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SOME SCHEMES FOR ON-LINE CORRECTION OF THE CLOSED ORBIT, DISPERSION AND BETA FUNCTIONS IN PEP* (A)

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Introduction

PEP has been operated successfully under computer control. It is necessary for colliding beam operation that the errors in closed orbits, dispersion and beta functions be corrected. The schemes in the PEP control program for on-line correction of these errors are described in this paper.

The orbit control tasks in the PEP control system perform the functions of data gathering, data presentation (color display, printing), calculation and setting of corrector magnets. The tasks are generally small and modular, taking information from the database, processing it, then returning the results to the database. The PEP operator communicates with the tasks through touch panels monitored by the Director program. The display task, which displays orbit and corrector information on a TV color display, provides the main information required by the operator.

The Orbit Calculator

The orbit calculator task enables the operator to manipulate orbit data stored in the many orbit registers. Manipulations are: fetching, storing, comparing and function calculation. Orbit information is stored in the database in various registers. Each register normally holds information for both e^+ and e^- beams, and for both horizontal and vertical planes. Each register holds: a) the displacement at all beam position monitors (BPMs), b) the strength of all correctors, c) calculated displacement and slope at the interaction regions, values of maximum and rms deviations through the regions, d) the time of the orbit scan (or calculation). The many orbit registers are necessary to provide flexibility. Registers are provided for: display, last scanned orbit, last calculated dispersion and beta functions, global and local corrections, RF orbits (separation of the e^+ and e^- orbits due to the RF acceleration, both calculated and scanned). An orbit stack (depth of four) is used for calculations; and a memory register is provided for the operator's convenience.

Local/Global Orbit Correction

Local orbit correction is done by changing the displacement and/or slope at the interaction regions. Local symmetric, anti-symmetric or combination bumps are made by changing the strength of two correctors on either side of the interaction regions. The corrections may be keyed in using the orbit correction touch panel, or by connecting the bumps to knobs by software. In the latter case the correction is monitored by reading the current in the corrector magnets as the knobs are turned. Four knobs may be connected at any one time allowing correction of x, x', y and y'.

Global orbit correction is done by minimizing the rms orbit deviation at the BPMs. Calculations are done for one particle type (e^+/e^-) and one orientation (horizontal/vertical) at a time. In this scheme the sensitivity matrix is calculated first. This matrix of partial derivatives relating the displacement at the BPMs to changes in corrector strength is derived from the expression[1]

$$\frac{\Delta x_i}{\sqrt{\beta_i}} = \frac{1}{2\sin\pi\nu}\sqrt{\beta_j}\,\theta_j\,\cos\nu(\pi - |\phi_i - \phi_j|). \qquad (1)$$

Two methods of selecting the correctors are now available:

1. One corrector is chosen as the most effective and the results are stored. Another corrector is then chosen that is the most effective partner to the first one, then a third corrector that is most effective with the first two, etc. The matrix manipulation subroutines come from the program MIKADO.[2]
2. Orthogonal sets of correctors are chosen by reducing the non-square sensitivity matrix to its single value form. These sets are then chosen in a manner similar to that of method 1, the singular values give the effectiveness of each particular set.

If all correctors are chosen then the two methods give identical results. Corrections may be applied on top of an existing set of corrections or by starting from scratch. In the latter case the orbit caused by the existing correctors is removed from the scanned orbit, and corrections are done on this orbit. Figures 1 and 2 show the result of a global correction to completely change the corrector pattern using the second orbit correction method with 10 sets of correctors. The predicted maximum and rms values were 4.24 and 1.60 mm;

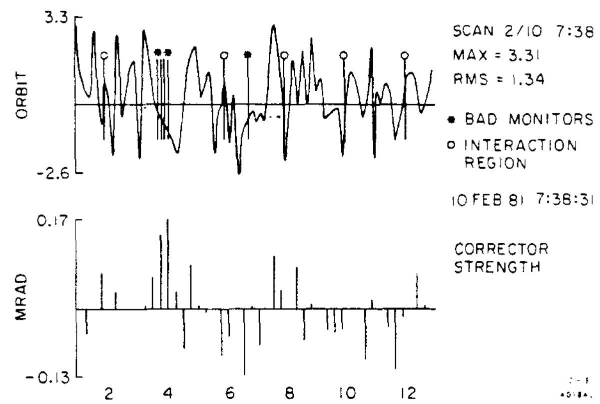

Fig. 1. Typical vertical orbit for an operating PEP configuration.

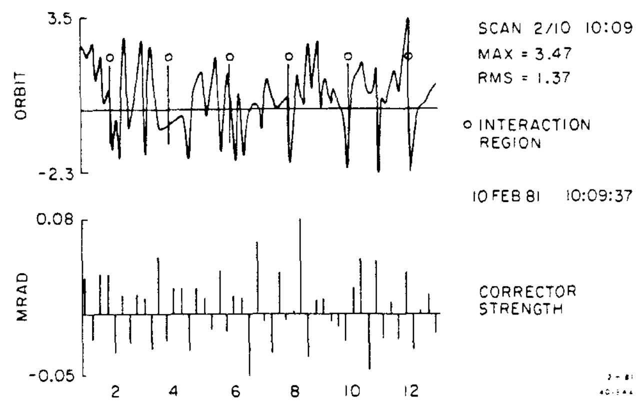

Fig. 2. Vertical orbit after global correction using method 2.

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those achieved were 4.27 and 1.58 mm. One iteration using 20 sets of correctors further reduced the maximum and rms values to 3.5 and 1.37 mm.

When correcting in the horizontal plane allowance is made for deviations of the machine energy from the ideal energy. The BPM data together with a knowledge of the dispersion function and corrector strengths allow us to find the energy deviation and the equilibrium orbit corresponding to this energy. The correction is calculated using displacements about this equilibrium orbit. At the end of the calculation the equilibrium orbit is added back in, taking account of changes in corrector strengths. In a similar manner we may subtract out the RF orbit of the positrons or electrons since this orbit is another form of equilibrium orbit. Here we may choose between scanned or calculated values.

Vertical Dispersion Function Correction

The dispersion function is measured by scanning two orbits with the RF accelerating system running at different frequencies. The change of momentum of particles on the synchronous orbit is given by $\Delta f/f = -\alpha(\Delta p/p)$ where α is the momentum compaction factor. Using the relation $\Delta x(s) = \eta(s)\cdot\Delta p/p$ we calculate $\eta(s)$ at all the BPMs. Examples of dispersion function (η) before and after correction are shown in Figs. 3 and 4. Two schemes are available for correction of the

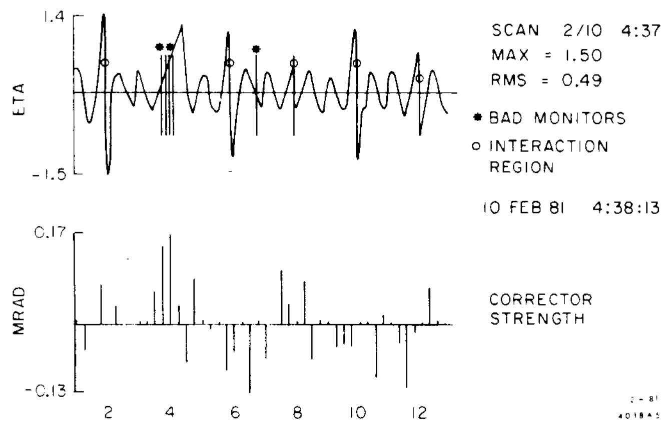

Fig. 3. Typical vertical dispersion function before correction.

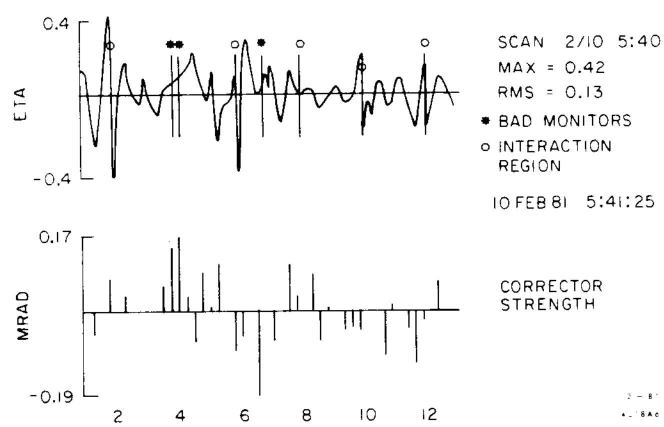

Fig. 4. Vertical dispersion function after correction.

dispersion function:

1) Correction by individual correctors.

The global correction of the vertical dispersion function is done by the same task that globally corrects the orbits. In this case the sensitivity matrix is the sensitivity of change in vertical dispersion function to change in corrector strength. This is calculated by using Eq. (1) twice. A change in one corrector causes a change in orbit at each quadrupole and sextupole. This change in orbit is a driving term for a change in dispersion function at every place in the ring. An efficient algorithm is used that does not require the integration over all quadrupoles and sextupoles for every corrector and BPM.

2) Correction by antisymmetric bumps.

The correction of vertical dispersion function by changing corrector strengths as above results in changes of orbit that may be undesirable. By using local antisymmetric bumps we may change the global dispersion function by introducing only local changes in orbit. Correction may be achieved empirically by putting local bumps onto the knobs and tweaking for minimum beam height. A task is being tested that makes corrections in all six interaction regions simultaneously using method (2) of the orbit correction scheme. Local bumps may also be undesirable and steering in the interaction regions may be determined solely by the requirements of the experimenters.

Beta Function Correction

Two methods are used for measurement of the beta functions:

1. Small changes are made to the currents flowing in the trim windings of the insertion quadrupoles and the change in machine tune caused by these variations is recorded. Using the first order perturbation formula[1] $\Delta\nu = \sum \beta\Delta K/(4\pi)$ relating the tune change $\Delta\nu$ to the change in focussing parameter ΔK we may estimate β at the insertion quadrupoles.
2. Small changes are made to a corrector magnet between the insertion qudrupoles and close to a BPM. Using Eq. (1) and assuming that the nearest monitor is close enough to the corrector that the beta function perturbation $\Delta\beta/\beta$ is the same at both, we calculate β_j. We then calculate β_i at the positions of the other BPMs. Because the phase term will be unfavorable at many monitors we change correctors at several interaction regions, summing the results with weight functions appropriate to the phase term.

Using the sensitivity function

$$\frac{\Delta\beta_i}{\beta_i} = \frac{-1}{2\sin 2\pi\nu}\,\beta_j\,\Delta K_j\,\cos 2\nu(\pi - |\phi_i - \phi_j|) \qquad (2)$$

we use method (2) of the orbit correction scheme to apply corrections ΔK to the trim windings. This task is at present used off-line from the control system. Figure 5 shows an uncorrected asymmetry in the beta

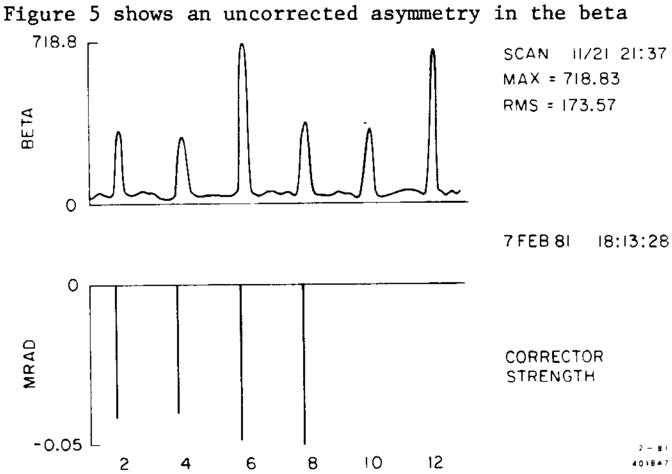

Fig. 5. Measurement of β function asymmetry (the strength of the orbit correctors used in the measurement is also shown).

function that was later corrected. For this calculation of the beta function, correctors in regions 2, 4, 6, and 8 were changed in sequence.

Performance of the Measurement and Correction System

At present the reproducibility of position measurement at 96 monitors is about 0.03 mm allowing us to measure the dispersion function to an accuracy of 1.3 cm. The absolute accuracy of the position measurement is difficult to determine. Using a measured orbit the correction programs will not predict a corrected orbit with peak displacement values less than 3 mm; but using a simulated orbit this peak displacement can be reduced many times further. (The simulated orbit is generated by random misalignment of magnets in a mathematical model). Some of the discrepancy could be due to position errors, the rest to deviations of the real machine from the computer model.

Orbit correction is used on a daily basis and both horizontal and vertical orbits may be reduced to 3 mm peak (1.3 mm rms) at the monitors. The accuracy of correction is enhanced by changing the model of the machine as represented by a configuration having the measured tune values. Local correction by symmetric and antisymmetric bumps is very successful, the orbit changes outside of the bumps being very small.

More time needs to be devoted to investigate the performance of dispersion function correction. Correction by local antisymmetric bumps performs much as predicted but is limited by the orbit requirements at the interaction points. Experiments have been started to simultaneously correct both the vertical orbit and dispersion functions.

Beta functions can be measured at the insertion quadrupoles to an accuracy of 10% by the focusing perturbation method, but not enough work has yet been done to determine the accuracy of the orbit change method. Using changes large enough to give reproducibility comparable to the other method may cause changes to the linearity of the machine due to orbit deviations through the sextupoles. The correction of beta function asymmetries also works well but a bad asymmetry requires iteration because Eq. (1) is only accurate to first order in $\Delta\beta$. To reduce time consuming measurement we shall later do the iteration on a mathematical model.

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