Optimization of rapid magnetic field control of the CYCIAE-230 cyclotron beamline

Aolai He, Zhiguo Yin, Qiqi Song, Tianjue Zhang, Peng Huang, Hongru Cai, Yang Wang, Bohan Zhao

China Institute of Atomic Energy, P.O. Box 275(3), Beijing 102413

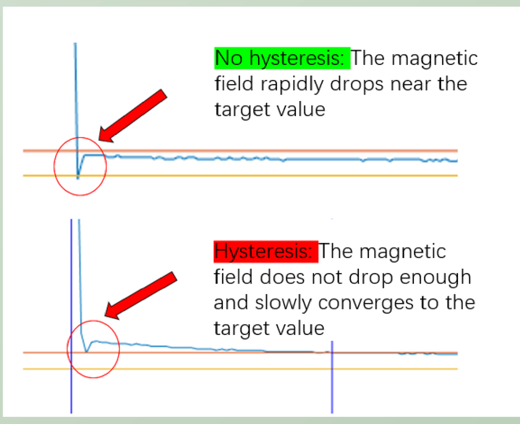
Abstract

Beamline control is essential to the Energy Selection System (ESS) of a proton therapy system. During the proton therapy process, the beam spot position to the nozzle should undoubtedly be stable and unchanged thus the field of each magnet of the beamline should be precisely controlled. In practice, however, due to the vast energy range of proton therapy (75MeV-230MeV), the dynamic response of the beamline usually shows unidentical performances at a different energy, e.g., the magnetic field may have a significant overshoot for some specific beam energy, or in contrast, the magnetic field my drop too slowly at other beam energies. This phenomenon compromises the energy change's overall performance concerning the speed. A dynamic PID parameter optimization method is reported in this paper to address this issue. According to the transfer function of each magnet, the entire energy range is divided into several subsections. Afterward, experiments are carried out to find the most suitable PID parameters for each energy section. Finally, the "beam energy - exciting current-PID parameters" lookup table (LUT) is generated and stored in beam line control system (BCS) for automation. Using the LUT during the treatment allows the beamline's energy setting to be adjusted automatically with the most appropriate PID parameter, guaranteeing the beamline's overall performance. The experimental results show the overall response time of the beamline magnetic field reduced from several hundred milliseconds to less than 65ms, which meets the design requirement of less than 80ms.

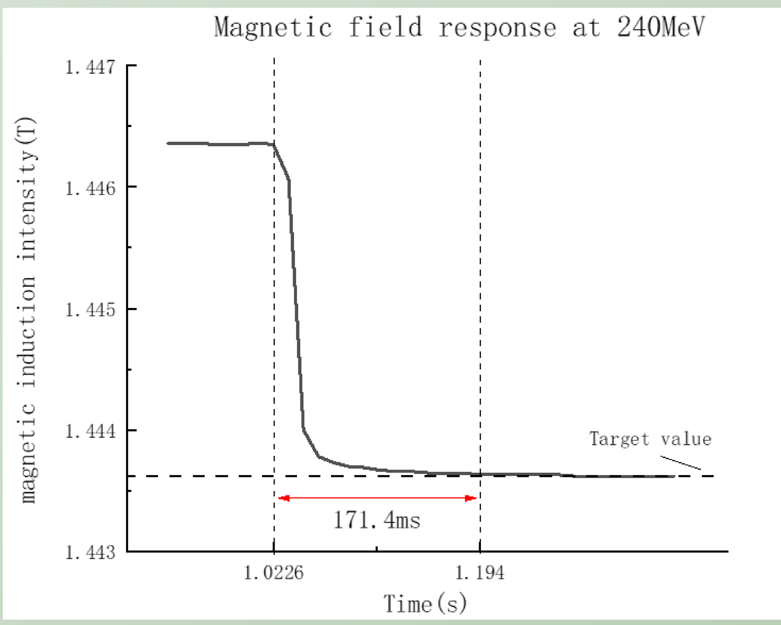
Magnetic field response before optimization

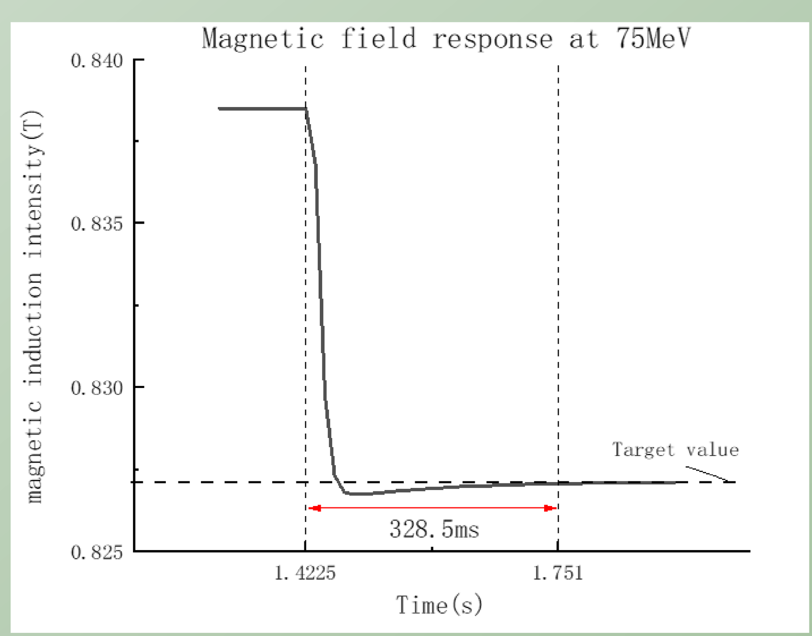
	dE（MeV）	dB（G）	dI（A）
Energy segment near 230MeV	0.81	30.99	1.2319
Energy segment near 150MeV	1.12	50.93	1.8627
Energy segment near 75MeV	1.89	121.03	4.2335

The lower the energy, the greater the dI for changing the same range of the beam position



The lower the energy, the greater the effect of hysteresis on the response

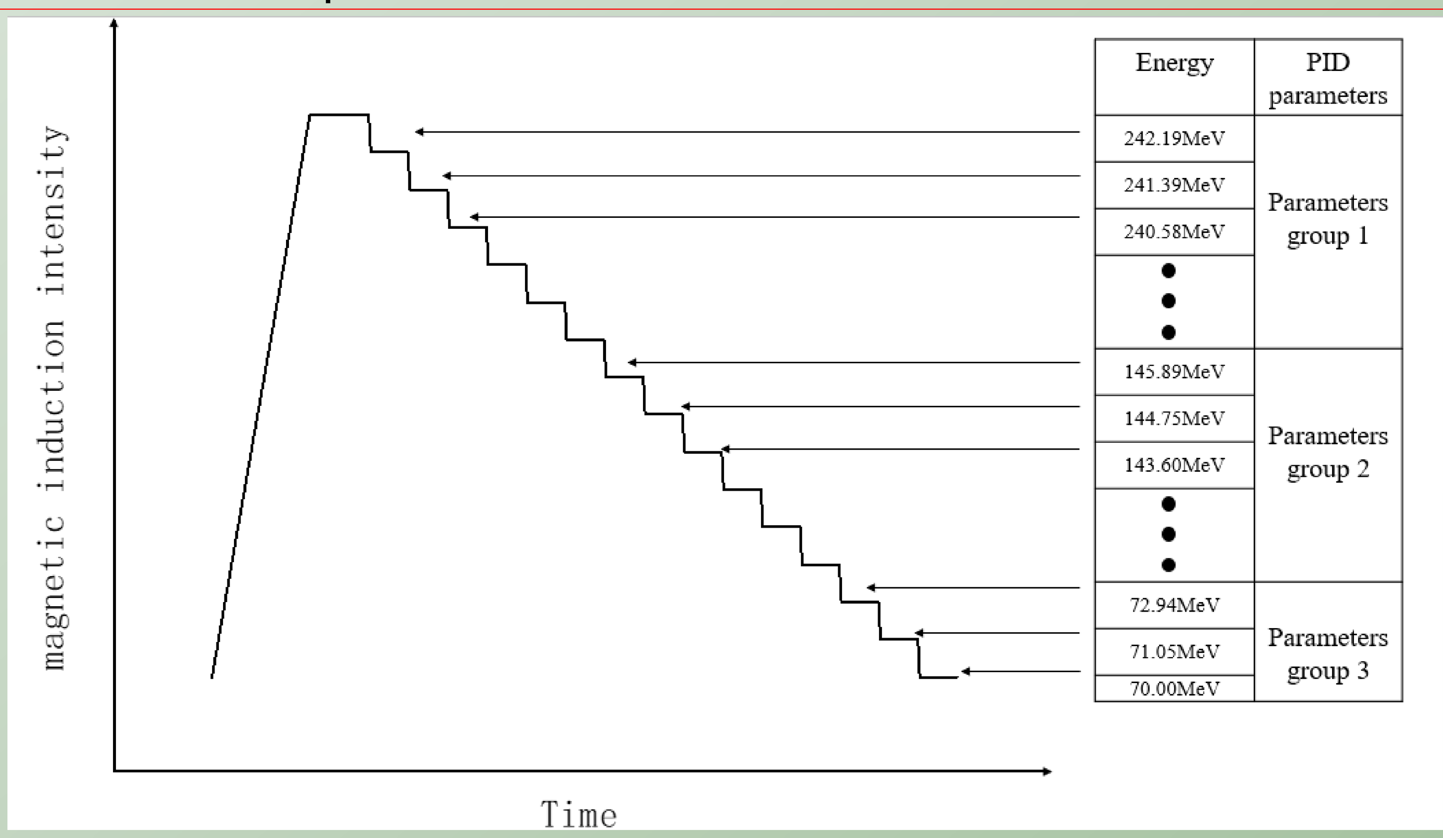




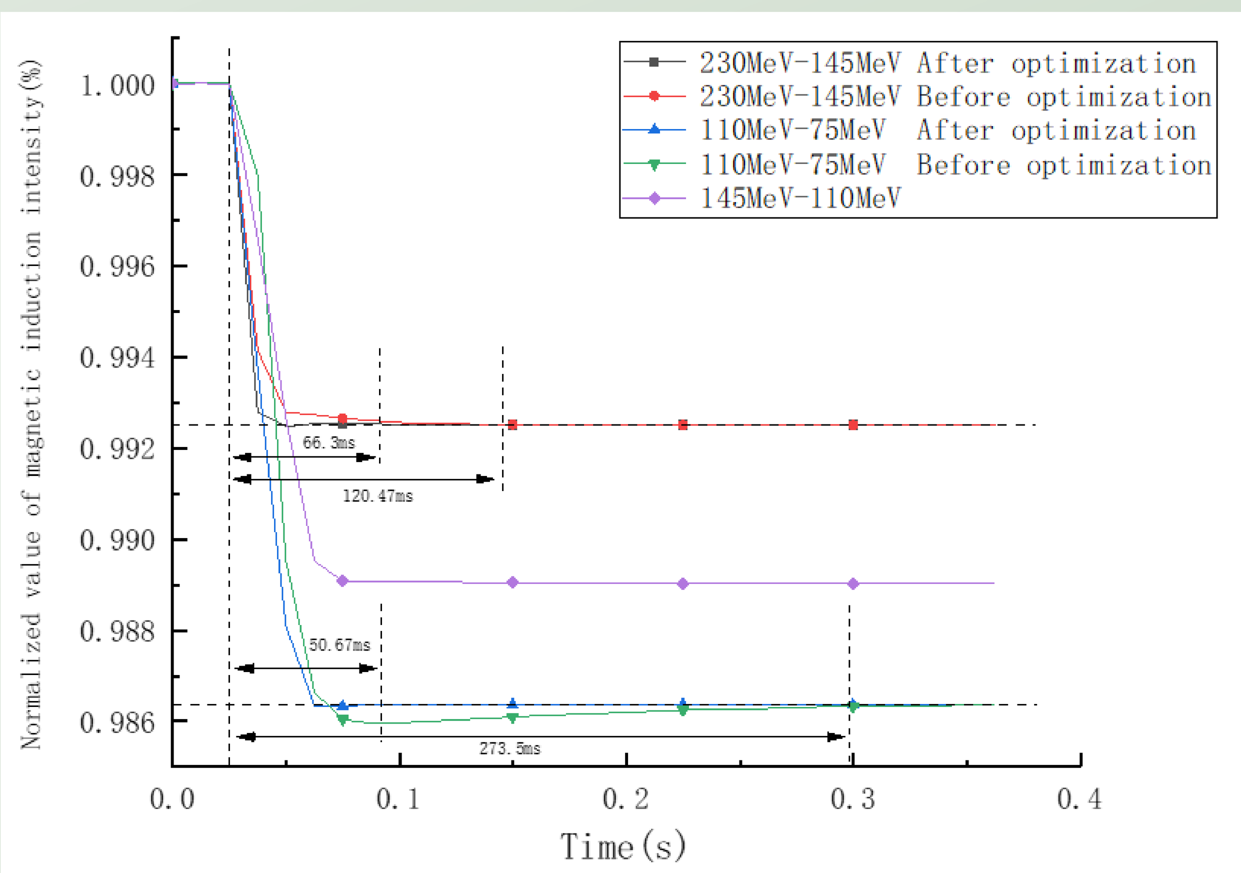
In the case of the same PID parameters, the dynamic response of the beamline usually shows unidentical performances at a different energy. The magnetic field drops too slowly at 230MeV (left) and have a significant overshoot at 75 MeV(right). The whole response procession takes too long.

Dynamic PID parameter optimization method

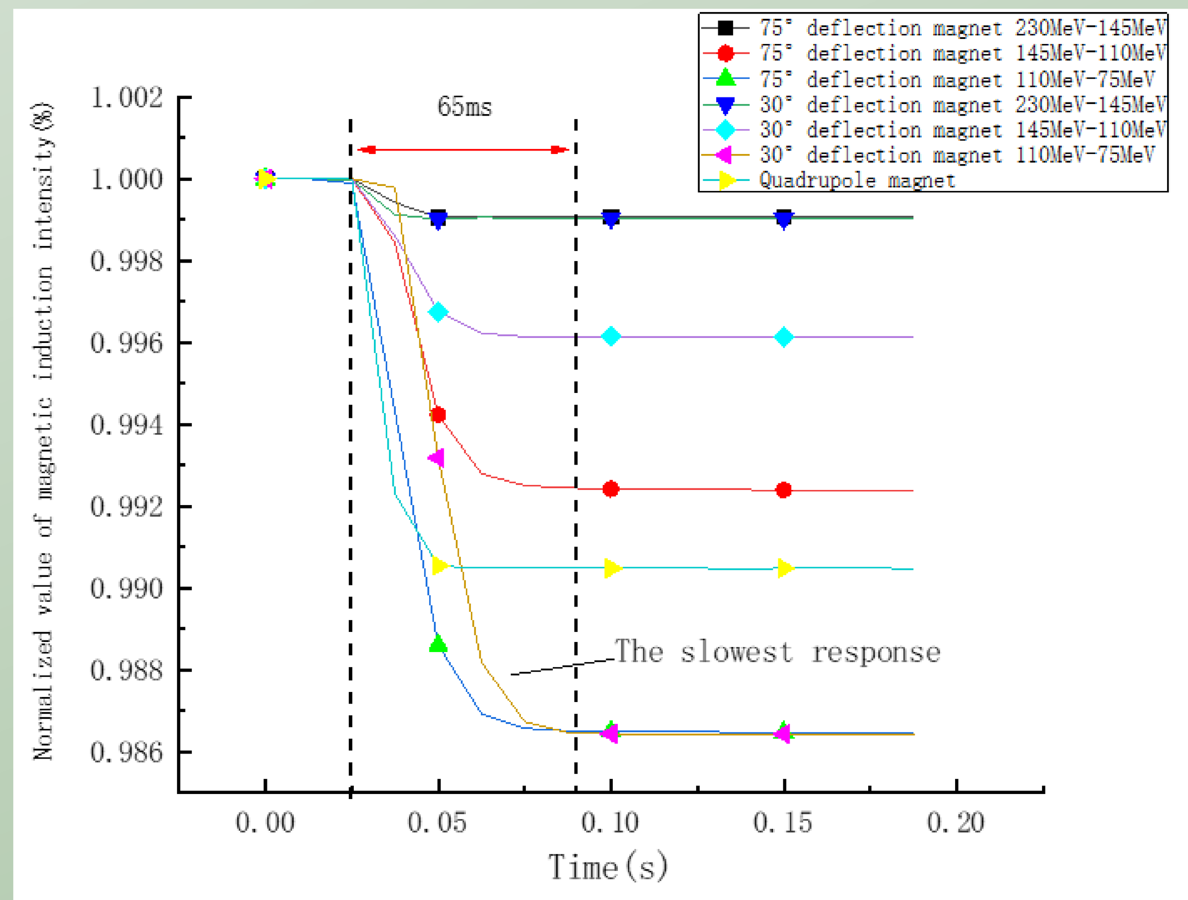
According to the transfer function of each magnet, the entire energy range is divided into several subsections. Afterward, experiments are carried out to find the most suitable PID parameters for each energy section. Finally, the "beam energy - exciting current-PID parameters" lookup table is generated and stored in BCS for automation. Using the LUT during the treatment allows the beamline's energy setting to be adjusted automatically with the most appropriate PID parameter, guaranteeing the beamline's overall performance.



Test results of the optimization process



The dynamic response of 60° bending magnet is analyzed as an example. After optimization , the dynamic responses of each energy segment were matched to the best PI parameters. Response time of 230MeV-145MeV segment decreases from 120.47ms to 66.3ms and the time of 110MeV-75MeV segment decreases from 273.5ms to 50.67ms.



For the dynamic response of all kinds of magnets, the 30° bending magnet has the slowest response speed in 110MeV-75 MeV segment (purple triangle curve), and the time is 65ms. So, the dynamic response of all magnets meets the design requirement, which is within 80ms.

Conclusions

In order to meet the requirements of fast dynamic response of magnetic field in proton therapy system, an optimal control method based on dynamic PID parameters is proposed in this paper. The experimental results show that the response time of the magnetic field is shortened from hundreds of milliseconds to 65 ms, which meets the design requirements within 80ms. The work in this paper has been applied to CYCIAE-230 in China Institute of Atomic Energy, and provides a new idea for solving the problem of slow magnetic field dynamic response of large magnets and realizing a more perfect proton therapy scheme in the future. But the excitation current control method in this paper is limited to feedback control. Due to the hysteresis of feedback control, the response time can only be improved to the order of tens of milliseconds. In the future, we will try to add feedforward control and other methods from the perspective of control system structure to further improve the response speed.