A GENERALIZED ORBIT CORRECTION SCHEME

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Abstract

The special operating conditions of ELETTRA have strongly influenced the orbit correction philosophy. A hybrid orbit correction scheme is presented whereby local orbit corrections at arbitrary positions and angles at three different light source points of each of the eleven user dedicated sections are performed that also maintain the global orbit stable. The method, the stability and the implications are presented and discussed.

1 INTRODUCTION

Beam orbit stability is a very critical issue in all third generation synchrotron light sources. In fact due to their low emittance, the amplification factor for closed orbit distortions against quadrupole misalignments is large, while the presence of strong sextupoles generate a high sensitivity to the optical distortions.

At ELETTRA orbit stability is even more important due to the mismatch between the injection energy (1 GeV) and the actual operation energy (2 and 2.4 GeV) and for the following two reasons give relatively low orbit stability and reproducibility:

1. Thermal load on the vacuum chamber due to synchrotron radiation moves the bpms and the quadrupoles they are attached to. Local orbit drifts up to 100 μ horizontally and 30-50 μ vertically in the middle of the straight sections have been measured, peaking 5 hours after ramping 320 mA to 2 GeV or 140 mA to 2.4 GeV. Since the thermal expansion is proportional to the beam current for fixed energy and no toping-up is possible the ring expands and contracts between refills.

2. Magnetic hysterisis due to errors in cycling or ramping (it has been observed that not cycling or ramping well a corrector can generate approximately an up to 0.1 mrad kick error)

Global and local orbit correction programs take care of the final orbit. Globally the orbit is kept below 800 μm rms horizontally and 400 μm rms vertically while locally is kept below 5 (μm and μrad) at the source points. The Beam Position Monitor (BPM) system (developed in house) consists of 96 (four button) bpm detectors each giving the horizontal and vertical beam position with a bandwidth for the closed orbit of 1 kHz, a resolution of 2 μm and an absolute accuracy of < 150 μm rms. The Beam Steering system consists of 82 combined H+V correctors 0.22 m long with a 140-130 Gauss maximum field strength.

The global orbit correction involves all BPMs and any correctors and is performed usually once per run while the local orbit correction uses selected BPMs, usually the ones near the straight sections and the appropriate correctors. Each of the 11 sections has 7 correctors while the 12th section reserved for injection has 5. Typically a four corrector bump is applied at each active straight section. Whenever the beam angle in the bending magnet source point has to be controlled a five corrector bump is applied instead. The correction frequency in this case is usually 5 minutes and is performed automatically. All orbit controlling software has been developed in house.

To complicate matters not all sections are to be corrected to zero position and angle. For some insertion devices a position offset and a certain angle is required (e.g. 2.5 mm and 1 mrad) if chicane operation is needed. Other experimental stations have noticed that they have better performance if a local orbit angle (especially in the vertical plane) is introduced at the source point. This is partially due to the fact that ELETTRA after eight years of continuous operations has gradually exceeded its alignment tolerances, set to ±200 μm in the horizontal and ±100 μm in the vertical plane. The alignment deterioration however is a slow process and local orbit settings do not change during a run, do however change during a year. The last survey has shown that the maximum vertical misalignment of about 500 μm occurred in the bending (combined function) magnets which can give an angle error of about 100 μrad in the downstream insertion device. Misalignments between the beam position monitors (that are fixed on the quadrupole magnets) and the insertion devices as well as shifts in the position of the insertion device magnetic shims can result in the manifestation of strong higher order magnetic multipole components in the insertion device magnets that influence the optics and hence the performance of the machine. Aging can not be considered as a probable factor of influencing the optics since it has been estimated 0.1% over 10 years[1].

2 AN EXTENDED LOCAL CORRECTION SCHEME

The up to now local orbit correcting program [2] did not always preserve the global orbit. While in the horizontal plane the global orbit rms did not change appreciably (30-50 μ peak to peak) between refills (every 23.5 hours) the vertical global orbit with the increase of the number of corrected sections and the deterioration of the alignment tolerance was becoming unstable and

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would even change by a factor of 2 although the local readings in most cases remained within the tolerance limits (i.e. 5 μm, 5 μrad). With the increase in the number of bending magnet beam lines and the installation of a short ID in one of the short straight sections where corrections would be needed too, it was evident that this correction procedure had to change.

A seven corrector bump scheme was developed and tested (incorporated in the Gloc program [3, 4]) acting in all sections except section 12 where a 5 bump was created instead. This scheme has the advantage that it involves the same number of correctors and conditions forming thus an orthogonal system that enhances the global orbit stability.

2.1 The seven corrector bump

Seven correctors, 5 from the current section n and 2 from the previous one n-1, are used. All BPM readings are translated into positions and angles at three distinct points (below shown as black points) per section: at the middle of the long straight section (between Cn.3 and Cn.4), at the middle of the short straight section (between C(n-1).7 and C(n-1).1) and at the bending magnet source point (between Cn.2 and Cn.3) as shown:

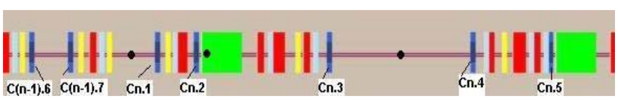

Figure 1: Seven corrector bump layout

The orbit displacement y and angle y' created by a corrector j of strength θ_j at a point i are:

$$y_i = A_{ij}\vartheta_j \quad \text{and} \quad y'_i = A'_{ij}\vartheta_j$$

where:

$$A_{ij} = \sqrt{\beta_j \beta_i}\,\sin\left(2\pi\left(\varphi_i - \varphi_j\right)\right)$$

$$A'_{ij} = \sqrt{\beta_j / \beta_i}\,\left(\cos\left(2\pi\left(\varphi_i - \varphi_j\right)\right) - \alpha_i \sin\left(2\pi\left(\varphi_i - \varphi_j\right)\right)\right)$$

with β,α the twiss functions and ϕ the phase advance. The local seven corrector bump equations can then be written as follows (n is the current section number):

Short straight sections middle:

$$\sum_{j=(n-1).6}^{(n-1).7} \vartheta_j A_{SSj} = y_{SS} \quad \text{and} \quad \sum_{j=(n-1).6}^{(n-1).7} \vartheta_j A'_{SSj} = y'_{SS}$$

At the bending magnet source point

$$\sum_{j=(n-1).6}^{n.2} \vartheta_j A_{Bj} = y_B \quad \text{or} \quad \sum_{j=(n-1).6}^{n.2} \vartheta_j A'_{Bj} = y'_B$$

At the long straight sections middle

$$\sum_{j=(n-1).6}^{n.3} \vartheta_j A_{LSj} = y_{LS} \quad \text{and} \quad \sum_{j=(n-1).6}^{n.3} \vartheta_j A'_{LSj} = y'_{LS}$$

closure conditions:

$$\sum_{j=(n-1).6}^{n.5} \vartheta_j A_{n.5j} = 0 \quad \text{and} \quad \sum_{j=(n-1).6}^{n.5} \vartheta_j A'_{n.5j} = 0$$

The solution of this 7x7 system gives the needed strengths per section and it is performed by standard matrix inversion i.e. not using SVD, since the solution has to be exact and should not permit approximations.

3 PERFORMANCE

The algorithm corrects each section at the three points to keep the local orbit constant. At the same time the absolute global orbit is kept stable within 10-20 μm as can be seen in Figure 2. The well seen separations (especially in the horizontal plane) are the orbit changes during refills and energy ramping.

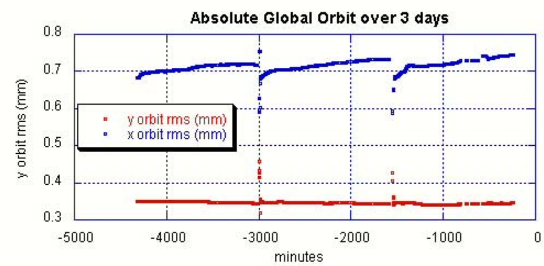

Figure 2: Absolute global orbit monitoring over three days.

In order to study the local behaviour of the system a series of controls have been performed. The convergence and the stability was very good, in fact the algorithm converges after a few iterations and corrects always to the set tolerances. To check out the reproducibility of the method on the orbit the position and angle at all three correction points of one section were locally monitored over some time. In the bending source point the angle was fixed. The program corrected to the preset tolerance of ± 5 (μm and μrad) in the LS , ± 5 μrad in the BSy' and ± 10 (μm and μrad) in the SS point. Figure 3 shows the reproducibility of the positions/angles set in section 1:

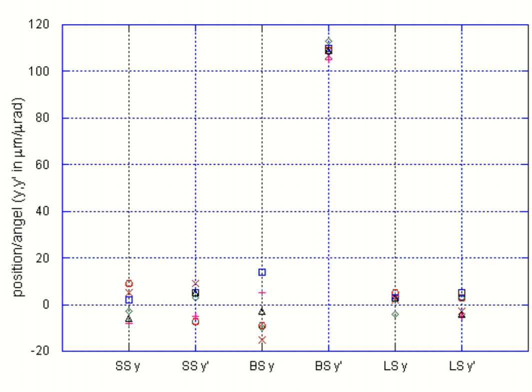

Figure 3: Reproducibility of the orbit (y,y') in a ten day period using the seven corrector bump algorithm.

SSy is the position of the beam in the short straight section, SSy' the corresponding angle; BSy is the beam position in the bending source point, BSy' the corresponding angle; LSy the beam position in the middle of the long straight section and LSy' the corresponding angle. The spreads remain always within the preset tolerances. At the bending magnet source point, the beam position had a spread of about ±15 μm but it should be mentioned again that simultaneous control of both angle and position is not possible. Next figure 4 shows the situation when only 4 corrector bumps are applied in the long straight sections.

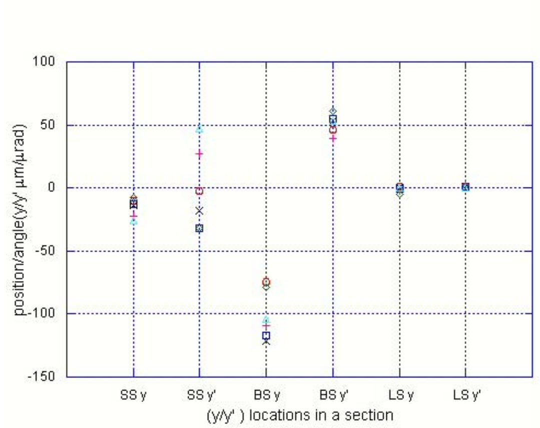

Figure 4: Reproducibility of the orbit in a twelve day period when only four corrector bumps are applied.

As expected larger spreads manifest where no local corrections are applied. The tests were performed for the vertical plane since this is more sensitive to general stability but similar conclusions have been drawn for the horizontal plane.

In the following table an example of setting all three points in all sections (respecting the user special setting requests) is shown:

Table 1: Full correction results for all sections (position y/ angle y' in μm/μrad)

	SSy	SSy'	BSy	BSy'	LSy	LSy'
Section 1	9	-7	-9	679	-5	-1
Section 2	18	0	31	-4	5	30
Section 3	-30	11	-21	112	8	-50
Section 4	13	-6	1	272	-11	-150
Section 5	3	1	11	-40	7	-5
Section 6	-8	6	-242	-145	8	80
Section 7	5	-4	-4	-11	-1	2
Section 8	1	-2	398	-9	6	-2
Section 9	-2	4	0	-11	-1	2
Section 10	6	-6	-1113	-180	-3	-3
Section 11	12	2	3	57	8	-8

From the above table the diversity of settings can be seen and appreciated. Almost all LS sections are user set and bending magnet source point angles are preset in section 6, 8 and 10. The remaining bending magnet source points are set arbitrarily to small beam orbit positions. The SS are arbitrarily set in order to test if the settings will be maintained. Since the system is fully defined and orthogonal there is always one unique solution.

4 CONCLUSIONS

The relatively low orbit reproducibility of ELETTRA for reasons explained in the introduction has obliged us to control beam position and angle in the middle of the insertion devices long straight sections almost since the beginning of the experimental activities. The chicane operation of a dedicated section (S9) needs special position and angle settings too. The near future plan to operate an already installed short insertion device in a short straight section of ELETTRA, the prospect of having more of those devices in the future and some specific demands from bending magnet beam lines for special source point angles, have pushed us towards the development of a fully fledged local orbit control algorithm. It has been shown that it is possible by means of this algorithm to both control position and angle in the short and long straight sections of ELETTRA as well as angle or position in the bending magnet source points. To control both angle and position at all three points, ELETTRA would need an additional corrector per section. The corrections maintain their preset local accuracy (e.g. ± 5 μm/μrad) and keep the global orbit constant (within ± 20 μm rms) enhancing thus the reproducibility of the beam orbit.

5 ACKNOWLEDGEMENTS

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