IMPROVEMENT OF QUADRUPOLE MAGNETS FIELD QUALITY IN SERIAL PRODUCTION *

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Abstract

Technology of production of quadrupole magnets for NSLSII main ring is presented in the article. Quadrupoles have laminated iron yokes and are manufactured in Budker Institute of Nuclear Physics. The technology includes the method of correction octupole and sextupole harmonics. Field quality measurements of the magnets are presented.

INTRODUCTION

NSLS-II [1], the new 3GeV 3rd generation light source, is presently under construction at Brookhaven National Laboratory. Six types of quadrupole magnets for main ring NSLSII were successfully manufactured in Budker Institute of Nuclear Physics (see fig 1). The magnets had three yoke length and use the same lamination shape. The lamination with thickness of 1 mm had two poles with a common back leg. The magnet aperture was 66 mm. One length magnets had two types of yoke side insertions. One of the types is used to accommodate X-ray extraction. The form of the insertions had no influence on the field quality, so magnet types will be referred to as "short", "middle" and "long" below.

Prescribed specification on field quality of quadrupole magnets are reviewed in the paper [2]. Magnets field quality is specified by harmonics volume. Harmonics are defined as coefficients in the Fourier expansion of the integrated radial or azimuthal component of the magnetic field (see attachment). Harmonics are well below 10^{-4} of the main field (1 "unit") at a radius of 25 mm.

Table1. Parameters

Magnets type	**9801 & 9802 (short)**	**9804 & 9807 (long)**	**9810 & 9813 (middle)**
Quantity	60	60	7
Yoke length	217 mm	415 mm	250 mm
Maximum field gradient	10.6 T/m	19.2 T/m	19.2 T/m
Ampere-turns	4.7 kA	8.6 kA	8.6 kA

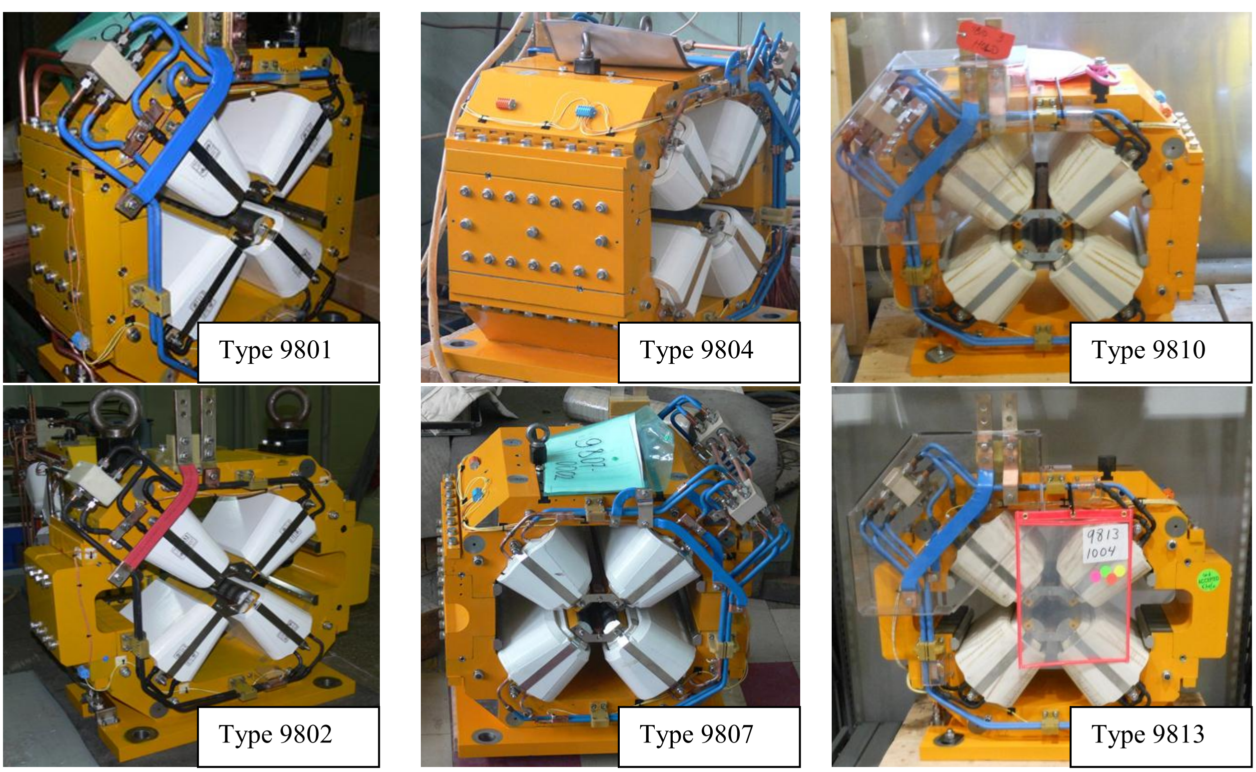

Figure 1: Quadrupole magnet types.

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MANUFACTURE TECHNOLOGY

The technology of magnets manufacturing includes high-precision lamination punching, yoke gluing in stacking fixture with movable wall, magnet assembling and tuning.

To avoid lamination shape distortion, the two stage punching was chosen. Initially rough die punched lamination blank with 6 mm allowance, and then high precision die punched final lamination. The lamination shape was monitored by measuring a pole gap of 1% samples. The deviation range for the pole gap was ±0.15 mm for lamination blanks and ±0.02 mm for final laminations. Also the lamination shape was monitored by measuring several samples of the laminations with a coordinate measuring machine. For example, the maximum deviation of the pole hyperbole shape with respect to the calculated ones was 6.5 μm, and the standard deviation of the distributions was 3.2 μm for one random lamination.

Ready lamination was stacked and glued in yoke halves with high precision. The precision was controlled by measuring pole gap along yoke. For example, measurements were carried out in twenty points along magnet axis for long yoke. Measurements of all long halves show standard deviation from average gap better then 10 μm. The volume of average gap was tuned by bar insertions (see figure 2) after magnet assembling.

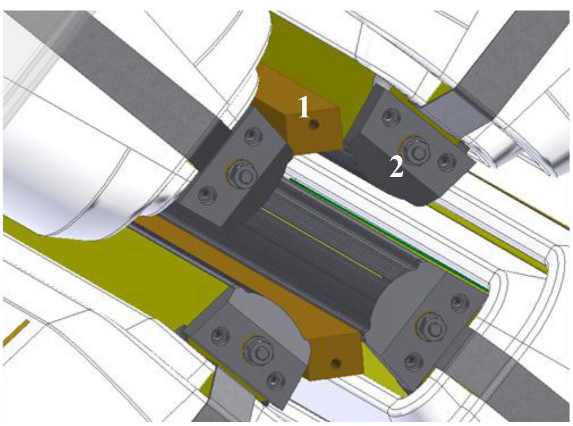

Figure 2: Magnet draft; 1 - bar insertion, 2 - nose piece.

The bar insertions had parallel surfaces and were fabricated from non-magnetic material. Its length is equal to yoke length for robust pole fixation. Width of the bar insertion was fitted to correct skew-sextupole a_3 and normal-octupole b_4 harmonics. Another advantage of using bar insertions to fix poles distance is increasing mechanical stability and therefore increasing magnetic field stability before and after magnet reassembly.

Reassembly tests were executed for all ready magnets. Typical harmonics changing was very small. For example for one random magnet #9804-0012 maximum changing was 0.15 units for harmonic b_4 (see figure 4).

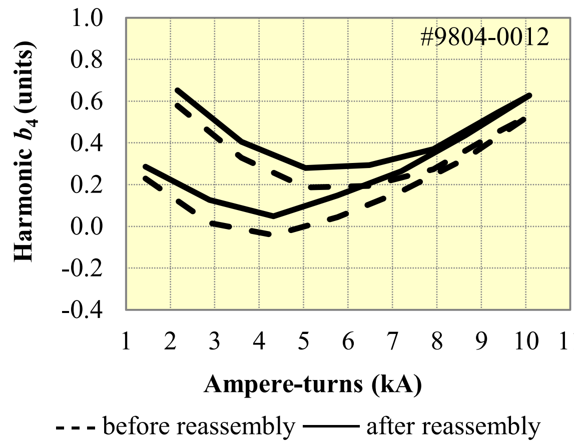

Figure 4: Measurements of harmonic b_4 dependence from current before and after reassembly.

The last elements installed on magnets were nose pieces. The nose piece was a part of pole with chamfer. Its length and height were 15 mm and 35 mm correspondingly (see fig. 1).

Nose piece fasten to yoke with stud. The fastening allow nose pieces to be shifted on 1 mm along pole face. The shift was used for corrections of sextupole, octupole and sometimes decapole harmonics. After the tuning, nose pieces got fixed by pins. One of the nose pieces well-known advantages is the integral increasing without increasing outer magnet dimensions. For long magnets the field integral was increased by 2.5 % and for middle ones by 5.1 % at design current.

Statistics for long magnets of low harmonics measurements before field tuning, and after installation of bar insertions and nose pieces, is shown on figure 4.

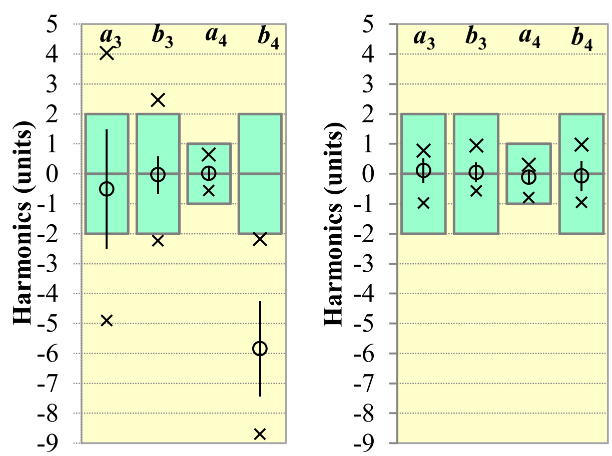

Figure 3: Statistics for 60 long magnets tuning. The circles show the mean value of each parameter, the lines give a ±sigma spread, and the x – the maximum and minimum value. Green rectangles show requirements. Left statistics show measurements before field tuning, right – after installation of bar insertions and nose pieces

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Harmonic b_4 shift is the result of poles gaps understating. The understating is needed for installation and fixation of bar insertions.

All tunings are carried out under continual control of magnetic field quality by measurements. For this case, special fast and high-precision measurement stand on the base of rotating coil was developed [3].

Final measurements of harmonics amplitudes $Ampl_n = \sqrt{a_n^2 + b_n^2}$ for all magnets manufactured at BINP for NSLS-II main ring are shown on figure 6.

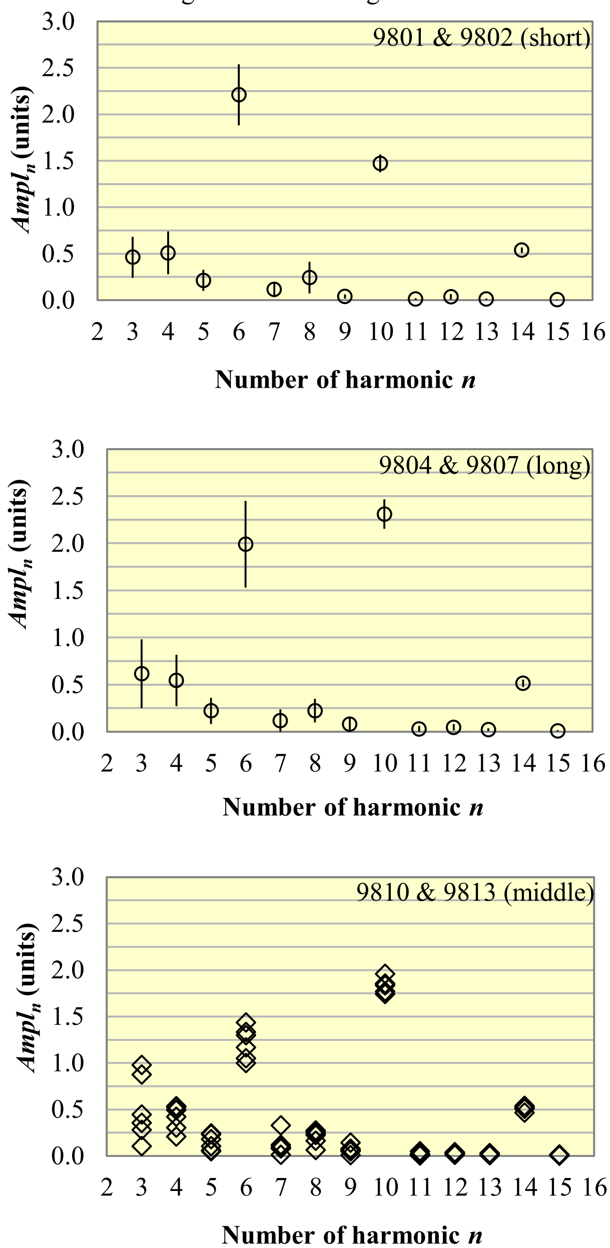

Figure 5: Statistic of magnetic field measurements for all magnet types. The circles show the mean value of each parameter, the lines give a ±sigma spread. The diamonds show volume of parameters.

CONCLUSION

The base of high field quality magnet manufacture in the described technology was high-precision lamination punching and high-precision half yoke gluing. No special control of poles gaps were exercised during magnet assembly. But assembled magnets were individually tuned, using bar insertions and nose pieces. The tuning was fast and showed good results for correction magnet fields in serial production. Bar insertions were useful not only for magnetic field correction, but also for field stability during magnet reassembly. The individual tuning of each magnet enables the manufacturing the whole series of quadrupoles with good magnetic fields. In the issue, field quality completely satisfied the prescribed specifications.

The methods elaborated can be used in further multipole magnet production.

ATTACHEMENT

The normal and skew 2n-pole integrated fields, B_n and A_n respectively, are defined as coefficients in the Fourier expansion of the integrated radial or azimuthal component of the magnetic field according to the following equations:

$$\int B_r(r,\varphi,z)dz = \sum_{n=1}^{\infty}\left[\frac{r}{r_0}\right]^{n-1}(B_n \sin n\varphi - A_n \cos n\varphi),$$

$$\int B_\varphi(r,\varphi,z)dz = \sum_{n=1}^{\infty}\left[\frac{r}{r_0}\right]^{n-1}(B_n \cos n\varphi + A_n \sin n\varphi).$$

The integrated quadrupole field is taken at $r_0 =$ 25 mm.

The relative strengths of the harmonics (in "units" of 10^{-4}) in a quadrupole magnet are defined as:

$a_n = A_n/B_2$, $b_n = B_n/B_2$.

ACKNOWLEDGEMENT

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REFERENCES

[1] F. Willeke, “Status of NSLS-II Project”, TUOBS3 PAC '11.

[2] J. Skaritka, "The Design and Construction of NSLS II Magnets", MO6PFP008 PAC '09.

[3] A. Tsyganov et al., “Stand for precision measurements of magnetic lenses for synchrotron radiation source NSLS-II”, WEPPC022, these proceedings.

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