

FAST KICKER

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Abstract

Pulsed deflecting magnet (kicker) project was worked out in BINP (Budker Institute of Nuclear Physics). The kicker design task is: impulsive force value is $1 \text{ mT} \cdot \text{m}$, pulse edge is 5 ns , and impulse duration is about 200 ns . The unconventional approach to kicker design was offered. The possibility for set of wires using instead of plates using is considered. This approach allows us to reduce the effective plate surface. In this case we can decrease effects related to induced charges and currents. In the result of modelling optimal construction was developed. It includes 6 wires (two sets in threes). Wires are 2 mm in cross-section. The magnet aperture is about 5 cm . Integral magnet length is about 1 meter . This length can be obtained by single magnet or by multiplied length of magnets array. Calculated field rise time (about 1.5 ns) satisfies the conditions. Induced current effect reducing idea was confirmed. For configuration with 3 wires pair (with cross section of 2 mm) induced current in one wire is about 10% and in the wall is about 40% . However for design with plates current is about 40% and 20% respectively. Obtained magnet construction allows controlling of high field homogeneity by changing currents magnitudes in wires. In general we demonstrated the method of field optimization. *Summary.* Optimal kicker design was obtained. Wires using idea was substantiated.

THE KICKER CONCEPT DESIGN

The kicker design should accept several requirements. The first one is vacuum chamber and kicker symmetry axis coincidences. The second one is that central angle should be about 90° . The optimisation parameter is magnetic field homogeneity in centrally located square area ($2 \text{ cm} \times 2 \text{ cm}$).

GEOMETRY OPTIMIZATION

Computer simulation was carried out for kicker's parameters optimization. Calculations were realised in FEMM and Maxwell. The central angle, the wires number and diameter was optimized.

The number of Wires

The initial geometry is shown in Fig. 1a. The wires with fixed diameters were placed in the vacuum chamber (with the radius of 7.5 cm) at a distance of 6 cm from its centre. The wires number arranges from 4 to 20. For comparison, geometry with plates was simulated (Fig. 1b). For simulating magnetic fields, the task formulated in harmonic analysis was solved on a frequency of 200 MHz . In this task wires are parallel connected to a current source. The impressed current in three left wires is $+1 \text{ kA}$, and in three right wires is -1 kA .

Simulation results allow us to obtain the follow geometry characteristic: field homogeneity, mean value of magnetic field in the centre of the magnet, and magnet impedance.

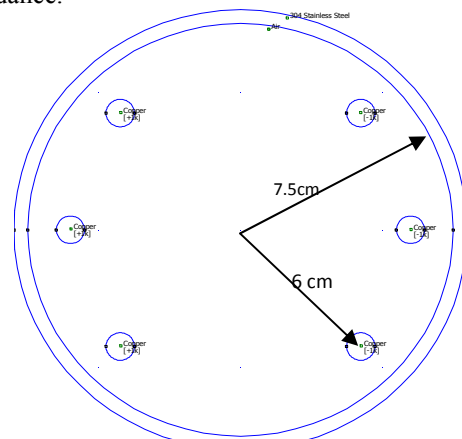


Figure 1a: Geometry concept.

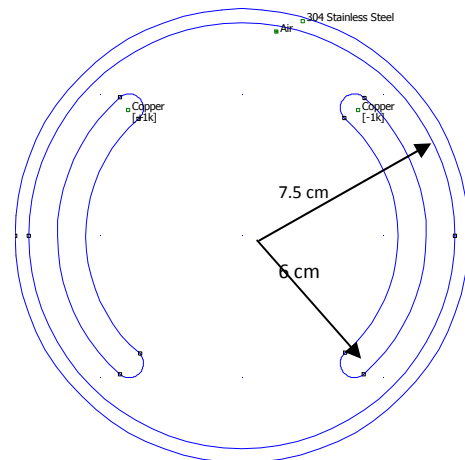


Figure 1b: Geometry with plates.

Field homogeneity is calculated according to Formula (1):

$$\delta B = \frac{B_{\max} - B_{\min}}{B_{\min}} \cdot 100\%, \quad (1)$$

where B_{\max} , B_{\min} – magnetic field maximum and minimum values, respectively, determined in centrally located square area ($2 \text{ cm} \times 2 \text{ cm}$).

The field homogeneity dependence on the wires number is shown in Fig. 2. Here we can see that homogeneity with using 6 wires is equal 1% , and it does not dramatically change with the wires number increase. However, the increasing number of wires leads to a lot of technical problems associated with the vacuum feedthroughs. Thus we should strive for the minimum number of wires.

The mean value of magnetic field is calculated under the same conditions as the field homogeneity. Calculation results are shown in Fig. 3. In this figure we can see that field mean value does not depend on the wires number.

Wire impedance is calculated according to energy method. To use this method two tasks were solved for the

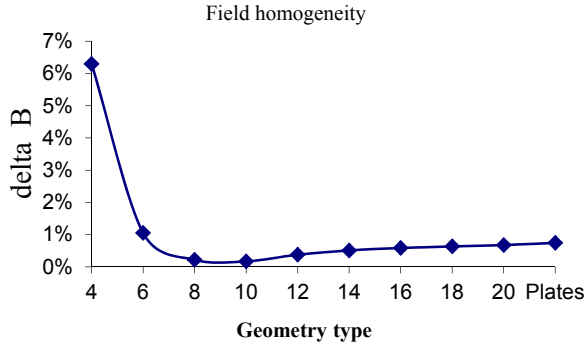


Figure 2: The dependence of field homogeneity from geometry type (total number of wires or plates).

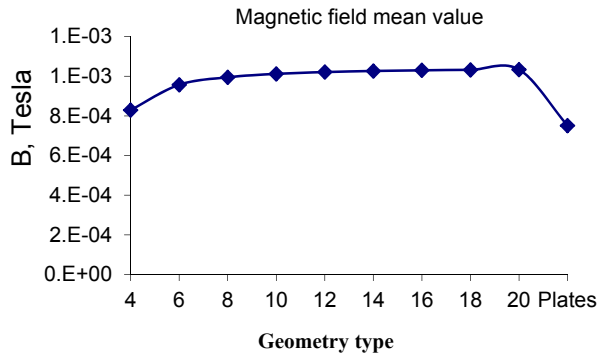


Figure 3: The dependence of magnetic field mean value from geometry type (total number of wires or plates).

different number of wires. The first problem is harmonic magnetic problem. The second problem is electrostatic problem. Energies of magnetic and electric fields can be calculated according to formulas (2) and (3):

$$W_m = \frac{1}{2} \sum I_k \Psi_k, \tag{2}$$

$$W_e = U^2 C, \tag{3}$$

where W_m and W_e are magnetic and electric field energies, respectively, I_k and Ψ_k are current through k-conductor and flux linkage generated by I_k .

Simplified equivalent electrical circuit of the magnet is shown in Fig. 4. The magnetic field energy can also be calculated from numerical simulation of field distributions in FEMM.

If we accept both conductor groups (LI1, LI2 – first group; LI3, LI4 – second group) to have equivalent inductances and neglect magnetic field linkage between conductors, we obtain expression for energy (4).

Expressing the values C and L from (3) and (4), respectively, we can obtain the impedance (Formula 5) [1]. The obtained expression allows us to estimate the impedance of the magnet using field energies (Formula 6).

$$W_m = \frac{1}{2} I^2 (L + L) = I^2 L. \tag{4}$$

$$Z = \sqrt{\frac{L}{C}}. \tag{5}$$

$$Z = \frac{U}{I} \sqrt{\frac{W_m}{W_e}}, \tag{6}$$

where U – voltage in the electrostatic problem, I – current in the harmonic problem, W_m – magnetic field energy, W_e – electric field energy.

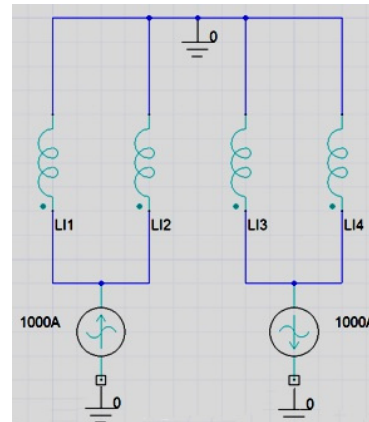


Figure 4: Simplified equivalent electrical circuit of the magnet.

Calculation results are shown in Fig. 5. We can see that if the wire number is equal 6, impedance is about 25 Ohm. So if current is 1 kA we need a modulator with an operating voltage of 25 kV.

Diameter of Wires

To determine the diameter of the wires the optimization problem was solved in Maxwell. In the initial geometry the diameter of the wires was varied. In the geometry centre a conductor with a current with amplitude of 1 A was located (Fig. 6). The dependence of the image current amplitude in each wire from its diameter was analysed.

One of the obtained dependences is shown in Fig. 6. The figure shows the dependence of the image current in

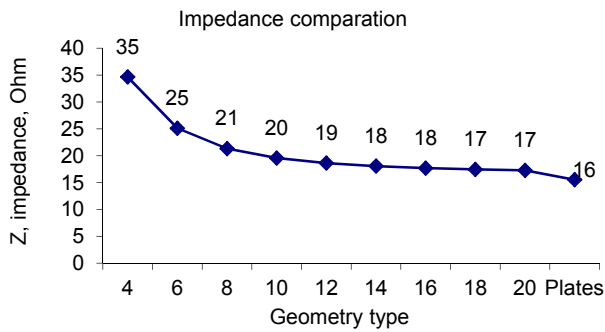


Figure 5: Impedance.

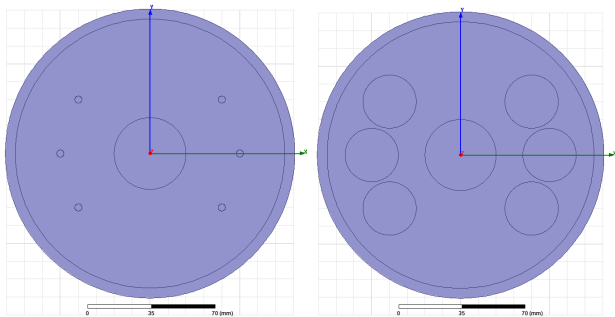


Figure 6: Image current calculation geometry (left – minimum radius, right – maximum).

the wall from the diameter of the wires. One can see that in the small diameter wires practically all the image current on the chamber walls. The plot shows that the wire diameter of 2 mm is enough.

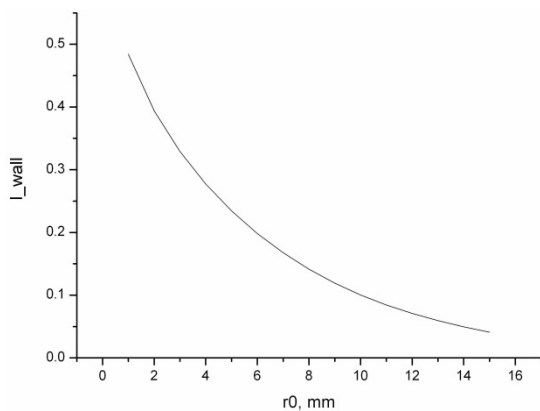


Figure 7: Image current on the wall.

Central Angle

To determine the central angle the optimization problem was solved in Maxwell. The central angle ranges from 40° to 140°. The optimization goal was the maximum homogeneity of the field in the magnet middle. The value of 1 corresponds to uniform field.

The result of the optimization is shown in Fig. 8. The plot shows that the optimum angle for maximum homogeneity is 74°.

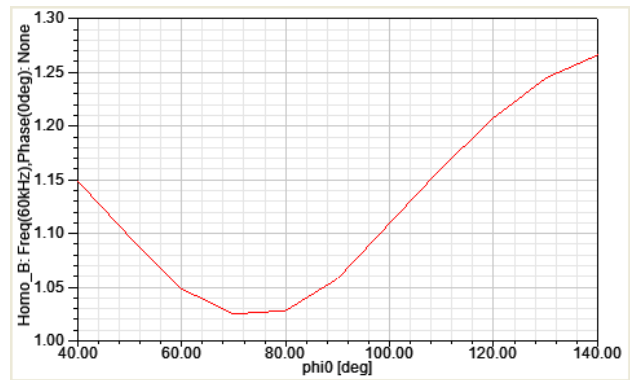


Figure 8: The central angle optimization.

SUMMARY

From these calculations we can formulate the optimal parameters in the Table 1:

Table 1: Summary Result

Parameter	Value	Unit
Total current in the conductors	1000	A
Total number of wires	6	
Central angle	74	Grad
Chamber diameter	150	mm
The distance to the centre of the wire	60	mm

REFERENCES

[1] M. T. A.W.Chao, *Handbook Accelerator Physics and Engineering*, Singapore: World Scientific Publishing Co. Pte. Ltd, 1999.