SOME THOUGHTS ABOUT PSB INJECTION PROCEDURES

C. Bovet
ERRATUM

SOME THOUGHTS ABOUT PSB INJECTION PROCEDURES
(SI/Note DL/69-19)

C. Bovet

Page 10, Reference 2, read correctly:

Introduction

The fact that the PSB consists of 4 rings renders it more complex than any other machine. On the one hand there will be four times more elements to control, on the other hand four identical behaviours might be controlled together.

In order to show which parameters must be kept independent for each ring a complete injection procedure will be described in detail. Nothing will be said about the linac-PSB transfer; one assumes that an automatic steering, upstream of the vertical distributor*), will get rid of any transverse jitter during the long linac pulse. Before the inflector two steering dipoles are used for each plane and their effects are measured on TV screens.

Pick-up electrodes are used all around the rings, of which two special ones positioned on each side of $|B|_1$ will allow to measure position and angle of the closed orbit at the injection point$^1$.

Q-measurements are not included in this procedure although they are implied and essential.

Some conclusions have been drawn from a computer analysis of the multiturn process. It was considered not necessary to include either space charge or longitudinal phenomena.

*) formerly called splitter
Abbreviations (see also Figs. 1, 2, 3)

- $ \alpha_l $ steering angle 1
- $ \alpha_2 $
- $ \bar{x}_j $ radial phase plane vector at point j
- $ \bar{z}_j $ vertical
- $ j = 1, \ldots, 5 $ see Fig. 1
- $ d_S $ inflector septum radial position
- $ \beta_S $ inflector septum angle
- $ \delta_S $ inflector septum thickness
- $ d_I $ beam center distance to the septum
- $ \alpha_I $ inflexion angle
- $ \alpha_K $ monoturn kicker angle
- $ \alpha_{Ki} $ multturn kicker angle ($ i = 1, 2, 3, 4 $)
- $ d(t) $ closed orbit displacement at spot 2.
Corrected closed orbit.

Ideal closed orbit.

FIG. 2
1. **Closed orbit at injection** (see Fig. 1)

In order to measure the closed orbit a beam must be made circulating in the machine. The most convenient way is to inject a pencil beam with the monoturn kicker.

Basic values are set up, for instance:

\[
\begin{align*}
\mathrm{d}S &= 30 \text{ mm} \\
\mathrm{d}I &= 10 \text{ mm} \\
\alpha_S &= 0
\end{align*}
\]

influenced by: closed orbit quality, linac beam emittance, septum stray field, etc.

The theoretical values of \(x_2, x_3, \alpha_I, \alpha_K\) will be computed. The procedure is then as follows:

1) adjustment of \(\alpha_l\) to reach \(x_2\) on TV2
2) adjustment of \(\alpha_2\) to reach \(x_3\) on TV3
3) measurement of \(x_5, x_6\) (2R-U, 3R-U)
4) measurement *) of \(M (x_5 | \alpha_I x_6 | \alpha_K)\)
5) alignment of the closed orbit along the whole circumference
6) measurement of \(\Delta x_5, \Delta x_6\)
7) adjustment **) of \(\Delta x_5, \Delta x_6\) by \(\alpha_I, \alpha_K\); check of adjustment
8) realignment: come back to 5).

For the vertical plane a similar procedure is required in which \(\alpha_I\) and \(\alpha_K\) are replaced by the vertical deflections \(\alpha_l\) and \(\alpha_2\).

Looking at the PU's along the circumference one has now a fairly good knowledge of the closed orbit at injection, furthermore the beam is now circulating and a correction of the closed orbit may be envisaged.

*) see Appendix I
**) see Appendix II
2. Correction of the closed orbit

As already stated in Ref. 1), the aim of correcting the closed orbit is:

i) to increase the machine acceptance both in H- and V-plane;
ii) to rectify the horizontal closed orbits of the four rings in order for them to be as close as possible to a mean value of \((x^3, x^3')\) at the injection septum.

If one can convince ourselves that the latter can be achieved, a lot of effort in construction and operation of the system may be saved:

- common radial displacement of the septa
- common angular displacement of the septa
- common inflector angle \(\phi I\)
- common amplitude of the kicked orbits for multturn injection
- common amplitude of the monoturn kickers.

For this we must pay a certain price: reduction of H-acceptance and a particularly good PU in l II (reliable despite the inflector fringe field and the radiation level at the spot).

The closed orbit will be corrected according to a mathematical process\(^2\) which gives a special weight to the l – RU1 and l – RU2 readings. According to statistical computations\(^2\) the corrected orbits will differ at the inflector by

\[
< \Delta x^3 >_{\text{rms}} = 0.9 \text{ mm}
\]

\[
< \Delta x^3'>_{\text{rms}} = 0.3 \text{ mrad}
\]

The relevant steps of the correcting procedure are:
9) measurement of the \( x_j, z_j \), with all PU's, averaged over many revolutions (computerized acquisition)

10) computation of the appropriate corrections

11) as 6)

12) as 7)

13) as 9) + following if necessary.

H and V corrections can be handled simultaneously. For each of the four rings figures have been obtained for \( \alpha V, \alpha 2V, \alpha I, \alpha K \). During the whole procedure \( x_2 \) was constant but \( x_3 \) has changed a little with \( \alpha I \).

The aim of the closed orbit correction at the inflector was to get the same \( x_3 \) with the same \( \alpha K \), whatever might be the closed orbit in the kicker (see Fig. 2). This will not be achieved exactly, as there are errors remaining after correction of the closed orbit (see above figures) and because of non-linearities of the fields in period 1 (from point 3 to 4).

3. **Monoturn injection**

For a monoturn operation of the machine the four rings must be run with equal \( \alpha I \) and \( \alpha K \) respectively. The mean values \( \bar{\alpha I} \) and \( \bar{\alpha K} \) are very likely the best ones.

It is then necessary to readjust the injection on each of the closed orbits by means of \( \alpha 1, \alpha 2 \). The steps are:

14) computation and setting up of \( \bar{\alpha I} \) and \( \bar{\alpha K} \)

15) measurement of \( \Delta x_5, \Delta x_6 \) and of \( \mathbf{M} \begin{pmatrix} x_5 \\ x_6 \\ \alpha 1 \end{pmatrix} \)

16) adjustment * of \( \Delta x_5, \Delta x_6 \) by \( \alpha 1, \alpha 2 \); check of adjustment

17) measurement of \( x_2, x_3 \).

*) see Appendix I
Remark: With the beam now circulating in the machine steps 15, 16, 17 which correspond to 4, 6, 7 may possibly be replaced by a two knobs manipulation looking at one or two PU's for vanishing coherent oscillations.

For an optimum running of the machine x2 and x3 must be the same for the four rings. When they are not the same a new choice of the septa position dS and angle φS has to be considered, taking into account the emittance of the full injected beam (till now a pencil beam has been used). In an extreme case, when x2 and x3 differ too much, a more sophisticated procedure, including some closed orbit dipoles, has to be applied.

4. Multiturn injection

For the multiturn process the basic parameters will have values like dS = 40 mm, dI ≲ 5 mm, φS = 0, QH variable. The previously described procedure has to be followed up to step 13).

Multiturn computations show that the optimum angle at injection, x3', is positive, varies with QH and the number of turns to be injected and is not a very effective parameter.

Still using a pencil beam one has now to adjust the φXi, so that the beam is put onto the closed orbit. For the φXi, one sets up theoretical values which correspond to the actual QH.

The closed orbit displacement d(t) (see Fig. 3) must be equal to x3 at the time of injection ti and after one revolution d(ti + Δtrev) must be small enough for the front of the beam not to hit the septum. A chopped linac pulse of about the length of a bunch would give the best conditions. The PU at point 5 must integrate the front of the pulse only.
The closed orbit $x_5, x_6$ has been measured at step 13).

We continue as follows:

14)' measurement of $\Delta x_5, \Delta x_6$ and of $M \begin{pmatrix} x_5 \\ x_6 \end{pmatrix} / aK_1$

15)' adjustment *) of $\Delta x_5, \Delta x_6$ by $aK_1, aK_2$; check of adjustment

16)' measurement of $\Delta x_5, \Delta x_6$ (after one revolution) and of $M \begin{pmatrix} x_5 \\ x_6 \end{pmatrix} / aK_3$

17)' adjustment *) of $\Delta x_5, \Delta x_6$ by $aK_3, aK_4$; check of adjustment.

The ratios of the $aK_i$ are now correct whatever amplitude or time derivative we use later on.

*) see Appendix I
The $\alpha Ki$ obtained for each ring are compared but only the ratios must be the same. Their values may be chosen by the injection timing so that multiturn injection is less critical than monoturn as far as the septa position are concerned.

Replacing the $\alpha Ki$ will possibly give a small slope to the bumped closed orbits, decreasing with time like $d(t)$, but this will have a smaller effect than a constant slope $x3'$ which proved to be of little influence (see above).
References


2. G. Guignard, Simulation numérique de la correction d'orbite fermée, SI/Note DL/70-2.

APPENDIX I

To adjust two coupled parameters $a_1, a_2$ by looking at the observables $x_1, x_2$ the most straightforward method is to find the matrix relation for increments:

\[
\begin{pmatrix}
\Delta x_1 \\
\Delta x_2 
\end{pmatrix} = M \begin{pmatrix}
\Delta x_1 \\
\Delta x_2 
\end{pmatrix}
\]

then $M^{-1}$ will give the change $\Delta a_1, 2$ needed for the wanted variations $\Delta x_1, 2$.

$M$ is determined experimentally by measuring

\[
\begin{pmatrix}
\Delta x_1 \\
\Delta x_2 
\end{pmatrix} \quad \text{for} \quad \begin{pmatrix}
\Delta a_1 = 1 \\
\Delta a_2 = 0 
\end{pmatrix}
\]

\[
\begin{pmatrix}
\Delta x_1' \\
\Delta x_2' 
\end{pmatrix} \quad \text{for} \quad \begin{pmatrix}
\Delta a_1 = 0 \\
\Delta a_2 = 1 
\end{pmatrix}
\]

so that

\[
M = \begin{pmatrix}
\Delta x_1 & \Delta x_1' \\
\Delta x_2 & \Delta x_2' 
\end{pmatrix}
\]
APPENDIX II

Any trajectory observed at points 5 (2\text{L}_3) and 6 (3\text{L}_3) may be written

\begin{align*}
x_5 &= x_{50} + a \cos (\delta + n2\pi Q) \\
x_6 &= x_{60} + a \cos \left(\delta + \frac{\pi Q}{8} + n2\pi Q\right)
\end{align*}

(II.1)

where

- \(x_{50}, x_{60}\) = closed orbit at points 5, 6
- \(a\) = coherent oscillation amplitude
- \(\delta\) = any phase angle
- \(\frac{\pi Q}{8}\) = phase advance from 5 to 6
- \(n\) = number of revolutions.

(II.1) are the parametric equations of an ellipse in a coordinate system \((x_5, x_6)\). The point \((x_{50}, x_{60})\) is the centre of the ellipse which is inscribed in a square surface.

In this diagram the phase advance per revolution is equal to

- \(q = \text{fractional part of } Q\), what corresponds to a clock wise circulation for \(4.5 < Q < 5\), and anti clock wise for \(4 < Q < 4.5\).
The axis ratio of the ellipse is

\[ r = \cos \left( \frac{\pi}{2} - \frac{Q\pi}{16} \right) / \cos \left( \frac{Q\pi}{16} \right), \]

with \( 1 < r < 1.497 \) for \( 4 < Q < 5 \).

When \( Q \) is unknown 5 equations like (11.1) i.e for instance two measurements of \( x_5 \) and three of \( x_6 \) are necessary for the mathematical solution which reduces to solving a system of 5 linear equations.

For pedestrian it is better to measure \((x_5, x_6)\) after \( i \) revolutions \((i = 0, 1, 2, 3 \ldots)\) and draw the corresponding points on a diagram \((\frac{1}{q} \text{ points are adequate to give an estimate of } (x_{50}, x_{60}))\).