DEVELOPMENT OF THE SUPERCONDUCTING BENDING MAGNETS FOR THE SR RING

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Abstract

The superconducting bending magnets with a bending radius of 0.5m and magnetic field of 4.0T have been developed. The bending angle is 90 degrees therefore four magnets are installed in the synchrotron radiation ring. The main coils of the bending magnets are the iron-free curvature dipole coils and the conductors are 3-divided keystone type. The shim coils are epoxy-molded quadrupole coils installed directly on the beam duct. The design of these coils was accomplished using computer simulation. The designed electron beam energy is 615 MeV and the radiation power from the beam to the magnet is 1kW so that the absorber cooled by liquid nitrogen is set in the beam duct. Test results validated the design.

Introduction

Synchrotron Radiation (SR) for industrial applications is one of the key technologies for the next generation; however, the usual SR ring system is too large to be applied for industrial use. Several companies are developing compact rings. Sumitomo Electric Industries, Ltd. (SEI), began development of a compact SR ring system using four superconducting magnets (S.C. magnets). The S.C. magnet, with its strong magnetic field, presents a compact SR ring design, because the strong magnet field can produce a small particle bending radius. The electron beam energy is designed 615MeV with a stored beam current at 200mA and a peak wavelength of 5Å. The designed bending radius is 0.5m.

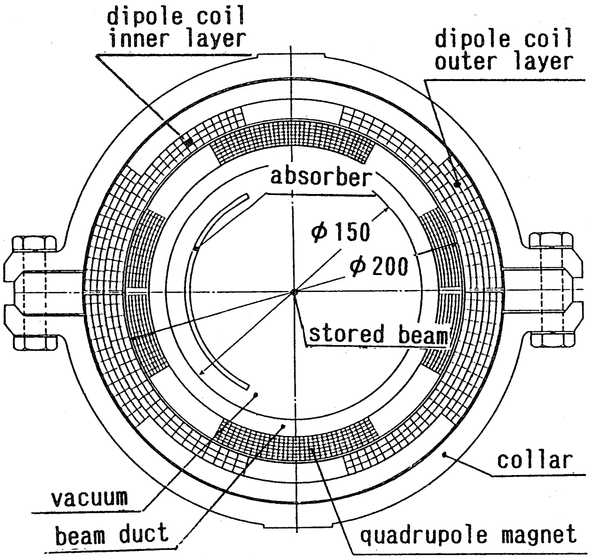

Fig 1. Cross section of the superconducting magnet.

Outline of the S.C. bending magnet

This magnet is made of two groups of coils. One is curved dipole coil, and the other is a curved quadrupole coil. Its cross section is described in Fig.1. Among the coil types for application to the SR ring, a dipole type coil(cosθ winding) was chosen. The advantage of this type is that the magnetic field distribution is the most homogeneous, but it is difficult to get many S.R. beamports. However, it is estimated that two beamports can be taken from the coil end. This dipole and quadrupole coil can be operated independently, so the magnetic field gradient (field index) of this bending magnet can vary with the quadrupole coil current. The magnetic field produced by the dipole coil is 4.0T when the main dipole coil current is 1774A and the current density is about 270A/mm^2. The field index can be varied from 0 to 0.5. The excitation rate is 0.34T/min.

No magnetic materials are used in this magnet to avoid magnetic saturation problems. Since the magnetic field distributions do not change with exciting current, their accuracy depend on only the power source's accuracy whose design value is 10^{-4}.

The structure of dipole coil is a double pancake coil, with an inner radius of 100mm and an outer radius of 123.5mm. The conductor type used in the dipole coil is a compacted strand cable. It is made of eight Nb-Ti strands and insulated by two kinds of Kapton thin tape (see Fig.2). The keystone angle is the average size of the outer and inner layers. The keystone figure cable is divided into three cables to reduce the current one-third. These 3 strands are wound in parallel and cured in a hot press. After forming this coil, these three cables are joined at the magnet end serially. This method has many advantages for making SR system compact. To make the same magnetic field, the volume of the power source, and current leads become smaller, and the consumption of liquid helium can be reduced.

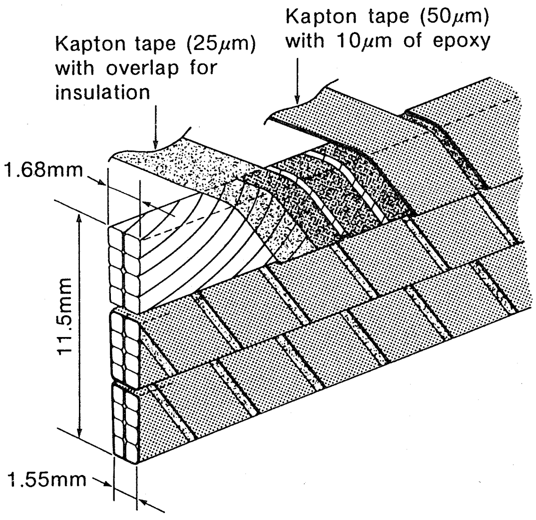

Fig 2. Structure of the 3-divided compacted strand cable.

The quadrupole coil set on the beam duct is molded by epoxy resin, and the dipole coils are fixed between the molded coils and the reinforcing collar which is fastened by bolts.

Its longitudinal length is about 2m. Since there is not adequate space for a vacuum pump near the magnet, a cold bore type similar to the cryo pump was adopted. The duct wall is cooled to liquid helium temperature. In order to avoid the increase of liquid helium consumption by SR power, there is a SR absorber inside of the beam duct. The absorber itself is cooled by liquid nitrogen, since it is also a kind of cryo pump.

Design method of magnets

Generally, for this iron-free type magnet, its magnetic field leaks into a wide area and includes large amount of multipole components. These multipole components disturb electron beam accumulation, therefore, the design of the magnet coil ends is very important. The magnet is designed considering the multipole components reduction. At first, a large diameter of dipole coil was selected, thus greater than octa-pole components could be ignored. Quad and sextuple components are still large. To compensate for these multipole components, two unique designs were considered. One is to place the quadrupole coil in the dipole coils. The main purpose of this design is adjustment of the field index. The other is forming the sextupole component of inverse polarity at the coil end. This component compensated the original sextupole component in coil main body and coil ends. Therefore at the coil ends, the distribution of leakage magnetic field and sextupole component of it vary drastic. Fig.3 shows these distributions at the median plane of this magnet. S means the distance from the bending section of 90 degrees. By making sextupole component at the coil end, the polarity of it changes between s=0 and s=100mm. Under these conditions, a good field uniformity of 5×10^{-4} more than 45mm at the coil center was obtained.

There are no precedents for SR ring construction using such a small bending radius and a iron-free magnet. The beam tracking calculations were performed to confirm the design results. For this kind of bending magnet, the linear isomagnetic treatment of beam optics and particle tracking is no longer adequate, because the end magnetic field of this type magnet leaks into a wide area, and the trajectory of the particles are changed by this field. Therefore a particle tracking computer code was developed. This code solves the 3-D motion equation by the Runge-Kutta method under a 3-D magnetic fields, so that their longitudinal distribution along the electron beam path was considered. To calculate the magnetic field of the magnet, we made a simulation model of dipole and quadrupole coils. Since this magnet is iron-free type, finite-element-method was not necessary. Therefore only the more important coil model was modeled. This program can treat multipole effects; however, one defect of using the Runge-Kutta method on beam tracking is the long solution time. Therefore, the dynamic aperture region cannot yet be precisely calculated. It is estimated horizontally about 70mm and vertically 15mm at the septum magnet.

The total ring design was done by the 2nd order beam tracking program. Results of the 2nd order simulation and 3-D real field tracking have good agreement when the initial emittance is small. The setting parameter of the current ratio between the dipole and quadrupole coil is calculated from the 3-D simulation code.

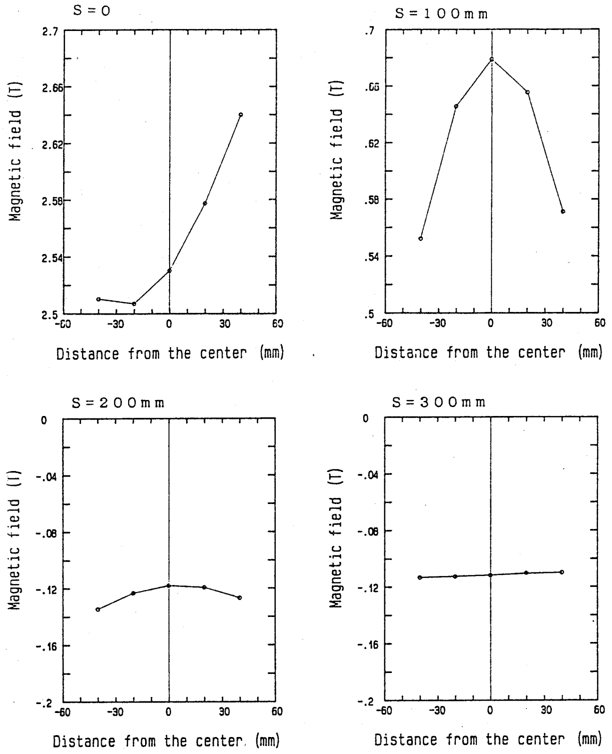

Fig 3. Distribution of the leakage magnetic field.

Magnetic field measurement

There are some difficulties when measuring the magnetic field of this magnet. One is the curvature of this magnet with a beam duct, and the other is the environment of the measuring point, such as at a liquid helium temperature and in a high vacuum. Therefore NMR sensor was used, however the NMR sensor can be used only in a good field region. Six NMR sensors are placed in the center of the magnet. In the coil ends, the magnetic field varies radically, so the NMR sensor can't be used. Thirty Hall sensor were finally chosen to measure the distribution of the magnetic field along the axis.

The magnet has been energized under a nominal current of 1322A. The results of the measurement dipole fields by using NMR sensors at the magnet center are displayed in Fig.4. In this figure, where solid lines represent design values, measured and design data are in close agreement. The variation of the dipole field along the electron path is shown in Fig.5. Again close agreement between measured and design values were obtained. In this experiment, by the thermal disturbance through the sensor holders, the magnetic field didn't reach the design value; however, in another series of experiments without sensor holders, it exceeded the designed field. Training results of this magnet is shown in fig.6. Current margin was taken about two times. When energized the quadrupole coil inside the dipole coil, reduction of achieved current wasn't observed.

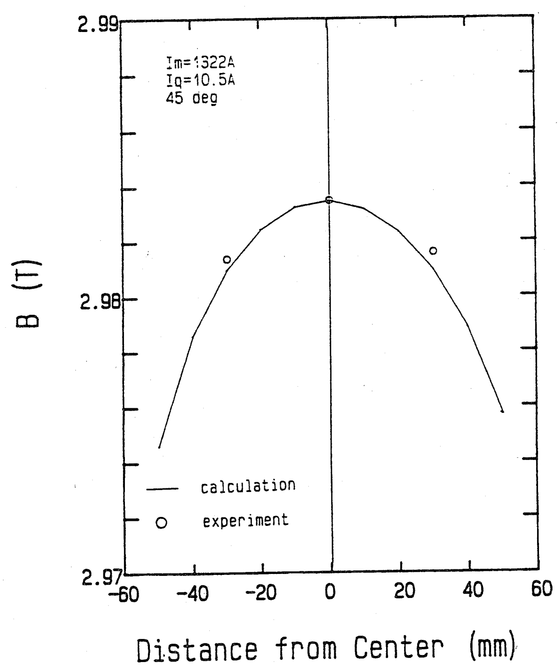

Fig 4. Magnetic field distribution at the magnet center measured by NMR sensors.

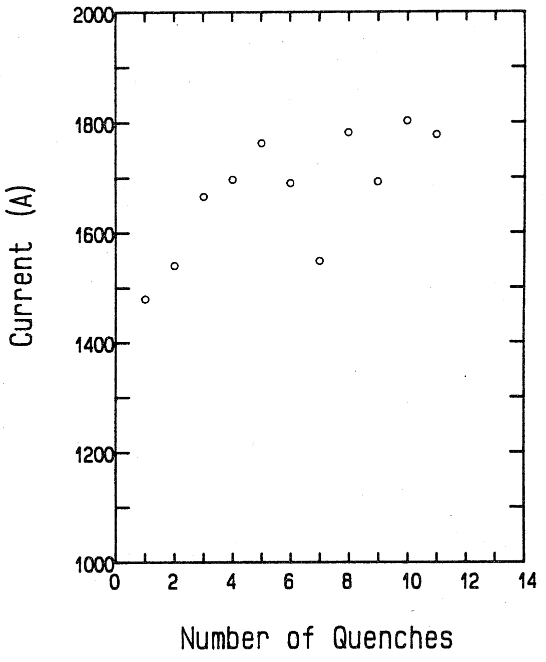

Fig 6. Training results.

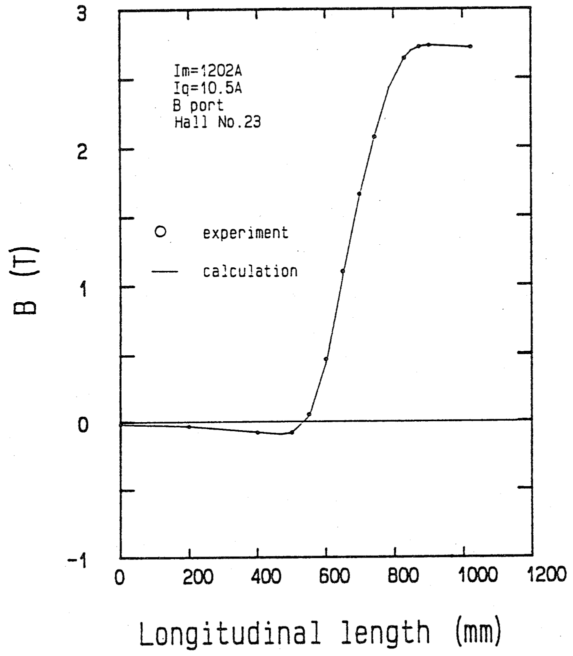

Fig 5. Magnetic field distribution along the electron path measured by Hall sensors.

Conclusions

A new type of iron-free bending magnet for a 615MeV SR ring with bending radius of 0.5m and magnetic field of 4.0T has been developed, and the measured data validated design.

One of these magnets was set in the SR ring in September 1989, and SR ring could accumulate several currents. Now other magnets are ready to be set in the SR ring.

Acknowledgments

The authors wish to thank Dr.Tomimasu of the Electrotechnical Laboratory for his useful advise.

This project is entrusted by the Research Development Corporation of JAPAN.

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