A NEW CLOSED ORBIT CORRECTION PROCEDURE FOR THE CERN SPS

W. Herr, T. Limberg*), J. Miles and R. Schmidt

SPS Division, CERN 1211 Geneva 23, Switzerland
*) Now at SLAC, Stanford, California 94305, U.S.A.

Abstract:

Using well known correction techniques and algorithms, we have built a new procedure to correct the closed orbit of the CERN SPS. The option to steer beam lines has been included allowing the establishment and optimisation of the first turn in the machine. As a new feature this correction procedures can take into account limited corrector strength. 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 simulations and its first application during the lepton commissioning period and the $p\bar{p}$ collider run in 1988.

Introduction

In the process of designing a new control system for the CERN SPS a new procedure was built to correct the closed orbit in which the possibility of correcting the trajectory in a beamline was included. This is particularly important for leptons which are injected at an energy of 3.5 GeV only a few seconds after the proton extraction at 450 GeV. Small remanent fields or distortions change the path of the leptons substantially and can lead to a beam loss on the first turn. Manual steering of the first turn is known to be very time consuming and requires advanced operator experience. The automatic first turn correction implemented last year greatly simplified and abridged this procedure.

The new procedure handles limitations of the correction dipole strengths. This is very important at high SPS energies where the maximum strength of the corrector coils is relatively weak.

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. The structure of the program allows to include different algorithms for the correction to be included in an easy way as an additional subroutine.

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, in particular, to study the performance of the correction algorithm when a closed orbit for LEP was corrected on one of the workstations used for the control of LEP.

The closed orbit correction procedure

A schematic view of our correction procedure is given in Fig.1. The entire procedure is built from independent, exchangeable modules and it consists of the pure algorithms like MICADO, a data processing and preparation part and the input/output part. Other independent modules are used to acquire the data from the beam position monitors and the current settings of the correction dipoles and to send the corrections back to the equipment. The data structure which contains this information can also be processed offline in modelling programs to allow an analysis of the orbit.

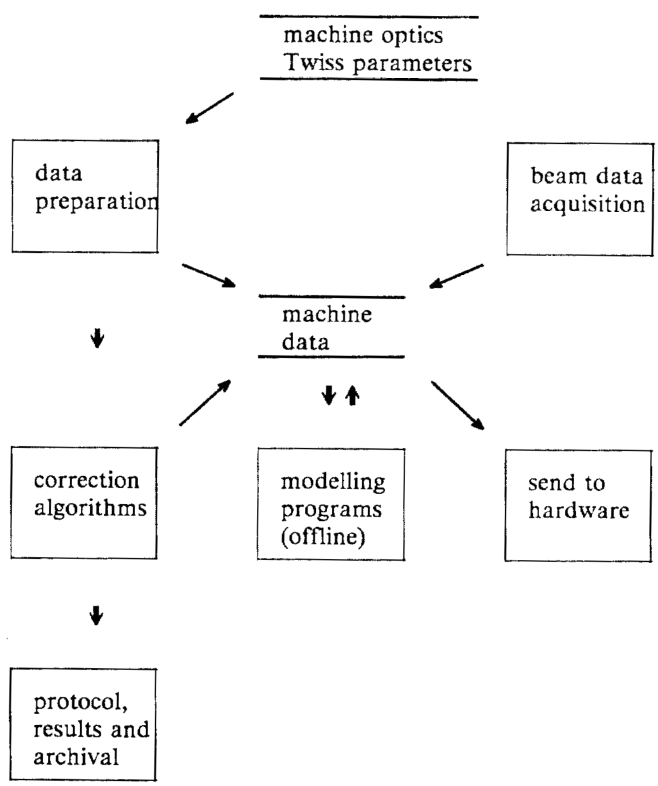

Fig. 1: Schematic view of the correction procedure.

Data preparation: Data processing is necessary to prepare the "raw" data like beam position from monitors, kicker strength and Twiss parameters for the use in the algorithms. It also means that doubtful hardware like monitors reporting obviously false beam positions must be recognised and treated accordingly. 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 formulae used for the response matrix are:

$$A(i,j) = \frac{\sqrt{\beta_i \cdot \beta_j}}{2\sin(\pi \cdot Q)} \cos((\mu_i - \mu_j) \cdot 2\pi - Q \cdot \pi)$$

for the closed orbit correction and:

$$A(i,j) = \sqrt{\beta_i \cdot \beta_j} \cdot (\sin(\mu_i - \mu_j) \cdot 2\pi)$$

for beam lines, where

μ_i, μ_j Phase at monitor and corrector ·
β_i, β_j β function at monitor and corrector
Q Tune of the machine

The energy error is taken into account by first determining this error from the measured orbit and then using a renormalised orbit in the correction algorithm. The energy error $\Delta p/p$ can be determined by minimising the expression

$$S = \Sigma (r_i - D_i \cdot \Delta p/p)^2$$

where r_i is the radial beam position at the i^{th} monitor and D_i the dispersion function at this monitor.

This is important if the beam is not centred on the nominal orbit since the correction would try to move the beam to the central orbit otherwise. For relativistic particles the length of the closed orbit and the mean radial position is determined by the RF frequency and dipole fields cannot change this mean value. Any attempt to correct this with dipoles would lead to wrong results. This option can be switched off by the operator.

If a beamline or the first turn is to be corrected, it requires a special treatment. First, the injection point has to be specified by the operator. Secondly, the response matrix has a triangular shape since monitors placed before a given kicker would not see its effect and different coefficients have to be used.

After the correction is calculated the relevant data (i.e. kicker strength) is written back into the output data structure which can then be picked up by the processes which send the corrections to the hardware.

Correction algorithms: Most of the correction algorithms in ORBCOR have been adapted without major changes and others have been added. The methods currently available are:

MICADO

The MICADO method works as described in [1]. It starts by examining all correctors and selects the one with 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. If a kick calculated with MICADO exceeds the maximum strength for a corrector, this corrector will be set to its maximum strength and will be disabled. The closed orbit after correction will be recalculated in this case and the operator will receive a warning message.

SIMPLEX

The SIMPLEX method was developed some years ago and has been successfully used in the CERN SPS. The closed orbit correction, subject to the maximum allowable corrector strengths, can be formulated as a so-called l_1 linear approximation problem. The SIMPLEX method solves the formulation of the constrained l_1 problem as a linear program. The original code is written in FORTRAN IV for the NORD console computers of the SPS and was easily incorporated into our procedure.

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

Organisation of input and output data

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 the beam position and the programs to send the corrections back to the equipment are written in "C". To solve this problem we have organised all our data in a MOPS data structure [2] which can be accessed by several high-level languages including both FORTRAN 77 and "C".

Optics and Twiss parameters for the SPS are provided in a standard data structure and a detailed description of this data structure can be found in reference [3]. It serves only as input and is not changed by our orbit correction procedure. Another MOPS data structure (COCOM) contains the data concerning the beam position monitors and the orbit correction coils and serves as a communication data structure between all the processes involved. In the environment of the control system this data structure must be accessible concurrently from several processes and we have decided to keep this data structure as a UNIX SYSTEM V shared data segment on the workstations to ensure a high efficiency [2]. This structure is loaded with data by the data acquisition programs written in "C" and this data is picked up by the orbit correction program. The calculated corrections and additional information (e.g. on disabled monitors etc.) are written back into this structure from where it can be send to the hardware by another process. 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. It allows the analysis of the data offline in modelling programs like PETROS [4].

Performance tests for the procedure

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 got some experience with our procedure.

First turn correction

After optimization of the injection of the positrons we used the first turn correction procedure to establish the first turn in the SPS and to optimise it afterwards. In Tab.3. we have given the results of four successive first turn corrections with 3 correctors each time. The results are given for the horizontal plane. The first turn could be clearly improved and the peak-to-peak distortion was reduced from approximately 54 mm to 24 mm and the r.m.s. value from 10.77 to 4.95. Several hundred turns could be observed in the machine after this correction had been applied.

Table 3: First turn correction with positrons in the SPS:

Correction number	r.m.s value	Peak to peak value
0	10.77	53.64
1	8.45	51.24
2	6.37	38.42
3	5.74	29.87
4	4.95	23.89

Closed orbit correction

After the first turn had been achieved and improved, we corrected the closed orbit of the positron beam and the results are summarised in Tab.4 for the horizontal plane.

Table 4: Closed orbit correction with positrons in the SPS:

Correction number:	r.m.s value:	Peak to peak value:
0	5.87	26.60
1	4.00	16.32
2	2.85	11.22
3	2.51	9.36

Correcting in this way the closed orbit at injection was sufficient to reach an energy of 18 GeV although further corrections during the ramp were needed to optimise the transmission. The difficulties we experienced were mostly due to hardware problems with the monitors or the correction kickers which are now loaded with newly developed function generators. Especially when a larger number of correctors should be used the effect of wrongly measured beam positions becomes important and we have restricted ourselves to a maximum number of three correctors each time.

First tests with the LEP machine

To study the performance of our procedure we tried to correct a simulated LEP orbit. The LEP optics parameters and the distorted orbit were generated with PETROS and the correction was done on the APOLLO workstations. Apart from providing the necessary space for the response matrix (for LEP this is a 280*540 matrix) no changes have been made to our programs. We have corrected the orbit with a small (3) and a large number (100) of correctors. With three correctors the orbit was improved significantly while with 100 correctors the resulting orbit was basically flat at 0.0. The time necessary for correction increased from a few seconds with three correctors to several minutes with 100 correctors on an APOLLO workstation.

SUMMARY

- Using existing closed orbit correction techniques we have built a procedure to correct the closed orbit and the first turn in the CERN SPS.
- 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 on-line 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.

REFERENCES

[1] B. Autin and Y. Marti; "Closed Orbit Correction of A.G. Machines using a limited Number of Magnets"; CERN ISR-MA/73-17 (1973).

[2] W. Herr; "MOPS a Data Structure Management System for the LEP/SPS Control System"; Proceedings of this conference, Chicago (1989).

[3] W. Herr, T. Limberg and R. Schmidt; "A Standard Data Structure for Optics and Twiss Parameters for the CERN SPS"; CERN/SPS/AMS/Note 88-06 (1988).

[4] K. Steffen and J. Kewisch; DESY PET 76/09 (1976).