# Specifications for the SESAME Magnets

SES-TE-AP-SPC-0002

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REVISION HISTORY

| Revision | Date | Description | Author |
|---|---|---|---|
| | | | |

# Contents

# Conventions

### *Reference frame*

The convention for the three geometrical axes is: s for longitudinal, x and z for horizontal and vertical.

### *Statistical definition of uncertainties and tolerances*

*Uncertainties* (errors) are estimates on the accuracy of the knowledge of parameters. *Tolerances* are upper bounds of errors estimated from beam physics calculations. All random errors and tolerances are expressed in σ of a random Gaussian distribution. The equivalent peak values are taken to be ±2σ, i.e. the peak-to-peak tolerances are given by 4σ.Independent components of uncertainties are added quadratically.

### *Energy range*

The specifications are given at the top energy and are taken to be identical at injection energy.

### *Units*

All values are in mm or mrad.

# 1. Dipole

## 1.1 Mechanical and alignment tolerances

### *1.1.1 Global alignment tolerances [s1]*

| *degree of freedom* | *rms tolerance* | *comments* |
|---|---|---|
| ds rms [mm] | 0.500 | provisional, not restricting |
| dx rms [mm] | 0.500 | |
| dzrms [mm] | 0.100 | |
| dphisrms [mrad] (roll) | 0.200 | |

### *1.1.2 Break-down of the uncertainties on ds [s2]*

| **ds** | ***uncertainties [mm rms]*** | ***comments*** |
|---|---|---|
| magnetic longitudinal center to mechanical long. center (estimated) | 0.250 | |
| mechanical longitudinalcenter to magnet reference points | 0.050 | mechanical references are less precise in the longitudinal direction, as compared to transverse, where the uncertainty is 5 times less |
| magnet support reference points to girder references | 0.008 | |
| survey accuracy for girders | 0.200 | |
| **combined uncertainties** | **0.325** | |
| **TOLERANCE** | **0.500** | from table 1.1.1 |

### 1.1.3 Break-down of uncertainties on dx [s2]

| dx | *uncertainties [mm rms]* | *comments* |
|---|---|---|
| magnetic axis to magnet reference points | 0.015 | |
| magnet reference points to girder references | 0.010 | |
| survey accuracy for girders | 0.100 | transverse survey more accurate than longitudinal |
| **combined uncertainties** | **0.102** | |
| **TOLERANCE** | **0.500** | from table 1.1.1 |

### 1.1.4 Break-down of uncertainties on dz [s2]

| dz | *uncertainties [mm rms]* | *comments* |
|---|---|---|
| magnetic axis to magnet reference points | 0.015 | |
| magnet reference points to girder references | 0.010 | |
| survey accuracy for girders | 0.100 | transverse survey more accurate than longitudinal |
| **combined uncertainties** | **0.102** | |
| **TOLERANCE** | **0.100** | from table 1.1.1 |

### 1.1.5 Break-down of uncertainties on $d\phi_s$ [s2]

| $d\phi_s$ | *uncertainties [mm rms]* | *comments* |
|---|---|---|
| magnetic horizontal plane to mechanical horizontal plane | 0.200 | |
| accuracy of alignment of the mechanical horizontal plane on the girders | 0.050 | Assumes shimming to an accuracy of ± 0.1 mrad |
| residual tilt of girders after alignment | 0.050 | |
| **combined uncertainties** | **0.212** | |
| **TOLERANCE** | **0.200** | |

## 1.2 Magnetic strength tolerances

The dipole magnet includes a quadrupole component . The baseline strategy will be to adjust the powering to obtain the correct global dipole field integral according to the magnetic measurements. A possible error on the quadrupole component will be taken care of by re-matching, based on the magnetic measurements. In case of a bias of the magnetic measurements, different for the combined function dipoles and the quadrupoles, the gradients of the QF and QD's will be scaled to cancel the observed tune shifts with beam.

### *1.2.1 Systematic imperfections [s2]*

| *component* | *uncertainty* | *tolerance* | *comment* |
|---|---|---|---|
| dipole field integral | $\pm 2 \times 10^{-4}$ | not constrained; can be adjusted. | uncertainty after correction by the transfer function: the residual uncertainty is the magnetic measurement accuracy of $10^{-4}$ rms. |
| quadrupole field integral | $\pm 2 \times 10^{-4}$ | $+150\times 10^{-4}$ (2.83 T/m)<br>$-450 \times 10^{-4}$ (2.66 T/m) | Can be corrected by the adjacent QD to get the designed tune, limited by the range of the QD magnetic-field. Outside of these tolerances, the magnet can be shifted sideways to modify the dipole field integral and use the transfer function to adjust the integrated gradient. |

### *1.2.2 Random imperfections*

| *component* | *uncertainty* | *tolerance* | *comment* |
|---|---|---|---|
| dipole field integral | $3\times 10^{-4}$rms [s10] | $15 \times 10^{-4}$rms | Criterion: 2 mm orbit deviation and its correction limited to 0.28 mrad;<br>for reference, the spread of field integral measured in ALBA is 13 $10^{-4}$ rms. |
| quadrupole field integral | $3\times 10^{-4}$rms [s10] | $50\times 10^{-4}$ | A potential beta-beat can be corrected by adjustment of the individual powered adjacent QD; Criterion: beta beat less than 5% ;<br>for reference, the spread of field integral measured in ALBA is 16 $10^{-4}$ rms. |

## 1.3 Multipole strength tolerances

These tolerances are calculated in [1] either in the case of an individual multipolar error ("one-by-one"), or all imperfections combined ("global model").
Reference radius is **20 mm**.

### *1.3.1 Systematic imperfections*

| *Field component* | *Tolerance on systematic harmonics, one by one* | *Tolerance on systematic harmonics, global model* | *comments* |
|---|---|---|---|
| b3 | - | - | not constrained, as chromaticity can be corrected with SF/SD; higher orders found to have no impact. |
| b4 | $\pm 15\times 10^{-4}$ [s7] | $\pm 10\times 10^{-4}$ [s7,s6] | |
| b5 | $\pm 10 \times 10^{-4}$ [s7] | $\pm 10 \times 10^{-4}$ [s7,s6] | |
| b6 | $\pm 10 \times 10^{-4}$ [s7] | $\pm 6\times 10^{-4}$ [s7,s6] | |
| b7 | $\pm 10 \times 10^{-4}$ [s7] | $\pm 10 \times 10^{-4}$ [s7,s6] | |

### *1.3.2 Random imperfections*

| *Field component* | *Tolerance on random harmonics, one by one* | *Tolerance on random harmonics, global model* | *comments* |
|---|---|---|---|
| b3 | $10 \times 10^{-4}$rms [s8] | | expected to be pessimistic (tracking with multipoles at the magnet ends) |
| b4 | $5 \times 10^{-4}$rms [s8] | | |
| b5 | $5 \times 10^{-4}$rms [s8] | | |
| a3 | $5 \times 10^{-4}$rms [s8] | | |
| a4 | $5 \times 10^{-4}$rms [s8] | | |
| a5 | $5 \times 10^{-4}$rms [s8] | | |

# 2. Quadrupoles

These specifications apply to the QF quadrupoles. For the QD quadrupoles, they can be relaxed at least by a factor 20 [s8].

## 2.1 Mechanical and alignment tolerances

### *2.1.1 Global alignment tolerances [s1]*

| *degree of freedom* | *tolerance (rms)* | *unit* | *comments* |
|---|---|---|---|
| ds | 0.500 | mm | not restricting, see Annex 2.2-2 |
| dx | 0.200 | mm | see Annex 2.2-1 |
| dz | 0.200 | mm | see Annex 2.2-1 |
| $d\phi_s$ (roll) | 0.500 | mrad | see Annex 2.2-3 |

### *2.1.2 Break-down of the uncertainties on ds [s2]*

| **ds** | *uncertainties [mm rms]* | *comments* |
|---|---|---|
| magnetic longitudinal center to mechanical long. center (estimated) | 0.100 | |
| mechanical longitudinalcenter to magnet reference points | 0.050 | mechanical references are less precise in the longitudinal direction, as compared to transverse, where the uncertainty is 5 times less |
| magnet support reference points to girder references | 0.050 | |
| survey accuracy for girders | 0.200 | |
| **combined uncertainties** | **0.235** | |
| **TOLERANCE** | **0.500** | from table 3.1.1 |

### 2.1.3 Break-down of uncertainties on dx and dz [s2]

| dx &dz | uncertainties [mm rms] | comments |
|---|---|---|
| magnetic axis to magnet reference points | 0.015 | |
| magnet reference points to girder references | 0.010 | |
| survey accuracy for girders | 0.100 | transverse survey more accurate than longitudinal |
| **combined uncertainties** | **0.102** | |
| **TOLERANCE** | **0.200** | from table 3.1.1 |

### 2.1.4 Break-down of uncertainties on d$\phi_s$ [s2]

| d$\phi_s$ | uncertainties [mradrms] | comments |
|---|---|---|
| magnetic horizontal plane to mechanical horizontal plane | 0.200 | |
| accuracy of alignment of the mechanical horizontal plane on the girders | 0.050 | Assumes shimming to an accuracy of ± 0.1 mrad |
| residual tilt of girders after alignment | 0.050 | |
| **combined uncertainties** | **0.205** | |
| **TOLERANCE** | **0.500** | from table 3.1.1 |

## 2.2 Magnetic strength tolerances

### 2.2.1 Systematic imperfections [s2]

| Type | uncertainty | tolerance | comment |
|---|---|---|---|
| QF & QD | $\pm 5\times 10^{-4}$[s5] | not constrained; TF can be adjusted. | uncertainty after correction by the transfer function: a systematic bias of the QF/QD measurement bench would introduce a systematic error; it can be corrected with beam, by scaling all QF/QD strength to restore both tunes. |

### 2.2.2 Random imperfections

| type | uncertainty | tolerance | comment |
|---|---|---|---|
| QF & QD | $0.1\times 10^{-4}$rms[s5] | not constrained; individual TF'scan be adjusted. | uncertainty after correction by the transfer function: a systematic bias of the QF/QD measurement bench would introduce a systematic error; measured beta beat canbe used for correction if the orbit sampling by the BPM is sufficient. |

## 2.3 Multipole strength tolerances [s1, s6]

These tolerances are calculated in [1] either in the case of an individual multipolar error ("one-by-one"), or all imperfections combined ("global model").
Reference radius is 24 mm.

### 2.3.1 *Systematic imperfections*

| *Field component* | *Tolerance on systematic harmonics, one by one* | *Tolerance on systematic harmonics, global model* | *comments* |
|---|---|---|---|
| b6 | $\pm 50\times 10^{-4}$ | $\pm 6\times 10^{-4}$ | |
| b10 | $\pm 10\times 10^{-4}$ | $\pm 10\times 10^{-4}$ | |
| b14 | $\pm 20\times 10^{-4}$ | $\pm 20\times 10^{-4}$ | |

### 2.3.2 *Random imperfections*

| *Field component* | *Tolerance on random harmonics, one by one* | *Tolerance on random harmonics, global model* | *comments* |
|---|---|---|---|
| b3 | | | |
| a3 | $700\times 10^{-4}$rms | $10\times 10^{-4}$rms | [s6], [s7] |
| b4 | $100\times 10^{-4}$rms | $5\times 10^{-4}$rms | [s6] , sensitive [s7] |
| a4 | $150\times 10^{-4}$rms | $10\times 10^{-4}$rms | [s6] , [s7] |
| b5 | $100\times 10^{-4}$rms | $5\times 10^{-4}$rms | [s6] , sensitive [s7], [s8] |
| a5 | $100\times 10^{-4}$rms | $50\times 10^{-4}$rms | [s6] , [s7] |

# 3. Sextupoles

## 3.1 Mechanical and alignment tolerances

### 3.1.1 *Global alignment tolerances [s1]*

| *degree of freedom* | *tolerance (rms)* | *unit* | *comments* |
|---|---|---|---|
| ds | 0.500 | mm | not restricting, see Annex 2.2-2 |
| dx | 0.200 | mm | see Annex 2.2-1 |
| dz | 0.200 | mm | see Annex 2.2-1 |
| $d\phi_s$ (roll) | 0.500 | mrad | see Annex 2.2-3 |

### 3.1.2 *Break-down of the uncertainties on ds [s2]*

| ds | *uncertainties [mm rms]* | *comments* |
|---|---|---|
| magnetic longitudinal center to mechanical long. center (estimated) | 0.100 | |
| mechanical longitudinalcenter to magnet reference points | 0.050 | mechanical references are less precise in the longitudinal direction, as compared to transverse, where the uncertainty is 5 times less |
| magnet support reference points to girder references | 0.050 | |
| survey accuracy for girders | 0.200 | |
| **combined uncertainties** | **0.235** | |
| **TOLERANCE** | **0.500** | from table 3.1.1 |

### 3.1.3 *Break-down of uncertainties on dx and dz [s2]*

| dx &dz | *uncertainties [mm rms]* | *comments* |
|---|---|---|
| magnetic axis to magnet reference points | 0.015 | |
| magnet reference points to girder references | 0.010 | |
| survey accuracy for girders | 0.100 | transverse survey more accurate than longitudinal |
| **combined uncertainties** | **0.100** | |
| **TOLERANCE** | **0.200** | from table 3.1.1 |

### 3.1.4 *Break-down of uncertainties on d$\phi_s$ [s2]*

| dphis | *uncertainties [mradrms]* | *comments* |
|---|---|---|
| magnetic horizontal plane to mechanical horizontal plane | 0.200 | |
| accuracy of alignment of the mechanical horizontal plane on the girders | 0.050 | Assumes shimming to an accuracy of ± 0.1 mrad |
| residual tilt of girders after alignment | 0.050 | |
| **combined uncertainties** | **0.205** | |
| **TOLERANCE** | **0.500** | from table 3.1.1 |

## 3.2 Magnetic strength tolerances

### 3.2.1 *Systematic imperfections [s2]*

| **Type** | *uncertainty* | *tolerance* | *comment* |
|---|---|---|---|
| SF & SD | $\pm 5\times 10^{-4}$[s3] | none | can be corrected via the transfer function based on magnetic measurements, down to the absolute accuracy of the measuring bench. Can be further calibrated with beam-based measurement of chromaticity. |

### 3.2.2 *Random imperfections*

By design, the sextupole strength is subject to errors driven by the settings of the dipole and skew quadrupole circuits, which are considered essentially random.

| **Type** | *uncertainty* | *tolerance* | *comment* |
|---|---|---|---|
| SF & SD | $<30\times 10^{-4}$rms [s3] | $100 \times 10^{-4}$rms [s4] | The large tolerance may stem from tracking with b3 alone. For reference, the spread of field integral measured in ALBA is 12 $10^{-4}$ rms. The LEP tolerance was 40 $10^{-4}$rms. |

## 3.3 Multipole strength tolerances

These tolerances are calculated in [1] either in the case of an individual multipolar error ("one-by-one"), or all imperfections combined ("global model").
Reference radius is 24 mm. These prescriptions shall be respected for combined excitation of the sextupole and corrector windings, the latter producing the maximum kick used in simulations, i.e. .28 mrd [1]. Indeed the correctors induce decapole components which became worrisome for the 7.24/5.20 working point [7] but less to the 7.24/6.20. In consequence the working point had to be moved to become less critical [8]. For random errors, it is assumed that the main harmonics to be considered are n=4 and 5, upright and skew.

### 3.3.1 *Systematic imperfections*

| ***Field component*** | ***Tolerance on systematic harmonics, one by one*** | ***Tolerance on systematic harmonics, global model*** | ***comments*** |
|---|---|---|---|
| b9 | $\pm 200 \times 10^{-4}$ | $\pm 20 \times 10^{-4}$ | possibly sensitive, see Annex 2.4-1 |
| b15 | $\pm 10 \times 10^{-4}$ | $\pm 10 \times 10^{-4}$ | |

### *3.3.2 Random imperfections*

| *Field component* | *Tolerance on random harmonics, one by one* | *Tolerance on random harmonics, global model* | *comments* |
|---|---|---|---|
| b4 | $3000 \times 10^{-4}$rms | $1000 \times 10^{-4}$rms | |
| b5 | $2000 \times 10^{-4}$rms | $1000 \times 10^{-4}$rms | |
| a4 | negligible effect | negligible effect | |
| a5 | $2000 \times 10^{-4}$rms | $1000 \times 10^{-4}$rms | |

# 4. Acknowledgements

The authors would like to express their deep thanks to thank A. Milanese, D. Tomasini, L. Walkiers for providing the design-parameter, magnetic-properties and mechanical tolerances for the magnets.

# 5. Sources

[s1]: E. Huttel et al., summarized in " strategy for magnet tolerancesv2EH.docx", 27/03/2014
[s2]: L. Walckiers et al., summarized in "strategy for magnet tolerancesv2.0.docx", 06/03/2014
[s3]: M. Ebbeni, L. Walckiers et al., measurement of the CERN sextupole prototype, 2014, to be released.
[s4]: M. Attal, Tolerance on sextupole strength errors, July 2014.
[s5]: M. Ebbeni, presentation to TAC, 29/09/2014.
[s6]: M.Attal, E. Huttel et al., Multipole and Alignment error Limits for the SESAME Storage ring Magnets, IPAC2014
[s7]: M. Attal, E. Huttel, The magnetic error tolerances in SESAME storage ring magnets, SESAME Note SES-TE-AP-TN-004,2014.
[s8]: E. Huttel, Multipole tolerances of the SESAME storage ring magnets, 25-05-2014, SES-TE-AP-TN-0002 Rev 0.1.
[s9]: E. Huttel, Effect of random multipole errors on the dynamic aperture and beta beat, 19-01-2013
[s10]: Estimates by D. Tommasini, 23/10/2014.

# 6. Annexes and Comments

## 6.1 Tolerances on beam parameters

| *Quantity* | *tolerance* | *justification* |
|---|---|---|
| Maximum acceptable H orbit rms distortion before correction | 2 mm | Reasonable corrector strength for correction 0.5 mrad [4] |
| Maximum acceptable V orbit rms distortion before correction | 2 mm | |
| Maximum acceptable H dispersion rms distortion | Not specified | emittance blow-up less than… |
| Maximum acceptable linear betatron coupling before correction | Not specified | Reasonable corrector strength for correction |
| Maximum acceptable $\beta$ beating (H or V) | 5% | loss of brilliance less than |
| Maximum correctable tune shifts | 1 | beta beating less than xx% flexibility in choice of working point |

| | | |
|---|---|---|
| Required dynamic aperture | ~ equal to the physical aperture | • injection: minimize loss of injected beam by betatron injection<br>• top energy: |
| Maximum allowable orbit drift over 8 hrs | 10% of beam size | |
| Maximum allowable tune drift over 8 hrs | 0.01 | |

## 6.2 Alignment

1. Alignment and dipole strength errors assumed for the SESAME design: M. Attal, Technical Note O-6 , 2006 (http://sesame.org.jo/sesame/images/sesame-publications/Technical_Notes/O-6.pdf) and new 2014 iteration:

| | Dipole | | | | | | Quadrupole QF | | Sextupole SV | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 rms error | dB/B<br>$2\ 10^{-3}$ | dh<br>0.2 mm | dv<br>0.2 mm | $d\varphi_s$<br>0.2 mrad | $d\varphi_y$<br>0.2 mrad | $d\varphi_x$<br>0.2 mrad | dx<br>0.2 mm | dv<br>0.2 mm | dx<br>0.2 mm | dv<br>0.2 mm |

M. Attal, the magnetic error tolerances on SESAME storage ring magnets, 7-2-2013

| Misalignment | **Dipole** | **Quadrupole** | **Sextupole** |
|---|---|---|---|
| dx = dy = ds (mm) | 0.2 | 0.1 | 0.1 |
| $d\phi_x = d\phi_y = d\phi_s$ (mrad) | 0.2 | 0.1 | 0.1 |

2. The longitudinal tolerance ds is provisional and not restrictive on machine performance. It will be confirmed or updated after the measurement of the dipole prototype in ALBA. It is agreed to increase it to 0.5 mm (or beyond) from its initial estimate of 0.1 or 0.2 mm given the absence of optical impact, EH mail 22/4/2014.
3. For all magnet types, the dφx and dφz are uncritical and are already determined from the dx and dy tolerances and need not be specified (EH). For dφs, it is agreed to increase its tolerance from 0.1 mradrms to 0.5 mradrms forsextupoles in "strategy for magnet tolerancesv3" 14-5-2014.
4. The accuracy of the magnetic alignment of the individual magnets of series like we have (several tens of magnets) strongly depends on the training of, and time spent by, the bench operators (LW).
5. Provisions for tuning the alignment in SESAME and on the measuring bench
   - The design of the SESAME magnet stands foresees adjustment by shims of 50 µm. The measuring bench has the same provisions.
   - Concerning the quadrupole and sextupole the roll can be corrected on a 0.1 mrad level mechanically, at girder assembly (since shim adjustment)
   - For the CERN/SESAME measuring bench an uncertainty of +/- 0.5 mrad error is stated if no particular effort required during measurement campaign compared to 0.1 mrad for SOLEIL and others.
6. Comparison with other machines:
   - LEP: transverse alignment to 0.15 mm rms, roll to 0.25 mradrms for a coupling ratio of 4%.
   - ALBA, SOLEIL and Diamond: transverse alignment to 0.025 mm rms
   - SOLEIL tolerances for a coupling ratio of 1% (Alain Lestrade, IWAA2004, CERN, Geneva, 4-7 October 2004)

| rms values | dipoles | quadrupoles | girders |
|---|---|---|---|
| ds [mm] | .5 | .2 | .5 |
| dx [mm] | .5 | .02 | .05 |
| dz [mm] | .5 | .02 | .05 |
| Φs [m rad] | .1 | .1 | .1 |
| Φs [m rad] | .2 | 1 | 1 |
| Φs [m rad] | .2 | 1 | 1 |

7. ESRF: accuracy of the alignment instrumentation reported to be 0.11 mm rms (D. Martin, G. Gala, IWAA2004), for typical coupling ratio less than 1%.
8. Mail from Dominique 7/5/2014:Pour l'alignement vertical, il me semble assez aisé de le réaliser dans les 0.1 mm, même en absolu sur l'ensemble de l'anneau car on peut réaliser un cheminement assez précis.Je ne sais pas quelles sont les tolérances demandées pour l'alignement transversal mais il me paraitrait assez judicieux de faire un réseau de points à l'extérieur de l'anneau donc dans le hall et de rentrer les coordonnées des points dans l'anneau via les trous des lignes qui sont vides pour l'instant, de matérialiser des points dans l'anneau et ensuite de faire un cheminement polygonal (angles et distances) entre ces points. Cela permettra au moins d'avoir un bon réseau initial et d'aligner les éléments par rapport à ces points.Quandmeme pas trop de problème pour l'alignement long. dans les 0.5 mm….. En fait, on peut atteindre 0.1 mm pour les petites machines avec du soin et des equipements appropries, mais il n'y a jamais eu de demande.

## 6.3 Magnet strength tolerances

1. Reference sextupole strength and perturbation by the orbit corrector (jpk 26/6/2014):

| ***case*** | ***Conditions*** | ***SF*** | | ***SD*** | |
|---|---|---|---|---|---|
| | | ***integrated strength*** | ***power supply current [A]*** | ***integrated strength*** | ***power supply current [A]*** |
| | magnet ratings | 27 T/m | 223 | 27 T/m | 223 |
| 1 | Q'=5 | | 73 | | 115 |
| 2 | Qx'=1, Qv'=2 | | 60 | | 99 |
| 3 | Q'~0 | | 56 | | 87 |

| **sextupole current [A]** | **dipole corrector current [A]** | **perturbation of the sextupole strength** | **corresponding rms error [$10^{-4}$]** |
|---|---|---|---|
| 250 | 20 | 2.3% | 115 |
| 223 | 10 | 1.3% | 65 |
| 115 (SD, case 1) | 10 | 2.5% | 125 |
| 73 (SF, case 1) | 10 | 3.9% | 195 |
| 99 (SD, case 2) | 10 | 2.9% | 145 |
| 60 (SF, case 2) | 10 | 4.8% | 240 |
| 87 (SD, case 3) | 10 | 3.3% | 165 |
| 56 (SF, case 3) | 10 | 5.1% | 255 |

This table was calculated from line 1 given by Louis, assuming only linear dependences. The error specification is $100 \times 10^{-4}$rms, extrapolated from studies of a case with errors of $30 \times 10^{-4}$ rms. We are almost on order of magnitude higher than the case tested for this first measurement at maximum sextupole current.

2. The uncertainty in table 3.2.2 is derived from the second measurement at the reference current of . ???

## 6.4 Multipole tolerances

### *6.4.1 General*

1. From tracking harmonics one by one to a global model, there can be some arbitrariness in reducing the various multipoles to achieve the wanted dynamic aperture. The harmonic tolerances for the global model are thus sufficient but not necessarily necessary.

### *6.4.2 Quadrupoles*

1. ALBA and SOLEIL specifications and achievements for various types of quadrupoles.

The tolerances are given for SQRT($A^2$+$B^2$)/B3. All values in 10^-4 units. Ref radius is 25 mm for ALBA and 30 mm for SOLEIL.

| *order* | *tolerance ALBA [$10^{-4}$]* | *harmonic* | *measurements ALBA* | | *measurements SOLEIL* | |
|---|---|---|---|---|---|---|
| | | | *average* | *rms* | *average* | *rms* |
| 2 | | | | 10 | | |
| 3 | 8 or 10 | b3 | -0.4 to 1.5 | ≤ 3 | -1.6 to 2.9 | ≤ 2 |
| | | a3 | -1.4 to 0.4 | ≤ 3.4 | 0.5 | 3.2 |
| 4 | 6 or 8 | b4 | -1.5 to 0 | ≤ 2.4 | -3.4 to -8.6 | ≤ 3.7 |
| | | a4 | -0.3 to 0.3 | ≤ 1.2 | | |
| 5 | 4 or 6 | b5 | | | | |
| | | a5 | | | | |
| 6 | 2 | b6 | -0.9 to 0.9 | ≤ 1.3 | 0.7 to 2.4 | 0.5 |
| | | a6 | | | | |
| 10 | 4 | b10 | -3.5 to -2.0 | ≤ 0.4 | 0.7 to 1.9 | 0.1 |
| 14 | 2 | b14 | -0.8 | 0.3 | 1.0 | 0.1 |
| rest | 1 | | | | | |

Magnetic center deviations: within +/- 0.03mm, typically 0.01 mm rms, tilt 0.04 mrad.
ALBA: Presentation by M. Pont, July 2011
SOLEIL: P. Brunell at al: Magnetic Measurements Results of the Dipoles,EPAC2006, Quadrupoles and Sextupoles of the Soleil Storage Ring.

### *6.4.3 Sextupoles*

1. ALBA specs and results

The tolerances are given for SQRT($A^2$+$B^2$)/B3. All values in 10^-4 units. Ref radius is 25 mm.

| ***order*** | ***tolerance [$10^{-4}$]*** | ***harmonic*** | ***measurements*** | | ***LEP tolerances at r=25 mm*** |
|---|---|---|---|---|---|
| | | | ***average*** | ***rms*** | |
| | | | | | |
| 3 | | b3 | | 12 | |
| 4 | 10 | b4 | -0.7 | 3.4 | 5rms |
| | | a4 | -0.7 | 3.2 | |
| 5 | 8 | b5 | -1.6 | 1.5 | 2rms |
| | | a5 | 1.1 | 1.7 | |
| 6 | 1 | b6 | 0.2 | 0.7 | 1 rms |
| | | a6 | 1.6 | 1.5 | |
| 9 | 5 | b9 | -4.3 | 0.4 | < 1 (systematic) |
| 15 | 7 | b15 | 2.3 | 0.3 | |
| rest | 1 | | | | |

Magnetic center deviation: within +/- 0.03mm.

2. LEP specifications for sextupoles random errors: all orders < $200\times10^{-4}$ at R=59 mm.