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Fast dipole magnet development.

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Abstract— For the simultaneous operation of several parallel free electron laser beam lines and/or accelerator test experiments it is mandatory to have a device capable of fast switching of electron bunches between the different beam lines with high accuracy. Such devices are the described pulsed dipole magnets.

Two magnets allow for an 8 degrees kick to a 1.6 GeV electron bunch. Time of increase of a magnetic field is less than 100 µs. Field delay from current is less than 2 µs due to that the core of a magnet is assembled from a 80 µm thick steel. Magnetic field integral B0 x L is 0.375 Tm. Magnets should operate at a frequency of 10 Hz. Particular attention was paid to minimizing the power dissipation due to Foucault currents. For this purpose, the magnetic field component perpendicular to the laminas has been minimized.

INTRODUCTION

For the simultaneous operation of several parallel free electron laser beam lines and/or accelerator test experiments it is mandatory to have a device capable of fast switching of electron bunches between the different beam lines with high accuracy. Such devices are the hereafter described pulsed dipole magnets. Necessary rate of increase of a magnetic field is 1.4 104 T/s. This rate is necessary to increase the field between two bunches at FLESH-II [1] facility.

CALCULATION.

Field computation code MERMAID [2] was used for numerical calculation of the magnet. 2D mode was used for optimization of cross-sectional pole profile. Integral magnetic field homogeneity was checked at 3D mode. Further, we made calculations by COMSOL [3].

The yoke shape was selected in accordance with the requirements of the homogeneity of the magnetic field integral and minimization of the magnet inductance. Cross-section of the magnet is presented on Figure 1. Coordinate system is shown on Figure 2.

The results of numerical calculations are given on Figure 3. The geometry of poles provide uniformity of a magnetic field integral in area 20 x 10 mm. The calculated inductance of the magnet does not exceed 50 µH. The non-symmetry of the integral of the magnetic field is explained by the need to use an odd number of turns and the fact that the windings are as close as possible to the gap. This is done to minimize the inductance of the magnet.

The yokes material used was electrical steel ET 3425. The thickness 0.08 µm of steel was chosen to be three times smaller than the size of the skin depth for 100 µs. The magnet maybe disassembled in the horizontal plane for a subsequent installation of the vacuum chamber. The geometry of poles allows uniformity of a magnetic field in area 20 x 10 mm. The main parameters and requirements for the magnet are specified as:

- Magnetic field integral B_0 x L 0.375 T m
- Air gap 40 mm
- Field quality < 10^{-3} ΔB/B
- Good field region B x H 20 x 10 mm
- Usable air gap width ≥80 mm
- Current 6500 A
- Maximum voltage 4000 V
- Inductivity ~52 µH
- Iron yoke length 260 mm
- Cooling water pressure drop 4 bar
- Total water flow rate 1.2 l/min
- Overall weight 160 kg

MECHANICAL DESIGN

The magnet half-core are made from the laminas of 0.08 mm thickness, assembled together with 10 mm thick composite epoxy materials end-plates. The coil consists of 7 turn and is manufactured from the copper conductor of rectangular cross-section 6x6 mm with 3 mm diameter round hole. The coils are vacuum impregnated with radiation resistant epoxy resin. The resin shall be vacuum degassed (below 1 mbar at a temperature of 65-70 ºC) until the mixture is free from air and impurities with low boiling points. For degassing, the mould with the assembled coils is heated up to 65-70 ºC and evacuated to below 1 mbar during several hours. The coils are then fully impregnated with the resin compound. During the impregnation process the temperature of the resin and the mould shall be maintained at a constant temperature. The insulation of the manufactured coils is tested after being immersed in water for 6 hours.

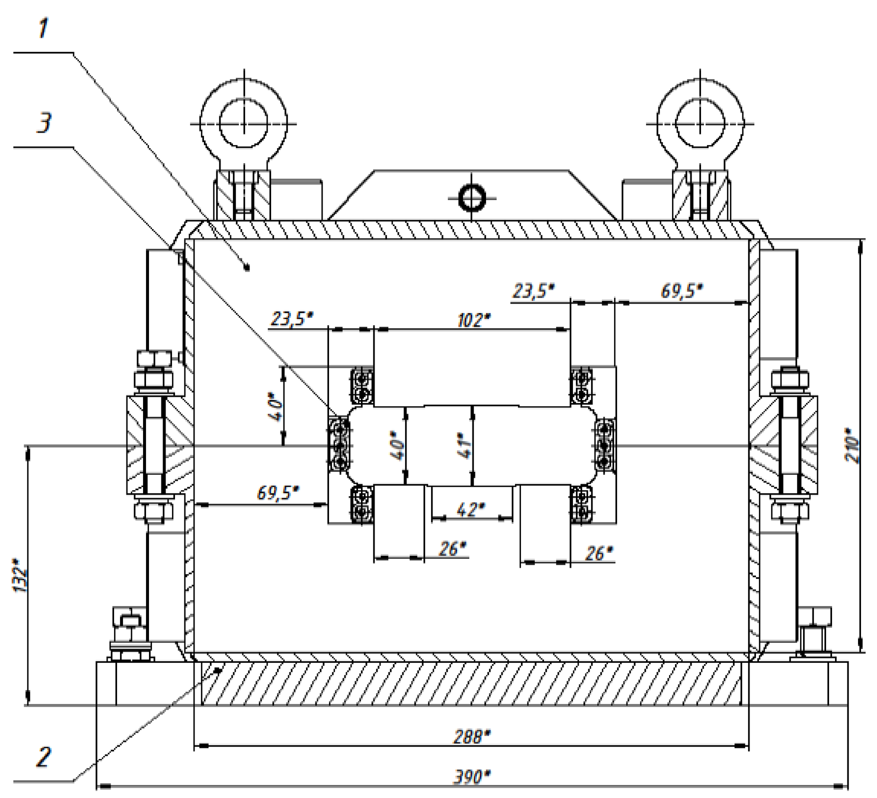


Fig. 1. Cross-section of the magnet.
1 – steel, 2- stainless steel, 3 -coil

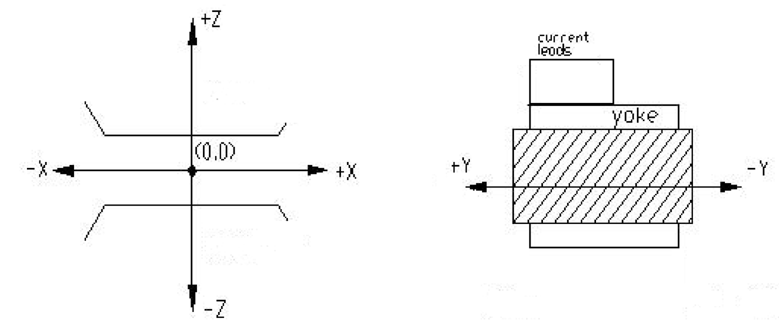


Fig. 2. Coordinate system
(current leads on the right side)

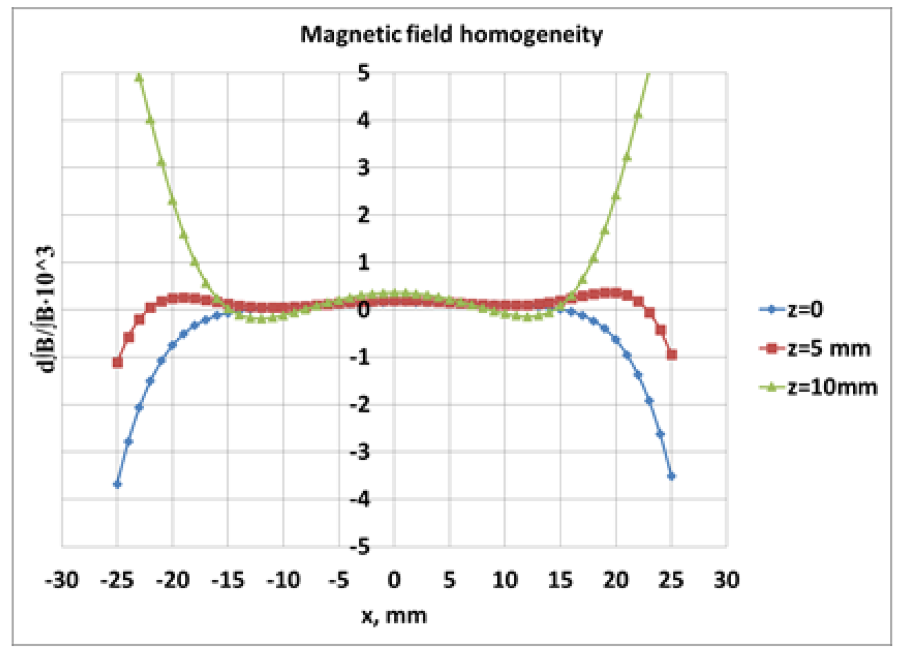


Fig .3. Field homogeneity of the integral magnetic flux density. Calculation

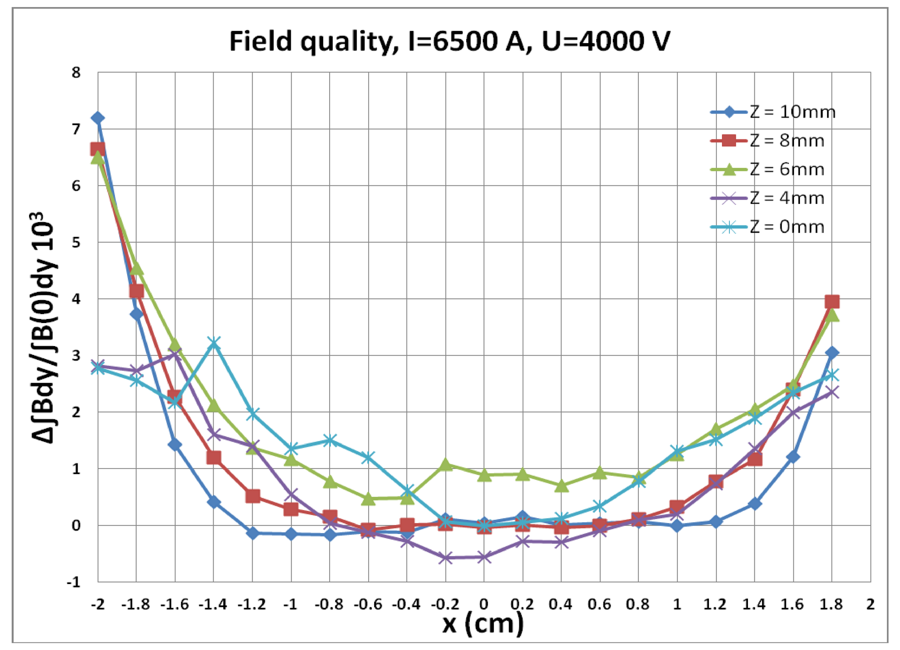
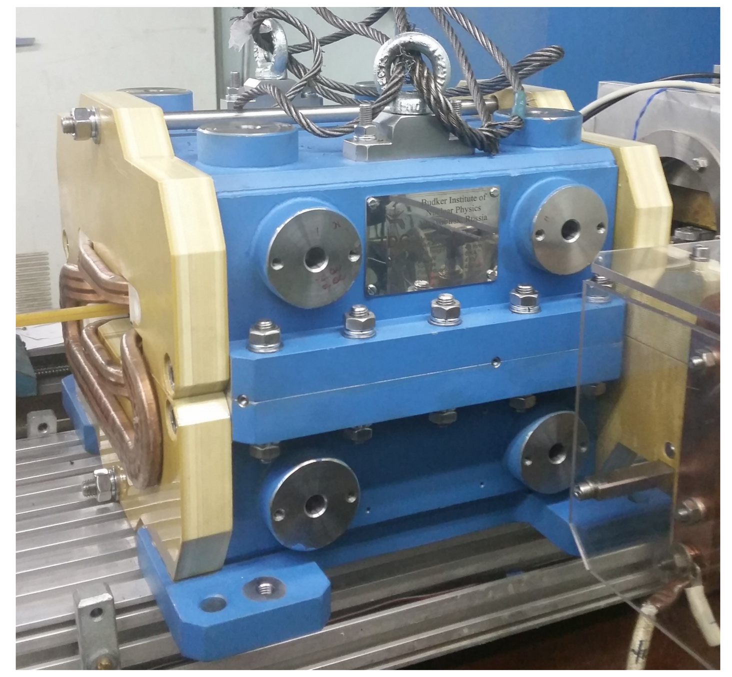


Fig. 4. Field homogeneity of the integral magnetic flux density. Mesurement

MAGNETIC MEASUREMENTS.

The measuring system was used a "long" coil for measuring integral of the magnetic field along y-axis. The integral of a magnetic field along an y-axis of a pulse dipolar magnet was measured by means of the one turn coil. Width of the coil is 2 mm, length is 350 mm. The coil moved on axis X at different values on axis Z. Power supply with U = 6 kV, I = 7 kA and pulse duration (half period) of 200 µs. The coil voltage, voltage at a magnet and current of a magnet were registered an oscilloscope. Coil voltage was also registered by the integration ADC. Fig.2. explains the coordinate system used during measurements. Field homogeneity of the magnetic flux density integral is presented in Fig.3.



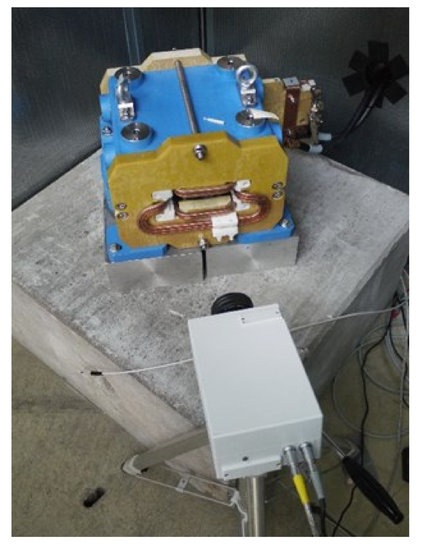


Fig . 5 Magnet and camera

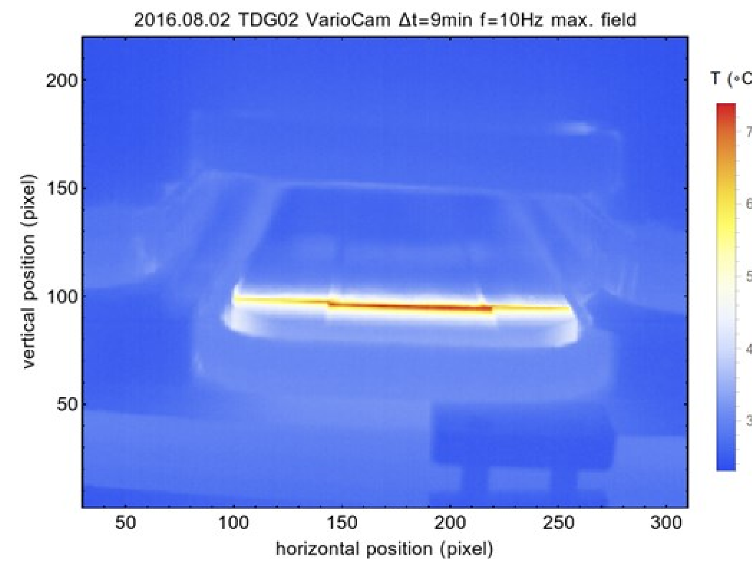


Fig . 6 Image of the temperature.

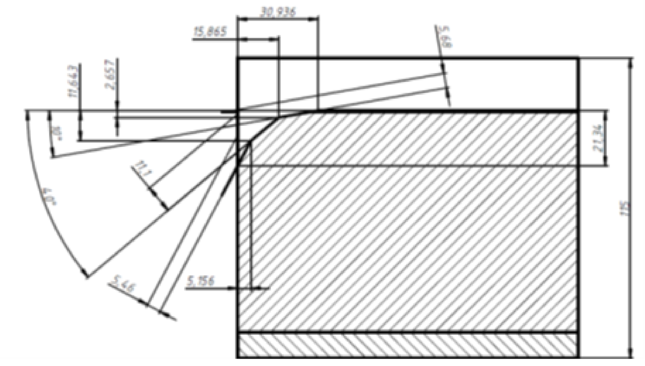


Fig . 7 Pole profile.

YOKE HEATING

During operation at a frequency of 10 Hz, it was found that the pole edge was heated up to 800 C. The temperature was recorded by the Variocam camera [ ]. The figure 5, 6 shows the location of the camera relative to the magnet and the image of the temperature. The reason for the heating was the Foucault currents. These currents arise due to the component of the magnetic field perpendicular to the plane of the plates. Numerical calculations were made in accordance with the formula for the power dissipation [5].

$$P \sim \sqrt{\frac{\mu}{\sigma\tau}}\frac{2\tau}{t}B^2$$

P is the power lost per unit volume (W/m3),
B is the peak magnetic field (T),
σ - is the conductivity,
µ is the permeability,
τ is the pulse rise time,
t is the time between pulses.

To reduce the heating, the shape of the pole end was chosen which reduced the component of the magnetic field perpendicular to the laminas. The profile of the pole is shown in the figure 7. The use of this profile made it possible to reduce the density of the power dissipation by three times.

CONCLUSION

The production of the pulse dipole magnets at BINP is well advanced. Magnetic measurement data together with an inspection report and reception tests establish the quality record for the acceptance of the magnets at DESY. The results show that the design fulfills the specification requirements and confirms the production methods at BINP. Preliminary tests have shown that the temperature of the magnet is within the suitable value.

ACKNOWLEDGMENTS

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