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**A NEW CLOSED ORBIT CORRECTION PROCEDURE FOR THE CERN SPS
AND LEP**

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Abstract:

Using well known correction techniques and algorithms, we have built a new procedure to correct the closed orbit of the CERN SPS and LEP. The procedure is driven by the input data and no assumptions on the machine are made. Identical programs can therefore be used for both LEP and the SPS. Several algorithms can be used to correct the closed orbit and additional features like first turn correction and harmonic analysis are incorporated in the procedure. Apart from necessary enhancements to the algorithms, we have defined a new data interface between the programs involved to achieve high flexibility and language independence and to increase its efficiency.

The correction procedure is described in detail and the performance is discussed using results from the SPS during the lepton commissioning period as well as from the experience during the LEP startup.

1. INTRODUCTION

The procedure was initially developed for the new control system of the CERN SPS [1]. For the commissioning of LEP minor modifications were made and new features were added.

The program is written in standard FORTRAN 77 and has been implemented on different computer systems. Great care was taken to define the interface between the program and the input and output data. References to a particular accelerator were strictly avoided inside the code. This made it possible to use the identical code for LEP and the SPS and, in principle, for any other circular machine. The structure of the program allows to include different algorithms for the correction in an easy way as additional program modules.

The input, e.g. the beam position at the monitors and the strengths of the correctors, is usually provided through the control system of the accelerator. This data can also come from modelling programs, which allows offline tests of the closed orbit correction. This facility was extensively used to study the performance of the correction algorithms.

2. THE CLOSED ORBIT CORRECTION PROCEDURE

The entire procedure is built from independent, exchangeable modules and it consists of correction algorithms like MICADO [2], a data preparation and the input/output part. Other independent modules are used to acquire the data and to send the corrections back to the equipment.

2.1 Data preparation

Data processing is necessary to prepare the "raw" data such as beam positions, corrector strengths and Twiss parameters for the use in the algorithms. Monitors and correctors which are marked as bad by the hardware are disabled and other algorithms to identify suspicious readings from monitors can be applied. The response matrix $A(i, j)$, which describes the orbit distortion observed at the i^{th} beam position monitor due to a unit deflection at the j^{th} correction dipole, is set up at this stage.

The energy error is taken into account by first determining this error from the measured orbit and then using a renormalised orbit for the correction procedure.

The correction of a beam line or the first turn trajectory in a circular machine requires a special treatment. First, the injection point and the particle direction (i.e. clockwise or counter clockwise) has to be specified by the operator. Secondly, the response matrix is reduced to a triangular shape since monitors placed before a given corrector do not see its effect and therefore different coefficients have to be used.

2.2 Correction algorithms and other facilities

Most of the many well known correction methods are based on minimising the r.m.s. orbit distortion. Some of the correction algorithms used in our procedure have been adapted from other programs without major changes and others have been added.

The methods currently available are:

MICADO

The MICADO method works as described in [2]. It starts by examining all correctors and selects the one which yields the smallest residual r.m.s. distortion. At every following iteration MICADO selects only one *new* corrector, keeping all correctors from previous iterations but recalculating their strengths. The number of iterations (i.e. number of correctors used) per correction can be set by the operator. The maximum strength of the correction coils is taken into account.

SIMPLEX

The SIMPLEX method for orbit correction was developed some years ago and has been successfully used in the old SPS control system. The closed orbit correction, subject to the additional constraint of maximum corrector strengths, can be formulated as a so-called l_1 linear approximation problem. The SIMPLEX method is used to solve this formulation of the constrained l_1 problem [9]. The norm l_1 [10], used as an estimate for the closed orbit deviation, penalises errors equally and therefore tends to discount measurement errors more efficiently than the norm l_2 used for the MICADO algorithm which works best if the errors are normally distributed. Alternatively, the norm l_∞ (Tchebycheff norm, [10]) can be used in SIMPLEX which allows to control the maximum beam excursion.

SHORT-RANGE-CORRECTION

The orbit can be corrected locally using one of the methods mentioned above while the orbit remains unchanged in the rest of the machine.

BEAM THREADING AND FIRST TURN CORRECTION

All the options mentioned above can be applied either to correct a closed orbit or to establish and correct the first turn of the particles in the machine, i.e. they can be used to correct a beamline.

HARMON

A harmonic analysis is performed on the input data and if required a new orbit is generated with a limited number of harmonics centred around the nominal Q value [3]. This allows a noise reduction for the following correction with any of the algorithms mentioned above.

SIMULATE

Calculates the effect of specified kicks on the orbit.

BUMP3

A bump is calculated with 3 correctors which can be specified by the operator. The bump is defined by the name of a beam position monitor and a bump amplitude.

BUMP4S

A bump is calculated with 4 correctors. The bump is defined by the name of a beam position monitor and a bump amplitude. If required, the slope at the monitor can be specified.

It should be pointed out that because the program computes the response matrix which defines the relationship between corrector strength and monitor measurements, other existing correction algorithms can be added easily to the procedure should this be required.

3. ORGANISATION OF INPUT AND OUTPUT DATA AND USER INTERFACE

A basic problem was the data organisation and the data communication between programs written in different languages. The algorithms are written in FORTRAN 77 while the code to acquire and display the beam position and the programs to send the corrections to the equipment are written in "C" [4]. To solve this problem we have organised all our data in a MOPS data structure [5] which can be accessed with several high-level languages including both FORTRAN 77 and "C" and can be used on many types of computers.

Optics and Twiss parameters are provided in a standard data structure and a detailed description of this data structure can be found in reference [6]. Another MOPS data structure contains relevant data from the beam position monitors and the orbit correction coils and serves as a communication data structure between all the processes involved and it is kept as a UNIX SYSTEM V shared data segment on the workstations to ensure a high efficiency [5]. The archival and retrieval of input data and corrections is simplified by the use of this data structure and a user friendly interface for this purpose has been built into this procedure. The consequent use of MOPS data structures also allows an offline analysis of the data in modelling programs like PETROS [7].

The execution of the program is controlled with *commands* which are either used to initiate an action or to set new parameters. The commands can be entered in interactive mode by the operator or in batch mode where they are read from a file. The latter allows the execution of complicated command sequences by the control room operators and also decouples the program from the man machine interface since the preparation of the command files can be done either manually or using a graphics interface.

4. PERFORMANCE TESTS FOR THE PROCEDURE

4.1 First tests with positrons in the SPS

During the first machine development periods which were dedicated to prepare the SPS for the injection of electrons and positrons into LEP, we have gained some experience with our procedure.

Two modes of operation have been used extensively, namely the possibility to correct the first turn of the particles and to correct the closed orbit globally. Both options worked to our expectations and are now used in the normal operation of the SPS.

A quantitative discussion of the performance for the SPS was presented in a previous report [1].

4.2 Experience with the procedure during the LEP startup

The program has been originally written for the CERN SPS, but since no assumptions on the machine were made, it could be used for LEP with minor modifications (i.e. increased buffer sizes for input and output). It was available at the first day of the LEP commissioning for first turn and closed orbit correction [8].

For the first turn correction two modes of operation were successfully used: a correction of the whole trajectory and a piecewise correction in regions with large orbit distortions.

As far as the closed orbit correction is concerned, the most straightforward strategy is to first identify and correct the major imperfections in the machine by using a global correction of the whole ring including a harmonic filtering. The procedure generally yields a closed orbit with a r.m.s. distortion of about 2.0 mm in both planes. Further improvements can be achieved either by concentrating on the correction of a special region of the machine (such as injection region, interaction points and straight sections) using the possibility of short range corrections or local bumps or by applying a global correction with many correctors (typically 10 – 20) with relatively weak correction kicks. Both strategies were successfully used for LEP where r.m.s. orbit distortions of less than 1.8 mm in both planes were regularly achieved. As a matter of fact, thanks to the reliable hardware for the beam position measurement, the agreement between the predicted and the achieved orbit surpassed our expectations. An illustration of the orbit correction applied to LEP is given in Table 1, which gives both, the r.m.s. distortion and the maximum peak to peak deviation as a function of subsequent corrections in the horizontal plane.

Correction number:	r.m.s value:	Peak to peak value:
0	8.41 mm	30.6 mm
1	2.96 mm	19.9 mm
2	1.79 mm	9.7 mm
3	1.54 mm	8.8 mm

Table 1: Closed orbit correction for LEP (horizontal plane):

The corresponding behaviour in the vertical plane is given in Table 2. In these particular examples five correctors are used for each correction.

Correction number:	r.m.s value:	Peak to peak value:
0	6.56 mm	25.4 mm
1	3.56 mm	17.9 mm
2	1.83 mm	10.7 mm
3	1.60 mm	8.9 mm

Table 2: Closed orbit correction for LEP (vertical plane):

SUMMARY

- Using existing closed orbit correction techniques we have built a procedure to correct the closed orbit and the first turn in both the CERN SPS and LEP.
- The necessary data is organised using the data structure management system MOPS and stored in UNIX SYSTEM V shared memory segments if it is used in the online environment.
- Offline simulations were used to test the performance and the reliability of the methods.
- First tests during the machine development periods for lepton commissioning were successful in correcting the first turn and the closed orbit of the particles.
- The correction procedure has been successfully used for the LEP startup in July and August 1989.

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