Online parameter identification and control in the commissioning of nozzle for CIAE proton therapy system

Zhiguo Yin, Rui Xiong, Qiankun Guo, Chuanye Liu, Tianjue Zhang
China Institute of Atomic Energy, Beijing, 102413, P.R. China

ABSTRACT

A dedicated pencil beam scan system is developed and integrated into the proton therapy system of China Institute by a joint effort of Pyramid Consult Inc. and China Institute of Atomic Energy. In nozzle commissioning, a proton beam with an intensity of tens nA is provided by the CIAE beam production system, including a 242MeV superconducting cyclotron and a fast energy variable beam transportation system. Most scanning devices are commercial products from the pyramid, including the ion chambers, helium beam path, magnet, and amplifier. A Scintillator camera system named Lynx from IBA provides position readouts of the beam spot during the commissioning. A dedicated controlling software and related strategy for the beam commission of the scanning system is developed by the CIAE team. In the commissioning, a straightforward irradiation consisting of 114 beam spots is carried out to evaluate the scanning magnets' nonlinearity and cross-talks. Afterward, Lynx generates these coordinates and analyzes them using the reported software. A modified 2D polynomial fitting, including Hyperbolic Functions, is invested in the commissioning to yield an open loop control accuracy in orders of millimeters. An iterative learning algorithm has also been developed to give even better accuracy. A 50mm separation irradiation map consisting of 37 points is carried out by combining these two corrections on the first commission day, reaching an accuracy of 0.55mm. An irradiation field of 250mmX250mm is also verified at the same time. The method and the first-day result will be reported in this paper.

Overview of the CIAE's Nozzle System

The CIAE installed nozzle system utilizes pencil beam scanning technology for dynamic scanning, capable of sweeping proton particles across energy ranges from 50MeV to 250MeV. Scanning operations occur at 2,300 millimeters from the isocenter in the coronal plane and 1,900 millimeters in the sagittal plane, with a maximum radiation field of 400mm x 300mm. A pixel ionization chamber at the nozzle's entrance monitors the incoming beam's position.

Downstream, dual-strip ionization chambers with 128 strips in both X and Y directions use online data fitting to assess and monitor the beam's characteristics at each scanning spot in real time.

This system is integrated with an X-ray imaging system and a rotating floor mounted on the gantry. The Y scanning magnet is designated for slower scanning operations. Helium gas is used in the beam path instead of air to reduce scattering side effects and maintain beam quality.

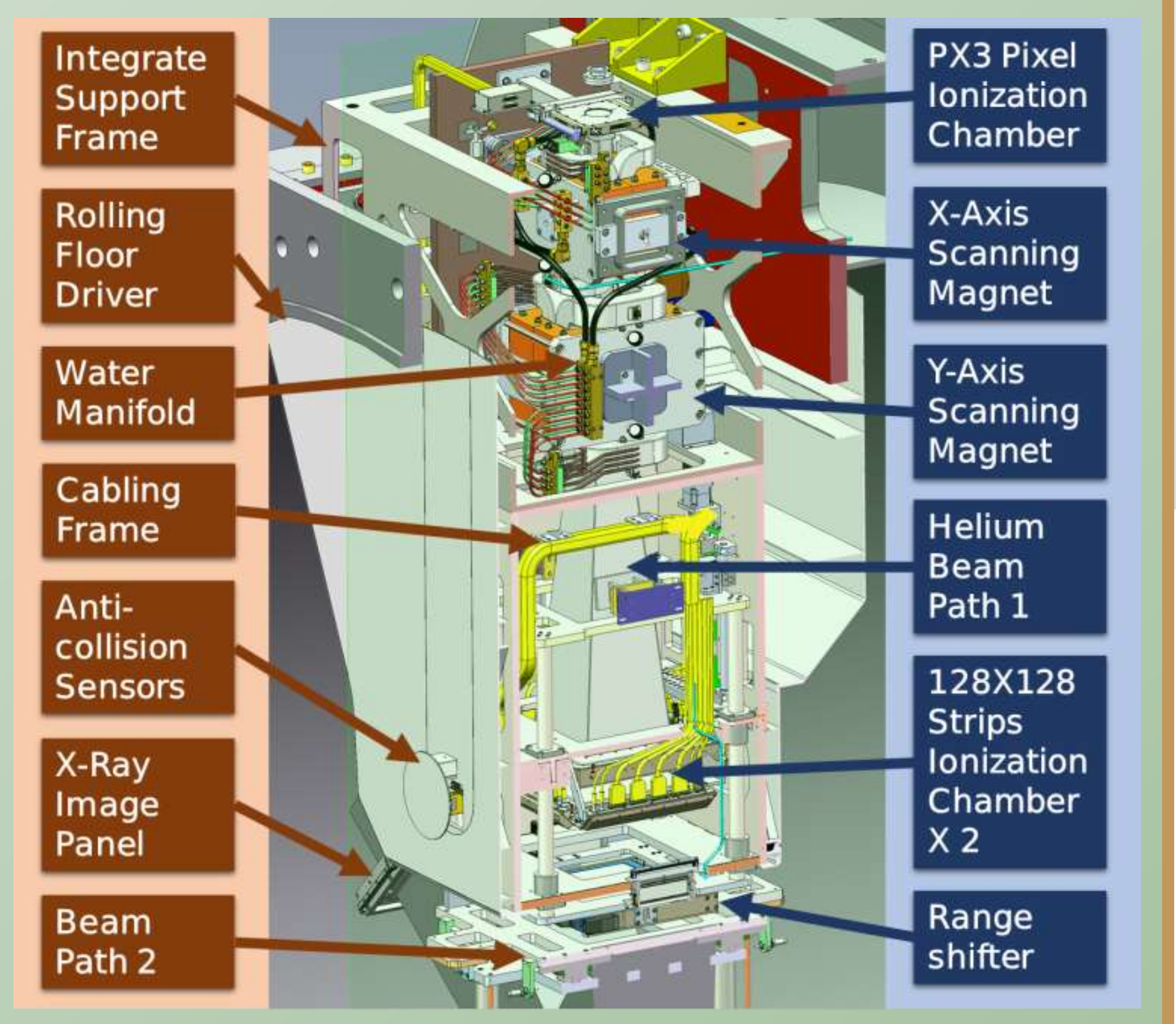
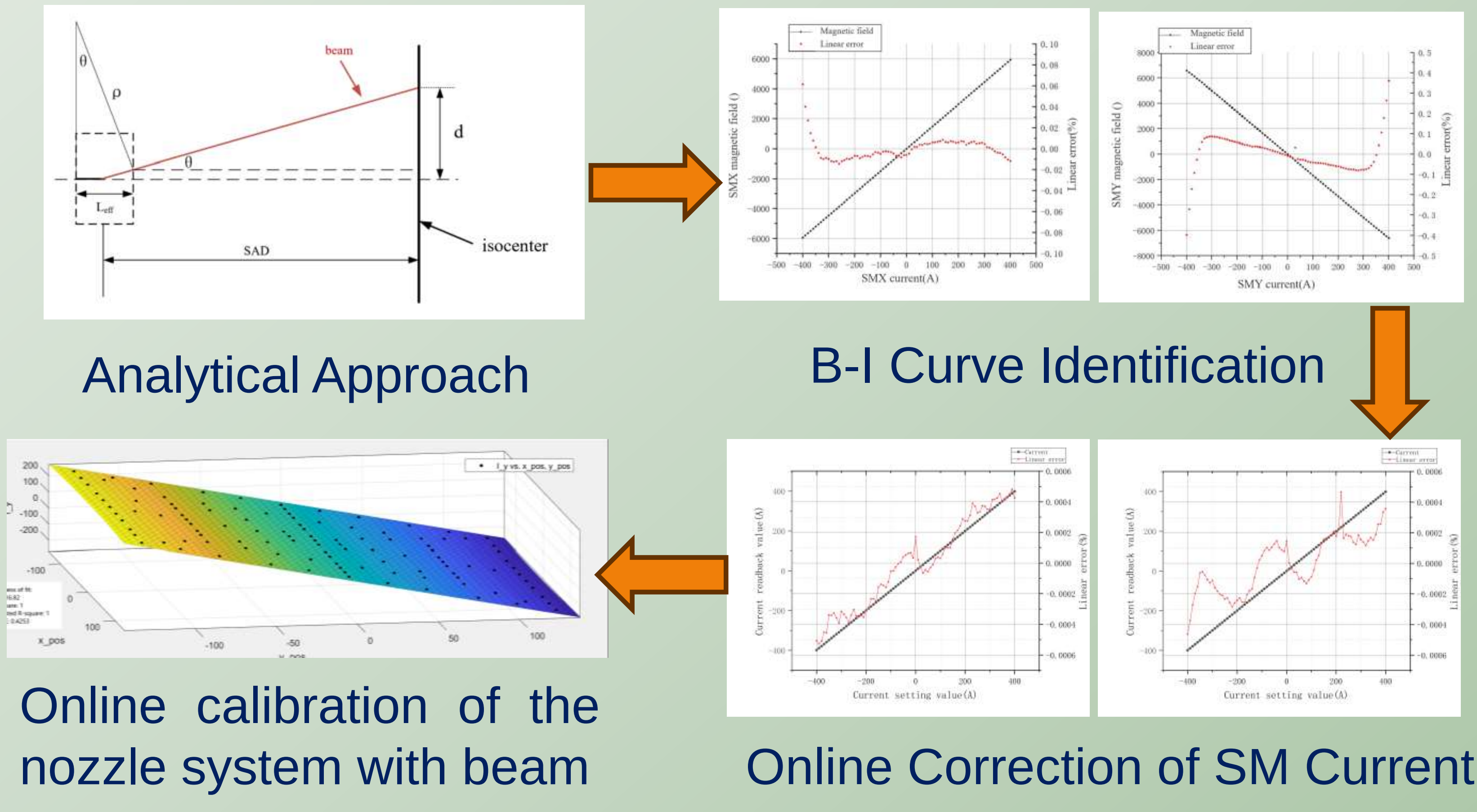


Fig 1. Layout of the nozzle system

Online Calibration Methods



Analytical Approach

B-I Curve Identification

Online calibration of the nozzle system with beam

Online Correction of SM Current

This calibration was performed every 20 MeV to establish a current-position lookup table for various irradiation beam energies.

To achieve higher accuracy, an iterative compensation algorithm adjusts the next spot's irradiation position based on the previous run's deflection error at the isocenter.

Scan Control System

The scan control system includes GUI host software, embedded control codes, and beamline hardware. Key components shown in Fig. 8 are the orthogonally positioned scanning magnets that control the beam's horizontal and vertical deflection. The magnets' power supply is managed remotely with a current sensor monitoring the delivered current. A Hall probe on the magnet yoke measures the magnetic field, while a pixel ionization chamber at the nozzle inlet aligns the beam. Downstream, dual strip ionization chambers monitor beam position, and a fast Faraday cartridge allows for beam shutdown within 100 milliseconds

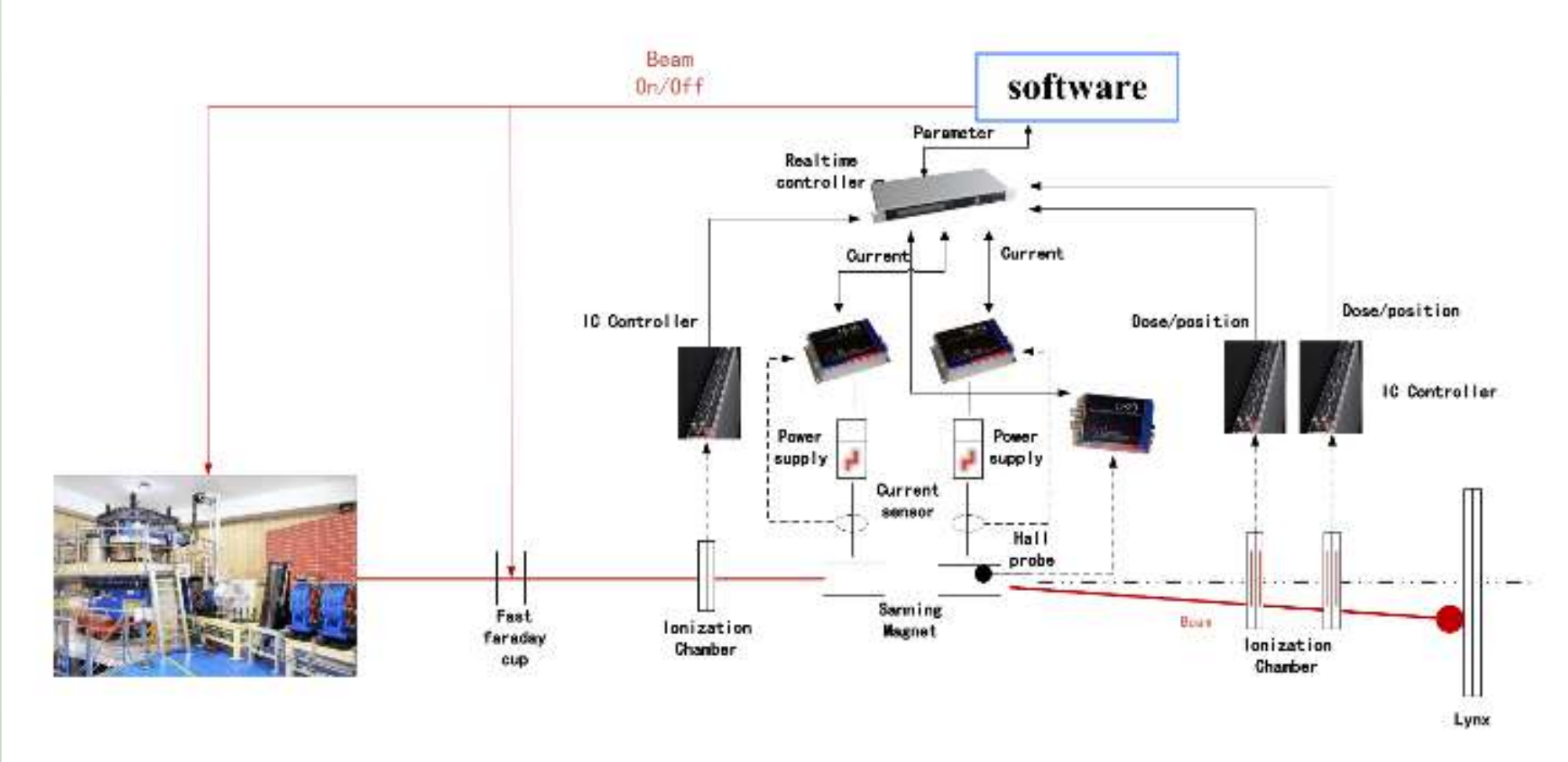
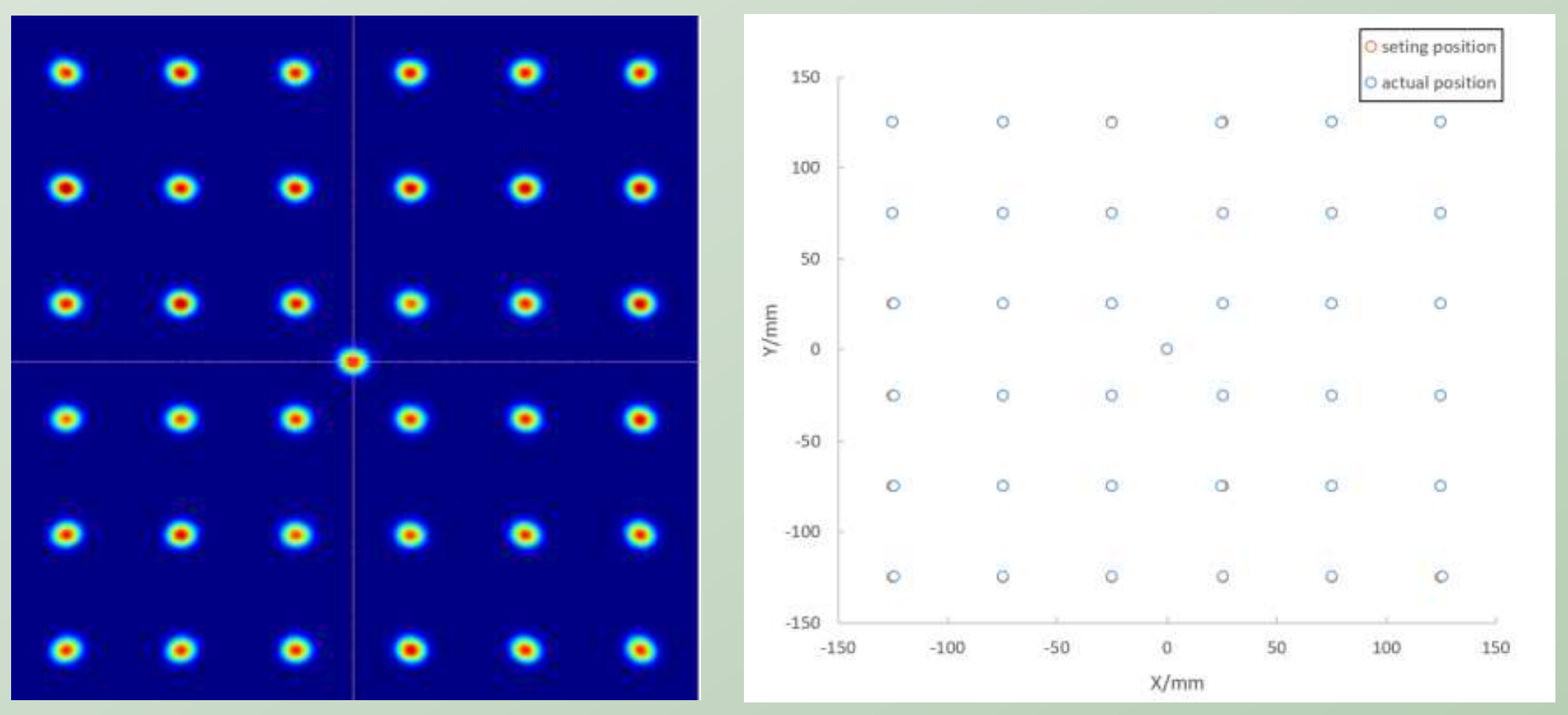


Fig 2. Architecture of the control system

Test Result of Irradiation Accuracy

The irradiation tests conform to the IAEA TRS 398 standard, using a square grid of beam spots with 50 mm spacing within a 250 mm by 250 mm field, energized by a 228.6 MeV proton beam.



a) Irradiation accuracy test image

b) Comparison of set and actual irradiation positions

Fig 3. Result of the irradiation accuracy test

The Lynx-PT scintillator, positioned at the isocenter, captured the irradiation patterns, and the data analysis from 37 points. We tests three different beam intensities .

Maximum position deviation
0.55 mm
Average deviation
0.15 mm

Conclusion

The CIAE's proton therapy system uses a polynomial surface fitting algorithm to link scanning magnet current with beam position, facilitating initial parameter calibration and identification. Tests under open-loop control maintained irradiation errors within 0.55 mm, achieving field dimensions of 266 mm × 269 mm. Building on these results, future developments will incorporate real-time control systems to increase precision and adaptability. This will allow for dynamic adjustments during treatments based on immediate beam position feedback, aiming to reduce irradiation errors further. Real-time adjustments are particularly vital for treating moving tumors and protecting adjacent organs, adapting to patient movement and tissue density variations during irradiation.

China Institute of Atomic Energy

24th IEEE Real Time Conference - ICISE, Quy Nhon, Vietnam