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FAST KICKER

V. Gambaryan, A. Starostenko, BINP SB RAS, Novosibirsk, Russia

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 mT*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 cylinders 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 cylinders (two sets in threes). Cylinders 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 cylinders pair (with cross section of 2 mm) induced current in one cylinder 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 cylinders. In general, we demonstrated the method of field optimization. On the basis of this work has been developed magnet design documentation. The magnet was made in BINP. At present is preparing the stand for magnetic measurements, launched works for the numerical simulation of beam dynamics in CST Studio. *Summary.* Optimal kicker design was obtained. Cylinders using idea was substantiated. Magnet was made.

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 angel should be about 90˚. The optimisation parameter is magnetic field homogeneity in centrally located square area (2 cm x 2 cm).

GEOMETRY OPTIMIZATION

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

The Number of Cylinders

The initial geometry is shown in Fig. 1a. The cylinders 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 cylinders 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 cylinders are parallel connected to a current source. The impressed current in three left cylinders is +1kA, and in three right cylinders is –1kA.

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.

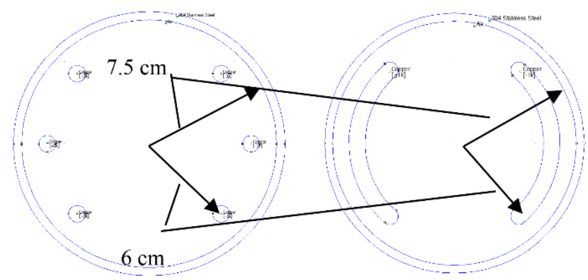

Figure 1: a). Geometry concept, b). Geometry with plates.

Field homogeneity is calculated according to Formula (1):

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

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

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

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 cylinders number.

Cylinder impedance is calculated according to energy method. To use this method two tasks were solved for the different number of cylinders. 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):

$$W_m = \frac{1}{2}\sum I_k \Psi_k, \qquad (2)$$

$$W_e = U^2 C, \qquad (3)$$

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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).

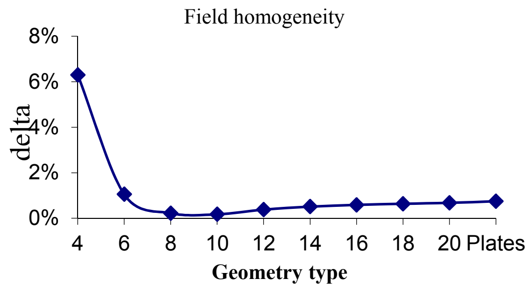

Figure 2: The dependence of field homogeneity from geometry type (total number of cylinders or plates).

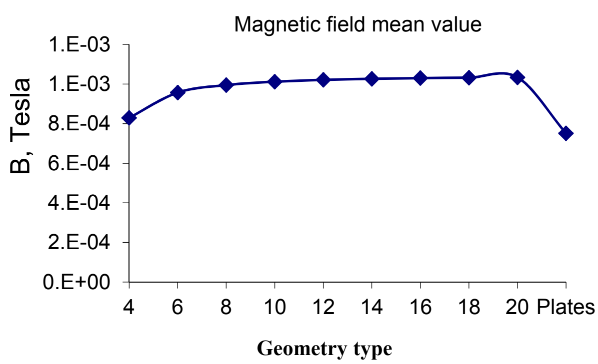

Figure 3: The dependence of magnetic field mean value from geometry type (total number of cylinders or plates).

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).

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

$$Z = \sqrt{\frac{L}{C}} \quad (5)$$

$$Z = \frac{U}{I} \sqrt{\frac{W_m}{W_e}} \quad (6)$$

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

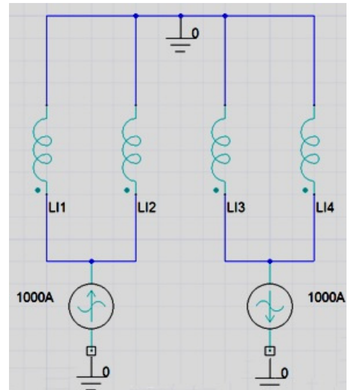

Figure 4: Simplified equivalent electrical circuit of the magnet.

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 Cylinders

To determine the diameter of the cylinders the optimization problem was solved in Maxwell. In the initial geometry the diameter of the cylinders 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 the wall from the diameter of the cylinders. One can see that in the small diameter cylinders practically all the image current on the chamber walls. The plot shows that the wire diameter of 2 mm is enough.

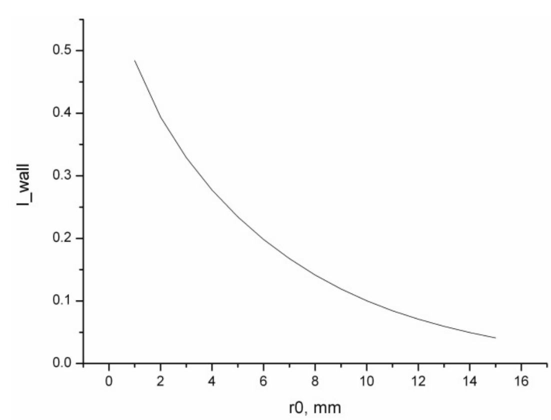

Figure 7: Image current on the wall.

Central Angle

To determine the central angle the optimization problem was solved in Maxwell. The central angle ranges

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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˚.

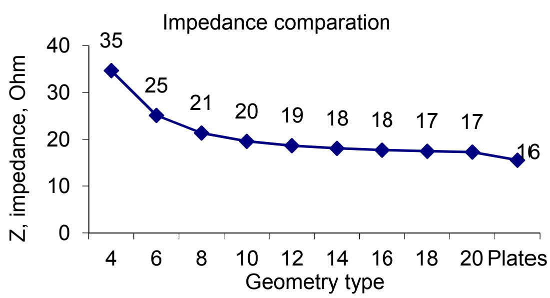

Figure 5: Impedance.

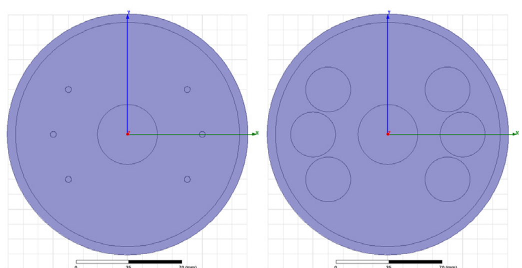

Figure 6: Image current calculation geometry (left – minimum radius, right – maximum).

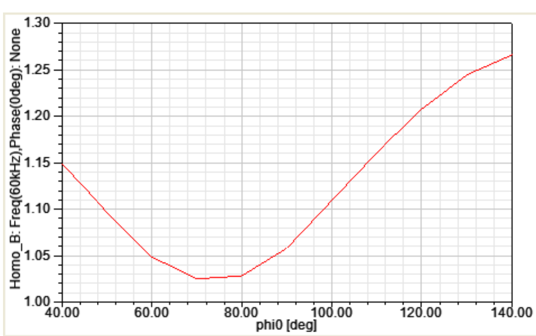

Figure 8: The central angle optimization.

THE KICKER ACTUAL DESIGN

Taking into account obtained results, the BINP designers developed a kicker prototype. The kicker dimensions were selected based on measurements. The magnet cross section is shown in Fig. 9. The physical magnet length is about 650 mm. The magnet aperture is 100 mm. The vacuum chamber diameter is 164 mm. The cylinder diameter is 28 mm. Manufactured magnet shown in Fig. 10. The cylinders are made of steel, as well as the body of the magnet. The ceramic feedthrough also was developed in BINP.

For the simulation of dynamics of charged particles beams the CST Studio is used. These simulations are in the initial stage. Only preliminary calculations have been held. One of the first results is shown in Fig. 11.

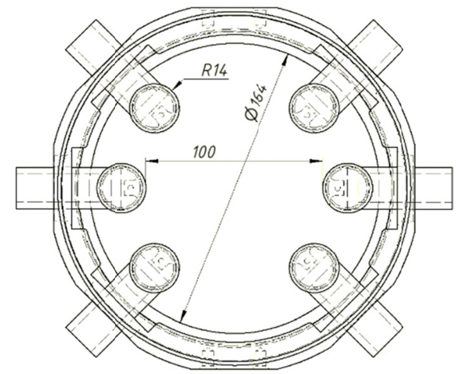

Figure 9: The kicker actual design (all dimensions are in mm).

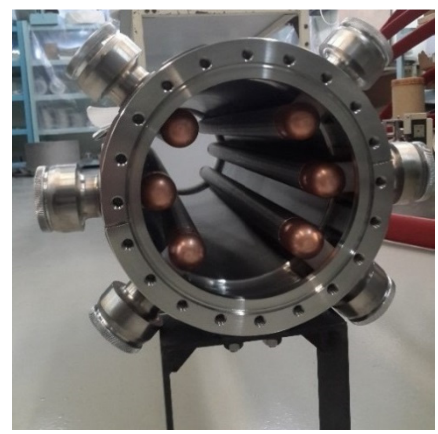

Figure 10: The kicker actual photo.

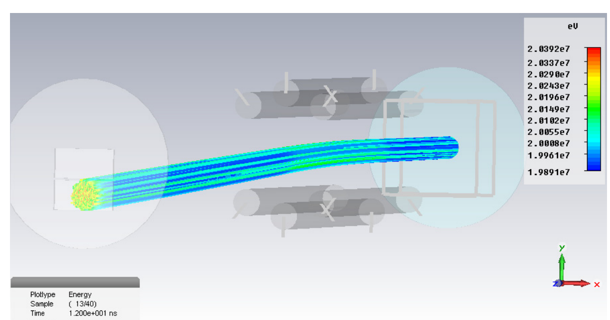

Figure 11: Beam dynamics simulation in CST.

SUMMARY

The design of non-conventional kicker was developed in BINP. The kicker was manufactured. In the near future work on the measurement of the kicker magnetic properties will be started.

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