CLOSED ORBIT MANIPULATION AND CORRECTION IN THE CERN ISR

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(presented in summary by L. Resegotti)

Abstract

The results from two different global methods of orbit correction are given together with descriptions of other beam manipulations involved in luminosity measurements.

Introduction

Since the natural closed orbits of the ISR do not exceed half of the design tolerances, the full design aperture of the machine is available. For this reason orbit corrections were not a major problem for the ISR running-in. However, the need for orbit correction and control soon became apparent for a variety of reasons. It has been observed that a global radial correction can reduce certain losses due to non-linear resonances. Local orbit bumps have been widely used to investigate the effects of beam proximity to the vacuum chamber wall on the vacuum pressure. Radial orbit bumps were needed to centre the beams in I6 for physics experiments. Finally, luminosity measurements, which consist of counting the beam-beam events with respect to the vertical super-position of the beams, require firstly, a global vertical orbit correction to minimise background and secondly, precise localised orbit displacements. The various facilities for orbit control have thus become familar in the ISR operation.

1. Basic facilities

Three control systems are used to manipulate the ISR closed orbit[1]. Firstly, the correction windings which are mounted on the main magnet units, are used to control the horizontal closed orbit. Secondly, the motorised jacks, which operate on the main magnet units, are used to control the vertical orbit and thirdly, the radial field magnets, which are more especially designed for beam adjustments in the intersection regions. Each of these systems can be employed in different modes of operation: to excite local orbit bumps, for global harmonic corrections and finally for global least squares corrections. In many instances the systems are used on-line with the ISR ARGUS computer.

2. Harmonic method of closed orbit correction

In brief, this method consists of making a harmonic analysis of the closed orbit distortion and then correcting selected harmonics. The method has some intrinsic advantages arising from the resonant properties of the ISR. This resonant response causes the orbit to be much more sensitive to those harmonics in the magnetic field errors which are close to the preferred oscillation frequency, Q, of the machine. Thus for naturally occurring errors in the magnetic field the orbit distortion is concentrated in the harmonics near to Q and conversely, less power is needed to excite the harmonics near to Q. It follows that in most cases the best correction for the minimum correction strength will be obtained by limiting an orbit correction to those harmonics close to Q. Owing to the resonant response of the machine, large amplitude harmonics distant from Q are likely to be caused by large isolated errors or random errors in the beam position observations. Such spurious harmonics would require relatively strong corrections and any errors made in these corrections would in turn produce distortions with frequencies near to Q. The exclusion of extreme harmonics from a correction avoids this type of error with little loss of efficiency.

The harmonic method of closed orbit correction has been especially developed for on-line use with the ISR ARGUS computer. A simple on-line orbit correction takes 10-15 minutes to perform. Firstly, the computer makes an automatic scan of the closed orbit rejecting measurements when they do not satisfy the criterion of internal consistency. (The operator can overrule these decisions if he wishes.) A harmonic analysis is then made and the correction computed for a range of harmonics selected by the operator. Before applying the correction, a theoretical prediction of the corrected orbit can be requested. This particular facility has proved very useful and accurate. Usually the predicted and measured orbits are virtually indistinguishable. For each of the three systems of correctors pre-calculated tables for exciting the basic harmonics are stored in the ARGUS memory and the correction settings are simply linear combinations from these tables. The program also gives corrections for the injection position and angle.

The most important problems facing an on-line calculation are those of failures in beam observation stations and correctors. The harmonic analysis is not unduly affected by the loss of a small number of beam observations unless these come from consecutive stations. Except for the very beginning of the ISR running-in, this has not posed any real problems. The failure of individual correctors is more serious, since this invalidates the harmonic tables. If the proposed setting of the missing corrector is small with respect to the other correctors, it can be simply omitted without much loss of efficiency. If, however, this is not the case the correction must be made from first principles. The ARGUS cannot make the necessary matrix inversions and so the data is sent to the CDC 6600 computer from a remote terminal in the ISR Control Room.

In general an orbit correction based on the 8th, 9th and 10th harmonics will reduce the ISR closed orbit distortion to 5 mm peak to peak or less. Figure 1 shows an example where the horizontal orbit distortion of 15.9 mm peak to peak was reduced to 4.4 mm by correcting the 8th, 9th and 10th harmonics with the correction windings. By including more harmonics and iterating, a correction can be improved but this is usually unnecessary. However, the method has been taken to its limit by correcting all harmonics up to the 14th and then iterating the correction to remove residual errors. After two cycles the horizontal orbit distortion was reduced from 15.3 mm peak to peak to 2.5 mm, but further cycles made no improvement. There is some evidence that the disproportionate increase in correction strength excited resonances in the beam and it is preferable to avoid this over-correction.

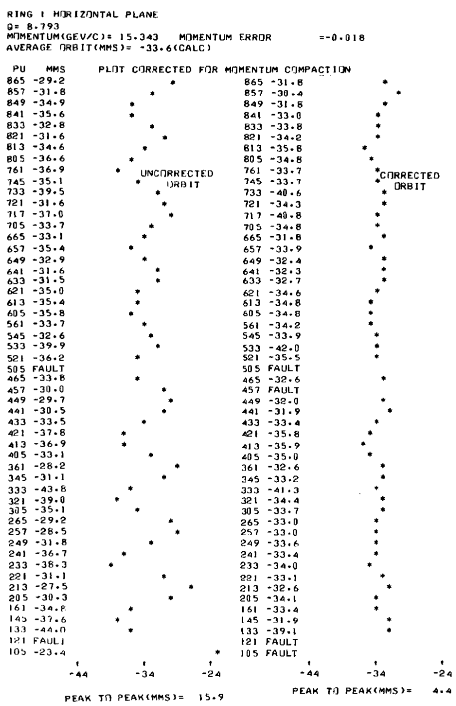

FIGURE 1. CORRECTION OF 8TH, 9TH AND 10TH HARMONICS.

All orbit manipulations are based on design data for the ISR corresponding to one working point in the Q-diagram. The inflexibility of this data inevitably introduces errors when Q-shifts are made. Figure 2 shows a horizontal orbit correction applied at four different points in the Q-diagram. The corrected orbit maintains its form very closely and this with other experiments has shown that a correction made anywhere in the region ± 0.1 about the design Q-values is universal in that region.

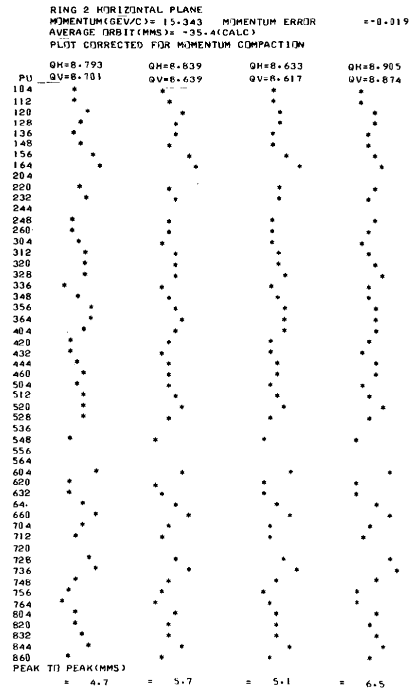

FIGURE 2. INVARIANCE OF AN ORBIT CORRECTION WITH Q SHIFTS.

3. Least squares method of closed orbit correction

The reduction of the sum of the squares of the orbit distortion is essentially a statistical problem, and therefore it is necessary to start by chosing an appropriate ratio between the number of observations and the number of correctors. The relationship between observations and correctors is contained in a matrix 'G', each column vector of which represents the effect of a unit deflection by a given corrector at each observation point. For the ISR 'G' has 53 rows and as many columns as correctors used. The observed beam positions of an orbit compose a vector 'Y'. The least squares method leads to a correcting vector 'Δ', such that,

$$\Delta = -(\tilde{G}G)^{-1}\,\tilde{G}Y$$

and the efficiency of the correction can be evaluated in terms of '$\tilde{Y}G\Delta$'. At first all correctors are scanned singly and the most efficient corrector, let us say 'A', is retained. The procedure is repeated to find the best doublet (A,B) where 'B' belongs to the previously rejected correctors. Further iterations are made in order to find a multiplet (A,B,...K) which contains a maximum of 10 correctors and gives a reduced peak to peak distortion which appears reasonable taking into account the accuracy of the observations and the correction strengths. The individual corrector strengths, though greater than those of the harmonic method, have never been prohibitive. Figure 3 shows a vertical orbit correction using the motorised jacks in Ring 2. Six correctors were used with displacements no greater than 0.6 mm and the distortion was reduced from 11.0 mm peak to peak to 3.8 mm. A similar correction was made in Ring 1. These corrections have been retained and it has been possible to postpone re-alignment of the machine, which was becoming necessary due to gradual ground movements. The vertical closed orbit has also been corrected by this method using the radial field magnets. For example, the peak to peak distortion of 12.0 mm was reduced to 4.5 mm. However, the radial field magnets are more commonly used for local orbit bumps in the intersection regions. Radial orbit corrections using this method have increased the available radial aperture by 10 mm.

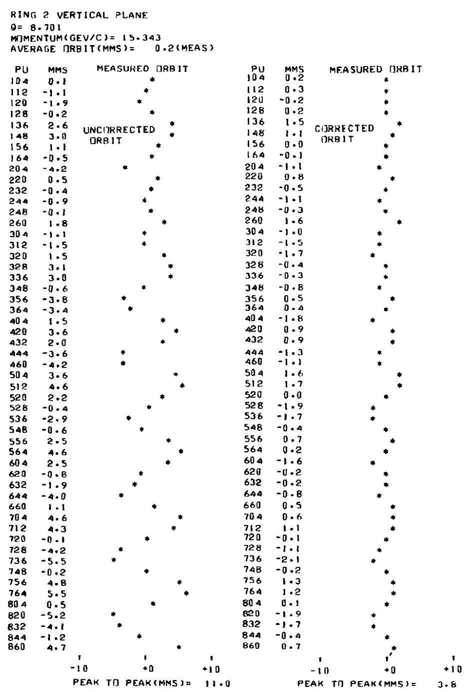

FIGURE 3. VERTICAL ORBIT CORRECTION USING JACKS.

4. Orbit preparation for physics experiments

The first step in orbit preparation for physics experiments is to globally correct the vertical and horizontal closed orbits in both rings. This is usually sufficient to ensure that the beams are well centred vertically in the crossing regions. A stack is then made in a resonance free region in the outer part of the vacuum chamber. Where needed, the beams are centred radially in the chamber with localised bumps. Figure 4(i) shows the radial closed orbit (at three positions across the chamber) with such a bump in intersection I6. Once these preliminary adjustments are completed, luminosity optimisation is carried out. Using the radial field magnets the beams are progressively separated vertically with localised bumps while the beam-beam interaction rate is monitored. This manipulation is computer controlled in several intersections simultaneously if desired. Once the optimum relative beam positions have been found, both beams are progressively displaced vertically without changing their relative positions. In this way the background is optimised while the interaction rate is unchanged. This manipulation is similarly computer controlled.

Figure 4(ii) shows two measured orbits with vertical bumps of +3 mm and -3 mm at crossing point I6. It can be seen that these bumps have no appreciable effect on the rest of the orbit, which is of fundamental importance to the optimisation experiments described earlier. The accuracy of these displacements is limited to approximately 1 % which is the precision of magnet current settings. There is also a radial variation in the bump height due to the beam's momentum spread (2 %) and due to the changes in the vertical betatron function (4 % with sextupoles). This can give a bump height variation of 6 % across the beam.

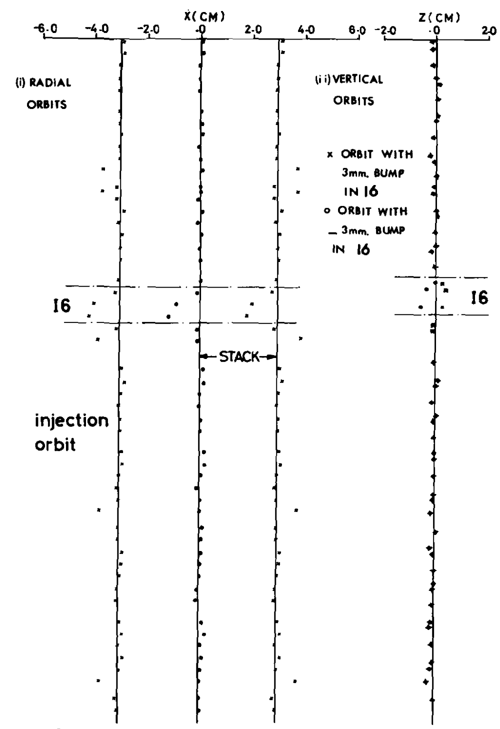

FIGURE 4. TYPICAL LAYOUT OF CLOSED ORBITS FOR PHYSICS EXPERIMENTS.

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Reference

1) L. Resegotti - Provisions for the Correction of the Closed Orbit Distortions in the ISR - Internal Report CERN ISR-MAG/68-30.