ORBIT PROCESSING FOR LEP

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Abstract The correction of a closed orbit or a trajectory requires great care in the preparation of the data from the beam monitors.Bad beam position monitors have to be identified and rejected and noise on the orbit measurement has to be reduced to its lowest possible level.Such an approach requires a careful analysis (both online and offline) of the measured orbit before any correction can be applied.This preparation part is presently achieved by applying different filtering algorithms on the data and the optional use of a harmonic analysis of the measured orbits.As far as the correction part is concerned, the experience rapidly demonstrated that a global correction scheme was not sufficient.As a matter of fact, some specific regions of the machine (straight sections or low beta insertions) require special considerations and have therefore to be corrected locally and individually.The same kind of localized approach is also used for optimising the orbit in sensitive areas like separators or the collimation systems.In this report we describe both the preparation of the raw beam position data and the strategies applied for the orbit correction during the LEP startup.A discussion of the behaviour of the LEP machine during its commissioning is also included.

Introduction

An essential ingredient for the successful operation of a particle accelerator is an efficient control of the closed orbit. This becomes even more important for the new large accelerators built with tighter tolerances for cost effectiveness or because they are built with superconducting magnets such as the LHC or SSC. A good orbit control is also required by the physics experiments to keep the background low in the interaction regions of storage rings.

The dynamics of particle beams is strongly influenced by the closed orbit:

- To avoid the possible excitation of synchro-betatron resonances the orbit distortions should be kept as small as possible through regions equipped with the radio frequency cavities.
- A bad closed orbit can also introduce non negligible coupling between the two transverse planes and can produce a sizeable vertical dispersion, which can in turn strongly increase the effective beam size and result in a loss of luminosity.

A good closed orbit is therefore necessary for a satisfactory performance of the accelerator and for machine studies, where a flexible orbit control is important.

For a very large accelerator with many beam position monitors (e.g. LEP with 504 monitors for each plane) it becomes more important to have a reliable measurement system and to identify and remove statistical fluctuations (e.g. noise) or systematic effects (e.g. offsets, bad monitors etc.). A substantial part of the work has been dedicated to prepare the raw data from the monitors for the orbit correction programs which have to rely on correct measurements in order to work successfully.

The programs for the closed orbit correction used in the SPS/LEP accelerator complex have been described in previous reports [1,2] and here we shall describe the important part of data preparation necessary before the correction algorithms can be successfully applied. In the next section the data preparation is described and afterwards the treatment of the data in the correction procedure is discussed.

In the last two sections we shall discuss the strategies used under different operational conditions and the experience gained during the startup of LEP and during almost one year of LEP operation.

Data preparation

Data processing is necessary to prepare the raw data such as beam positions,corrector strengths and Twiss parameters for their subsequent use in the correction algorithms. Contrary to our expectations, the use of the proper Twiss file happened to be a potential source of problems.As a matter of fact, the normal operation of LEP is linked to different optical configurations (back-up, injection and squeeze to low beta values for physics). Before any correction, one has therefore to make sure that the relevant optics is used.To achieve this, the program automatically compares the optical configuration registered by the orbit acquisition system (at the time the data was taken) to that presently used in the correction algorithms.Should the two flags be different, this will cause the program to stop with a corresponding error message.

Another part of the data preparation is to read the present corrector settings, which might be required to perform corrections on the "bare orbit" (see later). However, the main obstacle to an efficient closed orbit correction remains the identification of erroneous readings.Presently, the rejection of bad PU's can be achieved in three ways: first one can apply a systematic rejection of all monitors whose readings exceed a given number of standard deviations calculated from the raw data (typically 5 r.m.s.).Secondly, there exists an option which checks for large isolated readings (not surrounded by any reading comparable within a given percentage in amplitude) and proposes them for rejection.Finally, the operator has the possibility to disable suspicious monitors interactively on the display. This last option, which relies on pure experience, happens to be very useful once the r.m.s. of the orbit is already reduced to a low level.Since an automatised procedure for such a detection turns out to be essential, it is foreseen to also implement an approach based on a fit mechanism [3] which is not yet operationally available.

Once the bad PU's have been disabled, the data is not yet ready to be treated by the correction algorithms.One has to further account for two other effects: first it has been established that there exists an offset on the readings which could be related to the hardware of the acquisition system [4]. The latter is removed by running a dedicated program (bomcoroffset) which computes the offset by averaging the readings in the straight sec-

tions of the machine where the dispersion function is expected to vanish. Finally, the energy offset is removed from the readings. This operation is performed in the correction program before the actual correction is computed [1].
After this preparation part, the orbit is passed to the correction program.

Correction strategies

In this section, we shall try to illustrate the different steps which have been applied for the correction of the closed orbit during development periods. This is sensibly different from what is performed during a normal physics run where a minimum of additional corrections is aimed at. The strategy to be applied strongly depends on the configuration of the machine (injection, ramping in energy, low beta squeeze and physics runs).
Before the closed orbit can be corrected, one has to first get the beam circulating in the machine. This is achieved with the so-called "first turn" algorithm included in the correction package. This procedure allows to first establish and then correct the trajectory of the particles in the machine. It should be pointed out, that the first turn correction is performed on a single turn acquisition which can be requested from the monitoring system. It can be used either locally (restricted region of the machine) or globally. Apart for the running-in, this procedure is used every time the optical configuration of the machine is drastically modified (e.g. changing from 60° to 90° phase advance). It usually requires the computation of only a few correctors in each plane to have the beam circulating and to switch to the closed orbit correction mode.
This first step being achieved, one generally has to deal with a closed orbit with a r.m.s. value around 7-9 mm (which is about the limit for the particles not to hit the vacuum chamber).
When injecting into a new machine, one usually starts with an orbit of rather poor quality as mentioned above. In this case, it is essential to first detect the major imperfections in the machine by using a global correction. At this stage of the correction procedure, it proved extremely useful to reduce the orbit noise by applying a harmonic analysis on the raw data [5]: the correction package performs a Fourier transformation on the original orbit, retains only a specified number of harmonics around the central value and generates a new orbit which is then processed. Such a procedure is extremely powerful and rapidly yields reasonable orbits of the order of 2.0 mm r.m.s. with only a few correctors necessary (typically 5-10). Further improvements can then be achieved either by concentrating on the correction of a dedicated region or by a global correction with an increased number of correctors. Both strategies were successfully used for LEP where r.m.s. orbit distortions of the order of 1.2-1.4 mm in both planes are usually obtained with the help of 10-20 additional correctors. This corresponds to the value routinely achieved for the operation of the machine. Further improvements can still be achieved (see next section) but are presently too much time consuming to be incorporated in the operational procedures (careful study of the erroneous readings is then necessary).

With such an orbit, accumulation can proceed and finally the machine is prepared for the energy ramp. The latter is crucial for the closed orbit since one should distinguish between correctors compensating remanent field effects (should not be ramped) and those accounting for misalignments (have to be ramped). Apart from obvious constant contributions, like the compensation of the experimental solenoids, one usually ramps all the correctors. The ramping file which has to be prepared for subsequent use in operation is carefully established by ramping the machine in steps of a few GeV. At each step, the difference between the present orbit and the previous one is computed. This difference is then corrected. With this procedure, we basically achieve an orbit at top energy which is similar to that obtained at injection (which is used as the reference).
For the squeeze to low beta values, we also propose to use the difference approach but including an additional feature of the correction package (enable/disable regions of correctors). Since the squeeze is a modification of the optics in the insertions only, we correct the difference orbit globally but allowing only the correctors located in the insertions to be activated. This should help to force the orbit distortions to be corrected nearest to their origin.

At this stage the machine is ready to go into the physics mode. However, one still has to minimize the background related to the closed orbit in the experiments. This is achieved by a local correction (short length correction) where one chooses on the display both the precise region to be corrected and the requested number of correctors (presently, this operation has to be performed regularly).

It should be pointed out that the strategy described above only reflects one of the possibilities to proceed. At any step, the operator is free to select any combination of local/global correction according to his preferences.

As far as other features of the correction package are concerned (3 or 4 magnets bumps or simulation of kicks) they are not described here, since they are mainly used for MD purposes.

Experience

Experience during the LEP startup

During the LEP startup in July/August 1989 two modes of operation were successfully used: the correction of the first turn of the particles and the correction of the closed orbit, globally as well as locally.
In this period it rapidly became clear that our understanding of the beam monitoring system was not sufficient so that both a noise filtering and a careful inspection of the orbit measurements were essential for the performance of the procedure.
Some of the data preparation tools mentioned above were developed in this initial phase of LEP. An orbit distortion of less than 2.0 mm r.m.s. was generally achieved which was sufficient for the commissioning of the machine and the first successful physics runs [6].

Closed orbit correction during LEP operation

After one year of successful LEP operation one can draw some conclusions on the everyday performance of the closed orbit correction procedures.
During the setting up for a physics run not much time can be spent to achieve an excellent orbit and only those corrections are carried out which are necessary to prepare it for the physics programme.
The closed orbit distortions of 1.2 - 1.4 mm r.m.s. routinely achieved are certainly not optimal, but allow a satisfactory performance of the machine.
The different strategies described in the previous section have been successfully applied, but some problems remain to be solved:

- As already mentioned, it would be desirable to improve the automatic recognition of errors in the measurements.

This doesn't seem to be an easy task without using sophisticated and time consuming procedures [3] which can however be performed off-line.

- Another serious problem is the reproducibility of the closed orbit when the machine is restarted. This problem is not yet fully understood and limits the achievable quality of the closed orbit.It also explains why the number of correctors in use is steadily increasing with time. To avoid this unnecessary and misleading accumulation of correctors,it is possible to apply a so-called bare orbit correction. This procedure reads the strengths of the correctors currently used, substracts their contribution to the measured orbit and corrects the bare orbit. This typically enables us to reproduce a given orbit with 25 correctors where more than 100 were used. This problem definitively deserves some priority and a new correction strategy which is hoped to converge towards a better reproducibility is presently under test.

Experience during machine developments

The closed orbit procedure was written in a very flexible form so that it can be used to perform different tasks in machine development periods:

- The controlled manipulation of bumps for detailed studies of both the coupling and the dispersion in LEP was necessary and could be satisfactorily achieved. A special procedure has been produced which enables the closed orbit correction package to compute corrections for the coupling in the machine by using the dedicated skew quadrupoles as correctors [7].
- Similarly, different small procedures have been produced to help for different purposes such as the separation or the collimation systems.In fact the concept of "command files" [2] which can be prepared off-line has proven to be a very useful tool.
- Experience from dispersion and background studies emphasized the necessity to compute asymmetric bumps around the interaction regions.
- In the view of future developments for LEP (e.g. polarisation) a special machine development was dedicated to the attempt to achieve the best possible orbit correction. This experiment was carried out at 46 GeV, with a relatively weak positron beam only. Therefore the beam separation was switched off during this experiment. By carefully inspecting the measured orbits and identifying bad readings from the beam position monitors it was possible to reduce the vertical r.m.s. closed orbit distortion from 1.8 mm to about 0.7 mm within effectively less than one hour. In parallel the vertical emittance was measured with the LEP wire scanner. It was found that the effective vertical beam size at the position of the wire scanner was reduced by a factor two. The origin of this reduction could not be investigated in the time available, but it is most probably due to a strong decrease in the vertical dispersion. Five iterations with an increasing number of correctors were necessary and a total number of around 130 correctors (out of 280) were used. At this point the experiment was stopped but we are convinced that a further improvement to about 0.5 mm r.m.s. should be possible with some effort.
- Such good closed orbit corrections as those achieved during machine development sessions should be aimed at for normal operation.However, this could only be envisaged once the problems of the orbit reproducibility are better understood.As a matter of fact, it implies to recalculate both the ramping and the squeezing files, a time consuming operation which should not be repeated too often.
- Closed orbit corrections with a large number of correctors is usually a time consuming process. For this reason, it was hardly conceivable to perform such calculations during the preparation phase of a run for physics.A major improvement has been recently achieved by installing the correction part of the procedure on a fast workstation (APOLLO DSP10000).With this new feature, a correction of the LEP machine with 100 correctors by using Micado is computed within less than 60 seconds.

Conclusion

This paper summarizes our accumulated experience with the orbit processing of LEP.Since the start of the machine in July 1989, the closed orbit procedure worked reliably and rather satisfactorily.Our main objective was to collect as many information as possible on the behaviour of the correction procedure, such as to adapt it to the requirements.We feel that this objective has been achieved.

Presently a closed orbit with an r.m.s. of about 1.2 mm is routinely achieved in operation.As demonstrated in a machine development session, a much better orbit could be achieved with an expected r.m.s. value lower than 0.7 mm.

However, such a situation could only be envisaged for normal operation once the three problems are solved, which presently limit the performance: a better understanding of the behaviour of the beam acquisition system,better reproducibility of the orbit as a function of time and an improved detection of the suspicious monitors. These are the keys to an operational performance comparable to that obtained during machine developments.

References

[1] W. Herr et al.,'A New Closed Orbit Correction Procedure for the CERN SPS'.Proceedings of the IEEE Particle Accelerator Conference, Chicago (1989)
and CERN SPS/89-10 (AMS).

[2] D. Brandt et al.,'A New Closed Orbit Correction Procedure for the CERN SPS and LEP',Proceedings of the Int. Conf. on Accel. and Large Exp. Physics Control Systems, Vancouver (1989)
and CERN SPS/89-48 (AMS).

[3] D. Brandt,A. Verdier,'Exhaustive Search of Field Defect Compensation and Reading Errors in A.G. Machines', first EPAC, Rome (1988)
and CERN /LEP-TH/88-25.

[4] G. Baribaud et al.,'The LEP Beam Orbit Measurement System: Status and Running-In Results', this Conference.

[5] T. Risselada,'Tune Estimation and Noise Reduction Using Harmonic Analysis and Filtering of Orbit Measurements', LEP Commissioning Note 19, CERN (1989).

[6] D. Brandt et al.,'A Description of the Orbit Correction Procedure Used for the LEP Startup', LEP Commissioning Note 11, CERN (1989).

[7] J.P. Gourber et al.,'Compensation of Linear Betatron Coupling in LEP', this Conference.