

ORBIT - 3.0 - A COMPUTER CODE FOR SIMULATION AND CORRECTION OF THE CLOSED ORBIT AND FIRST TURN IN SYNCHROTRONS

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Abstract

A new computer program ORBIT - 3.0 for simulation and correction of the closed orbit and first turn in synchrotrons is described. The program works under WINDOWS 95/98/NT and is a full object oriented application. It has an interactive interface, enhanced graphical capabilities and on-line printing. The original algorithms DINAM - for closed orbit correction and FTURN - for first turn steering are described as well.

1 INTRODUCTION

One of the major tasks of the optimum operation of a cyclic charged particle accelerator of synchrotron type is the control and the correction of the equilibrium closed orbit [1].

A special problem is the first turn steering.

Many of the widespread computer codes created for general accelerator design - MAD [2], DIMAD [3], PETROC [4] and others possess features for calculating the closed orbit under the influence of random errors and incorporate one of the orbit correction methods. However these programs have no build-in capability for making statistics both of orbit and of its correction over an ensemble of some hundred or some thousand random machines. Such feature is very helpful during the accelerator design.

It is also advisable to compare different correction algorithms by means of computer simulations before to make your choice in favour of one of them.

In addition the problem of first turn threading and closing lies beyond the scope of interest of the above mentioned general purpose programs. Specialized computer codes have been developed for first turn steering.

Last but not least is the old fashion interface of all these programs. Designed as a rule in the 70^s for the monstrous old computers and gradually improved in the time these general accelerator design programs are not interactive and have limited graphical capabilities (usually a sort of off-line graphics). They are far from the now standard Windows-type interface as well.

In 1991 I developed the computer code ORBIT - 2.0, especially intended for closed orbit simulation and correction. The computer code was created for the needs

of the COler SYnchrotron COSY - Julich. ORBIT -2.0 was written in C and runs on PCs under MS DOS. This is a menu driven program with enhanced graphical capabilities. A UNIX version with off-line graphics and printing was developed as well.

Now a full MS WINDOWS 95/98/NT computer code ORBIT - 3.0 for simulation and correction of both closed orbit and first turn is available.

2 COMPUTER CODE ORBIT - 3.0

2.1 General Description

The computer code ORBIT -3.0 is a full MS WINDOWS 95/98/NT application. It is written in C++ and use all the advantageous of the object oriented programming. As a windows application ORBIT -3.0 has access to the big collection of WINDOWS resources and especially on-line printing of both text and graphics on all the installed printers. The program has an interactive interface and enhanced graphical capabilities.

The ORBIT 3.0 options are grouped in four groups: closed orbit simulation and statistics; processing of real orbit measurement data in order to produce some kind of additional information; correction of the measured or simulated orbits; first turn steering - Fig.1.



Figure 1. Computer code ORBIT - 3.0.

2.2 Orbit Simulation

It is very important to obtain a realistic predictions about the closed orbit behaviour in the future machine during the design period. The aperture of the vacuum chamber and the maximum strengths of the orbit correctors are determined on the base of the rms and maximum orbit deviations from the reference orbit. Knowing from the magnet measurements the dipole field errors ΔB and from the geodesy the expected transverse misalignments Δx and Δz and tilts $\Delta\theta$ of the elements one can calculate the statistical characteristics of the future orbit. In ORBIT - 3.0 this is done either analytically applying the formulae obtained in [5] or by means of computer simulations. In [5] the variance of the maximum orbit amplitude is calculated taking into account only the major four orbit harmonics. ORBIT - 3.0 calculates the value of the maximum orbit amplitude that will not be exceeded by 98% probability, the mean and the maximum rms deviations and the rms orbit amplitude.

Another approach used for making orbit statistics is the simulation. An ensemble of identical machines with errors generated by a random number generator with Gaussian distribution is investigated. Closed orbits in each machine are represented either by tables of orbit deviations in beam position monitors (BPM) and structure elements or graphically. The results of orbit statistics are shown as histograms of maximum orbit amplitude distribution over the ensemble.

The Fourier spectrum of the simulated orbit is calculated through the well-known relation between harmonics of the perturbations f_k , g_k and orbit u_k , v_k .

2.4 Orbit Information

This group of options embraces features for processing the data of real orbit measurements in order to produce some sort of additional information.

First of all it is possible for the picture of the measured orbit along the machine circumference to be shown on the screen and printed in a selected printer.

A task that one frequently faces in the practise is to calculate the orbit deviations between BPMs. ORBIT -3.0 offers two possibilities. In local interpolation mode the orbit deviations in some number of points along the circumference are calculated applying several interpolation methods. In general interpolation mode the orbit in all the structure elements of the machine is restored on the base of BPMs measurements.

Finally the Fourier spectrum of the measured orbit could be calculated trough FFT and shown on the screen.

2.4 Orbit Correction

ORBIT -3.0 includes six algorithms for orbit correction: harmonic correction , beam-bump , least-squares (LSQ) , singular value decomposition (SVD), Bacconier's method and DINAM. More information about these and other correction methods can be found in the revue paper [1].

Harmonic correction is realised with the opportunity to set individual weights for each harmonic.

Beam-bump correction is coded for the case of arbitrary deployed correctors and monitors.

LSQ correction uses either LU matrix decomposition or Gauss-Jordan elimination methods for response matrix inversion.

SVD correction makes use of the singular value decomposition of the response matrix A.

In Bacconier's correction method the goal function sets constraints on the corrector strengths thus reducing the influence of the remaining uncorrected higher harmonics of the correction.

DINAM is an original algorithm for orbit correction developed by the author and it will be described wider in the next chapter.

2.5 First Turn Steering

As we have mentioned in the introduction the first turn correction is a separate problem which frequently arises during the machine commitioning.

First of all we should thread the beam making it to perform a full turn around the accelerator. Having corrected the center of charge trajectory so that the beam goes entire turn around the ring we should close this trajectory, i.e. make the second turn to coincide with the first one.

ORBIT -3.0 includes options for both first turn threading and first turn closing. The algorithm applied for this in ORBIT - 3.0 will be described in the last chapter of this paper.

3 THE DINAM CORRECTION ALGORITHM

While the other orbit correction algorithms, described in details in [1], strive to compensate the orbit deviations only in the points where BPMs are situated the DINAM algorithm corrects the orbit over the whole accelerator ring. For that reason the criterion of correction quality is defined as the functional:

$$q = (1/2\pi) \int_0^{2\pi} \eta^2(\phi) d\phi \quad (1)$$

-[6], where η is the orbit and ϕ the machine azimuth.

As the orbit $\eta(\phi)$ is a random function of the azimuth we should improve this criterion by taking the mathematical expectation of the functional.

$$q = M \left[\left(\frac{1}{2\pi} \right) \int_0^{2\pi} \eta^2(\phi) d\phi \right] \quad (2)$$

With this choice of the correction quality we exclude the cases when the corrected orbit has approximately zero deviations in BPMs and relatively big deviations in between.

It is shown that the quality criterion can be put in the following form- [6]:

$$q = \frac{1}{N} \sum_{i=1}^N \eta_i^2 + \frac{1}{2} \sum_{p=1}^N \sum_{q=1}^K A_{pq} \eta_p \delta_q + \frac{1}{2} \sum_{q=1}^K \sum_{r=1}^K B_{qr} \delta_q \delta_r \quad (3)$$

where η is the orbit, δ is the corrector strength, N- the number of BPMs and K - the number of orbit correctors.

The coefficients A_{pq} and B_{qr} in (3) describe the optical parameters of the correction system and depend on ϕ_p , the azimuths of the BPMs and ϕ_q , ϕ_r , the azimuths of the correctors

The strengths of the orbit correctors are determined by the condition of minimum of q to occur. This leads to the following matrix equation for the correction vector $\vec{\delta}$:

$$\vec{\delta} = R \vec{\eta} \quad (4)$$

The matrix

$$R = -\frac{1}{2} A^{-1} B^T \quad (5)$$

where $A = \{A_{pq}\}$ and $B = \{B_{qr}\}$.

The matrix R depends only on the azimuths of the BPMs and of the correctors and for the given accelerator can be calculated prior to the correction.

Fig. 2 shows an example of DINAM orbit correction. The DINAM correction algorithm is relatively fast. It works reliably. It was used in the COSY-Julich and JINR-Nuclotron synchrotrons.

4 FIRST TURN STEERING

In order to thread the beam entire turn around the accelerator ring and make the center of charge trajectory to follow the injection orbit as close as possible an original first turn steering algorithm has been developed for ORBIT - 3.0.

The algorithm uses the least squares approach but allows for constraints on the corrector kicks to be set.

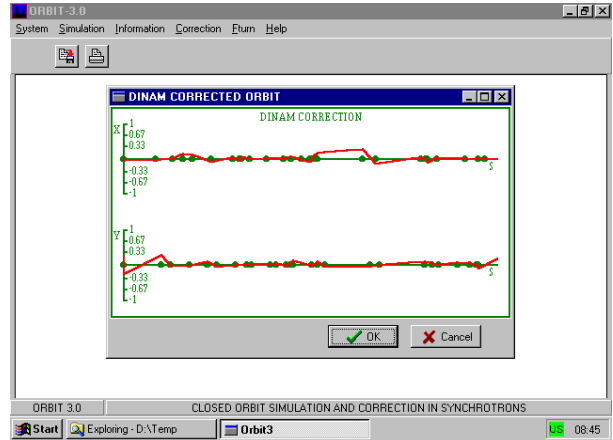


Figure 2. DINAM orbit correction.

The goal function chosen is:

$$\Psi(\varepsilon_j^*) = \sum_{i=1}^n [\eta_i^{BPM} - \eta_i^{des} + \sum_{j=1}^k a_{ij} \varepsilon_j^*]^2 \Rightarrow \text{Min} \quad (6)$$

We should look for the minimum of (6) to occur under the following constrains on the corrector kicks:

$$|\varepsilon_j| < \Delta \quad (7)$$

In the algorithm this is done applying the penalty function method.

The beam closing in ORBIT -3.0 is achieved by appropriate tuning of the last two correctors in the ring.

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