Development and commissioning of the beam diagnostics for CIAE proton therapy system

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ABSTRACT

A superconducting cyclotron based on proton therapy system has been developed at the China Institute of Atomic Energy(CIAE). The system has technical advantages such as high dose rate, fast energy varying, compact structure, and low energy consumption. From the cyclotron to the nozzle, the beamline employed 51magnets, including six 30°, one 60°, and two 75° dipoles. Its strict symmetry ensures better beam optics, such as achromatic aberration for a wide energy range beam. The beam diagnostics system has been developed in-house to meet the beam commissioning needs of such high-quality beamline. Along the beamline, the system includes 1) 7 standardized comprehensive diagnostic units; 2) 4 pairs of X-Y slits for energy selection and emittance re-definition; 3) several separate circular collimators, fast beam cutoff devices, and online monitoring ionization chambers for beam position, as well as Faraday cup for measuring beam intensity in the air section for flexible use. This paper will consider the design of the diagnostic system, the specialized electronics, and the EMC consideration. The dual wire structure for the pA-level weak beam will be introduced. The Ce doped yttrium aluminum garnet (Ce: YAG), which is an essential photonic material for proton beam profile measurement will also be present in detail.

Structure of Dual Wires Scanner

The scanned wire is a copper alloy strip with a width of 5mm and a thickness of 0.1mm. A bias voltage of 1.5kV is provided on both sides of the copper alloy strip to propel the emitted secondary electron and prevent it from flying back to the strip. As mentioned, the motion direction has a 45-degree angle compared to the gravitational direction. In the meantime, the scan wire has another 45-degree angle compared to the motion axis, as shown in Fig.1. The dual-wire scanner is a sub-nano ampere current measurement diagnostics device with a positional resolution of sub-micron.

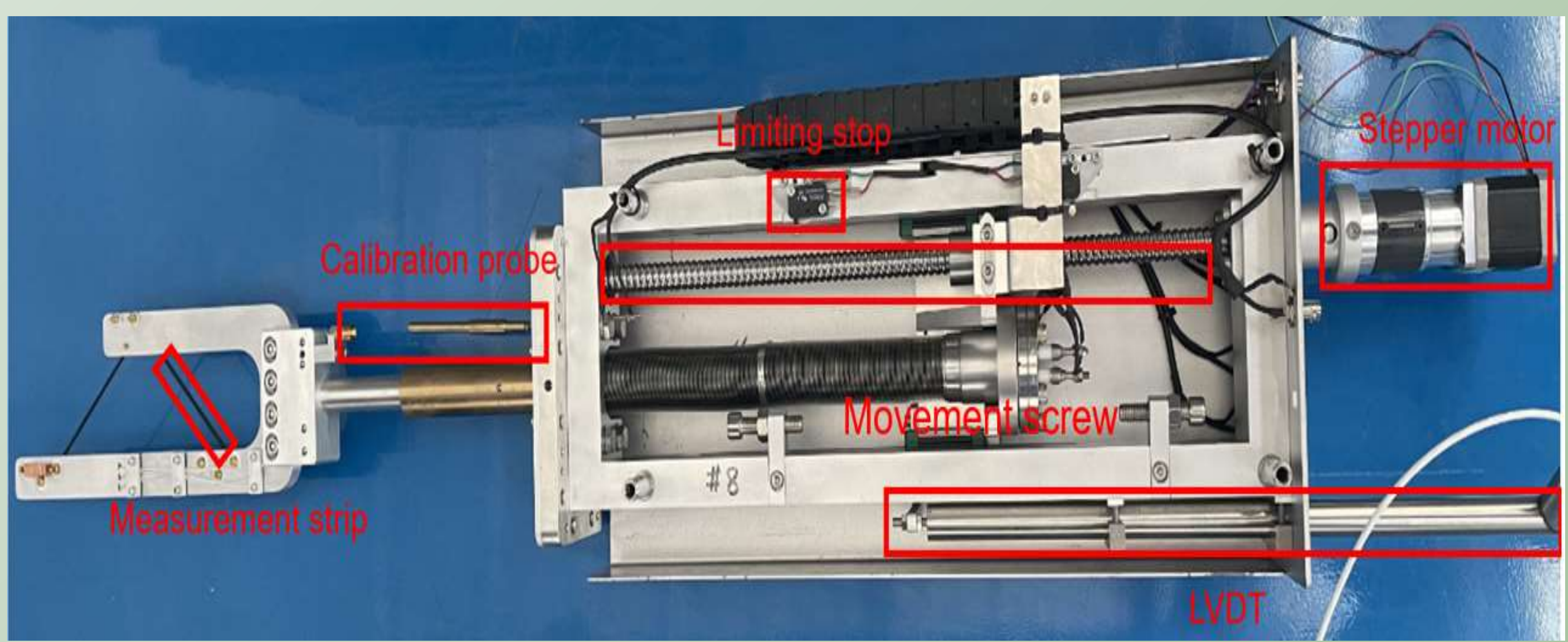
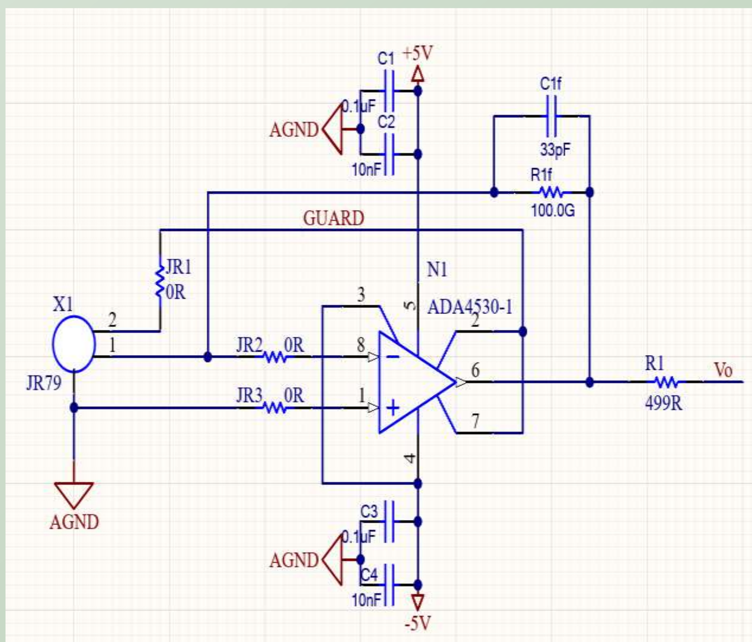


Figure 1. The structure of dual-wire scanner

Readout Electronics For pA Level Weak Beam

The dual wires scanner readout electronics chose the ADA4530-1 as the operational amplifier of the I/V conversion circuit. Its good properties are suitable for pA scale weak beam signal readout electronics. The scanning efficiency of the dual wires scanner is about 2%. Assume that the extracted beam intensity is 1nA, the signal intensity measured by the dual wires scanner is about 20pA, therefore, the value of the feedback resistance is 10G ohms, the sensitive of the I/V convert is 1mV/pA. It can meet the resolution requirement of the dual wires scanner readout electronics for CYCIAE-230 superconducting cyclotron. The I/V convert circuit is shown in Fig.2.



THE PARAMETERS OF THE ADA4530-1

Input bias current	<±20fA
Input offset voltage	<50uV
Input resistance	>100TΩ
Unity-Gain Crossover	2MHz

a) I-V convert circuit b) The parameters of the ADA4530-1

Figure 2. The I-V converter electronic circuit and parameters of ADA4530

Electromagnetic Compatibility Design

The signal cable adopts tri-coaxial cable, the inner core conductor of the tri-coaxial cable connects the signal source, the inner shield is driven by a protective circuit and the outer shield is grounded.

All the tri-coaxial cables are wrapped in a double-layer shielding sheath to prevent transmission signal leakage and external interference signal intrusion. The structure of the tri-coaxial and the shielding sheath is shown in Fig.3.

a) Tri-coaxial

b) shielding sheath

Figure 3. Tri-coaxial and shielding sheath

Beam Commissioning & Time structure

The beam profile monitor can provide position and size of the extraction beam to the physicist. (Fig.4)The software employs a digital signal processing technique that discerns the time structure of the beam. The sampling rate is set to 100 kHz, utilizing a Faraday cup to collect the original beam information and detect the edges of the macro pulses. By calculating the pulse frequency, the number of sampling points per cycle is determined, and the number of samples per macro pulse is calculated by duty cycle.

The macro pulse sampling data is retained and high-frequency noise is removed using a 5th-order Butterworth low-pass filter. The desired macro-pulse measurement is finally obtained.

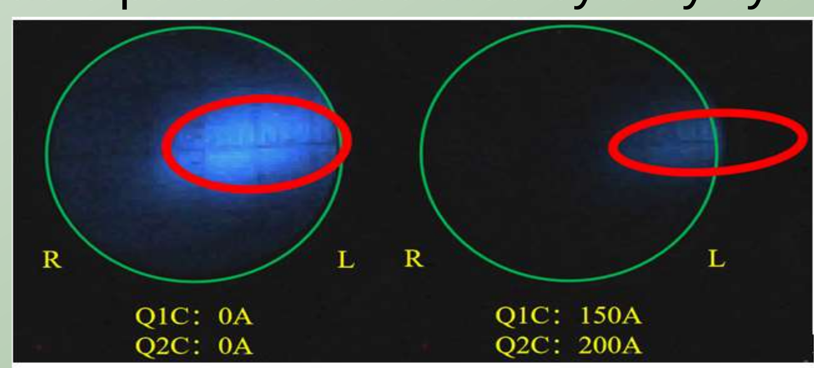


Figure 4. The measurement of the BPM

Future Work

The extracted beam intensity of the CYCIAE-230 superconducting cyclotron is several nano amperes, the brightness of the luminous for the beam profile monitor is related to the intensity of the extraction beam. CIAE has investigated a material(Ce:YAG) that is particularly suitable for beam profile detection in proton therapy. It has a very low intensity threshold for proton beam profile measurement. This not only prevents radiation damage cause by strong beam intensity to image capture equipment but also shortens the maintenance and replacement cycle of the beam diagnostic system. We will replace the old material(SiO_2) with this new material(Ce:YAG), this material as shown in Fig.5

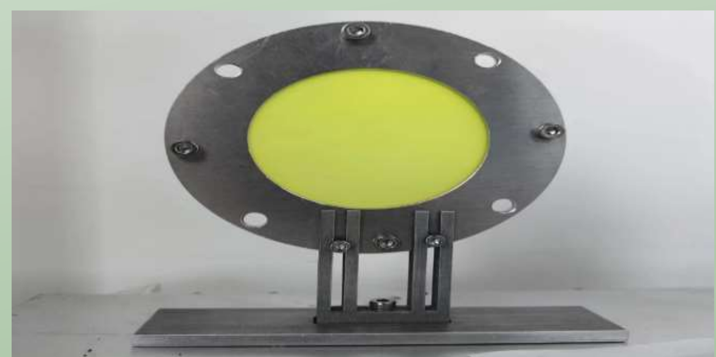


Figure 5. Ce:YAG for beam profile monitor

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