Orbit Correction in ELETTRA

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Abstract

The paper introduces the features of the high level software developed for the orbit correction, and recapitulates the entire process of orbit correction carried out during the commissioning of ELETTRA.

1. INTRODUCTION

ELETTRA is a third generation light source operating at 1.1 to 2 GeV [1]. The commissioning of the machine had started in October 1993 [2]. ELETTRA may be characterised by its large amplification factor for closed-orbit distortion against quadrupole misalignment, which originates from achieving the low-emittance beam. The orbit correction is therefore particularly important from the first stage of the commissioning. The low emittance also requires the presence of strong sextupoles, generating a large limitation on the stability of motion as well as a high sensitivity to the optical distortion. Thus, it furthermore becomes essential to correct the orbit to an accurate level to achieve the designed performance.

The software development for the orbit correction had been initiated on the same footing as other high level software for the machine control of ELETTRA, which access a common run-time data structure that interfaces the machine [3]. Two tools have been created for the correction of orbit: One that integrates all necessary operations for both the transferline and the storage ring provided with many options [4], which places in its core, the orbit correction software package COCU developed at CERN [5], and another, a dedicated program for the general local bump operation, which is particularly optimised for the routine adjustment of closed orbit in the insertion devices [6]. The control panels, having the role of the interface between these tools and the operator, had been built with the help of CPE, a C-code generator for the graphical user interface based on the X11 Motif toolkit, developed by the control group of ELETTRA [7]. The developed orbit correction programs have been successfully used for the commissioning as well as during the routine operation of ELETTRA.

2. DESCRIPTION OF DEVELOPED TOOLS

(i) Orbit

As already mentioned, the orbit correction program package COCU (Closed Orbit Correction Utility), developed at CERN had been employed as the basis of further software development [5]. COCU is equipped with well known correction schemes such as MICADO together with many

options, and is associated with an unique data structure management system MOPS (Multiple Object Partitioned Structure), which is particularly useful on the HP workstation with the use of shared memories [8]. Apart from several extensions made on COCU, a major effort was therefore made in the construction of the entire structure embedding COCU and MOPS, optimised for the machine operation (Fig. 1).

$$\begin{array}{ccccc} & \text{MOPS} & & & \\ & \uparrow\downarrow & & & \text{rpc's} \\ \text{COCU} & \rightleftarrows & \text{GUI} \rightleftarrows \text{Data bush} & \rightleftarrows & \text{Machine} \end{array}$$
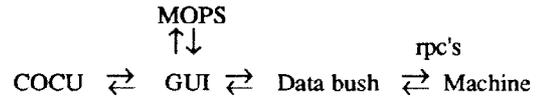
Fig. 1. Structure of the high level software Orbit [4].

What bind different parts of the structure is the control panel represented as GUI (Graphical User Interface), on which all actions of the operator can be entered as simple manipulation of graphical objects (called widgets). Data bush constitutes a common run-time data structure utilised by all high level software interfacing the machine via rpc's (remote procedure calls) [3]. The control panel consists basically of four parts (Fig. 2): The interface to the machine, orbit display, COCU operation, and option menus.
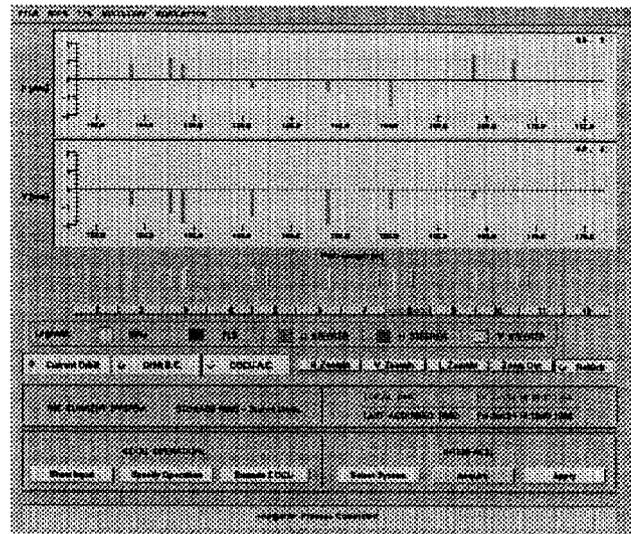
Fig. 2. Orbit control panel

The interface part selects the working system which may be the transferline, storage ring in the first-turn mode, or in the closed-orbit mode. There are buttons to acquire the orbit readings and the corrector strengths, and to apply the new corrector strengths to the machine. It may be stressed that the entire application can be linked to a simulated machine, and

for which two programs have been developed. GAP (Ghost Accelerator Program), a dedicated program to simulate the machine which can be linked to various high level software [9], and another is a modified version of RACETRACK [10]. Linkage to simulated machines has been shown to be quite significant in the developing and debugging stages as well as for the physical interpretation of real observations.

Orbit display provides three kinds of orbit to be compared. The current orbit, the one prior to the last correction, and the predicted orbit. With use of an option, a difference orbit can also be plotted. The display is scalable. The monitors and correctors represented as pushbuttons provide information on themselves or specify elements in the correction procedure.

COCU operation consists of creating an input and executing COCU, both of which are handled by simple panel operations: The user firstly selects a desired correction scheme (e.g. MICADO) in the selection menu. Then in the subpanel which appears for each scheme, one enters all necessary parameters. On top of existing correction schemes of COCU, several routines have been implemented. In view of the commissioning of the transferline and the first turn steering of the storage ring, two routines have been added which correct the displacement and/or the slope respectively at one and at two specified monitor locations using the upstream correctors. With respect to closed orbit corrections, the routine found in RACETRACK which consecutively minimises the displacement at monitors with three corrector bumps around the ring had been appended [10]. The implementation of the harmonic correction is in progress. There are also other minor improvements in the treatment bumps and in the maximum corrector strength.

Option menus at the top of the main panel provide many utilities. Files such as input and outputs of COCU and of the simulation program, and files containing the optics and orbit information or a list of statistics on the acquired orbit, can be opened activating a screen editor. There is also a series of useful operations: 1) A panel displaying of a list of enable/disable status of monitors and correctors which can be arbitrarily modified, which is then recognised by all the internal routines including COCU. 2) A panel displaying a list of new corrector strengths to be applied on the machine which can be varied on the panel. It has also options to set all strengths to zero or to modify the strengths using random numbers. 3) A simultaneous corrector setting. Since a non-synchronous setting of the corrector strengths may momentarily distort the orbit and lead to a beam loss, it employs a special server, which is developed to achieve the synchronisity [11]. Furthermore, the user can divide the setting into steps and control each step. 4) Difference orbit correction. By registering an orbit as a reference and activating this option, all subsequent operations will deal with the difference to the reference orbit including the orbit display. The option is useful in verifying and correcting orbit drifts as well as in studying the effectiveness of the corrections. 5) Sensitivity matrix measurement. With the monitors and correctors whose internal status is enabled, the routine measures the change in the displacement at a monitor due to a

given increment on the corrector strength, and compares the sensitivity with the model.

(i) Bump

Bump is a dedicated program [6], developed independently to create local bumps in an interactive manner (Fig. 3).
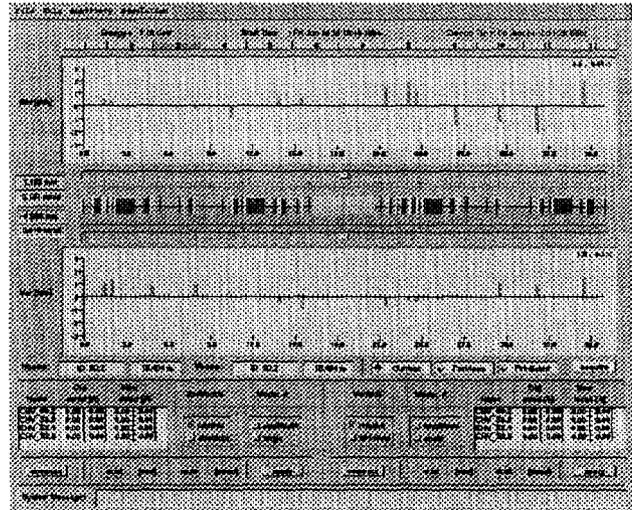
Fig. 3. Bump control panel

The panel displays the orbit in each plane, with the machine components appearing in between represented by pushbuttons, and with two graphical scroll bars up and below the magnets specifying the bump location in each plane. The user specifies the operation in the lower half of the panel which is divided into two parts for each plane. The buttons above the orbit display selects a section which is represented such that the insertion devices appears in the centre.

The orbit is displayed with bars at monitor locations representing the read values together with continuous curves in between them (Fig. 3). The interpolation is made by numerically fitting the trajectory taking into account the corrector kicks in between. Leaving additional unknown kicks possibly given by the quadrupoles, the resultant curve should well represent the actual orbit especially after corrections. The values of displacement and slope of the orbit at the bump location thus obtained are displayed on the panel. As in Orbit, i) current orbit, ii) orbit prior to correction and iii) prediction can be compared. Both three and four corrector bumps are provided which are distinguished by the number of correctors entered with the magnet buttons. All erroneous operations are disabled by the program. To simplify the routine corrections at the insertion devices and the dipole magnets, a click of the correspondent magnet button is programmed to fix automatically the bump location and the correctors to use.

3. ORBIT CORRECTION DURING COMMISSIONING

Reviewing the process of orbit corrections performed so far, it may be described as composed of three phases:

Phase I: Up to obtaining a control over the stored beam.

The first beam transport to the end of the transferline was achieved manually without difficulty already during the pre-commissioning phase. The smoothening of the orbit was subsequently carried out effectively with MICADO, using fluorescent screens. The first accumulation in the storage ring was achieved prior to any corrections. The first correction of orbit in the storage ring was nevertheless performed in the first turn mode with sextupoles on. Using MICADO, an improvement of roughly a factor of two was obtained in the rms and peak to peak values of the orbit in both planes. The result was however abandoned as it did not enable accumulation.

The first closed-orbit correction was therefore performed on the bare orbit without any correctors used whose rms values were (6.3, 4.1) mm, where the first value in the parenthesis is horizontal and the second, vertical, respectively. A combination of best corrector methods MICADO and SIMPLEX [5], and the local bump method (cf. Sec. 2) was usually employed, which, in a relatively short period, had brought the rms values to saturate around 0.5 mm in both planes. The measured optics, particularly the dispersion was observed to improve as the rms of the orbit decreases.

Phase II: Search for the limit of correction.

During this period, a number of additional operations and observations were made with respect to the orbit. To examine the whole system, a measurement of sensitivity matrix was carried out on the entire BPMs and correctors. The result gave a discrepancy from the model by 20~30% in both planes which was suspected to be attributed mainly to the mismatch in the fractional tunes. Since the simultaneous corrector setting enables to set all correctors to zero without reducing the beam current, the correction was repeated from the bare orbit, investigating the effectiveness of the corrections, the dependence on the maximum corrector strength, and the degree of agreement with the predictions. It was frequently observed that applying a horizontal correction induces a shift in the horizontal average orbit, which was compensated by adjusting the rf frequency.

To examine if saturation of the correction is due to a possible mispositioning of the BPMs, the dependence of rms values on the number of BPMs involved was investigated. It was found that by reducing the number by half to 48, the rms values decreased to (0.19, 0.22) mm, and by another half to 24 brought down to (0.15, 0.12) mm, thus not eliminating the possibility of mispositioning. To check the corrector system, a difference orbit correction was performed taking a well corrected orbit as a reference and moderately distorting the orbit by varying the corrector strengths with random numbers. The result revealed that while there is a fast convergence to the original orbit vertically, horizontally, once the path length is affected by a perturbation, the effect may be amplified by continuing the correction since the particles fix the path length by shifting the energy. Thus, it was confirmed necessary and largely helpful to subtract off a fitted dispersive

orbit from the horizontal orbit prior to performing a correction, which can be handled with COCU. Following a recalibration of the BPMs and the introduction of the above treatment which occurred almost simultaneously, the rms values had been reduced significantly.

Phase III: Present status.

Two different schemes have been taken for the subsequent corrections. One that allows a variation of the rf frequency if necessary, and the other which fixes the frequency to the nominal value. The importance of the latter is to be able to accumulate the linac beam in the synchronous filling mode. The best results in the former approach give rms of nearly 0.15 mm and peak to peak values of less than 1 mm in both planes at the frequency shifted downwards by roughly 4 kHz, while the latter gives results which are worse horizontally whose rms saturates around 0.25 mm.

An analysis on the orbit indicates that the 0th harmonic of the corrector field is strongly enhanced in the latter case. Such a path length deformation brought about by the correctors may be evaluated, in the linear theory, with the expression $\sigma = -\Sigma\,\theta_j\,D_j$, where θ_j is the kick angle of j-th corrector and D_j is the dispersion at the corrector position. σ can be also numerically estimated with an extended version of RACETRACK that follows a trajectory in the 6-dimensional space accurately up to 2nd order in the transverse displacement [12]. Extension of closed orbit search in 6-dimension is in progress which would simulate a sudden energy shift due a change in the orbit [13]. The evaluated σ is in good agreement between the two methods which shows a shortening of the path length by approximately 2.4 mm. This is also consistent with the reduction of rf frequency in the former case corresponding to a lengthening of the machine circumference by roughly 2.1 mm.

4. REFERENCES

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