Multiple redundant fuzzy-PID control technology for the scanning magnets of proton therapy nozzle

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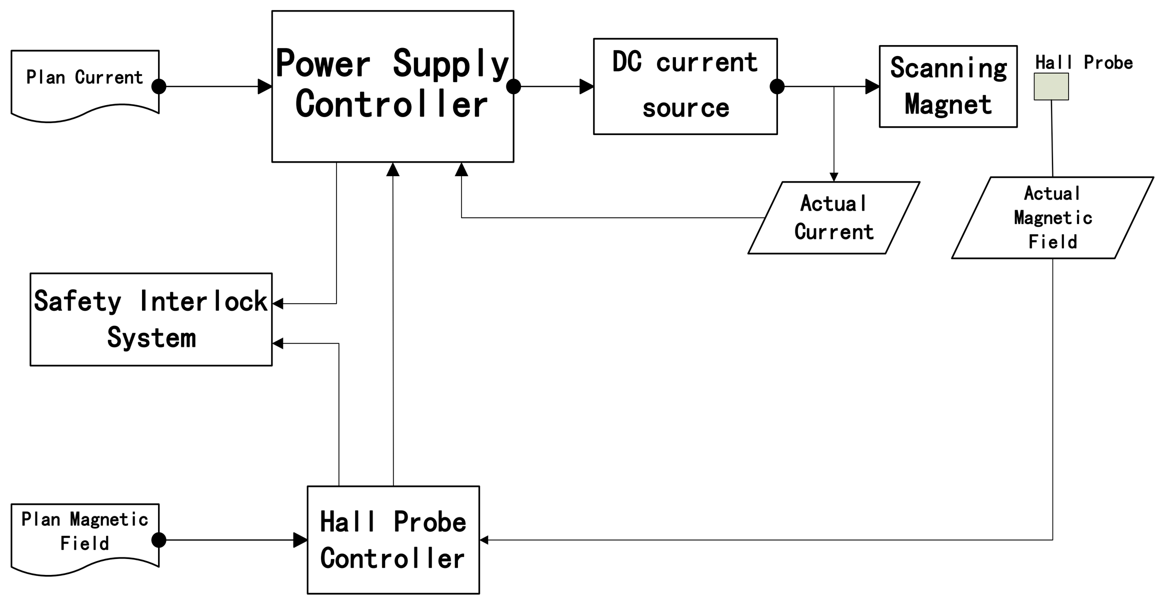
Introduction

The scanning magnets in the proton therapy nozzle control the deflection of the proton beam by changing the magnetic field, so that the position of the proton beam can be controlled precisely, within 0.5mm error at lateral and longitudinal position. In order to meet the function requirements for precise control of the beam position, a multiple redundant adaptive PID control system for scanning magnets is designed based on LabVIEW in this paper. It monitors the current of the scanning magnet coil and the actual magnetic field at the same time, then controls the output of the scanning magnet power supply separately through closed-loop positive feedback calculation, so that the entire magnetic field control system can maintain normal operation. And then add fuzzy-PID control technology in the closed-loop program to improve the system response speed and adaptive computing ability, and increase the stability of the system.

1.Redundant Structure Design

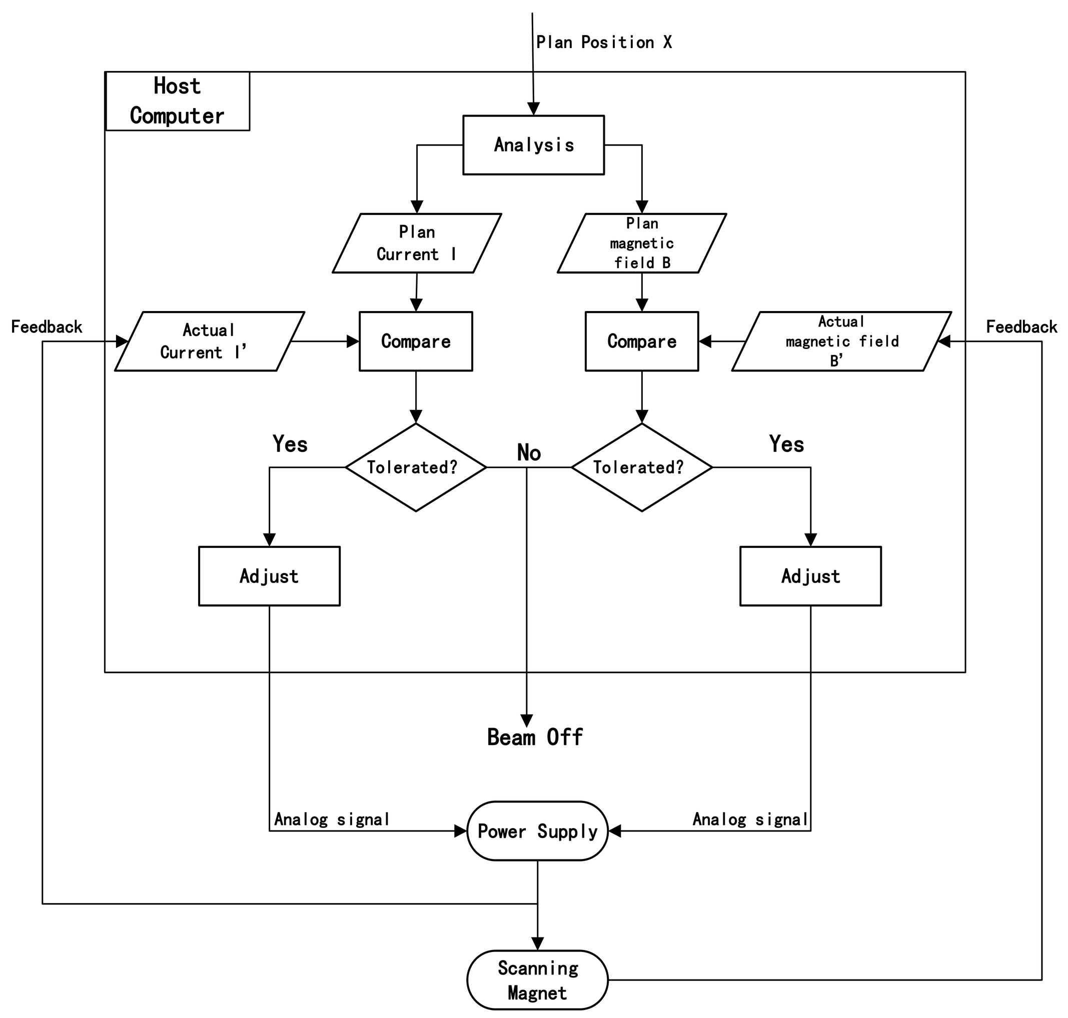


Structure diagram of scanning magnet closed-loop control system

The process is briefly described as follows:

The target position value is obtained by the host computer, and the planned magnetic field value and the planned current value are obtained according to the calculation. The Hall probe is installed inside the scanning magnet to monitor the actual magnetic field.

During the treatment, Hall probe feeds the actual magnetic field value back to the host computer through the Hall probe controller. At the same time, a current sensor module is added to the DC current source output to monitor the magnet power supply for normal operation, and monitor the actual output current value, and feed it back to the host computer as well. Then the control signal is adjusted online after comparing them separately with the planned values. The current source and the scanning magnet respond to the new control signal, the magnetic field changes. This process is repeated until the error is zero.



Flow chart of scanning magnet closed-loop control

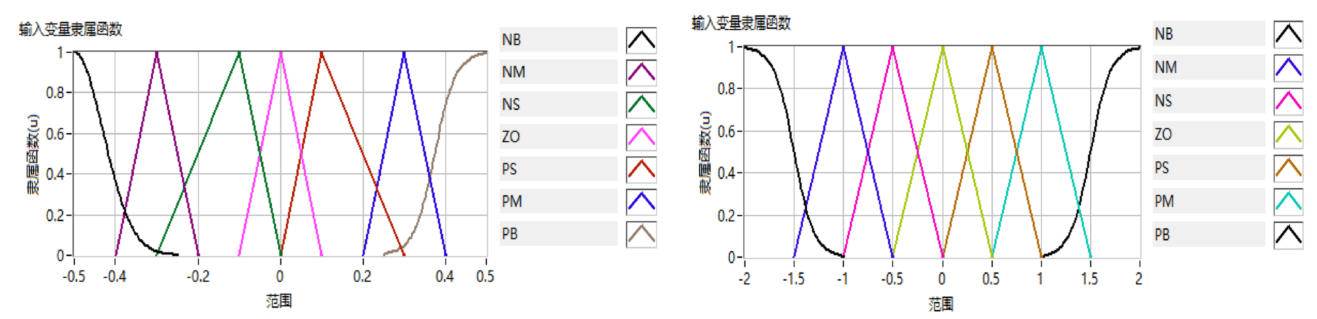
2.Fuzzy PID Algorithm Design

The system is designed with a two-dimensional fuzzy controller:

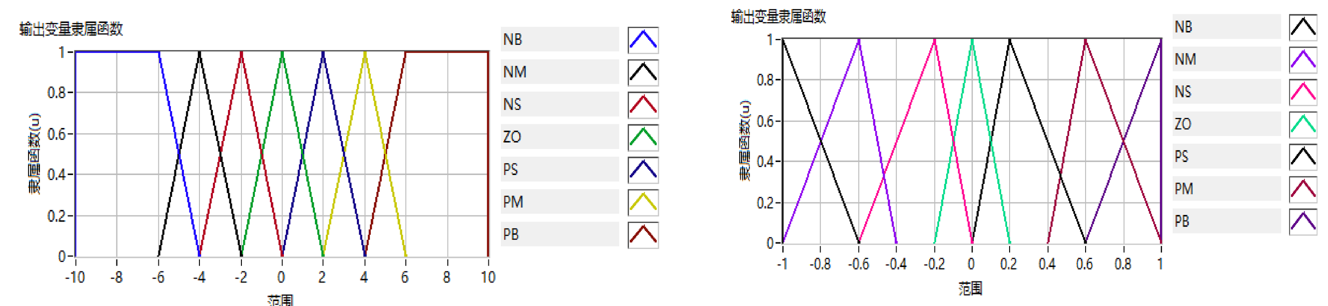
1.The input variables are set to the error **e** and the error change rate $\mathbf{e_c}$.

2.The output is set to the increment of PID parameters **△kp**, **△ki**.

They are all described by the of the 7 fuzzy linguistic variables, "Positive Big" (PB), "Positive Medium" (PM), "Positive Small" (PS), "Zero" (ZO), "Negative Small" (NS), " Negative Medium" (NM), "Negative Big" (NB).



Membership function of e and $\mathbf{e_c}$



Membership function of △kp and △ki

According to the influence of **Kp** and **Ki** on system stability and response speed, the fuzzy rules tables of **ΔKp** and **ΔKi** can be obtained, as shown in Table 1 and Table 2. The fuzzy rule is represented by If...then... , for example,If (e is NB) and (ec is NB) then (Δkp is NS) (Δki is NB).

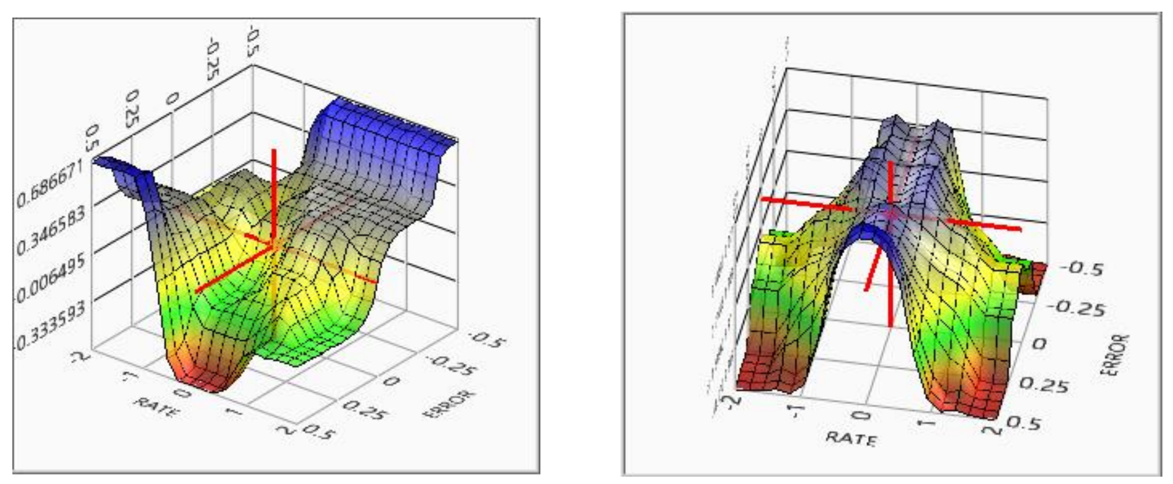
Table 1. Fuzzy rule table of △kp

	NB	NM	NS	ZO	PS	PM	PB
NB	NS	NS	PM	PM	PM	PM	PM
NM	ZO	ZO	PS	PS	PS	PS	PS
NS	ZO	PS	ZO	PS	PS	PS	PS
ZO	ZO	ZO	ZO	ZO	PS	PS	ZO
PS	PS	PS	NS	NS	ZO	ZO	NS
PM	PS	PS	NS	NS	NS	ZO	NS
PB	PM	PM	NM	NM	NM	NS	NS

Table 2. Fuzzy rule table of △ki

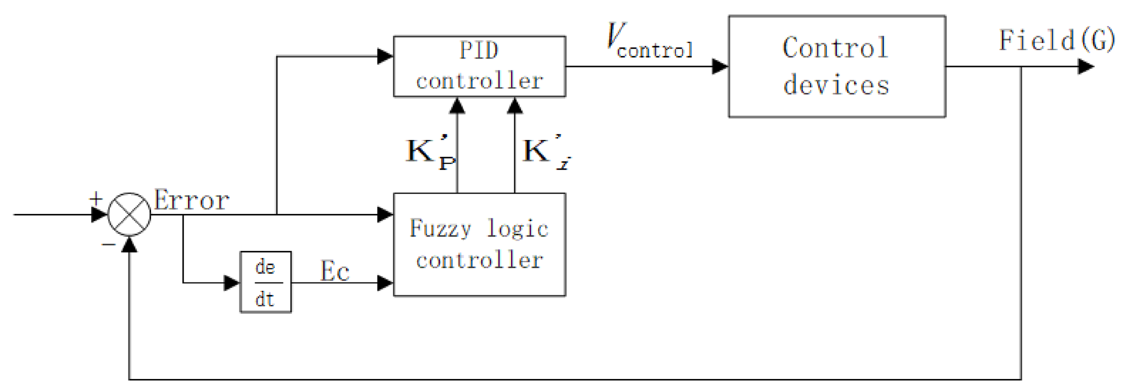
	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	PS	ZO	PS	NB	NB
NM	NB	NM	PS	ZO	PS	NM	NB
NS	NM	NS	PS	ZO	PS	NS	NM
ZO	NS	ZO	ZO	ZO	PS	ZO	NS
PS	NM	NS	ZO	PS	ZO	NS	NM
PM	NB	NM	PS	PS	ZO	NM	NB
PB	NB	NB	PS	PM	PS	NB	NB

Use the Fuzzy Logic Toolkit to design, edit and simulate the fuzzy controller. Open the fuzzy control editor, construct the control system analyzed above, and save the settings in .fc format so that the closed-loop control system software can call it at any time. The software is called at any time. Using the 3D Surface Graph toolbox, you can also get a three-dimensional relationship between the output variables and the input variables.



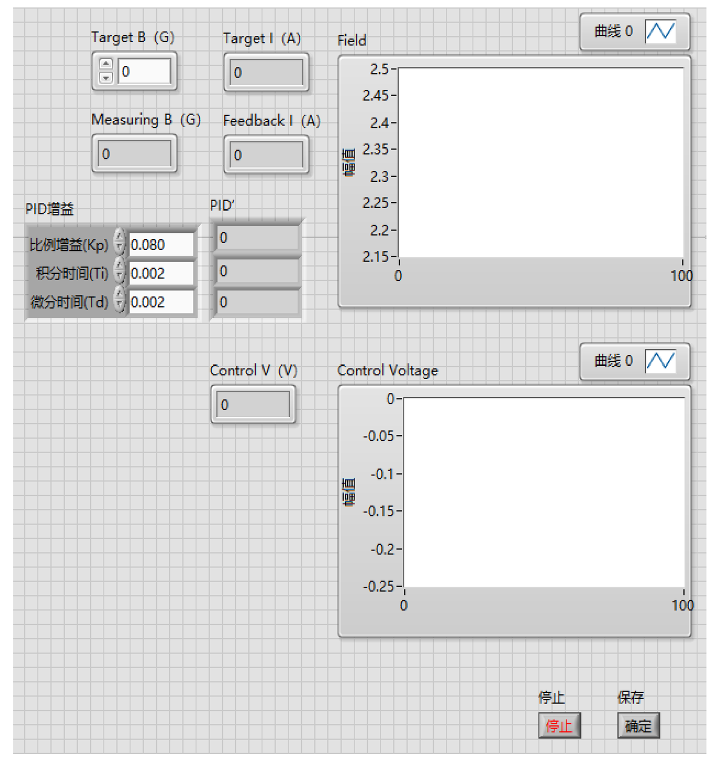
3D distribution of Δkp and Δki with input variables

In the LabVIEW platform, the designed fuzzy logic controller is added into the PID control algorithm to establish a combined PID fuzzy logic controller. The fuzzy controller obtains the fuzzy control variables Δkp and Δki in real time according to the input variable value. The final output values kp' and ki' of the PID control parameters are respectively the sum of the default value and the fuzzy control variable, and then the output control amount is obtained through the PID calculation.



Block diagram of the combined PID control system

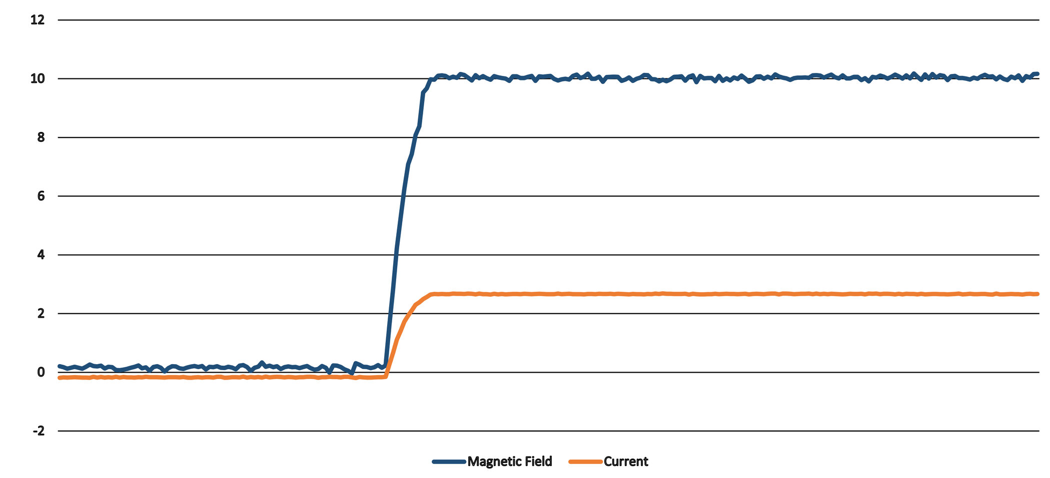
3.GUI Design and Test



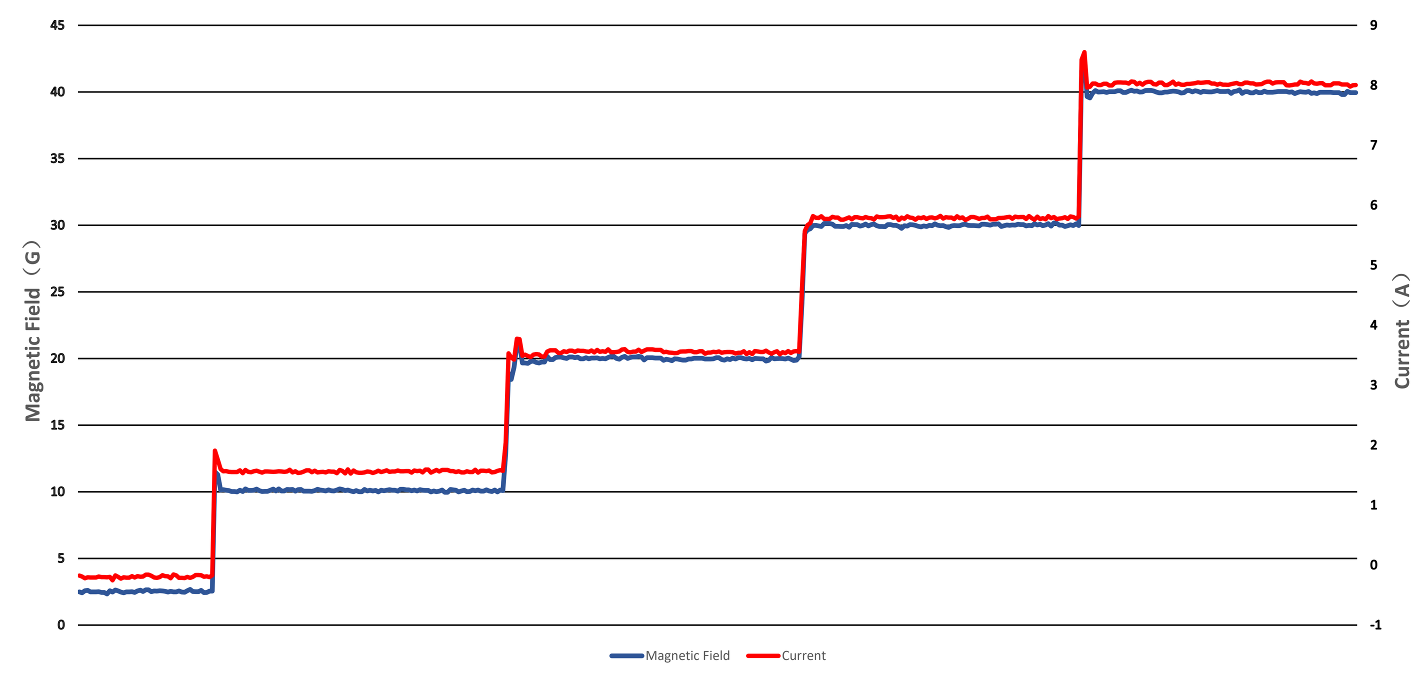
Control software GUI

The default value of the PID parameter is displayed in the PID gain table, and the parameters actually acting on the closed-loop system are the results in the PID' table obtained by the fuzzy control algorithm. In this user control interface, the target value is inputted manually, the actual magnetic field and actual current are read back and displayed , analog control voltage and its waveform are shown as well. The experimental data is saved in .txt format for analysis.

The experiment results show that when the target magnetic field value is set to 10G, the system response time is short and there is no obvious overshoot, and there is no obvious error in steady state.



Response curve（1）



Response curve（2）

when the target field is gradually increased from 10G to 40G, the actual maximum error ΔB never exceed 0.3G regardless of the target field. According to the HUST-PTF nozzle structure, the minimum magnetic field required in the actual treatment process can be calculated to be about 2300G,. In this experimental case, the control precision can be maintained at about 0.013%, which can meet the safety standard for treatment

Conclusion

In this paper, two redundant closed-loop systems are designed according to the structure of the pencil beam scanning nozzle in HUST-PTF. It can independently monitor the actual magnetic field and coil current, and the feedback control of the scanning magnet power supply is made together to ensure the continuous operation of the equipment within the safe range. Then the fuzzy logic control technology is introduced and the fuzzy PID controller is used in two close-loop subsystems of scanning magnet. The experiment results show that compared with the conventional single closed-loop controller, the multiple redundant adaptive PID closed-loop controller designed in this paper can improve the on-line monitoring capability of the scanning magnet control system, and improve the stability and universality of the system.