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Subject: **Multipole specifications for insertion devices in LF15**	**Author(s):** **R. A. Bosch**	
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ABSTRACT

Imperfections in the magnetic field of an insertion device affect the electron storage ring, thereby impacting the users of all beamlines. To minimize adverse effects, the manufacturer is required to meet specifications on the multipoles of the longitudinally integrated magnetic field. For 800-MeV ring operation in the LF15 low-emittance lattice, specifications are obtained for insertion devices located in the long straight sections and the short straight sections.

1. Introduction

Imperfections in the magnetic field of an insertion device may impact the users of all beamlines on the ring. Ideally, an electron is not deflected by passing through an insertion device, requiring that the longitudinally integrated transverse magnetic field [$\int_{-\infty}^{\infty} dz B_{x,y}(x_0, y_0, z)$] vanishes for all transverse coordinates x_0 and y_0. In our coordinate system, x is horizontal, y is vertical, and z is longitudinal. Deviations from the ideal field may be quantified by the integrated field's multipole moments. To minimize adverse effects, the manufacturer is required to meet specifications on the integrated field's dipole, quadrupole, sextupole, and octupole moments. In addition, specifications are given for the second-integral dipole error $\int_{-\infty}^{\infty} dz \int_{-\infty}^{z} dz' B_{x,y}(0,0,z')$, which causes an electron that enters on-axis to exit off-axis.

The specifications for the existing insertion devices [1] pertain to ring operation in the "base" lattice, which was the standard lattice for 800-MeV operation prior to 2002. They apply to an insertion device located in a long straight section. Since standard 800-MeV operation now uses the low-emittance LF15 lattice, we obtain specifications for operation in LF15. In addition to insertion devices located in the long straight sections, we obtain specifications for insertion devices located in the ring's short straight sections.

The specifications considered here are designed to minimize the adverse impact of magnetic imperfections upon beamlines that are not associated with the insertion device. Additional specifications are generally required for internal-field errors to ensure that the insertion device provides good performance for its users.

2. Multipole errors

A transverse magnetic field in a source-free region may be expressed as a sum of multipole contributions. Since the magnetic field of an insertion device is primarily transverse, this is approximately true for an insertion device's magnetic field and its longitudinally integrated magnetic field. For an ideal device, the multipoles of the integrated field are zero. Multipoles that depend upon the vertical magnetic field B_y are called normal multipoles, while multipoles that depend upon the horizontal magnetic field B_x are called skew multipoles.

For $n \geq 0$, the n^{th} normal multipole b_n and n^{th} skew multipole a_n of the integrated field are

$$b_n \equiv \frac{\partial^n}{\partial x^n} \int dz B_y(x,0,z) \Big|_{x=0}, \qquad a_n \equiv \frac{\partial^n}{\partial x^n} \int dz B_x(x,0,z) \Big|_{x=0}. \tag{1}$$

The multipoles for $n = 0$ are called dipole first-integral errors, the multipoles for $n = 1$ are called quadrupole errors, the multipoles for $n = 2$ are called sextupole errors, while the multipoles for $n = 3$ are called octupole errors. For $y = 0$, the integrated vertical and horizontal fields obey

$$\int_{-\infty}^{\infty} dz B_y(x,0,z) = \sum_{n=0}^{\infty} \frac{b_n}{n!} x^n, \quad \int_{-\infty}^{\infty} dz B_x(x,0,z) = \sum_{n=0}^{\infty} \frac{a_n}{n!} x^n. \tag{2}$$

In an alternate definition of the multipoles, the multipole errors are defined to be smaller by a factor of $n!$. With this alternate definition, the $n!$-terms are absent in eq. (2). When specifying multipole errors, it is important to note which definition is being used.

A normal dipole first-integral error causes a horizontal deflection of an electron passing through the insertion device, while a skew dipole first-integral error causes a vertical deflection. In addition to the normal dipole first-integral error [$b_0 = \int_{-\infty}^{\infty} dz B_y(0,0,z)$], we also consider the normal dipole second-integral error $\int_{-\infty}^{\infty} dz \int_{-\infty}^{z} dz' B_y(0,0,z')$. The normal second-integral error results in a horizontal offset of an electron passing through the device. In addition to the skew dipole first-integral error [$a_0 = \int_{-\infty}^{\infty} dz B_x(0,0,z)$], we also consider the skew dipole second-integral error $\int_{-\infty}^{\infty} dz \int_{-\infty}^{z} dz' B_x(0,0,z')$. The skew second-integral error results in a vertical offset of an electron passing through the device. For quadrupole, sextupole and octupole errors, we only consider the "first-integral" errors given by eq. (1).

To compute the effect of multipole errors upon the storage ring, we use the MAD code [2]. We consider localized errors that may be represented as a "general thin multipole" of zero length. Dividing a multipole error [as defined in eq. (1)] by the magnetic rigidity gives the multipole coefficient used in the MAD code to represent the error as a general thin multipole. For 800-MeV operation of Aladdin, the magnetic rigidity is 2.67 T-m.

For a dipole error, we require that the error be sufficiently small that the global feedback system can correct the orbit. In addition, a dipole error should reduce the beam lifetime by less than 10%, and modify the beam's transverse dimensions by less than 1%.

Quadrupole errors modify the ring's focusing, thereby changing the ring tunes and beam transverse dimensions. The ring tunes are automatically maintained by "tune-tracker" feedback's adjustment of the QF- and QD- quadrupole families. To minimize impact upon users, we require that the beam transverse dimensions change by less than 1% when tune-tracker feedback is active. In addition, we require that the ring's horizontal dynamic aperture be reduced by less than 10% to limit lifetime degradation. We compute the dynamic aperture by 1000-turn tracking with MAD [3].

For sextupole errors, we require that the change in the ring's horizontal and vertical chromaticity (as defined in MAD) be less than one to prevent head-tail instability. We also require that the horizontal dynamic aperture be reduced by less than 10% to avoid lifetime degradation.

For octupole errors, we require that the horizontal dynamic aperture be reduced less than 10%.

These requirements are summarized in Table I.

The above error requirements do not address the impact of an insertion device upon injection. In addition, we do not consider the effect of "dynamic multipoles", in which the longitudinal field integrals along an electrons' wiggling trajectory [4] differ significantly from the on-axis field integrals considered here. To verify that the dynamic multipoles from an insertion-device design do not reduce the dynamic aperture by more than 10%, a separate study using the BETA code [5] may be performed.

3. Insertion device in a long straight section (LSS)

A. Dipole errors

According to experimental studies of orbit bumps in a long straight section, global feedback can correct orbit bumps with $|x|$, $|y| \le 3$ mm, in which case the lifetime change is less than 10%. The horizontal beam size is barely modified by the orbit bumps, while the vertical beam size is modified less than 1% provided that $|x| \le 2$ mm and $|y| \le 0.3$ mm.

Global feedback pins the orbit in a long straight section at locations separated by ~ 4 m. A localized horizontal orbit deflection, pinned by global feedback, satisfies $|x| \le 2$ mm provided that the deflection is less than 2 mrad. A localized vertical orbit deflection satisfies $|y| \le 0.3$ mm provided that the deflection is less than 0.3 mrad. Thus, we require that the MAD normal dipole coefficient K_0L have magnitude less than 2×10^{-3}, while the MAD skew dipole coefficient should have magnitude less than 0.3×10^{-3}.

Multiplying by the magnetic rigidity of 2.67 T-m gives the specifications $|b_0| < 5\times10^{-3}$ T-m and $|a_0| < 0.8\times10^{-3}$ T-m.

A localized normal second-integral error maintains $|x| \leq 2$ mm provided that the error is less than 2 mm times the magnetic rigidity, i.e. 5×10^{-3} T-m^2. A localized skew second-integral error maintains $|y| \leq 0.3$ mm provided that the error is less than 0.3 mm times the magnetic rigidity, i.e. 0.8×10^{-3} T-m^2.

B. Quadrupole errors

For a normal quadrupole error located in the center of a long straight section, modeling with MAD of a thin multipole was performed. The modeling shows that the horizontal beta functions around the ring are modified by 1.8% while the vertical beta functions are modified by 2% when the MAD multipole coefficient K_1L has magnitude of 0.0125 m^{-1}. The beam dimensions are therefore modified by ≤ 1%. For $K_1L = \pm0.0125$ m^{-1}, the dynamic aperture reduction is less than 10%.

The upstream end of the 4-m straight section has horizontal beta function $\beta_x = 8.2$ m, which is a factor of 4.3 times the value of 1.9 m in the center. Since the β_x-perturbation around the ring is proportional to the value of β_x at the error location [6], maintaining β_x within 2% for an arbitrary error location requires that $|K_1L| < (2/1.8)(1.9/8.2)(0.0125\ \text{m}^{-1}) = 3.2\times10^{-3}\ \text{m}^{-1}$, i.e. $|b_1| < 9\times10^{-3}$ T.

Experiments indicate that a large portion of the beam's vertical emittance results from global coupling associated with the $\nu_x = \nu_y$ resonance, where ν_x and ν_y are the tunes. The global coupling from skew quadrupoles may be characterized by $C_0 = (1/4\pi) \sum_{\text{skew quadrupoles}} \left(\frac{a_1}{B\rho}\right)\sqrt{\beta_x\beta_y}\, \exp\{i[\mu_x - \mu_y - (\nu_x - \nu_y)\theta]\}$, where a_1 is skew quadrupole strength, $B\rho$ is the magnetic rigidity of 2.67 T-m, μ_x and μ_y are the betatron phases, and θ is 2π times longitudinal distance divided by the ring circumference [7]. The emittance ratio from global coupling obeys [7]

$$\frac{\varepsilon_y}{\varepsilon_x} = \frac{\alpha_x + \alpha_y}{\alpha_y} \frac{\pi(\nu_x - \nu_y)}{\sin[\pi(\nu_x - \nu_y)]} \frac{|C_0|^2}{(\nu_x - \nu_y)^2}\ , \tag{3}$$

where α_x and α_y are the horizontal and vertical betatron damping rates, which are nearly equal. According to measured beam sizes, the emittance ratio is about 3% for the standard tunes $(\nu_x\ , \nu_y) = (7.139, 7.234)$, so that $|C_0| \approx 1.15\times10^{-2}$. To ensure that a skew quadrupole error from an insertion device changes the vertical beam size by less than 1%, we require that the vertical emittance change by less than 2%, which requires that $|C_0|$ change by less than 1%. This requirement is met when the insertion device's skew quadrupole error a_1 obeys $|a_1| < [4\pi(B\rho)\big/\sqrt{\beta_x\beta_y}\,](0.01)(1.15\times10^{-2}) = 1.8\times10^{-3}\,\text{T}$, for the case of an error located in the center of the long straight section where $(\beta_x, \beta_y) = (1.9\ \text{m}, 2.5\ \text{m})$. In this case, the horizontal dynamic aperture is reduced by less than 10%.

For an error located at the upstream end of a 4-m device where $(\beta_x, \beta_y) = (8.2\ \text{m}, 3.1\ \text{m})$, a tighter specification applies: $|a_1| < [4\pi(B\rho)\big/\sqrt{\beta_x\beta_y}\,](0.01)(1.15\times10^{-2}) = 0.8\times10^{-3}\ \text{T}$.

C. Sextupole errors

For a normal sextupole error in the center of a long straight section, the chromaticity change is less than one when the MAD sextupole coefficient K_2L has magnitude less than 25 m^{-2}. The horizontal dynamic aperture reduction is less than 10% when K_2L has magnitude less than 0.5 m^{-2}. Thus we require that the normal sextupole error obey $|b_2| < (2.67\ \text{T-m})(0.5\ \text{m}^{-2}) = 1.3\ \text{T-m}^{-1}$.

A skew sextupole error does not change the computed chromaticity. The horizontal dynamic aperture reduction is less than 10% when K_2L has magnitude less than 1 m^{-2}. Thus we require that the skew sextupole error obey $|a_2| < (2.67\ \text{T-m})(1\ \text{m}^{-2}) = 2.7\ \text{T-m}^{-1}$.

D. Octupole errors

For a normal or skew octupole error in the center of a long straight section, the horizontal dynamic aperture is reduced by less than 10% when that the MAD multipole coefficient K_3L has magnitude less than 400 m^{-3}. Thus we require that the normal and skew octupole errors obey $|b_3|$, $|a_3| < (2.67\ \text{T-m})(400\ \text{m}^{-3}) = 1000\ \text{T-m}^{-2}$.

4. Insertion device in Short Straight Section 11 (SSS11, between bending magnets BD10 and BD11)

A. Dipole errors

According to experimental studies of orbit bumps in a short straight section, global feedback can correct orbit bumps with $|x|$, $|y| \leq 3$ mm; the lifetime change is less than 10% provided that $|x| \leq 1$ mm. The horizontal beam size is barely modified by the orbit bumps, while the vertical beam size is modified less than 1% provided that $|x| \leq 0.4$ mm and $|y| \leq 0.2$ mm.

Global feedback pins the orbit at locations separated by ~ 4 m. A localized horizontal orbit deflection, pinned by global feedback, satisfies $|x| \leq 0.4$ mm provided that the deflection is less than 0.4 mrad. A localized vertical orbit deflection satisfies $|y| \leq 0.2$ mm provided that the deflection is less than 0.2 mrad. Thus, we require that the MAD normal dipole coefficient K_0L have magnitude less than 0.4×10^{-3}, while the MAD skew dipole coefficient should have magnitude less than 0.2×10^{-3}. Multiplying by the magnetic rigidity of 2.67 T-m gives the specifications $|b_0| < 1.1\times10^{-3}$ T-m and $|a_0| < 0.5\times10^{-3}$ T-m.

A localized normal second-integral error maintains $|x| \leq 0.4$ mm provided that the error is less than 0.4 mm times the magnetic rigidity, i.e. $1.1\times10^{-3}\ \text{T-m}^2$. A localized skew second-integral error maintains $|y| \leq 0.2$ mm provided that the error is less than 0.2 mm times the magnetic rigidity, i.e. $0.5\times10^{-3}\ \text{T-m}^2$.

B. Quadrupole errors

For a normal quadrupole error located in the center of SSS11, MAD modeling shows that the horizontal beta functions around the ring are modified by 2% while the vertical beta functions are modified by 0.4% when the MAD multipole coefficient K_1L has magnitude of 0.005 m^{-1}. The beam dimensions are therefore modified by ≤1%. For $K_1L = \pm0.005\ \text{m}^{-1}$, the dynamic aperture reduction is less than 10%.

The upstream end of the 1.07-m device has horizontal beta function $\beta_x = 10.18$ m, which is a factor of 1.9 times the value of 5.46 m in the center. Since the β_x -perturbation around the ring is proportional to the value of β_x at the error location, maintaining β_x within 2% for an arbitrary error location requires that $|K_1L| < ((5.46/10.18)(0.005\ \text{m}^{-1}) = 2.7\times10^{-3}\ \text{m}^{-1}$, i.e. $|b_1| < 7\times10^{-3}$ T.

To ensure that a skew quadrupole error from an insertion device changes the vertical beam size by less than 1%, we require that $|C_0|$ change by less than 1%. This requirement is met when the insertion device's skew quadrupole error a_1 obeys $|a_1| < [4\pi(B\rho)/\sqrt{\beta_x\beta_y}\,](0.01)(1.15\times10^{-2}) = 1.5\times10^{-3}\,\text{T}$, for the case of an error located in the center of the short straight section where (β_x, β_y) = (5.46 m, 1.20 m). In this case, the horizontal dynamic aperture is reduced by less than 10%.

For an error located at the downstream end of a 1.07-m device where (β_x, β_y) = (10.18 m, 2.16 m), a tighter specification applies: $|a_1| < [4\pi(B\rho)/\sqrt{\beta_x\beta_y}](0.01)(1.15\times10^{-2}) = 0.8\times10^{-3}$ T .

C. Sextupole errors

For a normal sextupole error in the center of SSS11, the chromaticity change is less than one when the MAD sextupole coefficient K_2L has magnitude less than 6 m^{-2}. The horizontal dynamic aperture reduction is less than 10% when K_2L has magnitude less than 1 m^{-2}. Thus we require that the normal sextupole error obey $|b_2| < (2.67\ \mathrm{T\text{-}m})(1\ \mathrm{m}^{-2}) = 2.7\ \mathrm{T\text{-}m}^{-1}$.

A skew sextupole error does not change the computed chromaticity. The horizontal dynamic aperture reduction is less than 10% when K_2L has magnitude less than 1 m^{-2}. Thus we require that the skew sextupole error obeys $|a_2| < (2.67\ \mathrm{T\text{-}m})(1\ \mathrm{m}^{-2}) = 2.7\ \mathrm{T\text{-}m}^{-1}$.

D. Octupole errors

For a normal octupole error in the center of SSS11, the horizontal dynamic aperture is reduced less than 10% when the MAD multipole coefficient K_3L has magnitude less than 200 m^{-3}. Thus we require that the normal octupole error obeys $|b_3| < (2.67\ \mathrm{T\text{-}m})(200\ \mathrm{m}^{-3}) = 530\ \mathrm{T\text{-}m}^{-2}$. For a skew octupole error in the center of SSS11, the horizontal dynamic aperture is reduced less than 10% when the MAD multipole coefficient K_3L has magnitude less than 100 m^{-3}. Thus we require that the skew octupole error obeys $|a_3| < (2.67\ \mathrm{T\text{-}m})(100\ \mathrm{m}^{-3}) = 270\ \mathrm{T\text{-}m}^{-2}$.

5. Insertion device in Short Straight Section 12 (SSS12, between bending magnets BD11 and BD12)

A. Dipole errors

For dipole errors in SSS12, we apply the same criteria as in SSS11. Therefore, the first-integral dipole error specifications are the same as in SSS11: $|b_0| < 1.1\times10^{-3}$ T-m and $|a_0| < 0.5\times10^{-3}$ T-m.

Similarly, the second-integral error specifications are the same as in SSS11. A localized normal second-integral error maintains $|x| \le 0.4$ mm provided that the error is less than 0.4 mm times the magnetic rigidity, i.e. $1.1\times10^{-3}\ \mathrm{T\text{-}m}^2$. A localized skew second-integral error maintains $|y| \le 0.2$ mm provided that the error is less than 0.2 mm times the magnetic rigidity, i.e. $0.5\times10^{-3}\ \mathrm{T\text{-}m}^2$.

B. Quadrupole errors

For a normal quadrupole error located in the center of SSS12, MAD modeling shows that the horizontal beta functions around the ring are modified by 2% while the vertical beta functions are modified by 0.13% when the MAD multipole coefficient K_1L has magnitude of 0.005 m^{-1}. The beam dimensions are therefore modified by ≤1%. For $K_1L = \pm0.005\ \mathrm{m}^{-1}$, the dynamic aperture reduction is less than 10%.

A 1.07-m device has maximum horizontal beta function max(β_x) = 12.68 m, which is a factor of 2.4 times the value of 5.33 m in the center. Since the β_x -perturbation around the ring is proportional to the value of β_x at the error location, maintaining β_x within 2% for an arbitrary error location requires that $|K_1L| < ((5.33/12.68)(0.005\ \mathrm{m}^{-1}) = 2.1\times10^{-3}\ \mathrm{m}^{-1}$, i.e. $|b_1| < 6\times10^{-3}$ T.

To ensure that a skew quadrupole error from an insertion device changes the vertical beam size by less than 1%, we require that $|C_0|$ change by less than 1%. This requirement is met when the insertion device's skew quadrupole error a_1 obeys $|a_1| < [4\pi(B\rho)/\sqrt{\beta_x\beta_y}\,](0.01)(1.15\times10^{-2}) = 2.65\times10^{-3}\,\mathrm{T}$, for the case of an error located in the center of the short straight section where $(\beta_x, \beta_y) = (5.33\ \mathrm{m}, 0.397\ \mathrm{m})$. In this case, the horizontal dynamic aperture is reduced by less than 10%.

For an error located at the downstream end of a 1.07-m device where $(\beta_x, \beta_y) = (10.08\ \mathrm{m}, 0.78\ \mathrm{m})$, a tighter specification applies: $|a_1| < [4\pi(B\rho)/\sqrt{\beta_x\beta_y}\,](0.01)(1.15\times10^{-2}) = 1.4\times10^{-3}\ \mathrm{T}$.

C. Sextupole errors

For a normal sextupole error in the center of SSS12, the chromaticity change is less than one when the MAD sextupole coefficient K_2L has magnitude less than 3.65 m^{-2}. The horizontal dynamic aperture reduction is less than 10% when K_2L has magnitude less than 0.8 m^{-2}. Thus we require that the normal sextupole error obey $|b_2| < (2.67\ \mathrm{T\text{-}m})(0.8\ \mathrm{m}^{-2}) = 2.1\ \mathrm{T\text{-}m}^{-1}$.

A skew sextupole error does not change the computed chromaticity. The horizontal dynamic aperture reduction is less than 10% when K_2L has magnitude less than 3 m^{-2}. Thus we require that the skew sextupole error obeys $|a_2| < (2.67\ \mathrm{T\text{-}m})(3\ \mathrm{m}^{-2}) = 8\ \mathrm{T\text{-}m}^{-1}$.

D. Octupole errors

For a normal octupole error in the center of SSS12, the horizontal dynamic aperture is reduced less than 10% when the MAD multipole coefficient K_3L has magnitude less than 200 m^{-3}. Thus we require that the normal octupole error obeys $|b_3| < (2.67\ \mathrm{T\text{-}m})(200\ \mathrm{m}^{-3}) = 530\ \mathrm{T\text{-}m}^{-2}$. For a skew octupole error in the center of SSS12, the horizontal dynamic aperture is reduced less than 10% when the MAD multipole coefficient K_3L has magnitude less than 400 m^{-3}. Thus we require that the skew octupole error obeys $|a_3| < (2.67\ \mathrm{T\text{-}m})(400\ \mathrm{m}^{-3}) = 1070\ \mathrm{T\text{-}m}^{-2}$.

6. Summary

The error specifications for operation in the LF15 low-emittance lattice are summarized in Table II. The table also shows the previous specifications for ring operation in the base lattice with an insertion device in a long straight section [1]. The quadrupole, sextupole and octupole requirements for LF15 are comparable to the previous specifications. The dipole first and second integral requirements for LF15 are less stringent than the previous specifications, which may have preceded routine operation of "global feedback" to maintain the orbit.

When an insertion device multipole error equals its specified limit, the effect upon ring operation is near the limit of acceptability. If one or more insertion devices have several errors near their specified limits that are not corrected locally, the effect upon ring operation could be unacceptable. For errors that are not corrected locally, the manufacturer should be required to achieve multipole errors that are significantly below the specified limits in Table I.

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[2] H. Grote and F. C. Iselin, "The MAD Program (Methodical Accelerator Design) Version 8.1 User's Reference Manual," CERN Report No. CERN/SL/90-13, 1990.

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[5] L. Farvacque, T. F. Günzel, J. L. Laclare and A. Ropert, "BETA Users' Guide," third edition, 2001; see also L. Farvacque, J. L. Laclare and A. Ropert, "BETA User's Guide," ESRF Report ESRF-SR/LAT-88-08 (1988).

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TABLE I: Requirements to be obeyed by multipole errors.

Multipole error type	Requirements
dipole	Orbit correctable by global feedback. Lifetime reduction less than 10%. Transverse beam dimensions changed by less than 1%.
quadrupole	Transverse beam dimensions changed by less than 1%. Horizontal dynamic aperture reduced by less than 10%.
sextupole	Chromaticity (as defined in MAD) changed by less than 1. Horizontal dynamic aperture reduced by less than 10%.
octupole	Horizontal dynamic aperture reduced by less than 10%.

TABLE II: Multipole specifications for insertion devices.

Parameter	Base lattice: LSS	LF15: LSS	LF15: SSS11	LF15: SSS12
normal dipole 1st integral	0.1×10^{-3} T-m	5×10^{-3} T-m	1.1×10^{-3} T-m	1.1×10^{-3} T-m
skew dipole 1st integral	0.1×10^{-3} T-m	0.8×10^{-3} T-m	0.5×10^{-3} T-m	0.5×10^{-3} T-m
normal dipole 2nd integral	0.25×10^{-3} T-m^2	5×10^{-3} T-m^2	1.1×10^{-3} T-m^2	1.1×10^{-3} T-m^2
skew dipole 2nd integral	0.25×10^{-3} T-m^2	0.8×10^{-3} T-m^2	0.5×10^{-3} T-m^2	0.5×10^{-3} T-m^2
normal quadrupole	6.7×10^{-3} T	9×10^{-3} T	7×10^{-3} T	6×10^{-3} T
skew quadrupole	1×10^{-3} T	0.8×10^{-3} T	0.8×10^{-3} T	1.4×10^{-3} T
normal sextupole	2.5 T-m^{-1}	1.3 T-m^{-1}	2.7 T-m^{-1}	2.1 T-m^{-1}
skew sextupole	2.5 T-m^{-1}	2.7 T-m^{-1}	2.7 T-m^{-1}	8 T-m^{-1}
normal octupole	250 T-m^{-2}	1000 T-m^{-2}	530 T-m^{-2}	530 T-m^{-2}
skew octupole	250 T-m^{-2}	1000 T-m^{-2}	270 T-m^{-2}	1070 T-m^{-2}