EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
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CERN - PS DIVISION

PS/ PA/ Note 94-01 (MD)

CHROMATICITY CORRECTION IN THE PS

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2 February, 1994

EUROPEAN LABORATORY FOR PARTICLE PHYSICS

PS/PA/Note 94-1 (MD)
1 February 1994

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1. Introduction

The capability of adjusting the chromaticity $\xi_{x,y}$ determines whether or not high-intensity bunched beam is stable or unstable. More precisely, "head-tail" instability may be eliminated if the machine is operated with negative chromaticities below transition, and with slightly positive chromaticity above transition. Consequently it is of primary importance to know, and possibly to adjust, the working points of the different PS beams in operation. A "natural" working point in PS which has been proven useful for high-intensity beams above transition is Q_x=6.23, Q_y=6.31, and $\xi_{x,y} \geq 0$ (Ref. 1). With this working point, the beams are kept far from low-order resonances and may be accelerated to high energy (26 GeV/c) over a wide range of intensities without significant losses or emittance blow-up, and without the need of octupoles to damp the instabilities.

A convenient way of adjusting the PS chromaticity in both transverse planes is to use the pole-face windings and the figure-of-eight loop systems with three currents I_F, I_D and I_8, which allow to create independent multipole fields. To the first order, the tune and chromaticity changes due to the three current changes would then be given by the matrix equation (Ref. 1-2), for p<15 GeV/c

$$\begin{pmatrix} \Delta Q_x \\ \Delta Q_y \\ \Delta \xi_x \\ \Delta \xi_y \end{pmatrix} = \frac{1}{p} \begin{pmatrix} 0.131 & -0.079 & -0.0168 \\ -0.079 & 0.131 & 0.0168 \\ 1.48 & 0.84 & 0 \\ -1.04 & -1.18 & 0 \end{pmatrix} \begin{pmatrix} \Delta I_F \\ \Delta I_D \\ \Delta I_8 \end{pmatrix}$$

where p is the nominal particle momentum on the reference orbit.

The four parameters $Q_{x,y}$ and $\xi_{x,y}$ cannot be independently controlled with three currents. From the above 4×3 matrix, four different 3×3 inverse matrices with four coupling equation may be derived. Thus, specified working points will only be roughly achieved in this way. The most usual inverse matrix is

$$\begin{pmatrix} \Delta I_F \\ \Delta I_D \\ \Delta I_8 \end{pmatrix} = p \begin{pmatrix} 0 & 1.352 & 0.962 \\ 0 & -1.192 & -1.696 \\ -59.524 & 16.145 & 15.478 \end{pmatrix} \begin{pmatrix} \Delta Q_x \\ \Delta\xi_x \\ \Delta\xi_y \end{pmatrix}$$

with the coupling equation

$$\Delta Q_y = -\Delta Q_x + 0.008\Delta\xi_x - 0.038\Delta\xi_y$$

Other matrices have been derived for different momenta (p=10, 24, 26 GeV/c). For intermediate momentum values, the matrix coefficients are calculated by interpolation between the four given matrices (Ref. 2).

2. Chromaticity measurement

The chromaticity is defined as the relative change in tune with relative momentum deviation

$$\xi_{x,y} = \frac{\Delta Q_{x,y} / Q_{x,y}}{\Delta p / p}$$

where the momentum deviation relative to the nominal momentum may be either expressed by

$$\frac{\Delta p}{p} = \frac{1}{\eta}\frac{\Delta f}{f}$$

or, at constant magnetic field

$$\frac{\Delta p}{p} = \gamma_t^2 \frac{\Delta R}{R}$$

in which $\eta = 1/\gamma^2 - 1/\gamma_t^2$ is the phase slip factor, γ_t the relativistic factor γ at the transition ($\gamma_t \cong 6.1$ at $B \cong 2760$ Gauss in PS), f the revolution frequency on the reference orbit, Δf a change of the revolution frequency, and R the mean machine radius (R=100 m in PS).

Since the RF frequency f_{rf} is a multiple of the revolution frequency: $f_{rf} = hf$, with h the harmonic number, the last two formulae may be equivalently used to derive the relative momentum deviation from a change of the RF frequency, which induces a change of the beam radial position. Hence, measuring the machine tunes for various RF frequencies yields the relative tune deviation, and then the chromaticity.

The horizontal and vertical chromaticities have been initially measured in the PS along the magnetic cycle (C-cycle: 2.4 s long) for the high intensity antiproton production beam (Ref. 3). Measurements have been performed from p=3.6 GeV/c (timing clock=460 ms: $B \cong 1695$ Gauss) to p=26.2 GeV/c (timing clock=1300 ms: $B \cong 12560$ Gauss) by timing clock steps of 2 ms. Within this momentum range the C-cycle shape is identical to the magnetic cycle as required for the LHC beam (H-cycle: 3.6 s long). PS transition crossing occurs at timing clock≅534 ms: $B \cong 2760$ Gauss. Results are shown in Fig. 1: it can be seen that the vertical chromaticity is negative on the 26 GeV/c flat-top, which is not the expected result.

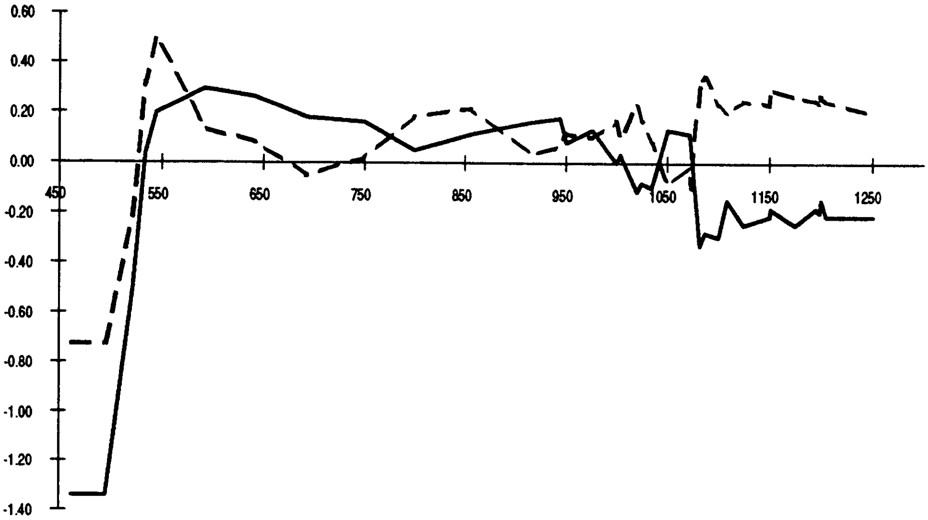

Fig. 1: Measured PS chromaticity before correction vs. C train in ms (timing clock). Dot line stands for ξ_x, continuous line for ξ_y (December 1992).

3. Chromaticity correction

Based on the above measurements, a chromaticity correction in PS has been carried out using the pole-face windings and the figure-of-eight loop.

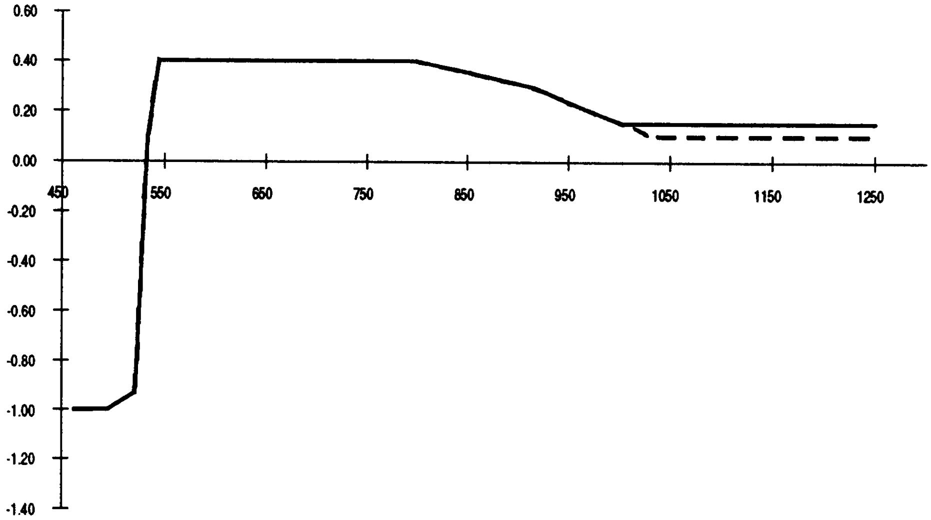

Fig. 2: Specified chromaticity vs. C train in ms. Broken line stands for ξ_x, continuous line for ξ_y.

Fig. 2 shows the required chromaticities in both transverse plane, taking into account the current limitations of the pole-face windings and figure-of-eight loop power supplies.

Hence, the horizontal and vertical chromaticities have been measured (timing clock steps of about 50 ms) after the corrections. The results are displayed in Fig. 3. Since the process of differentiation amplifies the errors on data, large chromaticity errors could somehow be expected. It was found that the mean relative change of the revolution frequency is roughly 0.008. Thus, an uncertainty of 0.005 on the tune measurement would cause a relative error of 0.1 on the chromaticity. More refine tune measurements should then be performed on the 26 GeV/c flat top to check the results.

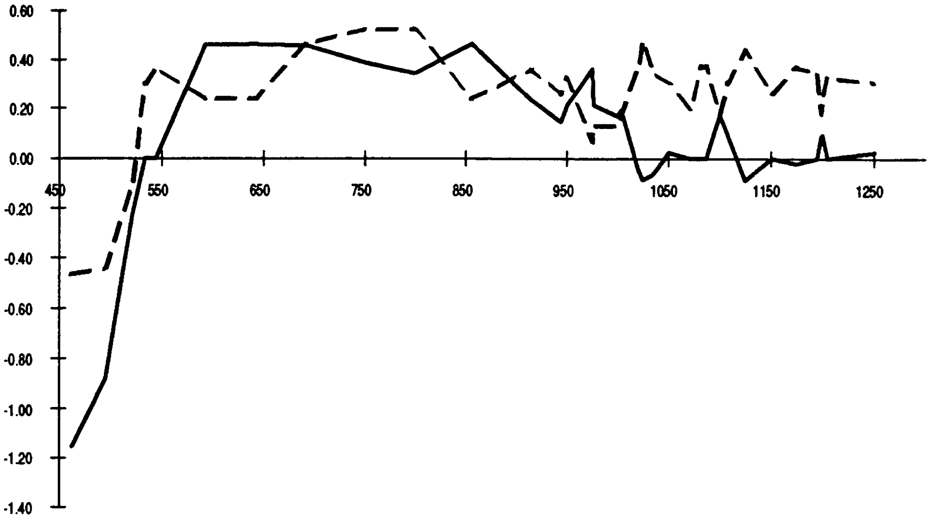

Fig. 3: Measured PS chromaticity after correction vs. C train in ms. Broken line stands for ξ_x, continuous line for ξ_y (November 1993).

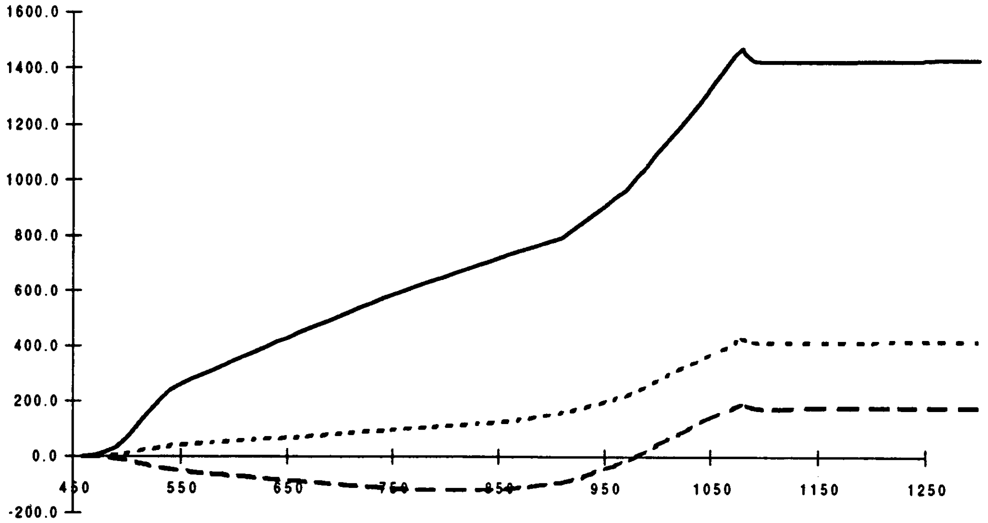

Fig. 4: Pole-face winding and figure-of-eight loop currents vs. C train in ms. Dot line stands for I_F, broken line for I_D, continuous line for I_8 (November 1993).

The pole-face winding and figure-of-eight loop currents after the correction are shown in Fig. 4. The currents have been established to provide the fastest chromaticity jump at the transition crossing. However, fast jumps of currents are not accepted by the pole-face winding and figure-of-eight loop power supplies. The new current values on the 26 GeV/c flat-top are: I_F=414 A, I_D=177 A, and I_8=1426 A, instead of the old values: I_F=400 A, I_D=200 A, and I_8=1251 A.

Conclusion

The performance of the antiproton production beam (on C-cycle) has been improved after the chromaticity correction since the octupoles are not needed anymore to damp the instabilities at high energy. On the other hand no significant losses and transverse emittance blow-up have been observed after the transition. A similar high-energy working point has been programmed along the magnetic cycle (H-cycle) as required for the LHC type beam. No "head-tail" instability has been observed above 3.5 GeV/c on this beam during the Machine Development session of December 1993.

Acknowledgements

We would like to thank R. Cappi and Ch. Steinbach for stimulating comments and helpful suggestions.

References

1 - R. Gouiran, Enroulements polaires de l'aimant du CPS, CERN/PS/SM 76-1, 1976.

2 - T. Risselada, Private communication.

3 - G. Azzoni, Mesures des chromaticités au PS, PS/OP/Note 93-1 (MD), 1993.