Fast Kicker for High Current Electron Beam Manipulation in Large Aperture

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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 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 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. Developed modelling optimal construction 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. 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.

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 cm x 2 cm).

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.

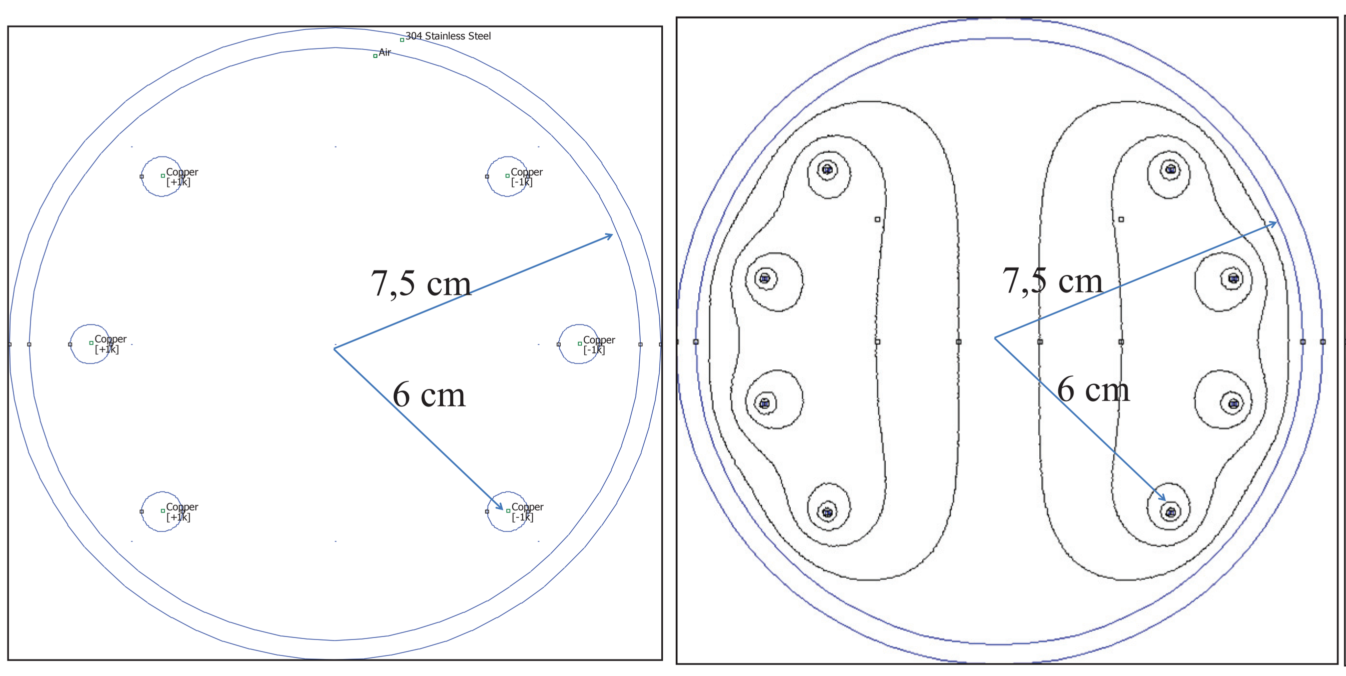

Fig. 1a: Geometry concept.

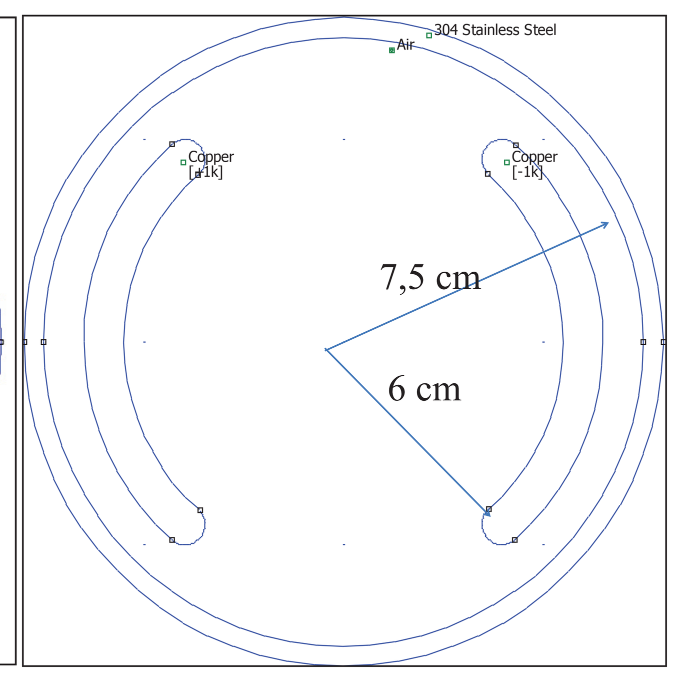

Fig. 1b: Geometry with plates.

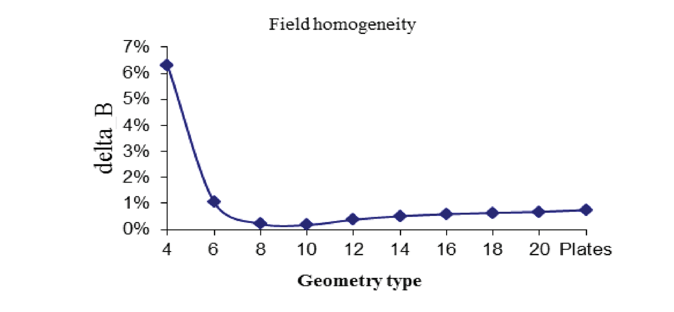

Figure 2.The dependence of field homogeneity from geometry type (total number of wires or plates).

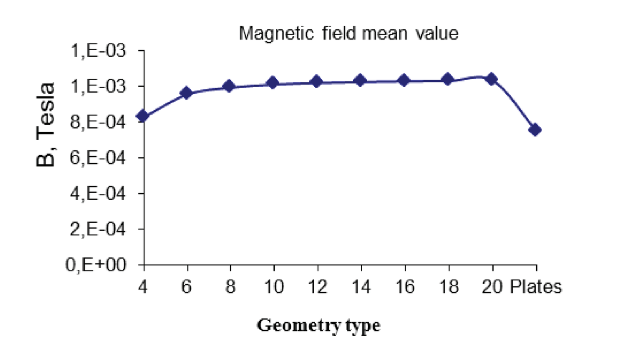

Figure 3. The dependence of magnetic field mean value from geometry type (total number of wires or plates).

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

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

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

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).

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

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

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

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

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.

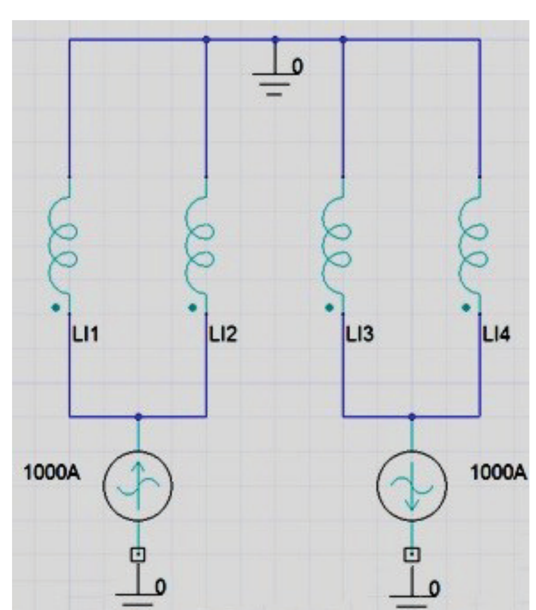

Figure 4. Simplified equivalent electrical circuit of the magnet.

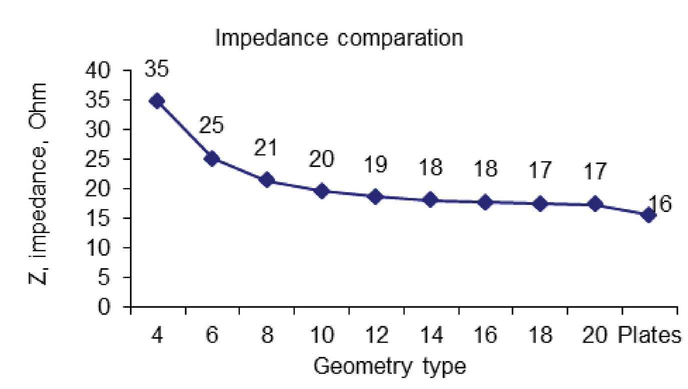

Figure 5. Impedance.

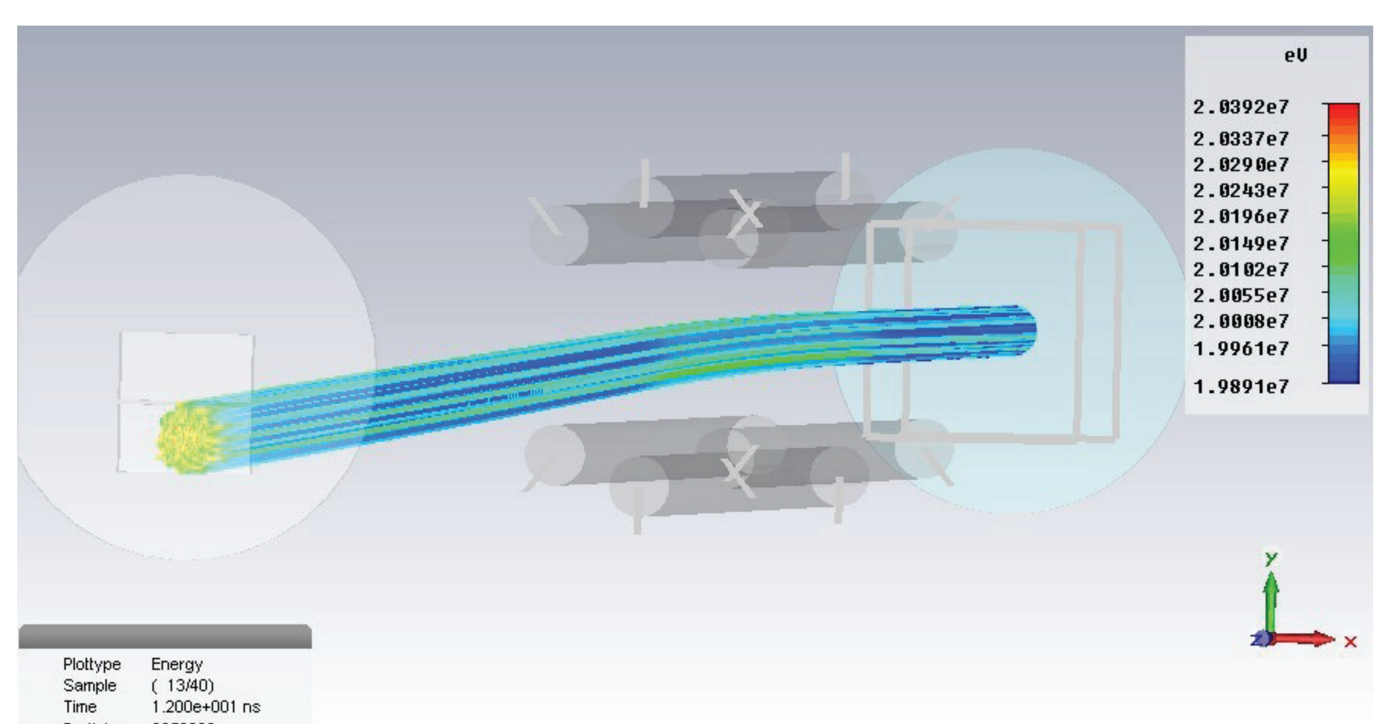

Figure 6: Beam dynamics simulation in CST.

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. 7. 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. 8. 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. 6.

SUMMARY

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

REFERENCES

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

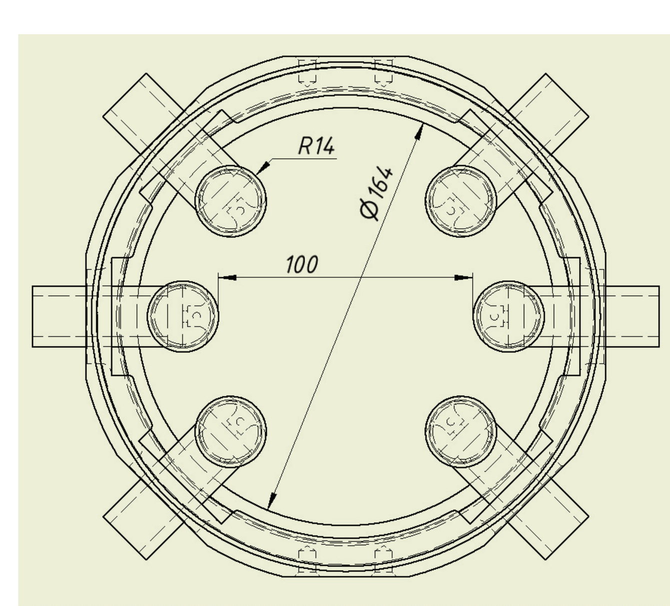

Figure 7: The kicker actual design (all dimensions are in mm).

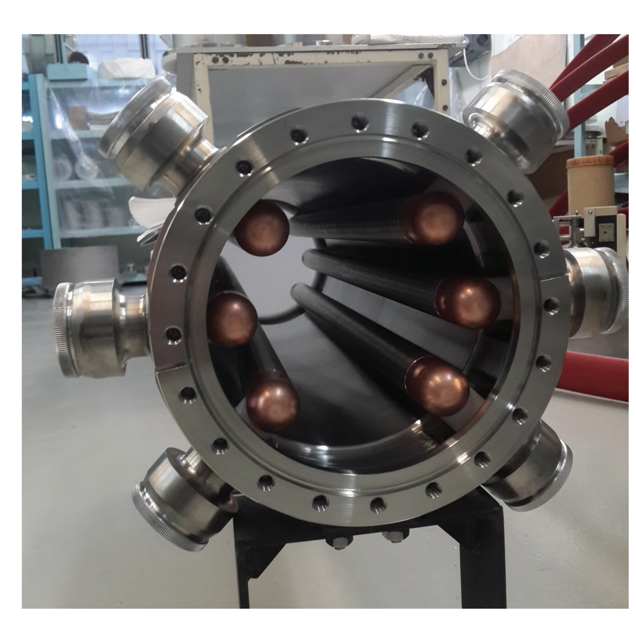

Figure 8: The kicker actual photo