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THE NSLS MAGNET SYSTEM.*

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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/mm^2. 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-clear aperture of 30 mm radius in the quadrupoles, x = ± 17mm the storage ring dipoles, and x = ± 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. Azimuthal constraint is provided by thick end plates and tie rods. Although the gluing method lengthens the assembly time due to the long curing cycle, welding the curved magnet assembly represents higher 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 poleface for the desired defocusing gradient -0.744 Tesla/meter and sextupole term B" = 11.7T/m^2 at a central field of B_o = 1.226T. This approach drastically reduces the tooling cost and shortens the production duration of the laminations and magnet assemblies.

Exciting coils are of single layer, multiturn pancake, four pancakes per magnet. In view of the high energy cost in this region, copper alloy is favored over aluminum alloys as the coil material. Current density of 2.3 amp/mm^2 was chosen. This current density was derived from the consideration of the magnet initial cost, installation cost of power supplies, cooling facilities, space requirement of the tunnel, handling method and operating cost.

2. Ring Multipole Magnets

A. Quadrupoles - There are two different types of quadrupoles of various length for NSLS project, namely, high gradient and low gradient. The design philosophy of these quadrupoles are similar. Pole contour is a hyperpolic 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 a 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 monolith structure. Current density of approximately 4 amp/mm^2 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.

B. Sextupoles - There is one type of sextupole for the whole project. Pole configuration is of 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 30° 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 this magnet.

Exciting coils are made of 7.1 mm square copper conductor with a 4.1 mm diameter cooling hole. Turn to turn and ground insulation is the same as for the quadrupoles. Current density varies from 2.4 amp/mm^2 for VUV ring to 6.2 amp/mm^2 for X-ray ring.

Multipole magnets are mounted on a common girder. Magnets will be precisely aligned in the assembly area. Subsequent alignment 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. Great

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cost savings are realized due to simplicity of winding solid wire coils.

4. Poletip Design, Construction Errors

The magnet poletips were designed[1] using POISSON[2] and checked using LINDA.[3] 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.[4] The tune shift caused by the expected field errors was estimated[5] in a lowest order, nonresonant approximation following the work of R. Servranckx[6] and Chao, Lee and Morton.[7] Random and systematic errors in the shape and assembly of the magnets were treated separately in the three rings. Results indicate that errors in assembly are at least as important to control as errors in die and lamination shape. 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 pole profile can be held below 0.32 mm^2. However, the keyholes in the mating surfaces of a multipole lamination can be realistically expected to match each other to no better than ± 0.05 mm, while adding considerably to fabrication costs. Therefore, it has been decided that the NSLS quadrupole quadrants 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 of the die, and should naturally match to better than ± 0.01 mm. If the keyholes were not mirror images, a systematic error in match which exceeds .05 mm could result.

5. Magnetic Measurements

A. Dipoles - The basis for mapping the dipole fields is a Rawson-Lush Type 920 rotating coil gaussmeter of 1.22 meter length with a Type 940 controller. The probe is mounted on a 3.5 m long lathe 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 fringing 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 B vs. I tolerance. 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 that of the reference generator, 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. Gross imperfections and assembly errors will be checked by measuring the major field component in the midplane at or near the ring closed orbit. Twist and midplane position error will be noted for each magnet and corrected if out of tolerance.

Absolute calibration of the probe will be done against an NMR guassmeter; 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 multipoles 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 analyzer, 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.

The short coil will be used to approve the prototype lamination for production, and to design the chamfer for the quadrupole end plates. The quadrupole lamination was designed to eliminate the 12-pole component from the central field of the quadrupole, however the end fields contribute large amounts of this unwanted harmonic. By judicious chamfering of the end plates, this error field can be minimized.[8] The short coil will establish the effectiveness of various chamfers. The long coil will be used for production measurements.

Chamfering of sextupole ends is not under consideration at this time. Here again the short coil will determine the correctness of the lamination design.

As in the dipoles, an NMR probe will verify the correct excitation current of the magnet under test, and will serve as an absolute reference standard.

It is unfortunate that at the time of writing the prototype laminations have not been received due to production delays; presentation of measurements will be done in the near future.

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References

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MAJOR MAGNETIC COMPONENTS FOR NSLS

Description	Ring Benders			Quadrupoles						Sextupoles	
	Booster	VUV Ring	X-ray Ring	Booster		VUV Ring	X-ray Ring			VUV Ring	X-ray Ring
				Typ A	Typ B		Typ A	Typ B	Typ C		
Quantity	8	8	16	4	4	24	24	16	16	12	32
B, B', B" (kg, kg/m, kg/m^2)	12.23*	12.23	12.13	79	100	90	130	130	130	1000	2520
BL, B'L, B"L (kg-m, kg, kg/m)	18.4	18.4	33	24	30	27	59	105	59	200	500
Gap ht, Bore dia. (mm)	55	55	10	10	10	10	10	10	10	10	10
Current (ampere)	1340	1470	1470	288	288	256	237	237	407	100	252
Power Dissipation (KW)	11	10.5	15	2.8	3.4	2.7	5	7.6	7.4	0.4	2.5
Good field region (mm)	50	68	68	60	60	60	60	60	60	60	60

*Gradient = -7.44 kG/m (defocusing)
Sextupole B" = -117 kG/m^2

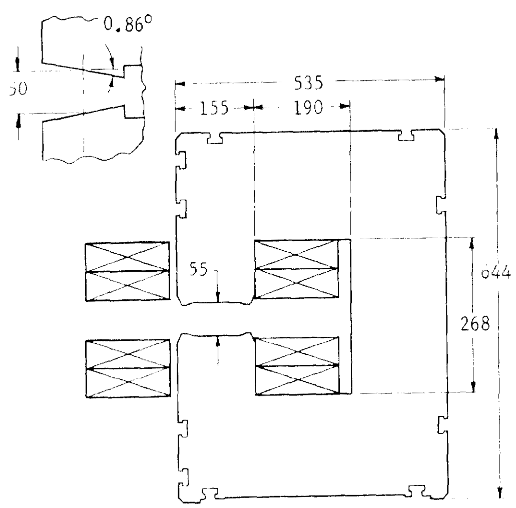

Fig. 1. Storage Ring Dipole.(Inset: Booster Pole Tip)

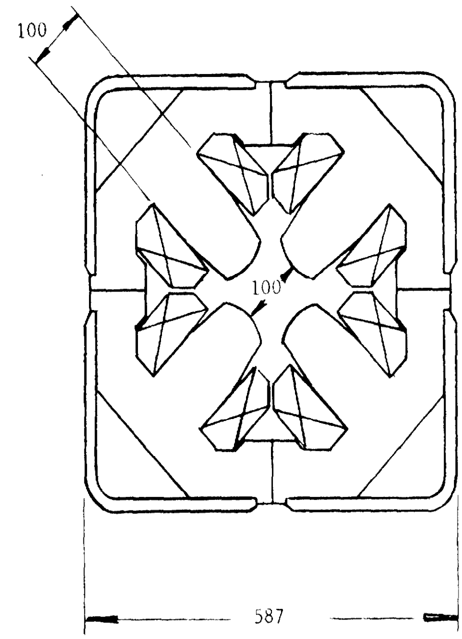

Fig. 3. High Gradient Quad.

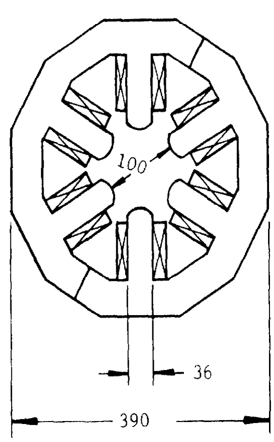

Fig. 2. Sextupole.

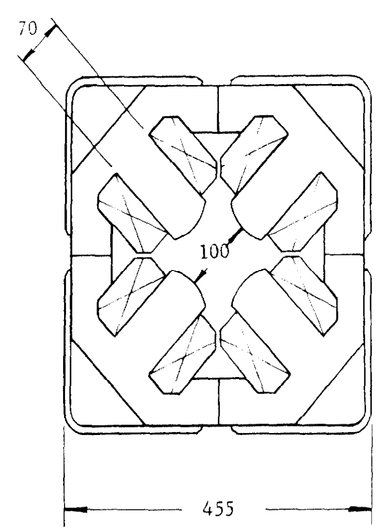

Fig. 4. Low Gradient Quad.