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Design and magnetic measurements of a hybrid wiggler for SR research program at VEPP-4

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Background

Experiments with beams of synchrotron radiation (SR) in a wide spectral range (from soft ultraviolet to hard gamma quanta) are carried out on a unique cyclic VEPP-4 storage ring. VEPP-4 is the source of synchrotron radiation with the highest energy of particles in Russia and is included in the 5 most high-energy cyclic SR sources in the world.

For obtain a stream of hard quanta (~ 10 ÷ 100 keV), a specialized electromagnet (wiggler) with an alternating longitudinal magnetic field (1.2 T) is used.

For improve the efficiency of experiments with SR on the VEPP-4 accelerator complex, a hybrid wiggler was designed and produced at the Budker Institute of Nuclear Physics. This wiggler consists of normally conducting poles with coils and permanent magnets, which allows to increase the magnetic field in the gap. Maximum field in new wiggler is 1.9 T. As a result, the photon flux in the region of 100 keV increases by 2 orders and in the 20-keV region, by 2 times [1]. The new wiggler will significantly expand the research program with synchrotron radiation on the VEPP-4 storage ring [2] [3]. The characteristics of the new and old wiggler are presented in Table 1

TABLE I
OLD AND NEW WIGGLER AT VEPP-4M

Parameter	Old wiggler	New wiggler
Maximum magnetic field	1.2 T	1.9 T
Period length	20 cm	15 cm
Number of main sections	5	7
Total number of sections	7	9
Pole gap	40 mm	30 mm

Conclusion

A hybrid wiggler was successfully created and tested at the Institute. In the course of magnetic measurements, correction currents were found. A table is created for raising the magnetic field of the wiggler, when the first and second integral of the field are zero. At present, the wiggler is installed on the VEPP-4M and waits for inclusion for subsequent tests.

REFERENCES

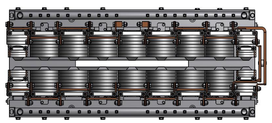
[1] G.Baranov et al. Hybrid Magnet Wiggler for SR Research Program at VEPP 4M. Phys.Procedia 84 (2016) 126-130, DOI:
[2] B.P.Tolochko et al. Status of dynamic diagnostics of plasma material interaction based on synchrotron radiation scattering at the VEPP-4 beamline 8. Physics Procedia, 84, 184-188, 2016, DOI: 10.1016/j.phpro.2016.11.032
[3] Levichev E.B., 2016. Status and perspectives of VEPP-4 complex (in Russian). Particles and Nuclei, Letters, XIII, 7.
[4]https://www.comsol.com/

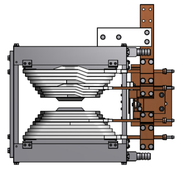
Design

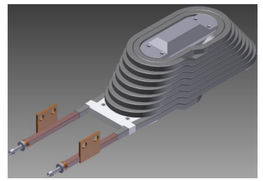
The wiggle poles are made of a single piece of electrical steel 10, machined on a CNC machine. The wiggler consists of 14 main poles and 4 poles with correction coils (Field layout is 1\2;1;1;1;1;1\2)..

Billets of Al-0.1wt%Ni and 5N-grade high-purity Al are used for the billet on billet continuous extrusion process.

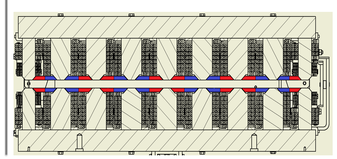
A record size Al-Ni with 40-strand cable co-extrusion of 57 x 12 mm² is realized.







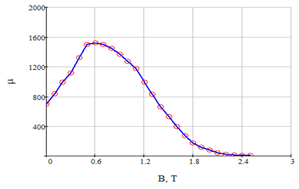
The coil consists of 16 turns stacked in 2 layers. The copper conductor is rectangular cross-section 13.5x13.5 mm with 7.5 mm diameter inner hole. The conductor is wound directly on the pole. The coils are vacuum impregnated with radiation resistant epoxy resin. The resin has to be vacuum degassed (below 1 mbar at a temperature of 65-70 ºC) until the mixture is free from air and impurities with low boiling points

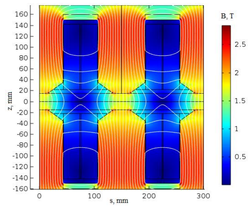


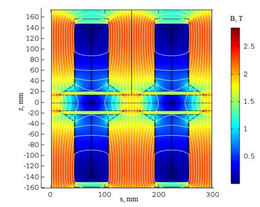
Permanent magnets are made of NbFeB alloy, have a magnetization of 1.2 T. They are installed between the poles.

Magnetic calculation

The finite element software COMSOL [4] was applied for magnetic fields simulation. Simulation was done for maximal current (2 kA). The wiggler poles were made of the electrical steel 10. At fig. the magnetic permeability dependence is presented.



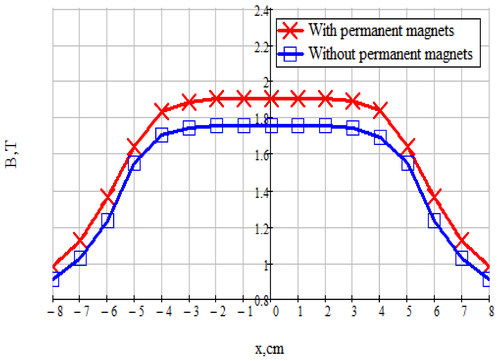




The distribution of the magnetic field in wiggler without permanent magnets (left); the distribution of the magnetic field in wiggler with permanent magnets (right)

One period was calculated because of the symmetrical shape. Figure 5 shows the distribution of magnetic flux with and without permanent magnets. Permanent magnets have a magnetization of 1.2 T. The magnetization inside the permanent magnets is parallel to the longitudinal direction of the wiggler

Magnetic measurements



Power supply with U = 60 V, I = 2 kA DC. Stability of power supply 5·10-5. The correcting coils are powered by 2 sources with U=15 V, I=1 kA.

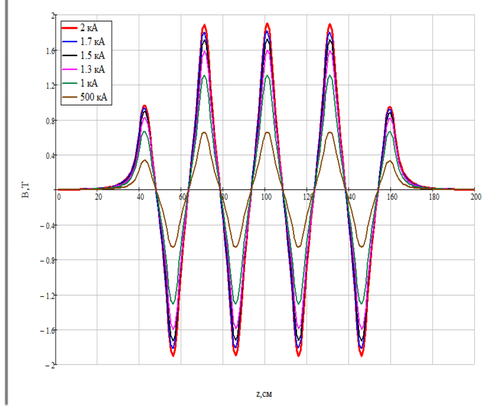
For the measurement, a carriage with 17 hall probes was used. Hall probes are located 1 cm each other. The probes have ±1 Gs absolute tolerance. Before the measurement, all the sensors were calibrated by NMR. Further, this carriage with sensors was pulled through the wiggler with steps of 0.5 cm. Figure shows the transverse distribution of the field at the center of the wiggler. Without permanent magnets, the maximum of the magnetic field is 1.75 T. Permanent magnets increase the field by 0.15 T to 1.9 T.

When the wiggler is turning on, it is important that during the rise of the field, the beam does not move along the angle and coordinate. For this, correction coils are used in the design. We performed a series of measurements on different currents and compiled a table for acceleration taking into account the correction of the first and second field integrals (Table 2).

TABLE II
RESULTS OF MAGNETIC MEASUREMENTS TAKING INTO ACCOUNT CORRECTION

Main current	Correction current (input source)	Correction current (output source)
2 kA	350 A	373 A
1.7 kA	179 A	206 A
1.5 kA	87 A	110 A
1.3 kA	27 A	34 A
1 kA	-20 A	-16 A
0.5 kA	-10 A	-4 A

The results of magnetic measurements at different currents



The offset of the beam orbit at the maximum current