Huazhong University of Science & Technology

Design study of a fast kicker magnet applied to the beamline of a proton therapy facility

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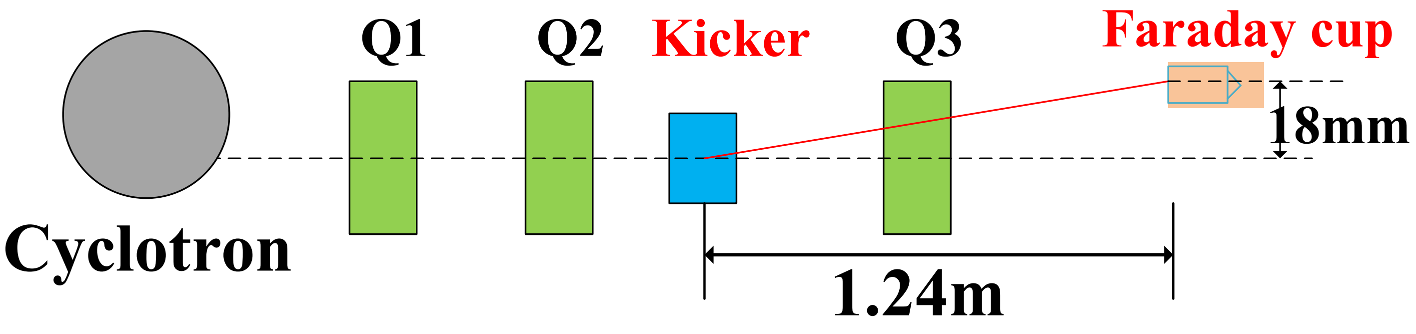
OUTLINE

- Physical requirement of the kicker magnet
- Electromagnetic and thermal simulations
- Technical design and considerations
- Conclusions

● Physical requirement of the kicker magnet



Layout of the kicker magnet

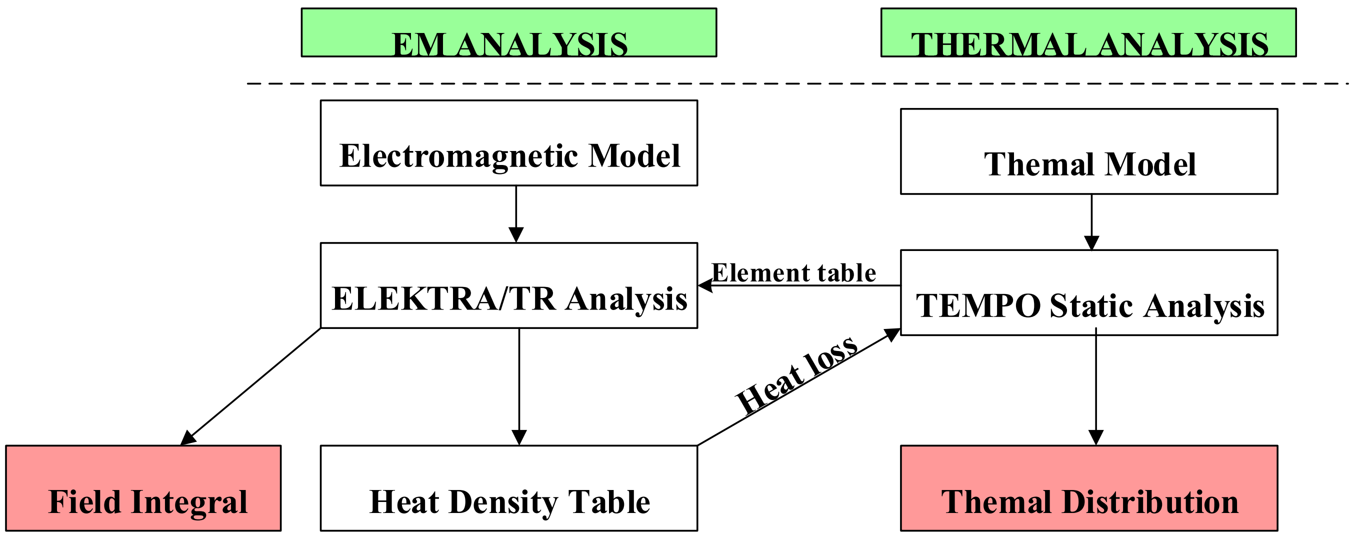
Kicker magnet is located at 1.24m upstream of Faraday cup / beam stop. It switches ON/OFF the beam during spot scanning intervals and in safety situation.

Kicker main specifications

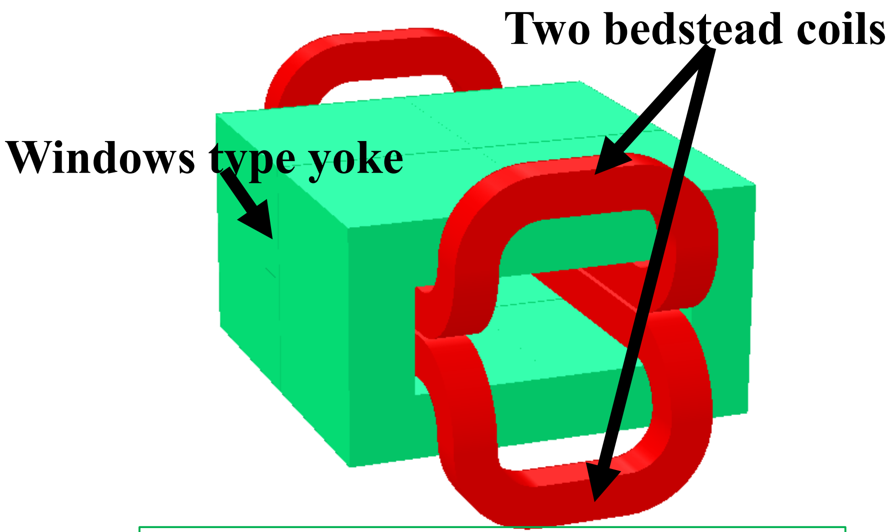
Name	Parameter
Deflection angle	10.36 mrad
Magnet gap	50 mm
Integral field	0.0252 T·m
Magnet length	200 mm
Number of coil turn	4 Turns/pole
Magnetic field	0.101 T
Good field region	±30 mm(vertical) ±14 mm(horizontal)
Coil Induction	44 μH
Max repetition Frequency	500 Hz
Rise/fall time	100 μs

- Deflect the 250MeV proton beam to the downstream beam stop, during transverse scanning intervals and energy modulation.
- The rising/falling speed (100us level) is important, then the repeatability.
- The 10% overshoot can be tolerated, from degrader beam simulation.
- <1% remanence field within 200us
- Repetition frequency up to 500Hz

● Electromagnetic and thermal simulations of the kicker



Procedure of electromagnetic and thermal analysis

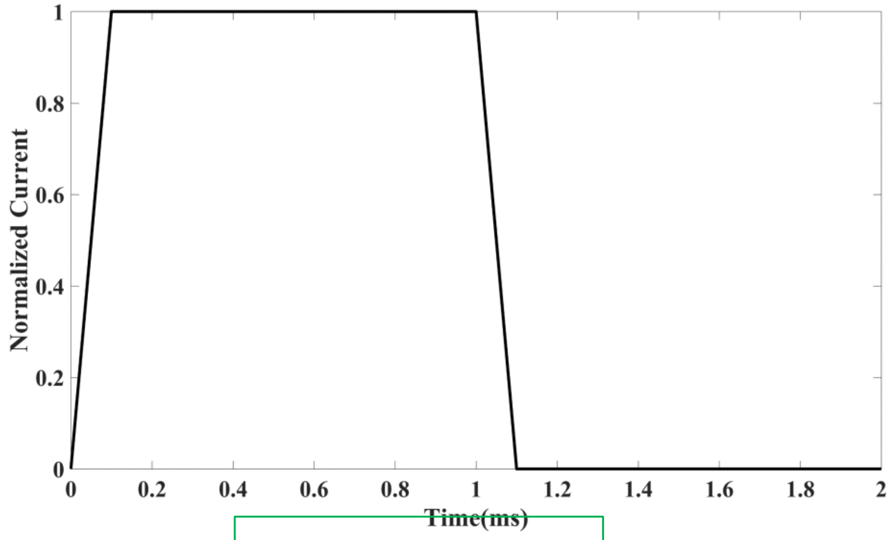


OPERA model of kicker magnet

1. A table file of average heat density value over a cycle is calculated by

$$HEAT = \frac{\sum_{1}^{n} heat_i * (t_i - t_{i-1})}{t_n}$$

2. Then the average power of each element is import to the unsolved TEMPO Static Analysis and carried out.



Drive Current

● Materials parameters of magnet yoke

Materials: 1) Laminated steel
2) MnZn Ferrite

➢ Laminated steel:

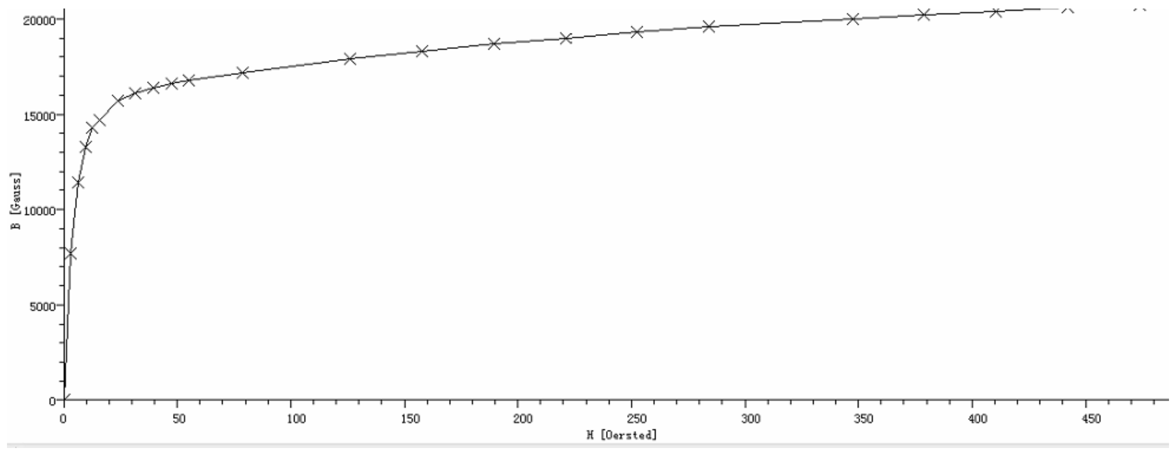
A. anisotropic with a packing factor of 0.95;
B. no current along the laminated direction
C. Nonlinear B-H curve

Parameters	**Laminated Direction**	**Other Direction**
Conductivity	3.5e+6 S/m	0
Transfer coefficient	5.4W/m/K	368 W/m/K

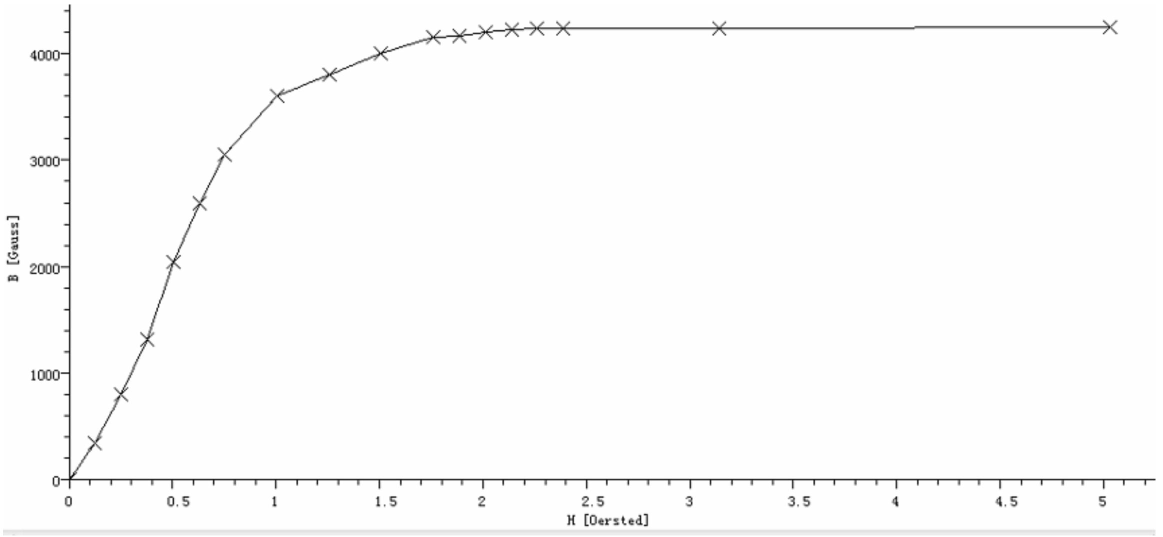
➢ MnZn ferrite:

A. Isotropic, can be regarded as one block
B. low conductivity
C. Nonlinear B-H curve

Parameters	**MnZn**
Conductivity	0.33S/m
Transfer coefficient	5 W/m/K

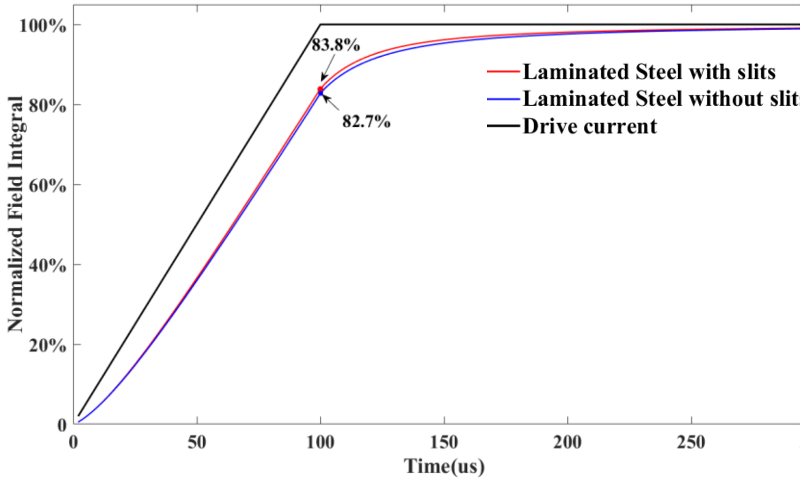


B-H curve of laminated steel

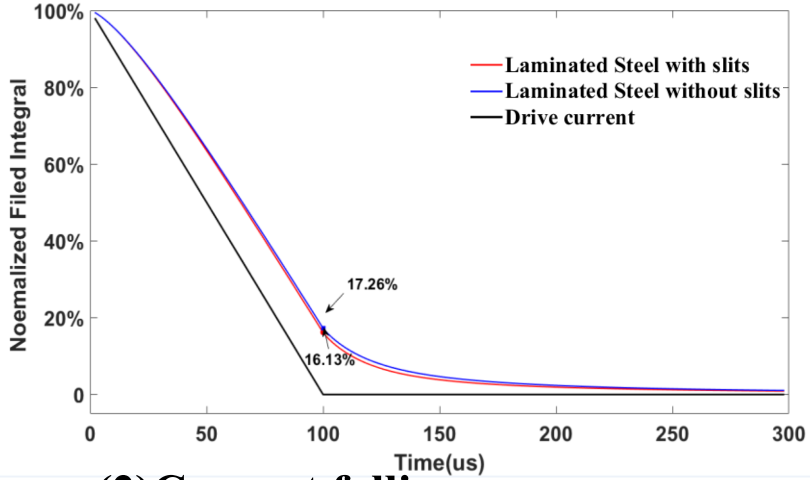


B-H curve of ferrite

● Integral field and thermal simulations of the laminated steel yoke

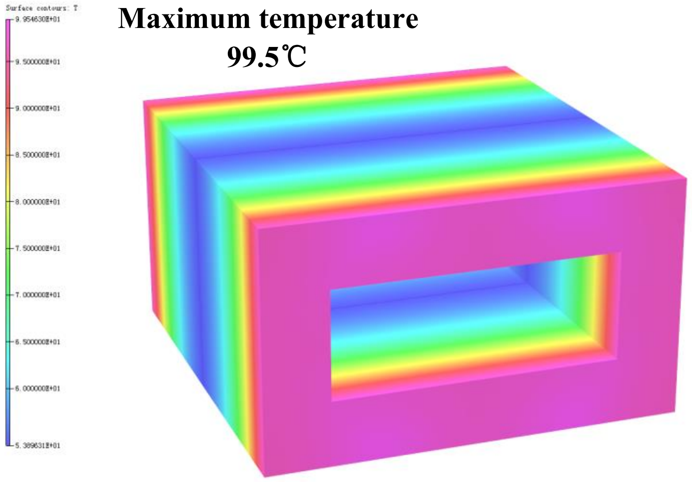


(1)Current rising process

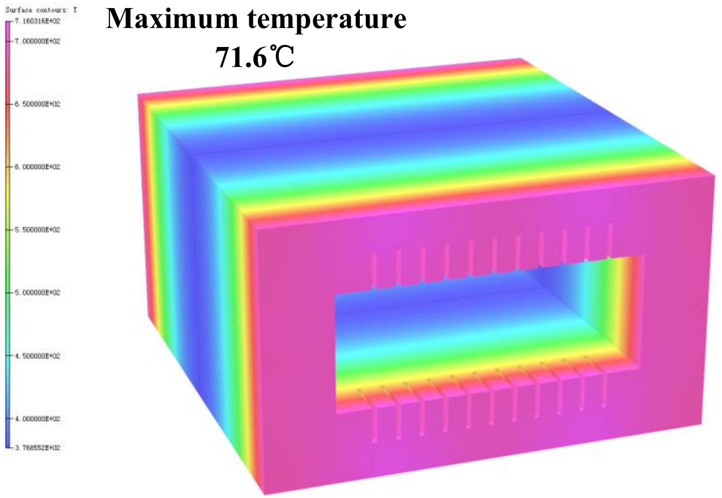


(2)Current falling process

	No slits	Slits
Normalized field @ 100us, rising process	82.7%	83.8%
Normalized field @ 100us, falling process	17.26%	16.13%
Temperature	99.5°C	71.6°C



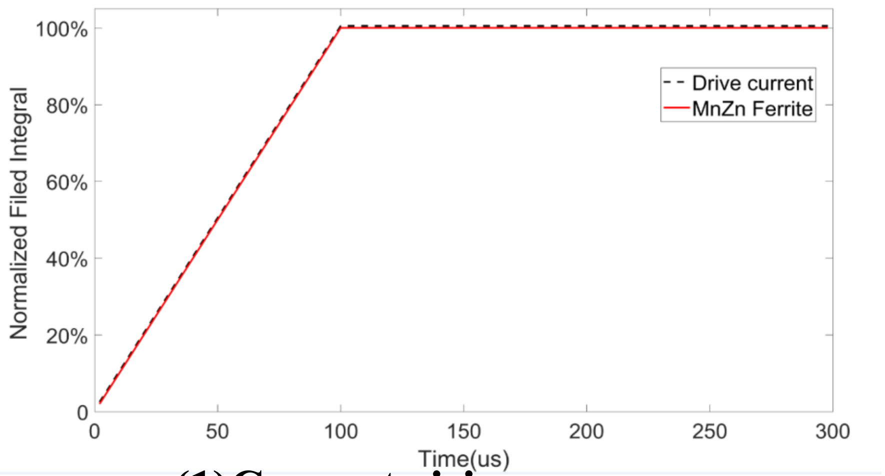
(3)Temperature distributions of Laminations of iron core without slits



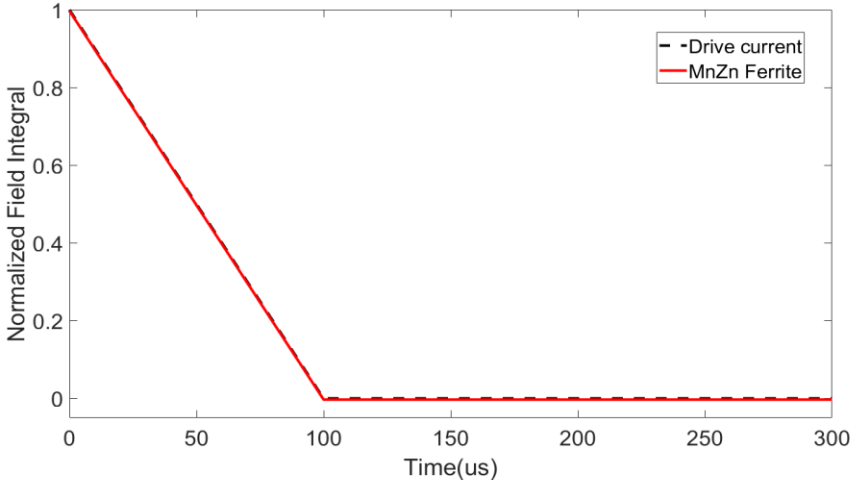
(4)Temperature distributions of Laminations of iron core with slits

- ➢ Slits in the end laminations of iron core can reduce temperature rising caused by eddy current at pole end;
- ➢ But it has minor influence on hysteresis of the magnetic field.

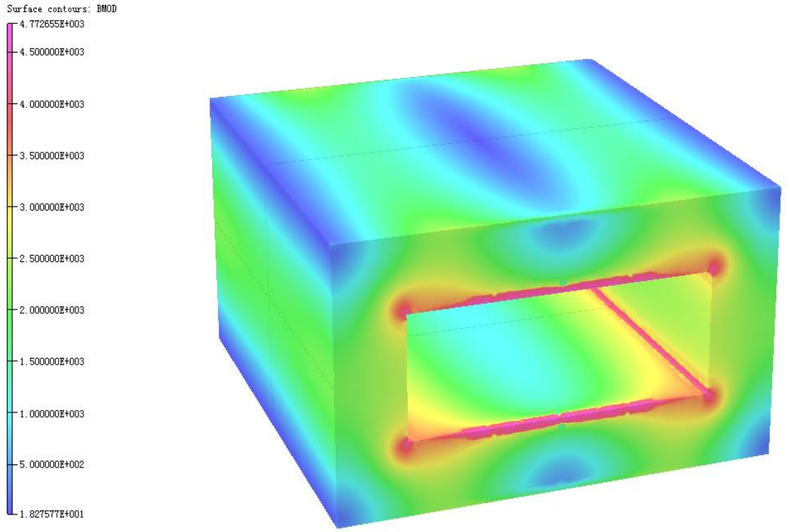
● Integral field and thermal simulations of ferrite yoke



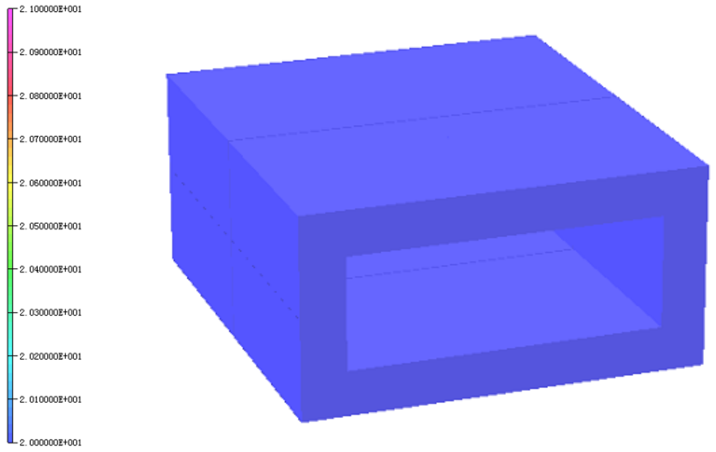
(1)Current rising process



(2)Current falling process



(3) Saturation area



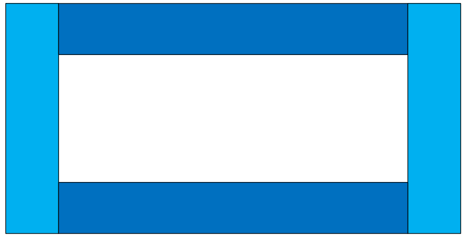
(4) Temperature distribution

- **The field integral follows the drive current wave;**
- **Saturation only in the edge of window pole end;**
- **There's almost no temperature rise.**

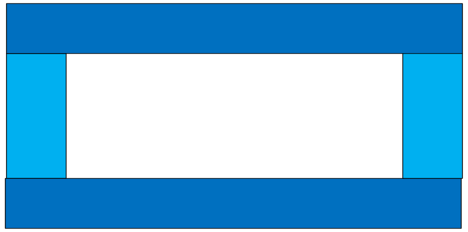
● Technical design of the kicker magnet

A. MnZn Ferrite is chosen as the magnet core

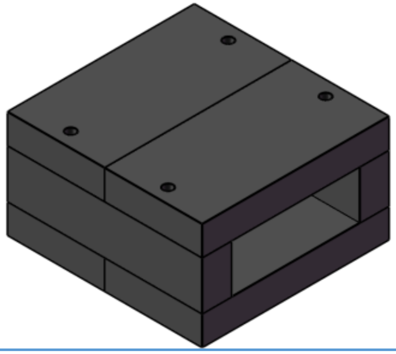
a) C shape core



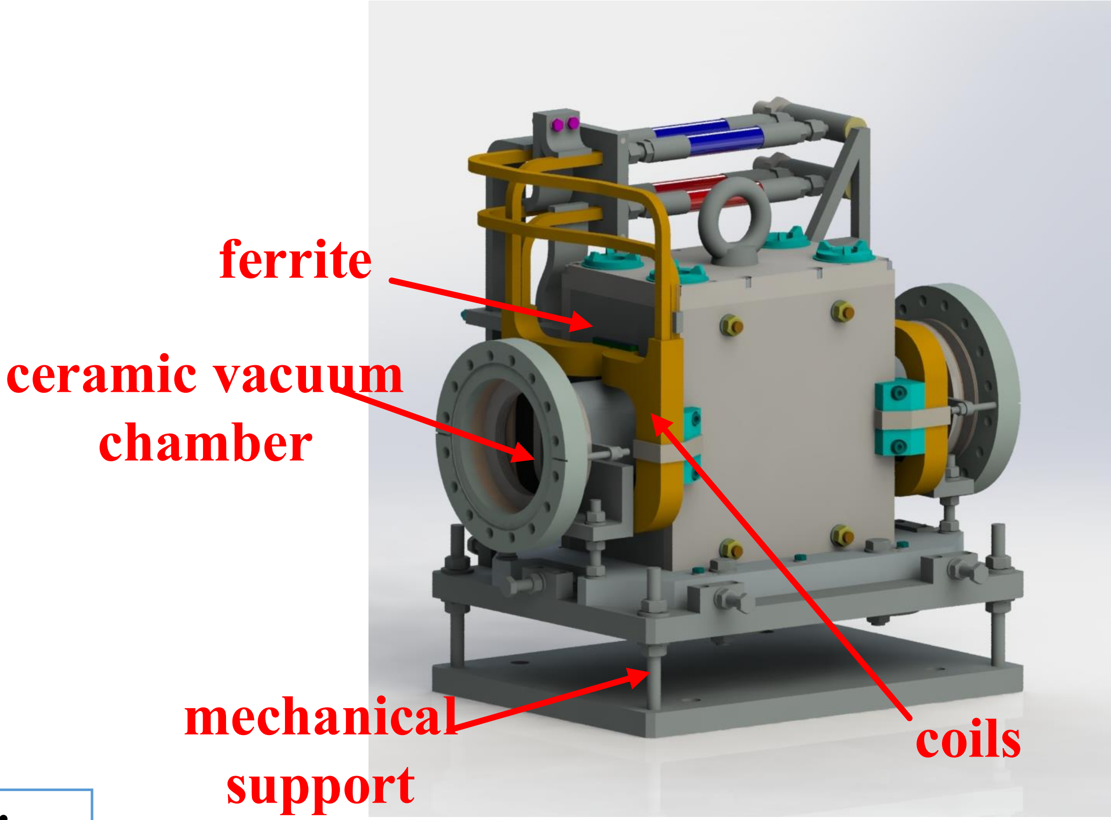
b) Four blocks core-A



c) Four blocks core-B



Six ferrite blocks configuration



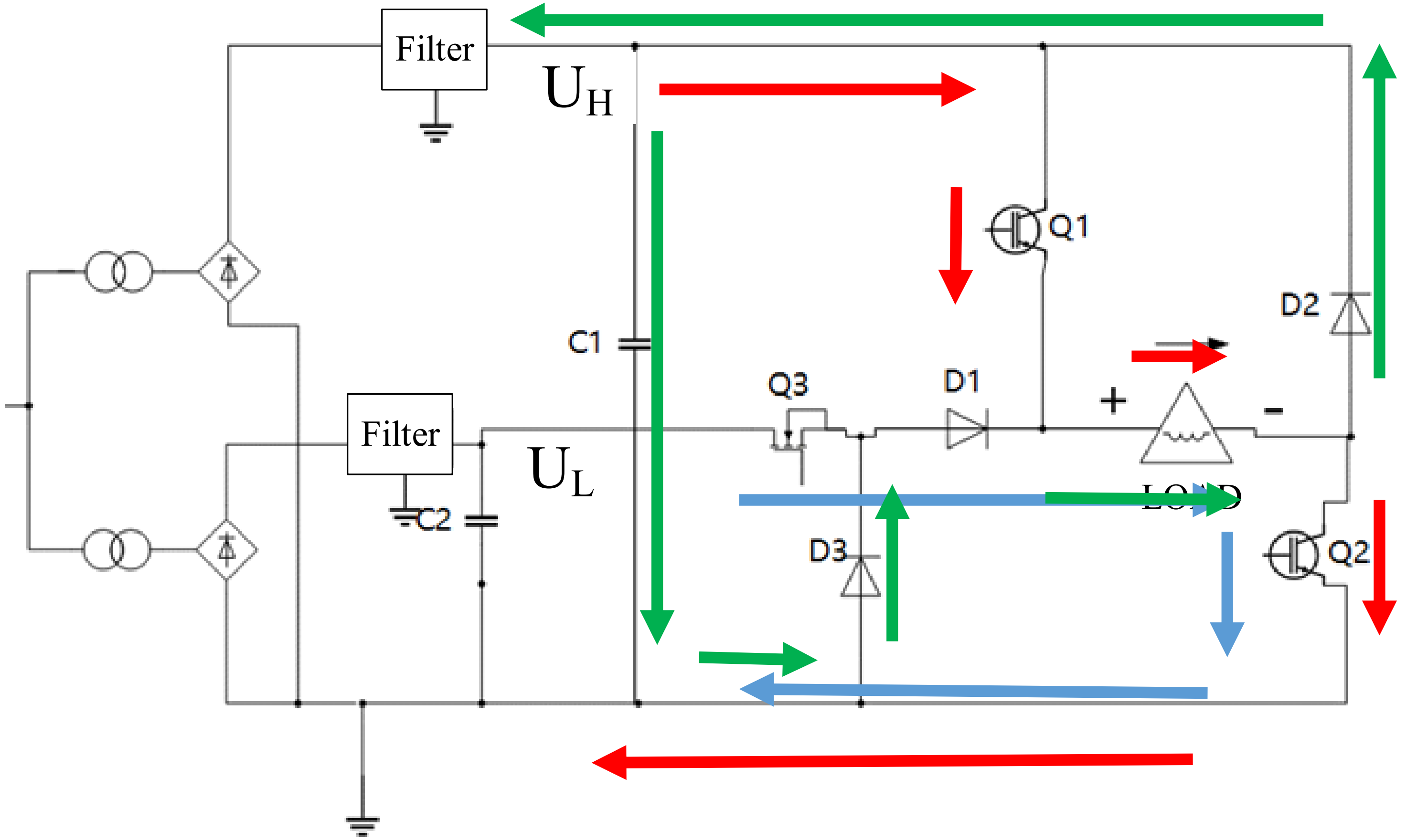
Main components of the kicker magnet

B. Ceramic vacuum chamber

C. Less coil turns to decrease inductance (4 Turns / Pole)

D. Optimization of mechanical fixture for the magnet core, to avoid vibration during operation

- **Schematic design of power supply**



Rising : Q1,Q2 open; $U_h \rightarrow Q1 \rightarrow Load \rightarrow Q2$

Holding : Q3,Q2 open; $U_L \rightarrow Q3 \rightarrow D1 \rightarrow Load \rightarrow Q2$

Falling : All close; load→D2→C1→D3→D1

Parameters setting:

$$U_H = L\frac{di}{dt} + IR \approx L\frac{di}{dt}$$

$$U_L = IR$$

Parameters of cable can not be ignored;

The cable length of 10m will be considered

L_C=8uH R_C=1.3mΩ

Characteristics:

I. Open loop in rising process; close loop in steady state;

II. In order to reach the response speed (rising/falling time 100us level), some specs can be lowered, such as overshoot, accuracy. But it can also meet the physical requirement of the kicker magnet.

R. Künzi et al, Kicker Converters for Fast Proton Beam Bending, EPE-PEMC 2004, Riga, September 2004.

- **Dynamic magnetic field measurement**

☐ Long searching coils：

- ➢ Field integral measurement
- ➢ Homogeneity measurement

Length: 600mm
Width: 4 mm
Turns of coils: 6 turns

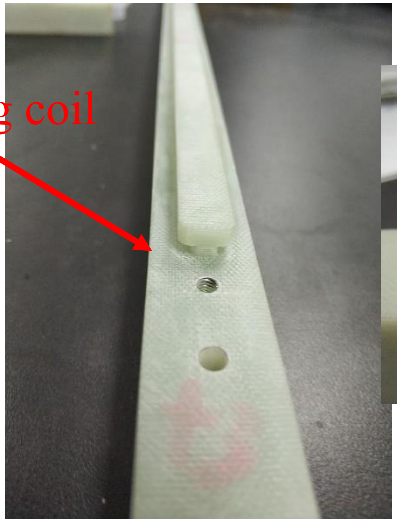
☐ Small searching coils

- ➢ The central magnetic field.

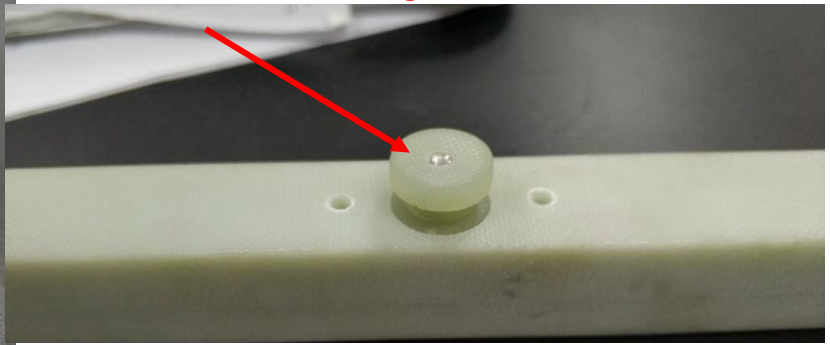
Diameter :5mm;
Turns of coils: 40 turns

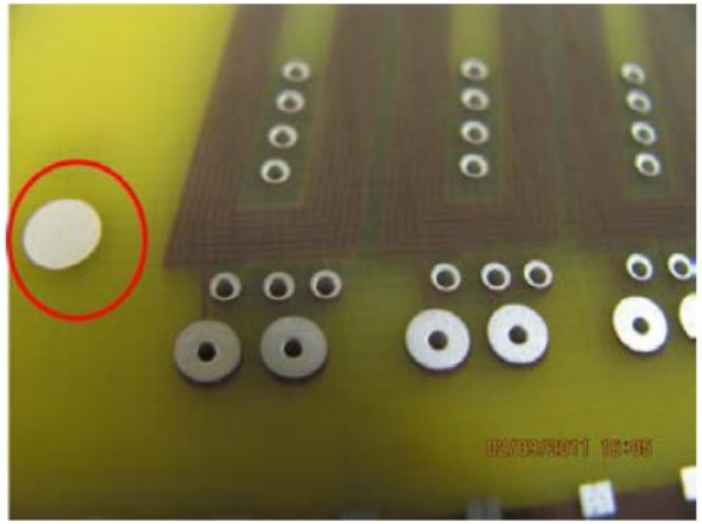
- **Low drift for the RC-integrator**
- **Parameters of the coils may drift along time**

Long searching coil



Small searching coil





A array searching coil made of PCB is now considered *.

*G. Golluccio et al., "PCB coil array for measuring curved accelerator dipoles: two case studies on the MedAustron accelerator", *in proceedings of IMEKO 2014*

Summary

- Two type of material for the kicker magnet core was compared: 1) laminated steel; 2) MnZn ferrite. MnZn ferrite was chosen, which avoids eddy current and related hysteresis effect of the magnetic field;

- Technical design and optimization was accomplished, by using: 1) six-block MnZn ferrite configuration for the magnet core; (2) Ceramic vacuum chamber.

Future plans

- Two types of searching coils measurement system: 1)Copper wire winding searching coils; 2)Printed circuit board (PCB) searching coils, will be implemented. Accuracy, stability and reliability of the searching coils will be compared and tested.

Thank you for your attention!