CLOSED ORBIT MEASUREMENT AND CORRECTION AT SUPER-ACO*

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Abstract

Modern synchrotron light sources require an accurate, stable and reproducible beam positionning. The design of the BPM and of the detection system for Super-ACO are described. The overall relative precision of the measurements is about 30 μm at constant intensity.

The codes routinely used to correct the closed orbit within the accuracy of the measurements are presented. The residual r.m.s. of the C.O. readings is around 50 μm. Surprising orbit dependance with current and drift with time are reported and discussed.

Introduction

Super-ACO was designed in the years 1982-83 so as to provide an accurate closed orbit measurement, using 16 BPM, each of these located in between two quadrupoles on both sides of the long straight sections. Sixteen beam steerings in the vertical plane (defocussing quadrupoles) and 24 in the horizontal plane (16 in the focussing quadrupoles and 8 in the magnets) can be powered independently or arranged in the so-called, position and angle orbit bumps, $\Delta_{x,z}$ and $\theta_{x,z}$. Such orbit bumps can be provided either for the undulator beam lines or for the bending magnet beam lines, but not for both simultaneously. We describe below the performances of the system, the schemes for C.O. corrections and some unforeseen and not yet fully understood problems encountered in the orbit measurements.

The B.P.M.

A detailed description of the BPM, mechanics, feedthroughs, geometrical accuracy and performed vacuum tests is given in ref.[1]. Fig. 1 shows the geometry of the BPM. It is built from a massive block of stainless steel fixed onto a neighbouring quadrupole through a mechanical support. The various uncertainties on the determination of the BPM geometrical center as compared to the theoretical orbit are summarized below :

- difference between magnetic and mechanical axis of the quadrupole : $\begin{cases}\overline{\Delta z} = +.06\text{ mm},\ \sigma_z = .09\text{ mm}\\ \overline{\Delta x} = -.06\text{ mm},\ \sigma_x = .13\text{ mm}\end{cases}$

$$\left.\begin{array}{ll}\text{- quadrupole alignment uncertainty :} & \pm .05\text{ mm}\\ \text{- support/quadrupole uncertainty :} & \pm .05\text{ mm}\end{array}\right\}\pm .1\text{ mm}$$

- geometry of the BPM itself : $\pm.05\text{ mm} \pm.05\text{ mm} = \pm.1\text{ mm}$

A quadratic combination of all these errors give the following numbers $\delta x = .19$ mm, $\delta z = .17$ mm.

No measurement of the BPM electrical axis by the wire method was attempted to and reliance was instead put exclusively on the accuracy of the various machinings, the quality of the feedthroughs and that of the quadrupole design and construction.

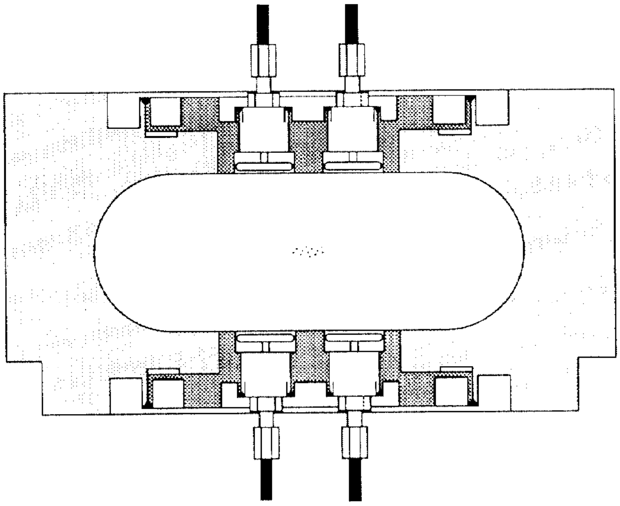

Fig. 1 : B.P.M. cross section.

The Detecting System

The detecting system is shown in Fig. 2. The signal from each individual electrode is fed to a PIN diode multiplexer through a cable, 30 m long, identical for the 4 electrodes of a BPM to within 20 cm. The multiplexer itself is built in two stages. The first stage comprises 8 subunits, each of these receiving the signals from 8 electrodes (2 BPM). The outputs of the 8 subunits are fed to the second stage of the multiplexer. This is followed by a 110 dB attenuator, variable in 10 dB steps and by an S.C.D. "Nuclétudes" amplifier with gain 36 dB (30 dBm). A single peak detector is used for all the 64 electrodes signals, thus ensuring the same response for all the channels.

The peak voltage of an electrode converted by a 16 bits ADC is fed to a Z80 microprocessor which, at a frequency of 1 kHz, increments the channel number and resets the zero of the peak detector. Thus, each electrode is read 16 times per second. The microprocessor is also used as a digital filter which averages the voltage of a given electrode by a method of Infinite Impulse Response. In actual facts, the last average is corrected by the difference with the new value weighted by 1/32. The computation of the closed orbit is done permanently. The central PDP1144 computer

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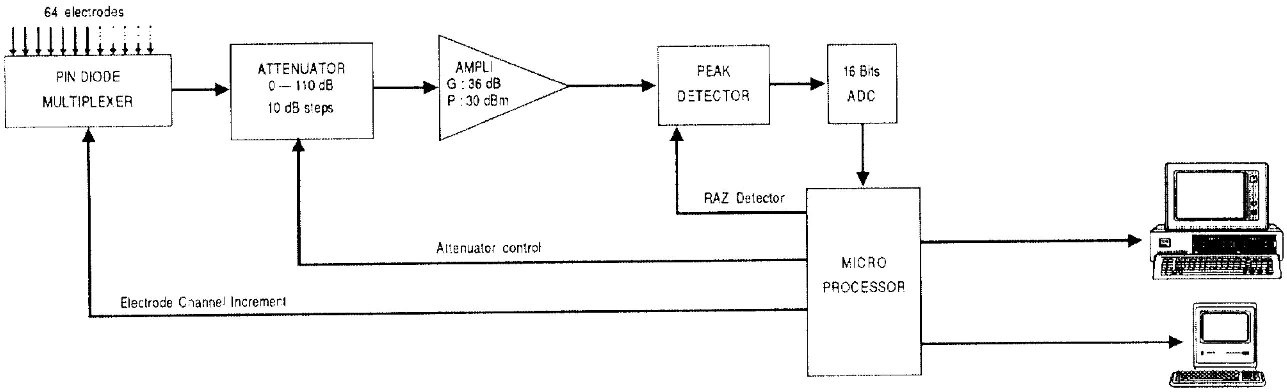

Fig. 2 : Block Diagram of the Detecting System

has access to the data stored in the microprocessor for different tasks of orbit correction described in § 4).

The peak detector has a very linear response, but one cannot avoid the consequences of the diode detection threshold which is equivalent to an offset of 0.13 volts. The step attenuator is automatically adjusted, anytime one of 64 signals is not within the chosen range 2.8 to 10 volts. Thus the peak detector offset introduces a systematic error ranging from 4.6 to 1.3 % on the closed orbit measurement. For a closed orbit corrected to within 300 µm, the maximum systematic error would be 14 µm. The above mentionned systematic error was checked by measuring an orbit which had intentionally large excursions, up to 6 mm, with 2 attenuator settings differing by 10 dB. The difference was found to be 3.8 % with an r.m.s. of 2.6 % for the 16 positions. The result of this measurement is therefore 3.8 ± .65 % to be compared to an expected average of 2.85 %.

Characteristics of the System

The system has a very large range of current per bunch capability, probably limited by the multiplexer. The largest bunch current ever reached was 165 mA, but routinely a 2 bunch operation with 110 mA per bunch is performed. No number can be set on the system sensitivity, but the smallest step which can be displayed is 10 µm. The reproducibility of the orbit measurement was checked at fixed machine settings keeping the current constant. With 2 bunches, the x and z reproducibility has an r.m.s. of respectively 20 and 15 µm. For the operation with 24 bunches it is worse, 50 and 20 µm r.m.s. respectively. This seems to be connected with the synchrotron oscillations and specially with their fluctuations.

C.O. Correction Schemes

Three methods have been developped successively on Super-ACO in order to steer the closed orbit. The first one proceeds by choosing the most effective correctors [2] and the second one uses C.O. bumps (position or angle). Combining these two schemes, one can compensate the main C.O. distorsions and adjust it precisely at certain points on the ring circumferences, while increasing the distorsions elsewhere.

Since more and more beam lines are progressively used on Super-ACO (presently 4 from undulators and 9 from the bending magnets) and owing to a required accuracy of ± 0.1 mm for the source points, a method of global correction including all the correctors was developped. The principle is after G. Guignard [3]. It consists in minimizing the sum of the squares :

$$\psi = \sum_{i=1}^{n} p_i \left(y_i + \sum_{j=1}^{m} a_{ij} x_j \right)^2 + \gamma \sum_{j=1}^{m} x_j^2$$

where :

- n is the number of BPM and m the number of dipole correctors.
- p_i is a weight factor at station i and γ the weight connected to the limit of total corrector current.
- y_i is the C.O. distorsion at station i and a_{ij} the effect of corrector j at i.
- x_j is the current of corrector j to determine.

Cancelling the partial derivatives $\frac{\partial \Psi}{\partial x_k}$, $k \in [1,m]$, one has to inverse a m x m square matrix, symmetric and quadratic. All its eigen values are real and positive and its eigenvectors make an orthogonal base where the solution vector $\vec{x}$ can be expressed. One can use the classical numerical method [4] searching successively the eigenvalues with the largest modules.

Based on these considerations, a numerical code has been developped. In almost all cases, it cancels exactly the C.O. excursion with reasonable corrector currents. In the case of 30 correctors, the calculation takes 2 minutes. For a given set of correctors the eigenvalues and the eigenvectors are calculated and stored in the computer, thus making the calculation of the corrector currents almost instantaneous.

For practical use, the code is included in the control system. All the operations are automatically performed : measurements, calculations and corrections. Daily, after 2 or 3 of these cycles, each lasting one minute, the closed orbit is precisely adjusted. Fig. 3 shows a typical example of an orbit prior and after such a correction. The results are extremely good with r.m.s. of 25 and 50 µm respectively in the x and z directions for a 2 bunch filling.

Closed Orbit Measurements

With the residual closed orbit distorsions getting smaller and with the increasing confidence in the reliability of the detecting system it became clear that large orbit changes were experienced at Super-ACO during a beam filling decay from 450 to 150 mA. In this current range, orbit changes of the order of 2 to 300 µm were commonly observed. A special investigation described below was carried out with in mind to separate the effect of beam current change from the drift with time at constant current.

In the 24 bunch mode, a closed orbit was measured for a beam current of 450 mA. Then, in a time interval of about 100 s, the beam intensity was reduced to 30 mA and new orbit measurements were taken during half an hour. Two observations can be made. An orbit jump in the radial direction of average 700 µm is measured in the dispersive sections, whereas in the non dispersive sections the average is compatible with zero. When interchanging the dispersive and non dispersive sections the orbit jumps follow. Everything looks as if the beam energy was changing by an amount of $5\ 10^{-4}$. The second trend is a drift with time of the low current orbit following the abrupt change of intensity. The drift looks exponential with a time constant of the order of 1/4 hour. Furthermore, the amplitude of the drift is not identical for all the stations but is roughly of the order of a few hundred µm.

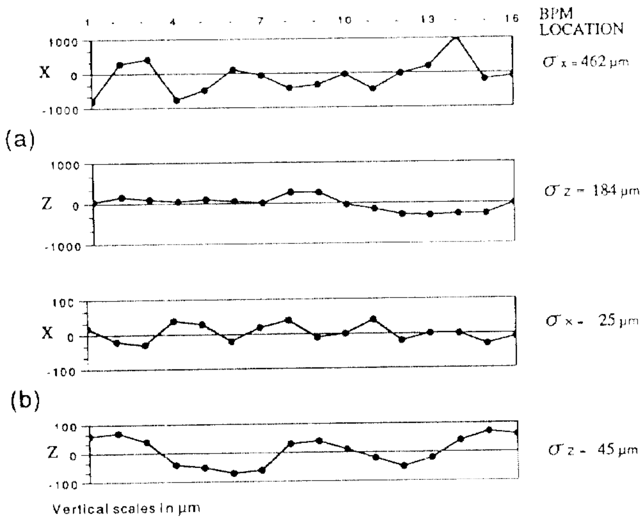

Fig. 3 : Closed Orbit Measurement
(a) Before correction
(b) After correction.

In the 2 bunch mode, the bunch intensity was reduced from 100 mA to a few mA. No orbit jump is observed in the dispersive sections but orbit drifts are again present everywhere.

In both cases, no such effects as mentionned above were observed in the vertical direction. If anything, they are least reduced by a factor of 10. Furthermore the amplitude of the drift in the radial direction is proportional to the total current. This amplitude, when normalized to the total current, displays the machine symmetry with $v_x = 4.7$. In fact a single kick in the RF section would reduce the norm by a factor 4. The required kick has a strength of $E \times l = 10^5$ Volts.

The normal behavior of the orbit in the vertical direction excludes a large number of possible mechanisms. The drift with time as well as its proportionality to total current restrict to a large extent possible RF mechanisms. The problem is still investigated at LURE.

Acknowledgments

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