ADJUSTMENT OF THE WORKING LINES IN THE ISR

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(presented in summary by L. Resegotti)

Abstract

The various adjustments of the betatron oscillation frequencies which have been made since the beginning of the ISR running-in period are described in relation with their global effects on the beam behaviour. The effects of the correcting elements (poleface windings, sextupoles, etc.) have been measured and correction methods developed for the necessary shaping of the "working line" in the Q_H/Q_V diagram.

Introduction

In the ISR, the whole available aperture of the vacuum chamber is used for injection and stacking. Therefore, the beam properties and in particular the betatron frequencies (Q values) must be carefully controlled over this full region. In the design of the pole profile of the combined function magnets a sextupolar component has been incorporated in order to give constant Q values across the aperture[1]. At the same time, poleface windings (PFW) fed by 24 independent power supplies and 2 sets of sextupole lenses in mid-F and mid-D locations, respectively, have been provided to correct for saturation effects and to give a large flexibility in the adjustment of the Q values and of their momentum dependence. The purpose of this paper is to describe the various Q adjustments which have been made from the beginning of the ISR running-in period. It is concerned mainly with results of Ring 1, but the two rings are very similar.

1. Measuring techniques

The vertical and horizontal betatron frequencies were measured directly with the "Q-meter"[2] using a small injected beam which was displaced across the aperture by RF acceleration as used for beam stacking. In the beginning of the running-in period, this displacement was made by varying the main magnetic field. At medium field levels (15 GeV/c) with small Q corrections, this method gives the same results. At higher field levels, saturation in the main magnet and the larger Q corrections which are needed cause appreciable discrepancies and this simple method cannot be used. The effect of crossing a resonance was measured by the percentage intensity loss which resulted for a beam displaced at a constant speed (0.3 cm/s) across the aperture ("aperture scan").

2. Effects of the correcting elements

The Q shifts produced by each set of correcting elements (F and D poleface windings, mid-F and mid-D sextupoles) have been measured in Ring 1 at medium field level, corresponding to a particle momentum of about 15 GeV/c. The 12 poleface windings F and the 12 poleface windings D were excited in such a way as to add pure quadrupolar, sextupolar or octupolar components to the field. The calculation of the currents was based on magnetic measurements and the ISR ARGUS computer was provided with the corresponding tables. Figure 1 gives the results concerning the poleface windings in the F units. The amplitudes of the multipolar field components were measured using the field display system[3] and expressed by the relative variations of the field indices and of their first and second derivatives with respect to the radial coordinate. The average radial position of the orbit is characterized by the corresponding relative change in proton momentum, $\Delta p/p$, with respect to the centre line.

To within a few percent, all these results can be represented by expressing the increments of $Q_{H,V}$ and of their first derivatives

$$Q'_{H,V} = \frac{\partial Q_{H,V}}{\partial(\Delta p/p)}$$ and second derivatives

$$Q''_{H,V} = \frac{\partial^2 Q_{H,V}}{\partial(\Delta p/p)^2}$$ as linear combinations of the increments of the field indices and of their derivatives. As it was expected from the magnetic measurements, no saturation effects appeared and for different momenta, the correcting currents have simply to be scaled linearly. The ISR computer has been programmed to set automatically these currents according to the required values of $\Delta Q_{H,V}$, $\Delta Q'_{H,V}$, $\Delta Q''_{H,V}$.

3. Adjustment of the working lines

The Q values were first measured in Ring 1 at 15 GeV/c without any correction. They are represented by a small "working line" in the Q_H/Q_V diagram (see Fig. 2).

Resonance lines have been traced on the same diagram up to the 7th order. Crossing a resonance line by the working line produces:

- a certain loss (depending on the speed) when the beam is moved through the corresponding radial position;
- a continuous loss (due to a diffusion process) from a stack built across this region: this loss reduces the lifetime of the beam.

In particular, the conditions of the bare machine at 15 GeV/c were found unsuitable because of the strong third order resonance $3\ Q_V = 26$ which was in the stacking region and which produced more than 60 % loss in the aperture scan.

In the first ISR runs this line was simply shifted into a resonance-free region of the Q diagram using a pure quadrupolar correction. More than 2 A were stacked using these new lines - typically 2.75 A in Ring 1 at 15 GeV/c on 27th January 1971 (the day of the first beam beam collisions) with the line ANNA, 0, 0* (see Fig. 2). However, their use was limited by:

- radial blow up of the beam at injection resulting in a reduction of the stacking efficiency;
- a strong intensity limitation between 2 and 3 A. When one tried to stack beyond this threshold, rapid loss occurred followed by a saw-tooth-like sequence of build-ups and losses.

To overcome these instabilities, it was found necessary to increase the dependence of both Q_H and Q_V on momentum by adding a sextupolar correction. Lines with moderate $\frac{\partial Q_{H,V}}{\partial(\Delta p/p)}$ like CLEO, 1.5, 0 for 15 GeV/c (see Fig. 2) were enough to prevent the instability of injection and gave good results for stacking low intensity beams. In Ring 1, decay rates of less than 10^{-5} min^{-1} were measured with beams below 1 A. However, the strong intensity limitation remained present and working lines with larger $\frac{\partial Q_{H,V}}{\partial(\Delta p/p)}$ were investigated. These lines, which necessarily crossed several resonances, were located in the Q diagram according to the following criteria:

- resonances had to be of high order and crossed between injection and the bottom of the stack (practically the centre line);
- for injection the working point had to be not too close to a resonance to avoid instabilities.

Many lines were set up in this way; FATA, 1.5, 1 (see Fig. 2) being an example for which only 5th order resonances are crossed outside the stacking region.

However, for all these working lines which are not straight the values of $\frac{\partial Q_{H,V}}{\partial(\Delta p/p)}$ vary with the radial position and results were different when the position of the stack was changed. Therefore, in order to obtain straight lines the PFW correction computed in terms of multipolar components was completed by an additional one, determined by a different method. The local gradient changes required for suppressing the residual Q-shifts were computed at a discrete number of radial positions inside the aperture: then the necessary PFW currents for producing these gradient changes were determined by using the results of measurements of the influence of unit currents in individual PFW circuits. The best smoothness in the distribution of the currents was obtained when this method was applied only for small residual Q-shifts, after having approached as much as possible the required working line by using multipolar corrections. At this level of precision the Q values are influenced (to within a few digits in the third decimal) by the shape of the closed orbit and, therefore, the closed orbit corrections had to be set before the final Q adjustments.

By reducing the working line of the bare machine to a point in the Q diagram (Q_H and Q_V constant across the aperture), the PFW correction methods provided the starting point for creating families of working lines corresponding to sets of values of ΔQ, $\Delta Q'$, and $\Delta Q''$, which could be applied using the ISR computer. A large number of working lines were established in this way for the different momenta chosen for the ISR tests. Some of them had even larger $\frac{\partial Q}{\partial(\Delta p/p)}$ like SE22 or included a large octupolar correction like OLGA, -0.75, 1.4, two lines which were established at 22 GeV/c (see Fig. 2). A special interest has been given to lines in which one of the $\frac{\partial Q}{\partial(\Delta p/p)}$ is negative like IRMA and which can be located more easily in a resonance free region of the Q diagram.

Investigation of these different working lines is continuing in the ISR. To date the highest current (6.3 A) achieved at 15 GeV/c was stacked with the working line 15FA (see Fig. 2). At this intensity level the incoherent Q-shifts produced by the stack itself becomes appreciable. Recently, preliminary measurements of this effect confirmed the theoretical value contained in the ISR parameter list ($\Delta Q = -0.03$ for 20 A at 28 GeV/c).

Conclusion

The adjustment and shaping of the working line in the ISR has been developed to a high degree of precision and flexibility. The correcting method combines, for the poleface windings, an analysis of the produced field pattern in terms of multipolar components and a study of the influence of the excitation of each individual circuit. The effects of the correcting elements (poleface windings and sextupoles) in terms of measured Q variations fulfil the requirements of machine operation. The study of the beam behaviour for a number of specified working lines has constituted an interesting diagnostic tool besides permitting significant increases of stacked intensity and a preliminary selection of suitable operating conditions for colliding beam runs.

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* Each working line has been given a name. The name itself is characteristic of the Q values on the centre line and the two figures are the $\Delta Q'_H$ and $\Delta Q'_V$ which are added, using generally the sextupoles.

References

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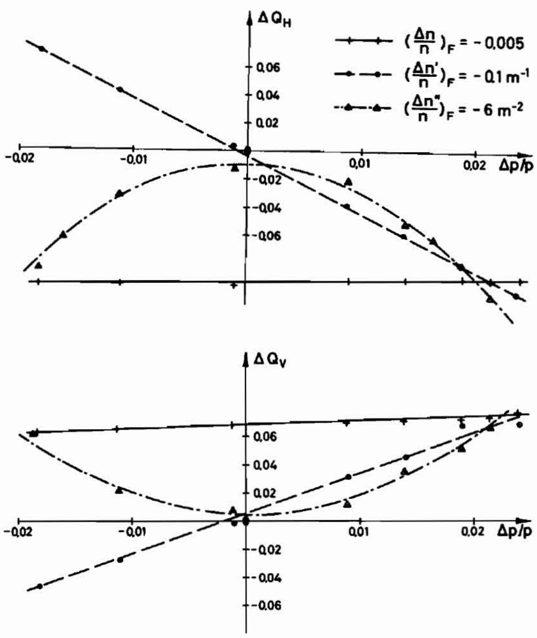

Fig. 1 Effects on Q_H and Q_V of pure multipolar components produced by the poleface windings in the F-units

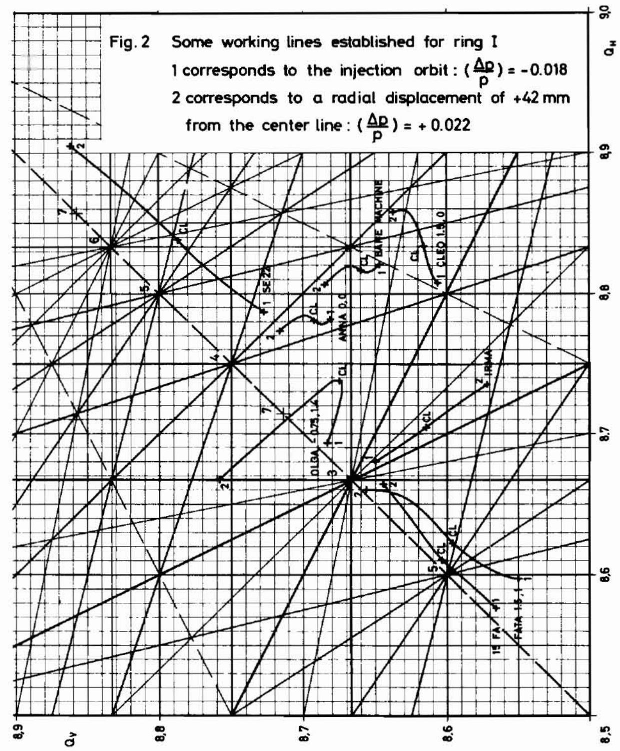

Fig. 2 Some working lines established for ring I
1 corresponds to the injection orbit : $(\frac{\Delta p}{p}) = -0.018$
2 corresponds to a radial displacement of +42 mm from the center line : $(\frac{\Delta p}{p}) = +0.022$