QUADRUPOLE HARMONICS TUNING BY NOSE PIECES*

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Abstract

Six types of quadrupole magnets for NSLS-II main ring have been manufactured at the Budker Institute of Nuclear Physics. Some types of magnets have nose pieces on poles. Nose pieces permit the correcting of magnetic field harmonics. Corrections of octupoles, sextupoles and allowed harmonics have been implemented. Also for some magnets, corrections of amplitude of dependence sextupole harmonic from current have been implemented.

INTRODUCTION

The magnets had three yoke length (see table 1). Yoke of all magnets were glued from the same type of laminations. The lamination had two poles with a common back leg and thickness of 1 mm. 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.

Table 1. 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

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.

The great labour has been applied to obtain the required field quality [2].One of the additional elements, which used to improve the field quality, was nose pieces. They were installed on middle and long magnets.

NOSE PIECES

Nose piece is a part of pole with chamfer. Its length and height are 15 mm and 35 mm correspondingly (see fig. 1). Nose piece fasten to yoke with stud. The fastening allow nose pieces be shift on 1 mm along pole face. The shift was used for corrections of sextupole, octupole and sometimes decapole harmonics.

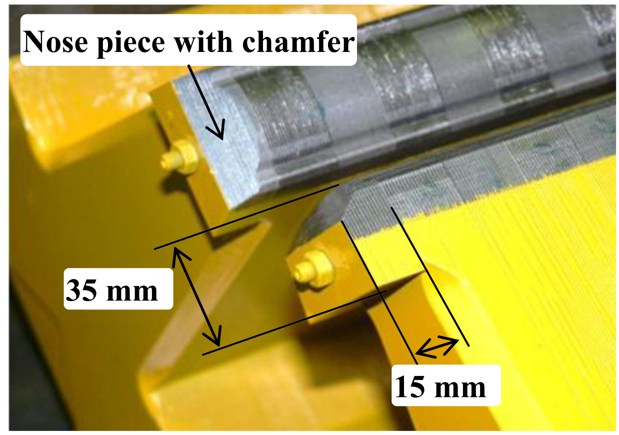

Figure 1: Nose pieces on one halve of magnet yoke.

The corrections demand the continual control of the magnet field quality. So, nose pieces position was tuned on the magnetic measurement stand [3] by iterations of tuning first then measuring the result changes. Usually three-five iteration was enough for tuning the field quality to achieve the desired result. Figure 2 shows measurements of lowest harmonics of magnet before the nose pieces installation and after the tuning. After the tuning, nose pieces got fixed by pins.

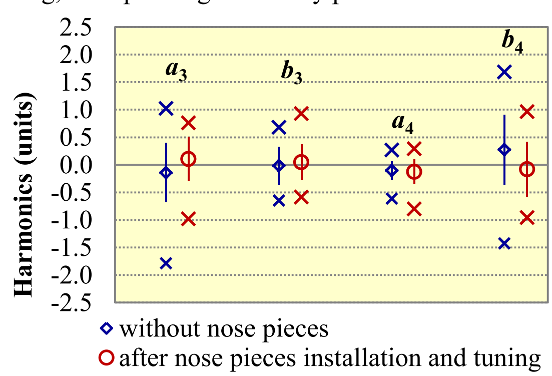

Figure 2: Statistic for 60 long magnets tuning. The circles and diamonds show the mean value of each parameter, the lines give a ±sigma spread, and the x – the maximum and minimum value.

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.

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SEXTUPOLE HARMONIC DEPENDENCE OF CURRENT

In quadrupoles with yoke composed of two halves a_3 and it dependence of current can be big. The main effect observed for long magnets. First measurements of the field quality of magnet #9807-0001 show Δa_3 = 4 units in the required range 65-100% of design current.

Special parallel lamination sorting was employed to make one halve of yoke identical with the other. As a result, all magnets had less Δa_3 than first. Figure 3 shows the statistic of measurements of Δa_3 for long magnets.

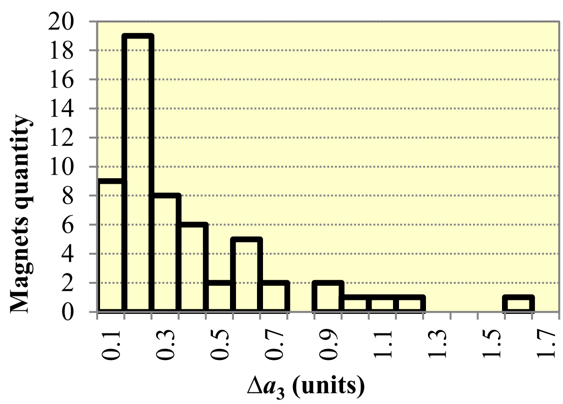

Figure 3: Statistic Δa_3 in 65÷100 % of design current range for 60 long magnets.

As experiment, an additional method of decreasing Δa_3 was checked on some magnets. The idea of this method is the shortening of length of nose piece, which are installed on one of yoke halves. Figure 4 shows example of the experiment for the magnet #9804-0009, whose top nose pieces were shortened by 0.2 mm.

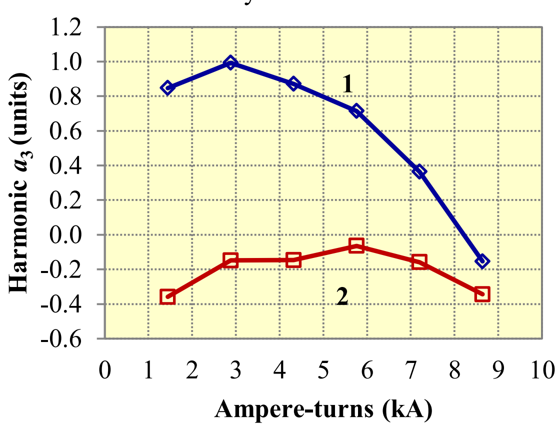

Figure 4: Measurements of harmonic a_3 dependence from full current for magnet #9804-0009: 1 - magnet without nose pieces; 2 - nose pieces were installed on magnet.

Applicability of the method is limited because shortening of some of nose pieces results in the increasing volume of a_3. To correct a_3 nose pieces were shifted after installation.

MODIFIED NOSE PIECES

The lamination profile was chosen to achieve small allowed harmonics in 2D. Immediately magnet edges in 3D increase harmonic b_6. Chamfers, which were placed on yoke ends, fitted b_6 to the required range ±3 units, but increased b_{10}. For some short magnets b_{10} goes to the boundary of requirements (see table 2).

Table 2. Statistic of allowed harmonic terms for ampere-turns 8.6 kA

Magnets type	short	long	middle
Yoke length	217 mm	415 mm	250 mm
Chamfer size	8 mm	13.5 mm	13 mm
b_6	-2.1±0.5	-1.2±0.2	-2.2±0.3
b_{10}	-2.3±0.2	-1.8±0.1	-1.5±0.1
b_{14}	-0.5±0.03	-0.5±0.02	-0.5±0.03

It was offered to modify nose pieces profile to decrease all allowed harmonics at the same time. By the instrumentality of MERMAID software [4] the profile was designed (see figure 5).

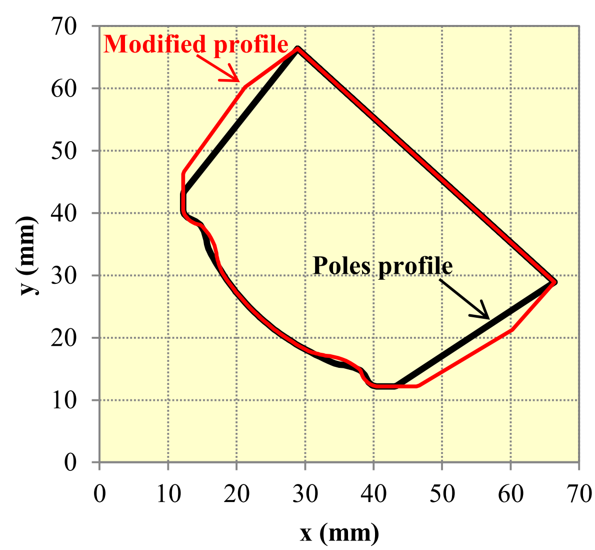

Figure 5: Nose pieces profiles

The set of nose pieces was manufactured with the calculated profile. In the experiment, the modified nose pieces were installed on magnet #9813-0001 and magnetic fields were measured. Then, usual nose pieces, which profile corresponds to yoke pole profile, were installed on the same magnet and magnetic measurements were done again.

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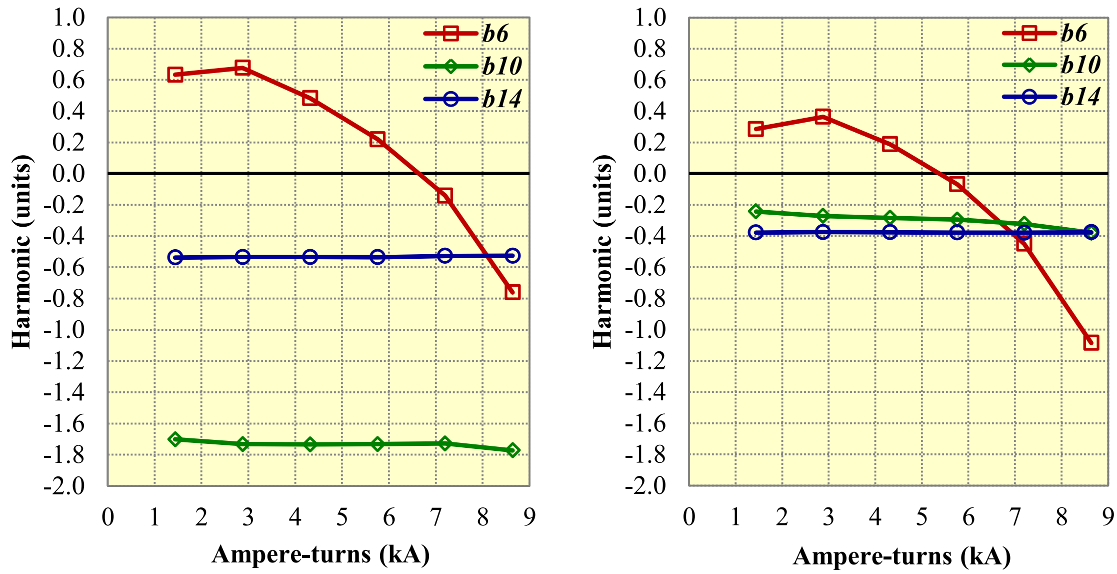

Figure 6: Measurements of harmonic terms dependence from current for quadrupole #9813-0001. Graphs show measurements for the same magnet with different nose pieces types: left – nose pieces have profile the same as yoke poles, right – nose pieces have **modified** profile.

Measurements of dependence allowed harmonics from current for this two cases are shown figure 6. Measurements show that the goal to decrease harmonic b_{10} without increasing other allowed harmonics was achieved.

CONCLUSION

Nose pieces not only increase field integral, but also can be used to make fast correction of some harmonics.

Fabricating nose pieces with profiles different from yoke poles profiles allow manufacture "good quadrupole" magnet. "Good quadrupole" means that magnet has fields with small allowed harmonics in the body of magnet and small integral field allowed harmonics simultaneously. Theoretically, yoke poles and nose pieces profiles can be fitted to achieve allowed harmonics as small as necessary at least for one current (b_6 show appreciable variation with current).

ATTACHMENT

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:

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

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