COMPUTER CONTROLLED BEAM LOCAL RADIAL PERTURBATION AND ROTATION IN CERN PS

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Introduction

The low-energy corrections of the CERN Proton Synchrotron beam closed-orbit are much facilitated by the application of suitable currents in the additional coils to achieve a horizontal or vertical field. The horizontal corrections are obtained by means of coils known as Back-Leg-Windings (BLWs). In addition to the normal low-energy corrections, these coils could also be used to perturb the beam by a given amplitude depending on the energy, the radial betatron oscillations per turn Q_R and the location where this "bump" is required. An added stipulation of course is that the achievement of the desired perturbation of a given amplitude should not set-up unnecessary oscillations of any significance elsewhere in the beam.

The localised perturbation could have several uses for the beam gymnastics or diagnostics: it can be of assistance as a probe to calibrate position monitors; it can help in localising throttle points of the beam due to multipolar effects (or mechanical obstructions) or it can also be used for intensity optimisation by moving the beam to its position of maximum intensity.

This contribution summarises the basis upon which this probe-like activity of the beam is carried out on-line via the Main-Control-Room console using controlled power supplies, function generators and multiplexer.

A novel aspect of this work shows that it is possible to achieve the perturbation of a given amplitude at any desired location in the PS ring by the application of equal currents in the four well-chosen BLWs. The equal current condition holds not only for an ideal machine Q=6.25 but also for any other operational Q value. This analytic basis much simplifies the computations and, would also make hardware reductions possible in the future because in principle, only one function generator is sufficient for all 4 multiplexed power supplies to the PS-BLWs.

General Background

The BLWs have been wound at the focussing sectors of the 100 PS magnets which repeat in the FOF DOD manner, i.e., each magnet consisting of a focussing (F) and defocussing (D) half-sectors with a field-free straight-section (O) between any two magnets. Each focussing sector has one turn of a BLW connected in series with the turn at the next focussing sector with the straight section (O) in between, resulting in a total of 50 BLWs of two turns each.

Using the PS numbering scheme, the 50 BLWs are effective at every straight section between 1 and 99 and have a maximum upper limit of 10 Amperes applicable in each winding via the 50 new power supplies[1,2]. The availibility of these special power supplies implies a significant improvement over the earlier schemes[3,4]; given the PS radial Q_R at a given energy and the position where a local perturbation is desired in terms of the straight section number, it is possible to deform the beam at that location by a specifed amplitude within the limitations of the 10 A applicable current.

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We need to apply currents in four different BLWs to produce a symmetric and closed deformation at a desired location without setting up undesirable oscillations elsewhere in the ring. Hence the 4 BLWs have an additive effect in producing the perturbation required at a given location and a compensatory effect elsewhere.

In terms of the normalised phase space, Fig. 1 illustrates the application of the currents in the 4 BLWs to produce the deformation K at a straight section location n; Fig. 2 (a) shows[1] the choice of the 4 BLWs required for the location n being an even straight section while Fig. 2 (b) shows the similar choice for n being odd. In both cases, the 4 BLWs selected are located at odd straight sections as physically placed in the ring.
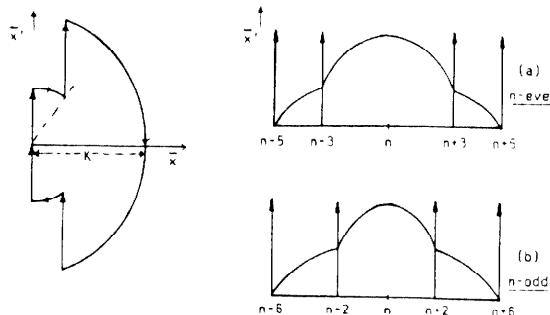

Fig. 1   Fig. 2

Computational and Control Requirements

For a given machine radial Q_R and a specific low-energy time point in the PS cycle (pulse A, B or C depending on synchronisation), it was envisaged to perturb the beam at a given straight-section location (NSS) in the ring by a certain amplitude in equivalent millimetres. The freedom to perturb the beam by a desired amplitude is obviously limited by the total amount of current (10 A) that may be applied in any one of the required 4 power supplies. The same BLWs are also used for horizontal dipole corrections and therefore, some of them may already have some existing current in them. Hence, depending on the location where the "bump" is required, the upper limit is usually less than 10 A.

Naturally, this limit is not only different for odd and even n but it has also to be somehow translated from maximum Ampere value for each of the 4 BLWs into a single overall maximum possible perturbation (KMAX) at a given location NSS=n. This translation and conversion depends on the known parameters of the PS and is dealt later.

Given the upper perturbation limit of KMAX eq. mm, it was envisaged to be able to input at the console the desired 'bump' amplitude KREQ such that KREQ<KMAX. The inputting of KREQ was to be done initially via the keyboard with the possibility later to be facilitated via the console shaft-encoder.

For rotating the desired "bump" in the beam to any location in the PS ring, it was also foreseen to be able to do this via the console keyboard by typing the appropriate NSS and changing to any location as required; future extensions to this would also enable it to be done via a console shaft-encoder or a tracker-ball.

The overall philosophy is perhaps best illustrated in Fig. 3 which clearly indicates in a simple manner the logical structure of the required facility.

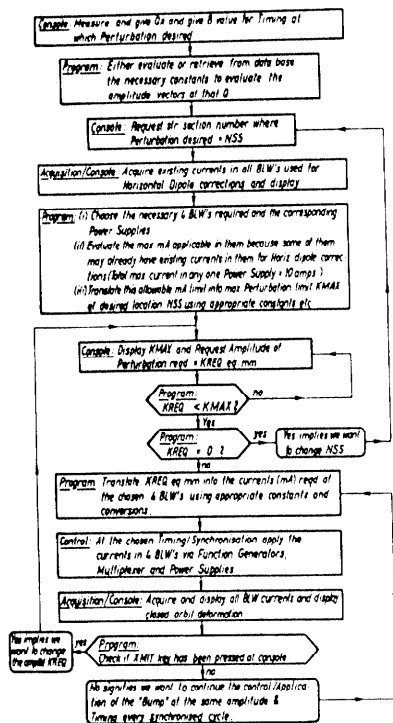*The Generalised Requirement Philosophy in Modular Schematics*

Fig. 3

Geometric and Power Considerations

In the normalised phase space representation, one complete revolution (2π) of the circle is equivalent to one complete betatron oscillation and if we consider the angular straight-section separation as θ_1 between each of the 100 straight-sections, then one complete betatron oscillation is given by $100\ \theta_1/Q$ radians. Hence we get $\theta_1 = 2\pi Q/100$. In general Q is given by $Q=Q_R+Q$ where $Q_R=6.25$ for CERN PS. Therefore,

$$\theta_1 = \frac{\pi}{8}\left(1 + \frac{\delta Q}{Q_R}\right) \qquad (1)$$

From Fig. 2, the straight-section separation for a perturbation at an even location n is $2\theta_1$ (i.e. n-5 to n-3) in the upper right-hand quadrant of the normalised phase-space while for the n-odd case, it is $4\theta_1$ (i.e. n-6 to n-2). This, for the ideal $\delta Q=0$ case, leads to a displacement of $\pi/4$ for n even and $\pi/2$ for n odd, as shown in Figs. 4 and 5 respectively.

Fig. 4   Fig. 5
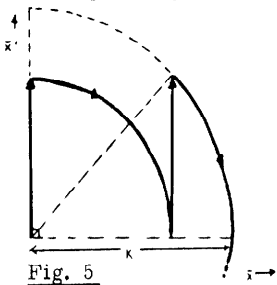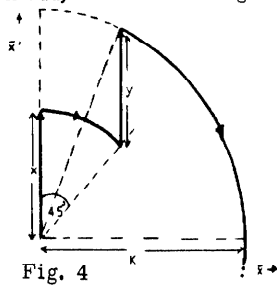
To prevent large disparities in power dissipation in the 4 BLWs, it may be shown[5] that it is reasonable to make the currents in all 4 windings equal to each other at ideal Q, i.e. $x=y=x'=y'$ where x' and

y' are the 'mirror' images of x and y in the lower half of Figs. 4 and 5. These amplitudes may be readily derived from the figures. However, for $Q=Q_R + \delta Q$, we have several possibilities for x and y derivations over the small range of interest $(6.10 \leqslant Q \leqslant 6.50)$. Starting with $x = y$ for $Q=6.25$, we can have: (a) both x and y have new, unequal values for $Q\neq6.25$; (b) either x or y is fixed at the ideal value but we vary the other for $Q\neq6.25$ and (c) both x and y have new equal values (see Appendix) for non-ideal Q.

The Applied Strategy

For a desired perturbation K at any location NSS, the amplitude of vectors required on the transverse phase-plane is given by the various equations of cases (a), (b) and (c) derived in ref. (5). It is clear that any one of these three possibilities (a), (b) and (c) above would be applicable to achieve K. However, there are certain disadvantages in using the techniques (a) and (b).

For the case (a), the results show that starting with the equal values for $Q=6.25$ case, the amplitude vectors would always be unequal for all other Q values; their computation has to be done using trigonometric functions which depend on δQ and the appropriate constants stored for real time operation. Approximations may be made, but with the penalty of increased computations; similar arguments of complexity can also be put forward for the technique (b) for both odd and even cases because complicated formulae need to be evoked to yield the amplitude vectors which are unequal for all $Q\neq6.25$.
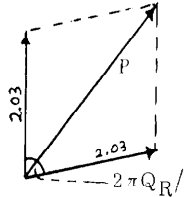
An additional argument against the technique of case (a) is that 4 constants need to be evaluated and stored (xodd, yodd, xeven, yeven) for any one Q value because the location NSS may be odd or even. If a database type of approach is to be used to store all the constants for any one Q then, this technique doubles the amount of storage required as compared to case (c). However, some savings may be made by storing trigonometric functions and taking advantage of their recursive nature so that the same database could be used for both odd and even location "bumps". But this in turn increases the computational work after retrieval from the database.

The real advantage of the strategy (c) is that the final solution yields the amplitude vectors which are all equal to each other at any one Q, i.e., we can perturb the beam by applying equal currents in the 4 appropriate BLWs. The Ampere values would of course differ for odd and even cases but in either case, the 4 currents would be equal depending only on the Q value. This means that in a database approach, if we limit our interest in Q variations of $6.10 \leqslant Q \leqslant 6.50$, we need to store only 41 constants for the n-even case and 41 constants for the n-odd, yielding a total of 82 constants only. The technique of case (b) would also require only 82 constants but the vectors would always be unequal except in the $Q=6.25$ case (hence a disadvantage by power and hardware considerations).

In terms of the hardware reduction and simplification, equal amplitude vectors imply equal-slope Function Generator ramps and flat top as well as equal currents in the 4 chosen power supplies to the BLWs. Hence one Function Generator is sufficient to drive all 4 power supplies instead of 4 individual Function Generators.

Conversion of KREQ mm Into Amperes for BLWs

For the PS, 1 A in a magnet winding corresponds to a deflection of 2.03 eq. mm at injection energy (B=147.7 Gauss)[3]. However, for each BLW, we have one turn of the winding on a magnet connected in series with a turn on the next magnet[1], hence the 50 BLWs. The net effect of 1 A at injection in one complete BLW on the straight-section inbetween any two magnets is therefore the vector sum, i.e.,

$$p = 2.03(2 \cos(\pi/16)) \qquad (2)$$
$$= 3.981988$$

Therefore, at injection energy corresponding to B=147.7 Gauss, 1 Ampere in a BLW corresponds to 3.981988 eq. millimetre radial perturbation.

At higher energies, the same current produces a proportionally smaller perturbation and for a radial perturbation of R eq. mm, at an energy corresponding to $B=B_a$ Gauss, we need:

$$R \cdot (B_a/B_{inj}) / 3.981988 \qquad \text{Amperes} \qquad (3)$$

In other words, $(B_a/B_{inj}) \cdot (1/p)$ Amperes per 1 eq. mm.

Formulation of equations

The Appendix shows that in the n-even case, the desired perturbation K eq. mm is obtained by the 4 equal amplitude vectors each of $x = K/2 \cos\Theta_1$ eq. mm. However, a current I_h may already exist in one of the chosen 4 BLWs. Since we have an upper limit of 10 A in each BLW, this sets an upper limit on the maximum possible perturbation by the reduced amount of current $(10-I_h)$ applicable in each. Hence using eqn. (3),

$$(10 - I_h) = x_{max} \cdot (B_a/B_{inj}) / p \qquad (4)$$

$$KMAX\Big|_{even} = (10 - I_h) \cdot p \cdot 2 \cos\Theta_1 \cdot B_{inj}/B_a \qquad (5)$$

For a desired perturbation K ($\leqslant$ KMAX) at an even location, the current in each of the 4 chosen BLWs is then given by:

$$I_x\Big|_{even} = K \cdot (B_a/B_{inj}) / 2 p \cos\Theta_1 \qquad (6)$$

The equations for an odd location perturbation are of the same form with $\cos\Theta_1$ replaced by $\cos 2\Theta_1$ as shown in the appendix.

As a matter of interest, for $B_a = B_{inj}$, $I_h = 0$ and the upper limit being 10 A in each of the chosen 4 BLWs for a given straight-section location, we get KMAX of 73.57 and 56.31 eq. mm for the even and odd locations respectively.

General Conclusions

The above strategy has been adopted and the necessary computational and design work carried out according to Fig. 3. Hence a fully operational facility is available via the Program Request Unit to per-turb the PS beam radially and rotate it in the ring to any straight-section location desired.

Presently, this is carried out via the Injection Console in the Main Control Room using IMLAC PDS1 display computer linked to the IBM 1800. The facility has been included in the ISAAC Interpretive System[6], enabling other essential facilities like the deformed closed orbit etc. to be displayed simultaneously on the console.

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3) Burnod, L.: Perturbation radiale localisee de l'orbite du PS, MPS/CO Computer 70-5, 19.5.70

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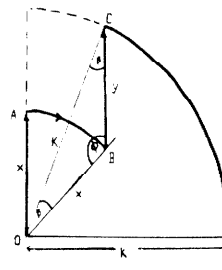
6) Potier, J.-P.: Private Communication.

Appendix

Fig. 6

Using Fig. 6 for both even and odd cases for simplicity, we have the angle traversed AÔB as $2\Theta_1$ for n-even and $4\Theta_1$ for n-odd and Θ_1 is as in eqn. (1) for non-ideal Q.

If all 4 vector amplitudes are constrained to be equal then, y=x and we get

$$K = 2 x \cos\beta \qquad (A.1)$$

$$x = K/2 \sin(\phi/2) \qquad (A.2)$$

therefore

$$x = y = K/2 \cos\Theta_1 \qquad \text{(n-even)} \quad (A.3)$$

$$x = y = K/2 \cos(2\Theta_1) \qquad \text{(n-odd)} \quad (A.4)$$

For a required perturbation K at a given even or odd straight-section location, eqns. (A.3) and (A.4) yield the general values of the vector amplitudes required. In both the cases, we have constrained them to be equal (all 4 equal in each case) and this equality condition is dependent only on Θ_1. This in turn depends on the Q of the machine and so at any specific occasion when a perturbation is desired, the Q measured beforehand yields all the necessary information to evaluate eqns. (A.3) and (A.4).