THE NSLS MAGNET SYSTEM.

J. Galayda, R. N. Heese, H. C. H. Hsieh, and H. Kaper

Abstract

An overview of the National Synchrotron Light Source magnetic component system is given. Design parameters, construction methods and measurement procedures for the dipoles and multipole are presented for the storage rings and booster synchrotron.

Introduction

The design of the magnets of the National Synchrotron Light Source is determined by the following considerations: 1) Low power consumption. Current densities in the coil packages of all magnets are 2.3-6.2 amp/mm². 2) A race track coil configuration is used, as it is less expensive than saddle-shaped coil. 3) High field accuracy within a beam stay-stable aperture of 30 mm radius in the quadrupoles, \( x = \pm 17\) mm the storage ring dipole, and \( x = \pm 25\) mm in the booster dipole.

Magnetic measurements on the multipole magnets will be performed using a harmonic analyzer and long and short coils. The bending magnets will be measured using a rotating coil gaussmeter. Gaussmeter probe positioning and data acquisition are completely automated.

Sections 1, 2, and 3 of this paper describe the bending magnets, multipole magnets and correction components, respectively. Section 4 outlines the poletip design procedure and mentions some design considerations influenced by error analysis of the magnets. Section 5 describes the magnetic measurement systems.

1. Ring Benders

Ring benders are "C" type magnets, with 1.5 mm thick laminations made of Armco specially cold rolled magnet steel. The magnet assembly is curved, with parallel ends. Laminations are glued into sub-blocks by using 3M structure adhesive No. 2216 (clear), heat cured at 350°F for a duration of 10 minutes. The curvature of the magnet is approximated by a series of straight sub-blocks with appropriate front face angles. The sub-blocks are mechanically anchored on top of a rigid girder. Axial constraint is provided by thick end plates and tie rods. Although the gluing method lengths the assembly time due to the long curing cycle, welding the curved magnet assembly represents a risk of thermal distortion. Since there are only thirty-two (32) ring bender assemblies for the whole project, any rejection of the magnet assembly due to dimensional variation caused by thermal distortion presents substantial financial loss to the magnetic components' budget. Therefore, the gluing method is favored.

It was decided at an early stage of the project that the ring bender laminations will be identical for both VUV & X-ray rings. The booster will utilize the same punching dies, except with some minor modification of the pole face for the desired deocusing gradient -0.744 Tesla/meter and sextupole term \( B'' = 11.7T/m²\) at a central field of \( B = 1.226T\). This approach drastically reduces the cooling cost and shortens the production duration of the laminations and magnet assemblies.

2. Ring Multipole Magnets

A. Quadrupoles - There are two different types of quadrupoles of various lengths for NSLS project, namely, high gradient and low gradient. The design philosophy of these quadrupoles is similar. Pole contour is a hyperbolic curve truncated with straight lines at the outer edges. Pole stems have parallel sides so that race track type coils, rather than a more expensive saddle type, can be used. The magnet core is broken into quadrants so that the low power consumption coil can be fitted onto the pole stems. Two quadrants of core and coils will be assembled and precisely aligned on a fixture and rigidly tied together by bolts located at the end plates. From this point on the magnet will be treated as if made of two half core assemblies. It is believed that better assembly precision can be achieved by this method. The magnet assembly will be vertically parted in the machine to accept the vacuum chamber. Exciting coils are made of 9.3 mm square copper conductor with a 5.2 mm diameter cooling hole. Turn to turn insulation is provided by 0.18 mm thick fiber glass tape half lapped, ground insulation is provided by three layers of 0.18 mm thick fiberglass tape, half lapped. Coils will be vacuum-pressure impregnated with epoxy to make a monolithic structure. Current density of approximately 4 amp/mm² is used for the majority of the quadrupoles. Magnet laminations are made of the same material as that of the ring bender. Laminations are tied together by welding a formed steel angle onto laminations and end plates.

3. Sextupoles - There is one type of sextupole for the whole project. Pole configuration is perfect circular type. Pole stems are straight with two parallel edges so that a race track type coil can be used. The core assembly consists of two halves, parted at 90° with respect to the vertical axis to accept vacuum chamber in the ring. Laminations are tied together by tie rods. No gluing or welding is required. This greatly reduces the assembly time of the magnet.

Exciting coils are made of 7.1 mm square copper conductor with a 6.1 mm diameter cooling hole. Turn to turn and ground insulation is the same as for the quadrupoles. Current density varies from 2.4 amp/mm² for VUV ring to 5.2 amp/mm² for X-ray ring.

Multipole magnets are mounted on a common girder. Magnets will be precisely aligned in the assembly area. Subsequent alignments in the ring will be much faster as a result.

3. Correction Components

All correction components have solid steel core, low current (less than 10A) and high impedance. Cooling of coils relies on free convection only. This approach greatly simplifies the power transmission, and coolant transportation requirements in the ring.
cost savings are realized due to simplicity of winding solid wire coils.

4. Poletio Design. Construction Errors

The magnet poletips were designed using POISSON and checked using LINDA. Several mesh configurations were tried for each magnet. Sensitivity of the dipole magnet field to construction errors was checked using POISSON. Field errors due to errors in shaping and assembly of the multipole magnets were estimated following the work of K. Halbach. The total error caused by the expected field errors was estimated in a lower order, nonresonant approximation following the work of R. Servanckx and Chao, Lee and Morton. Random and systematic errors in the shape and assembly of the magnets were created separately in the three rings. Results indicate that errors in assembly are at least as important to control as errors in die and laminations. In practice, the 45° symmetry of the laminations before assembly can be made accurate to ± 0.1 milliradians. The expected r.m.s. area of error bumps in profile can be held below 0.32 mm². However, the keyhole in the mating surfaces of a multipole lamination can be realistically expected to match each other to no better than ± 0.01 mm, while adding considerably to fabrication costs. Therefore, it has been decided that the NSLS quadrupole and sextupole halves will be assembled so that each quadrant or half is the mirror image of its mate. This arrangement allows lower order error harmonics, e.g., octupole in the quad, to be generated by errors in lamination shape. However, assembly tolerances should be considerably reduced since the mating alignment pin keyholes were cut by the same part at the die, and should naturally match to better than ± 0.01 mm. If the keyholes are not mirror images, a systematic error in the final assembly, which exceeds ± 0.05 mm, can result.

5. Magnetic Measurements

A. Dipoles - The basis for mapping the dipole fields is a Rawson-Lush Type 920 Rotating coil gaugemeter of 1.22 meter length with a Type 940 controller. The probe is mounted on a 3.5 m long table the bed fitted with a 3-axis absolute position measurement system capable of repeatedly placing the instrument at a given position with an accuracy of ± 0.01 mm. A computer drives the probe positioning system in 3 axes by selected increments, and the field and position data is stored on tape for later analysis.

It is planned to measure completely only the first magnet of each type; i.e., to explore the fringe field completely and measure all minor field components. For production measurements, the magnets will be compared to the first (or standard) magnet as to effective length tolerance and 3 vs. I. They will be checked for twist by determining the vertical position of the magnetic midplane at or near the ends of the magnet. This is accomplished by rotating the probe by 90° relative to the vertical field component, so that the voltage produced by the rotating coil is 180° out of phase with one of the reference generators, thus making the probe sensitive to variations in the longitudinal field. This method can be used quite far into the body of our magnets because of their strong curvature. Some imperfections and assembly errors will be checked by measuring the major field component in the midplane at or near the ring closed orbit. This effect will be noted for each magnet and corrected if out of tolerance.

Absolute calibration of the probe will be done against an NMR gaugemeter; this device will continually monitor the current being fed to the magnet under test by measuring the field of a "standard magnet" (either a magnet of the same type as is being measured or a special magnet expressly for this purpose).

B. Multipoles - The ring multipole so far consist of quadrupoles and sextupoles. The apparatus used to determine the field quality consists of a "short" coil and a "long" coil. Both coils are rectangular in shape and are rotated about one of their sides. The output of the coils is fed to a commercially available harmonic analyser, which samples the waveform produced at 32 intervals per coil revolution, and uses a discrete Fourier analysis to decompose the signal into its first 16 harmonics. Large harmonic signals greater than the 32-pole can cause errors; experience however shows that these are of no consequence for well designed magnets.

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## Major Magnetic Components for NSLS

<table>
<thead>
<tr>
<th>Description</th>
<th>Booster Ring Senders</th>
<th>Quadrupoles</th>
<th>Sextupoles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VUV</td>
<td>X-ray</td>
<td>VUV</td>
</tr>
<tr>
<td>Quantity</td>
<td>8</td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>B, B', B''</td>
<td>12.23</td>
<td>12.13</td>
<td>79</td>
</tr>
<tr>
<td>(kg, kg/m(^2))</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>B, B', B''</td>
<td>18.4</td>
<td>33</td>
<td>24</td>
</tr>
<tr>
<td>(kg/m(^2))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gap ht, Bore dia. (mm)</td>
<td>55</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Current (ampere)</td>
<td>1340</td>
<td>288</td>
<td>288</td>
</tr>
<tr>
<td>Power Dissipation (kW)</td>
<td>11</td>
<td>15</td>
<td>2.8</td>
</tr>
<tr>
<td>Good field region (mm)</td>
<td>50</td>
<td>68</td>
<td>68</td>
</tr>
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*Gradient = -7.44 kG/m (defocusing)*

Sextupole B'' = -117 kG/m\(^2\)

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**Fig. 1. Storage Ring Dipole. (Inset: Booster Pole Tip)**

**Fig. 2. Sextupole.**

**Fig. 3. High Gradient Quad.**

**Fig. 4. Low Gradient Quad.**