NONLINEAR SHUNTING AS A METHOD OF MAGNETIC FIELD CORRECTION IN QUADRUPOLE LENSES*

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Abstract

The quality requirements for magnetic field of elements in modern particle accelerators are high. For example, the harmonic fields quadrupole lenses main ring synchrotron source NSLS-II manufactured in BINP SB RAS must have no more than $1\div2\cdot10^{-4}$ from the field at 75% of the aperture of the lens. In the production process of magnetic lenses to adjust the fields of various methods of mechanical improvements are used, resulting in the increased time and the cost of production. The report proposes a method for precise non-destructive correction of some of the harmonics of the magnetic field of quadrupole lenses. The correction is performed using an additional element – the non-linear current shunt of coils. The report contains experimental data showing the possibilities of this method.

INTRODUCTION

In the Brookhaven laboratory, USA, synchrotron 3GeV light source NSLSII [1] is currently being constructed. For the main ring in BINP, several types of quadrupole lenses were designed and manufactured [Table1].

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.

To obtain the required field quality, many efforts were applied.

There are different tuning techniques of magnetic field during quadrupoles manufacturing. Most of these techniques require mechanical improvements.

The purpose of this article is to propose method of correction sextupole components using nonlinear shunt in power supply circuit of the quadrupole lens.

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

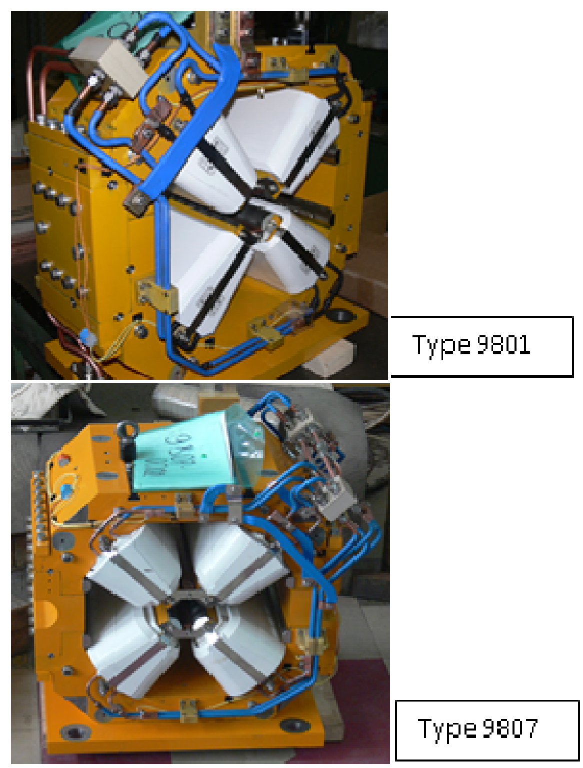

Figure 1. Two types of magnets, the experimental data are used in this article

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CURRENT SHUNT

The quality of the magnetic field of quadrupole lenses immediately after its production may not meet the specified parameters for many different reasons. Mechanical rework of magnetic core requires significant labor costs, which forces to search the other ways of adjusting quadrupole lenses. On the basis of the practical work, the method of adjusting sextupole harmonic of a magnetic field is proposed.

This method is the addition of a current shunt of quadrupole coils. The method of the current shunt is known [3]. But in this link, shunting only single coil of quadrupole lens is mentioned.

Figure 2. The cross section of the quadrupole with an asymmetric arrangement poles relative to the horizontal axis.

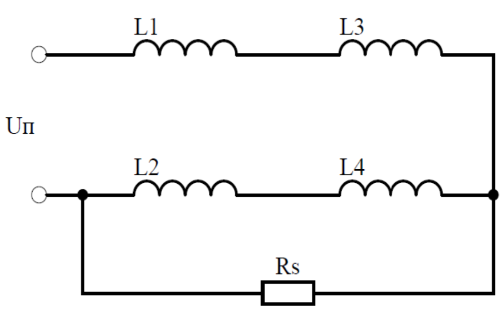

Figure 3: Scheme of shunting bottom coils of quadrupole lens. L1, L3 are top coils in quadrupole lens, L2, L4 are bottom ones. Rs is passive shunt.

Figure 2 shows the asymmetry of the poles. This means asymmetry of the magnetic field in the upper and lower gap. We can compensate this asymmetry by reducing the current in both bottom coils.

Typically, multipole coils are powered as a series circuit from a single power supply. We can change the value of currents in different coils or separate the power supply system or deliberately introduce asymmetry in quadrupole power. To do this, we need to add a current shunt to the lower coils, see Figure 3. Similarly, we can correct the asymmetry of the vertical axis if we add a shunt to side coils.

Figure 4 shows the result of the magnetic field correction. The current of shunt is ~ 0.25% of the operating quadrupole current.

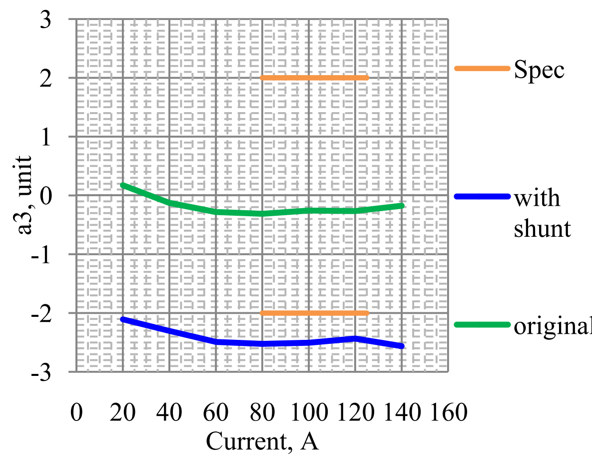

Figure 4. Result of correction of sextupole components in the magnet 9801-0015

NONLINEAR CURRENT SHUNT

Usually, customers have requirements on the harmonics value in the range of the operating current of the magnet. And if for some reason there is current dependence [4] of a sextupole component in the range of operating currents, shunting to be done must be current-dependent. An example of such a shunt may be an electrical circuit consisting of both passive components and the component of the nonlinear current characteristics, such as diodes, as shown in Figure 5. Thus, you can adjust sextupole component with complex non-linear form in the whole range of the operating current.

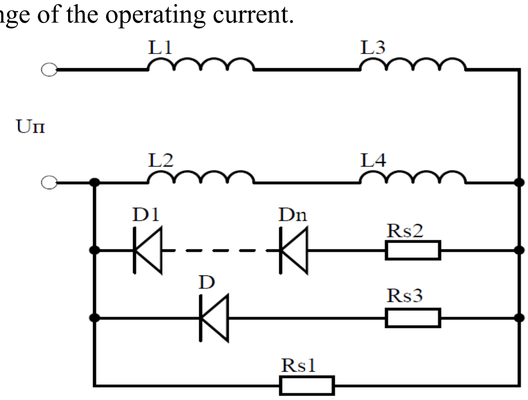

Figure 5. The general case of a non-linear shunt at the lower coils in a quadrupole lens.

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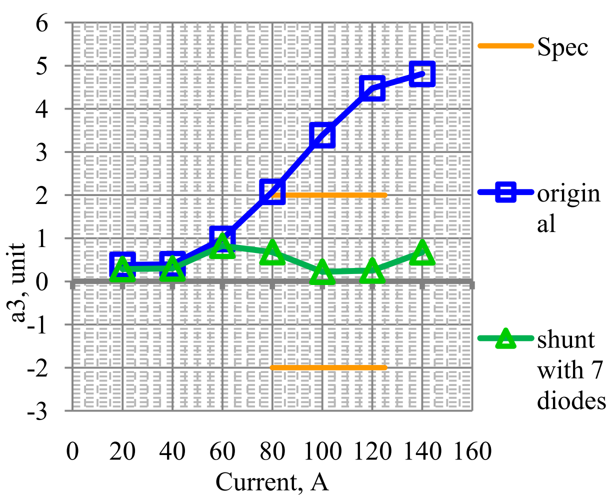

Figure 6. The correction sextupole components in the magnet type 9807.

Figure 6 shows the case of the quadrupole lens, requiring correction because the value of sextupole component in the operating current range varies from 2 to 5 units. By selecting the shunt and a number of diodes, we can adjust the lens.

In this example, the maximum current shunt is ~ 0.7% in the working range of currents.

THE METHOD OF NONLINEAR SHUNT ELEMENTS SELECTION

The possible method of selection of the nonlinear shunt elements is as follows. At first it is necessary to measure the dependence of the calibration values sextupole components of the current shunt. This function will be different for different types of the quadrupole lenses design. We measure the form of the function of sextupole components in the range of operating currents in the first measurement of the magnetic field in the custom of the quadrupole lens. On the basis of this data, the amount of necessary correction, non-linearity and calibration factor is determined by the number of non-linear elements and the value of shunt resistance.

CONCLUSION

The main advantages of this method are its simplicity and reversibility in contrast to the mechanical methods of correction. The feature of this method - the magnet is not considered as a thin lens because the method changes the magnetic field along the longitudinal axis of the lens, not locally.

This technique is not applicable or applicable only partially for the quadrupole lenses with supply voltage less than a few volts.

ACKNOWLEDGMENT

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