Construction
of
the Superconducting 7.5 Tesla Wiggler

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Abstract

The superconducting wiggler (a wavelength shifter) with a maximum field of 7.5 Tesla at the central pole was manufactured under the cooperation with Budker Institute of Nuclear Physics (BINP), Russian Federation. The design is based on three parallel superconducting dipoles. The field is produced by two elliptic and four rectangular NbTi-coils assembled symmetrically above and below the vacuum chamber. The cryostat of the wiggler, which consists of inner helium vessel and outer container and helium supply tank, has a warm bore at its center to pass the e-beam chamber. The wiggler is energized by two parallel power supplies to control the integrals of magnetic fields as being zero and is protected from quenches by the protecting circuit that is composed of dump resistors and thyristor switches. The maximum field at wiggler center was measured to be 7.65 Tesla and the first and second integral were less than 20 Gauss-cm and 70 Gauss-cm^2 ,respectively. Most of all parameters of wiggler were good as we expected.

1. INTRODUCTION

Strong field wigglers have been installed in a straight of a storage ring to enhance the performance of the machine for short wavelength users and to provide new possibilities for SR experiments. A wiggler is not a main element of the lattice and does not reduce the reliability of the storage ring. But there are several effects on beam dynamics which appear due to the non-idealities of the magnetic field of the wiggler.

The wiggler under description consists of a three-pole magnet with superconducting coils cooled by liquid helium, a cryostat with helium supply tank above it, current leads and quench protection system, and a vacuum chamber which will be connected to the storage ring vacuum chamber. The main parameters of the wiggler are listed in Table 1.

Parameters	Values
maximum field field on beam axis	
central pole (Tesla)	7.5
side pole (tesla)	-1.75
pole gap (mm)	48
vertical aperture (mm)	26
orizontal aperture (mm)	84
tored energy (KJ)	≈ 100
total weight of magnet(Kg)	1300

Table 1 Main Parameters of the Wiggler

2. MAGNETIC DESIGN AND MANUFACTURE

A view of three-pole wiggler is presented in Figure 1. The wiggler design is based on three parallel superconducting dipoles. The magnetic field is produced by 2 elliptic and 4 rectangular type coils with Nb-Ti wires assembled symmetrically with respect to vacuum chamber for e-beam.

The main element of magnet is the two central coil with maximum field of 7.5 Tesla on the electron orbit and 4 side poles are to compensate the orbit distortion due to the magnetic field from the central poles.The shape of the central pole was got as a result of connecting two arcs with radii of 918 mm and 40 mm. The central coil consists of two different superconducting windings. One winding was wound over the other and the connection between these windings as well as between all other windings are away from the region of strong field in order to reduce the possibilities of quenches due to the connection resistance. The current density of the central coils is determined that the higher field region has lower current density and vice versa. The use of iron poles enable to produce a higher magnetic field than the corresponding one without iron pole. The contribution of it is about 1.5 Tesla. The iron yoke provides the return paths of magnetic flux and supports the coils.

The magnetic gap is maintained by the non-magnetic stainless steel slabs located between the upper and lower iron yokes.The magnetic field of the wiggler was simulated with the MERMAID code developed at BINP, Russia. The flux distribution is shown in Figure 2. The magnetic field and the result beam trajectory along the wiggler axis are presented in Figure 3.

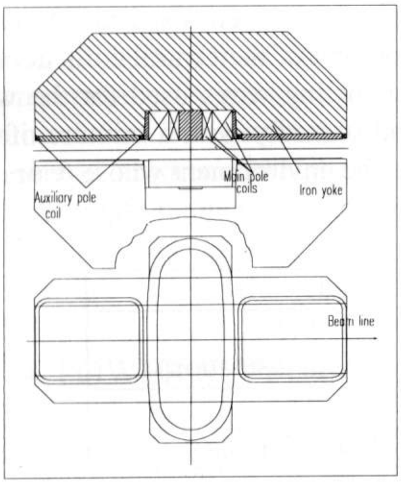

Figure 1 Schematic View of Wiggler Coils

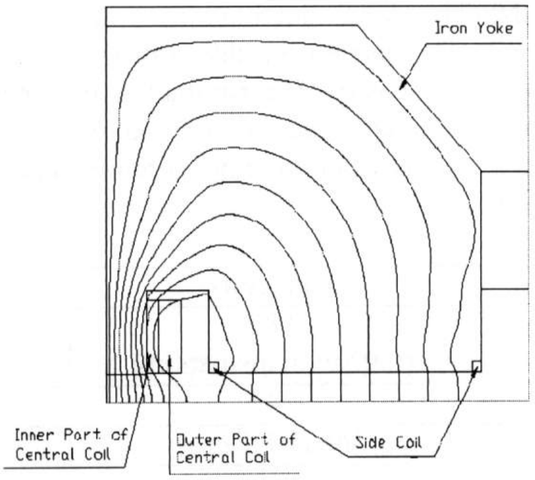

Figure 2 Magnetic Flux Map

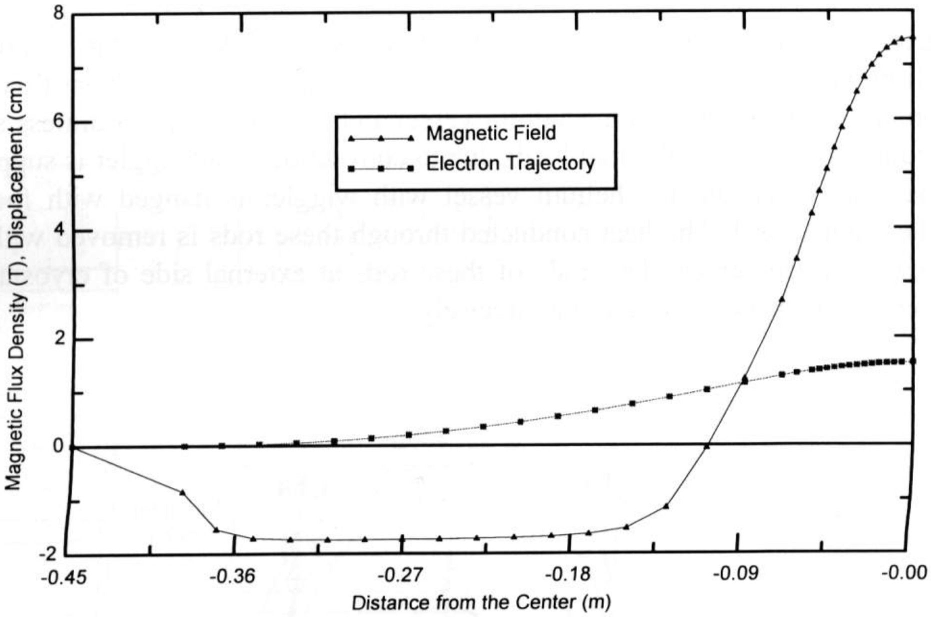

Figure 3 Magnetic Field and Electron Trajectory inside Wiggler

During the manufacture of a superconducting coil a several forces must be considered. First, the differences of thermal expansion coefficients between the materials used make mechanical forces. It is necessary to distribute it uniformly inside the coils to protect against the damages due to strong stresses . Second, the extremely high magnetic pressure inside coil will produce the expansion of the central coil. The 5 layers of stainless steel wire were wound over a superconducting coil to resist against the movement of superconducting wires. The last, carbon plastic slabs are used as the mechanical restraint between the longer curvature parts of the central coils and the iron yoke. The very small thermal elongation of it compared to iron yoke enable to press these parts of the coils during cooling down.

Two types of Nb-Ti superconducting wire with lacquer insulation were used to fabricate the wiggler coils. The wire diameter for the side coils is smaller than that of the central coils in order to optimize the field-current density. The parameters of superconducting wires used for the wiggler coils are summarized in Table 2.The wiggler coils were wound wettedly with a mixture of epoxy resin and aluminum oxide and after winding coils were cured in the environment whose temperature was 120 C for 12 hours.

parameters	main coils	side coils
diameter(mm)	0.87 (0.92 with insulation)	0.7 (0.75 with insulation)
ratio of NbTi:Cu	0.43	0.43
critical current (A)	360 at 7 Tesla	230 at 7 Tesla

Table 2 Parameters of Superconducting Wires

3. CRYOSTAT DESIGN AND MANUFACTURE

The wiggler is inserted in a helium cryostat. The drawing of the cryostat is shown in Figure 4.The inner helium vessel is surrounded by the nitrogen screen to reduce the heat flux from outside due to radiation. The spaces between the helium vessel and the outer warm stainless steel vessel is maintained vacuum to reduce the thermal loads due to convection. The wiggler is supported by side walls of the helium vessel and the helium vessel with wiggler is hanged with four invar rods connected to the outer vessel. The heat conducted through these rods is removed with the thermal contacts with the nitrogen sereen. The ends of these rods at external side of cryostat are used to align the wiggler with respect to storage ring precisely.

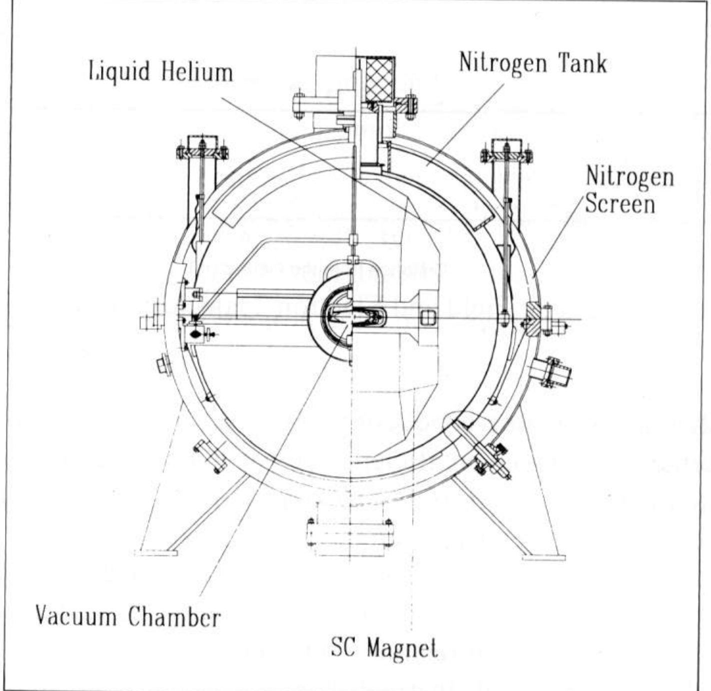

Figure 4 Wiggler Cryostat

The wiggler coils are connected permanently with the current leads which are cooled down by evaporated gas helium from the helium vessel. The wiggler vacuum chamber for electron beam has room temperature. To reduce the heat flux, it is also surrounded with the nitrogen screen and vacuum insulation. The heat due to the absorption of synchrotron radiation is removed by the water-cooled photon absorbers which is installed inside the vacuum chamber. The calculated liquid helium consumption rate is about 72 litter a day but the measured one was about 80 litters per day.

4. POWER SUPPLY AND QUENCH PROTECTION SYSTEM (QPS)

The general view of the electrical connections between coils and power supplies is shown Figure 5. Two power sources enable to control the magnetic field integrals being zero. One of them can be regulated from - 30 A to 100 A to compensate the magnetic flux from another power supply. QPS are coupled with power supplies to open the circuit at start of quench. QPS consists of thyristor switchs, quench detectors, capacitors and dump resistors. The thyristor switch is intended for fast open of wiggler circuit if superconductivity quenches. The dump resistor extracts the stored energy from the coils during quenches.

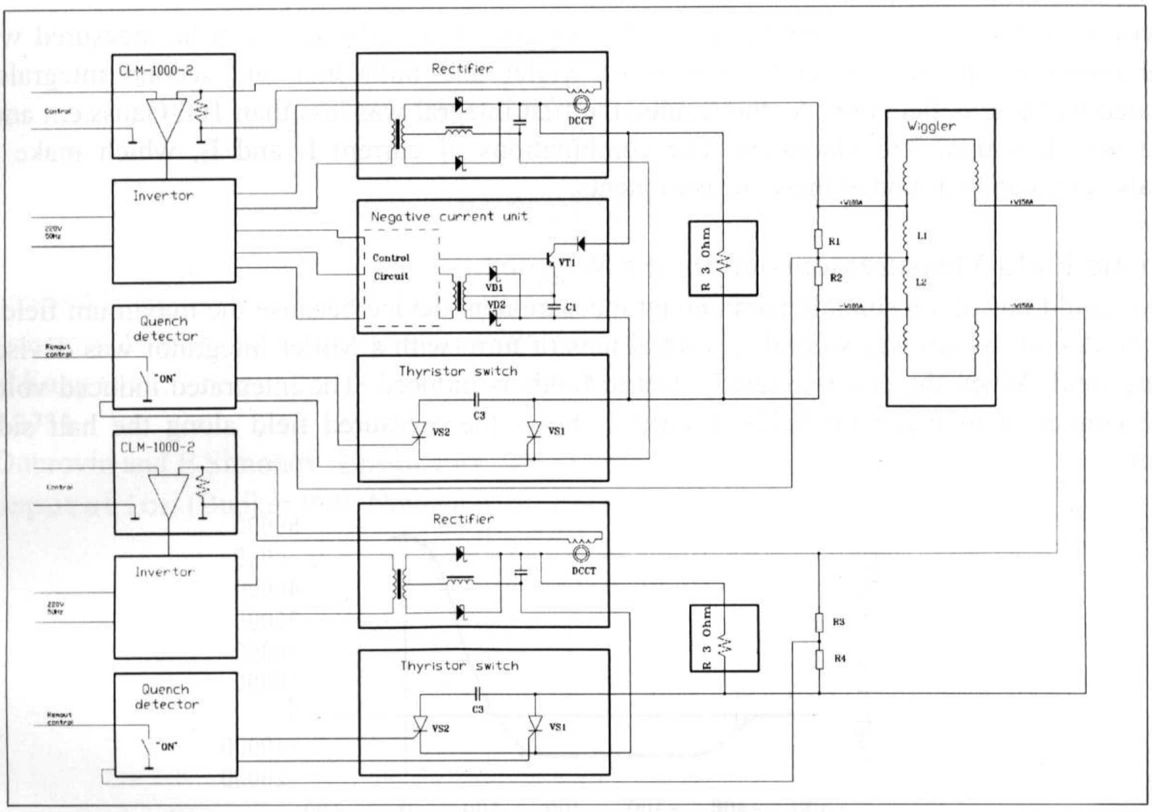

Figure 5 Diagram of Power Supply and Quench Protection System

5. TESTS AND MEASUREMENTS

Magnetic Measurements of a Field Integral

A method of a straight wire with a current was used for field integral measurements. This is based on a similar behavior of the wire with a current in a magnetic field to that of electrons moving along a orbit in a storage ring. Figure 6 shows the schematic view of the measurement system.

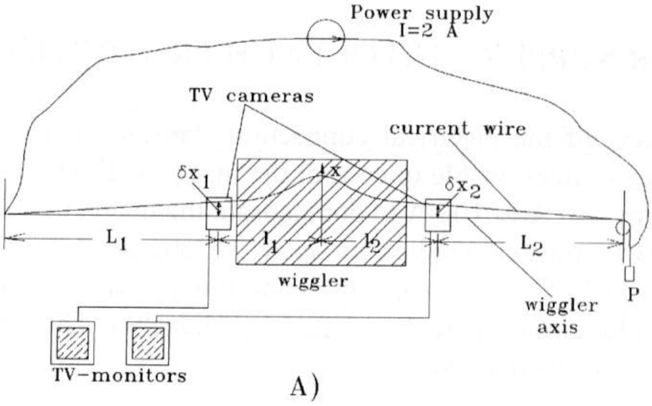

Figure 6 Schematic View of Field Integral Measurements

The wire is distorted by a Lorentz force in the wiggler. The deflections can be measured with a optical measurement devices at both ends of wigler and both first and second integrals are calculated by these deflections. As the results, the first integral was less than 100 Gauss.cm and the second was less than 350 Gauss.cm^2.The combinations of current I_1 and I_2, which make field integrals zero, can be found at these measurements.

Magnetic Field Measurements along the Wiggler

We could not find a suitable commercial measurement device because the maximum field was too high. A coil, which was wound a several tens of turn, with a Miller integrator was devised to measure fields.When the coil is rotated, electric fields is induced. The integrated induced voltages can be converted to magnetic fields. Figure 7 shows the measured field along the half side of wiggler.

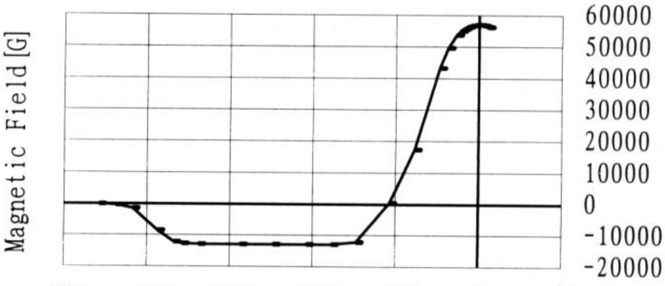

Figure 7 Measured Magnetic Field inside Wiggler

Quenches and Training

To achieve the maximum field with the wire's critical properties, a several quench is indispensable. From the Figure 8, each quench increases its magnetic field. It' due to removals of coils tension stored during manufacture. The first plot was conducted without iron yoke, so these data were estimated from the measured currents with the MERMAID. But the second one was obtained in a condition that the wiggler was assembled fully with its own cryostat.

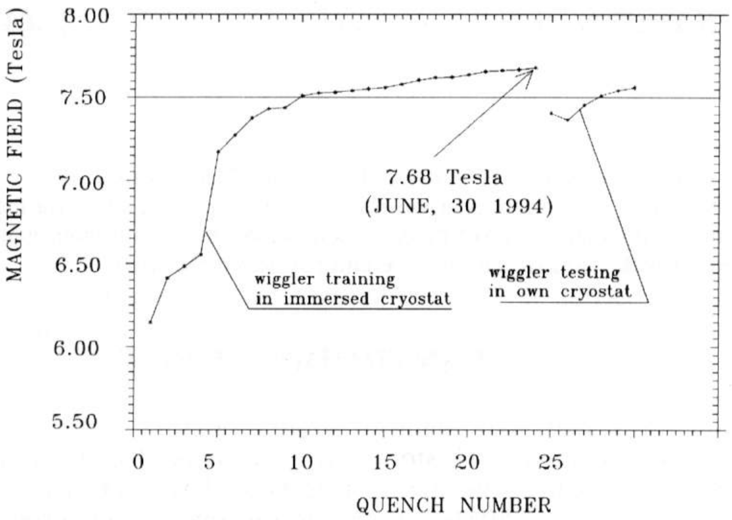

Figure 8 Quench History

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