for the help and cooperation from the operators of the test beam line. Thanks are also given to the members of the beam instrumentation group for their useful discussions and suggestion.

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