Transverse profile measurement of beam for 230MeV proton therapy beamline using scanning wires

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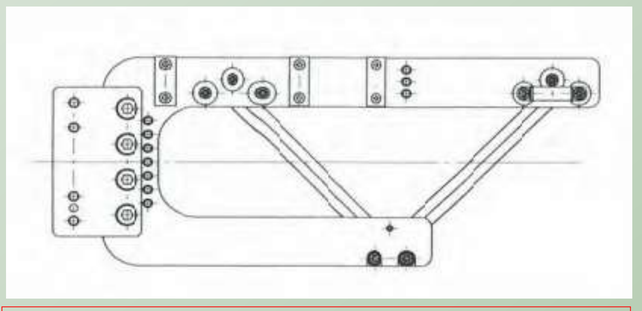
Abstract

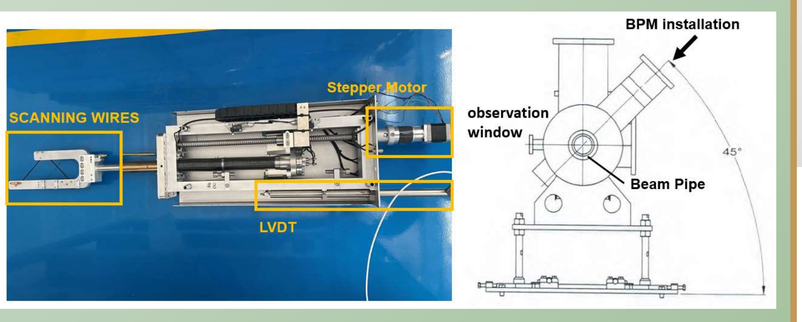
A superconducting cyclotron-based proton therapy system has been developed at the China Institute of Atomic Energy (CIAE). For the 230MeV proton therapy cyclotron (CYCIAE-230), the beam profile is crucial for the adaptation of the proton therapy planning system and an important basis for the commissioning of the beam line. CIAE designed the scanning wires device for the proton therapy facility, which is for high-resolution profile measurements. A readout electronics unit with fA resolution has been included to adapt to the small signal of scanning wires. The data process unit uses ZYNQ-7035 together with 24-bit ADCs and transmits measurement results via MOD-BUS TCP protocol. The diagnostic electronics are placed close to the beam profile monitors (BPM) to reduce the analogue signal transmission distance. To adapt to the mode of the pulse beam during the beam-line commissioning, using the RF system signal trigger sampling, to prevent the signal aliasing. Besides that, a Butterworth filter and a mean filter were used to filter measurement noise. The design of this scanning wire diagnostic system will be reviewed in this paper, together with several measurement results.

General description of scanning wires

The scanning wire is designed as a double wire structure with an angle of 90°. The measuring target is a long blade of Be-Cu with a width of 5mm and a thick-ness of 0.1mm. The bias wire of Mo-Au is symmetrically installed on both sides of the measuring blade, the distance is 5mm, and the diameter of the bias wire is 0.1mm. A stepper motor drives head movement and a linear variable differential transformer (LVDT) is used to provide head position. BPM boxes are installed at a 45° angle. Two signal blades pass through the beam at a 45° angle.



The Head of scanning wires



Design overview of the beam diagnostic electronics

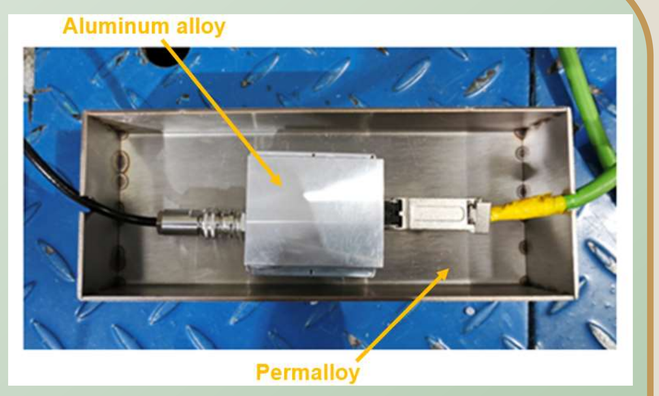
Low input bias current (≤20fA) amplifier ADA4530-1 used in the readout electronics. A guard ring is designed to reduce leakage current. Two ultrahigh PSRR linear regulators have been included to provide a power supply.

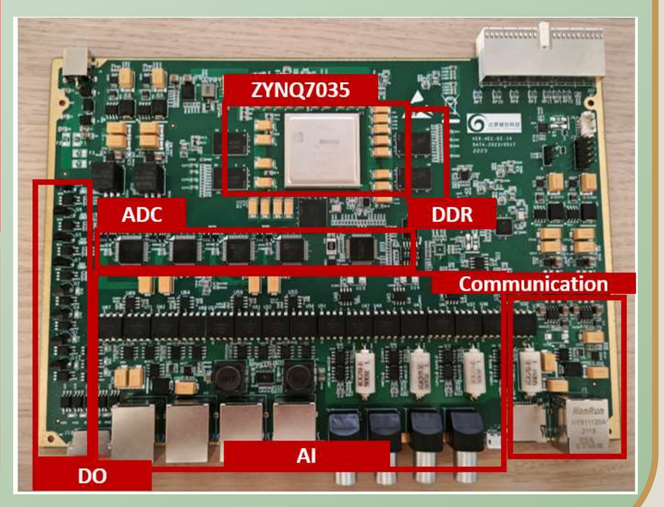
For improved electromagnetic compatibility (EMC), this readout electronics is mounted in metallic enclosures for shielding from external electromagnetic noise, the inner shielding box material is aluminum alloy, and the outer shielding box material is permalloy.

The data process unit:

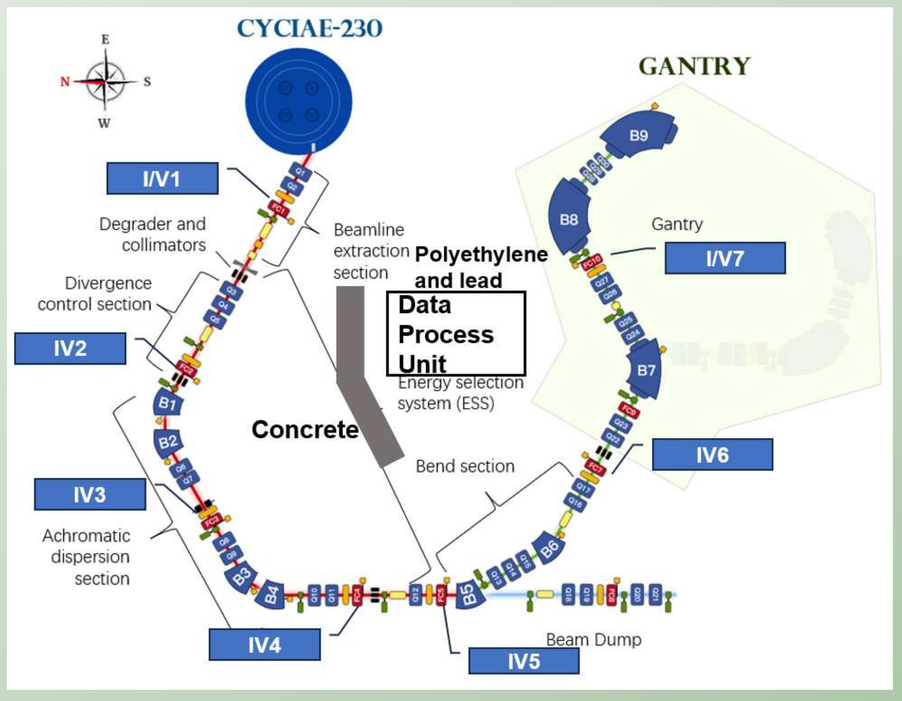
- Low-pass filter
- ADC
- ZYNQ-7035

The system transmits measurement results via MODBUS protocol.





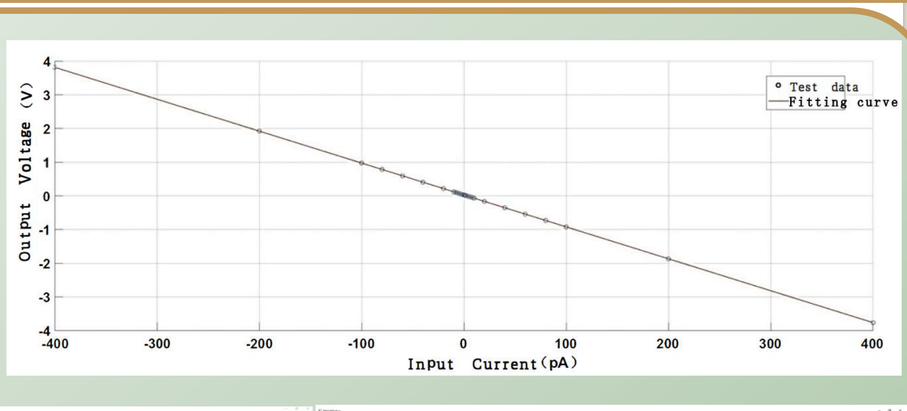
Design of the small signal transmission

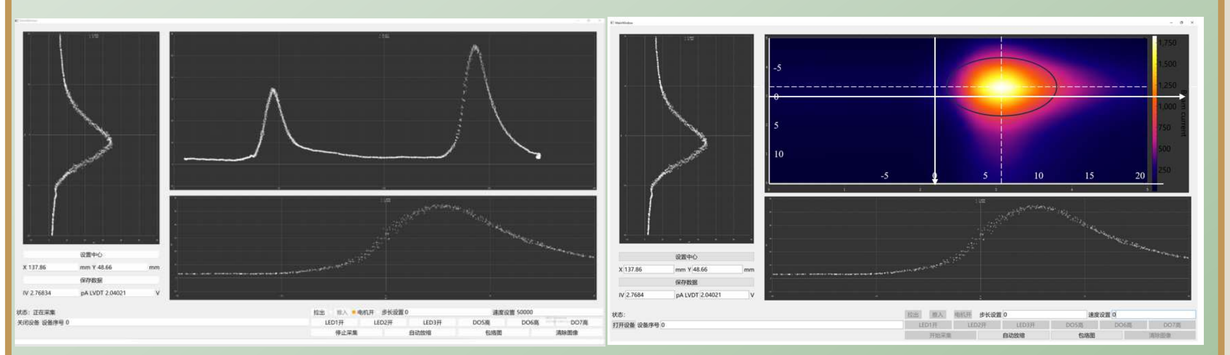


The read electronics are connected to the data processing unit through a 10-15m network cable. The data processing unit is placed behind a concrete wall surrounded by lead bricks and polyethene panels to shield neutrons.

Experimental results

The input and output are linear with a sensitivity of 10^{10}V/A and the residual sum of squares of fitted curves is 1.37×10^{-5}.





In the Y direction, the peak beam current of BPM is 34.2pA, and in the X direction, the peak beam current of BPM is 53.6pA.

Conclusions

CIAE uses scanning wires for proton therapy beam profile diagnostic. Diagnostic electronics have been designed to adapt to the small current of scanning wires. The readout electronics is based on a feedback amplifier and the data process unit is used for high-speed digital signal process and digital communications. Diagnostic electronics were placed next to the BPM boxes to reduce analogue signal transmission distance. By using metal shielding and digital optical communication to improve electromagnetic compatibility. Using RF signals to synchronize electronics sampling with Butterworth low-pass filters and mean filters. Diagnostic electronics with resolution to 100fA and the maximum relative error is 3.75%. The resolution of the beam position is better than 0.2mm.