CLOSED ORBIT CORRECTION OF THE CERN ANTIPROTON COLLECTOR RING

M. Martini and L. Rinolfi
European Laboratory for Particle Physics (CERN)
CH-1211 Geneva 23

Abstract

Various results obtained from the closed orbit correction system are presented. The acquisition system consists of 60 beam position monitors; the set of correctors comprises 56 quadrupoles. Furthermore the 24 bending magnets may also be considered as horizontal correctors. All closed orbit corrections are achieved by displacing transversely quadrupoles or moving longitudinally dipoles (more practically by shimming the dipoles). The correction software ORBCOR [1] minimizes the mean square deviation of the orbit at pick-up stations. The calculations make use of an Antiproton Collector lattice created by MAD program.

The horizontal and vertical closed orbit corrections have been successfully accomplished in June 1987. A last horizontal correction took place in March 1988, after ring realignment to improve machine acceptances. Starting from rms and peak-to-peak values of 3.5 mm and 12.0 mm, they were reduced to 1.3 mm and 5.1 mm.

Orbit Measuring and Correcting Systems

The orbit measuring system in the Antiproton Collector ring is made of 60 electrostatic pick-ups (32 for horizontal plane and 28 for vertical plane) installed inside the quadrupoles. Six types of pick-ups have been designed [2] in order to take into account the vacuum pipe shape (circular, rectangular) around the machine. Each pick-up consists of two half-sine shaped position electrodes Δ (transversely symmetric) and one cylindrical shaped intensity electrode Σ. The system sensitivity allows measurements on bunched beams of an intensity of 2×10^9 to $2 \cdot 10^{10}$ particles.

The voltages induced on the 60 pick-ups are amplified and sequentially transmitted to four multiplexers which feed two normalizer modules. Their output analog signals Δ/Σ are then sampled for appropriate conversion in beam positions by means of a specific acquisition program. Measurements showed that the beam displacement is a slightly non-linear function of $u = \Delta/\Sigma$ voltage. Therefore, the program calculates the displacements at the pick-up location as:

$$x[\text{mm}] = a_0 + a_1 u + a_2 u^2 + a_3 u^3$$

for the horizontal pick-ups, and

$$y[\text{mm}] = a_0 + a_1 u(1 - c x^4)$$

for the vertical pick-ups, where a_0 to a_3 and c are coefficients found by careful measurements.

Furthermore, electronic chains may be calibrated, on user's request, to consider small fluctuations of preamplifier gains. To achieve this, an oscillator module applies sine signals to the pick-up electrodes to simulate $\Delta/\Sigma = 1, -1$ and 0. Thus the acquisition program calculates the appropriate calibration sequence V_C+, V_C- and V_{C0} for each pick-up, the $u = \Delta/\Sigma$ voltage being corrected by means of formulae:

$$u_C = 2 \frac{u - V_{C0}}{V_{C^+} - V_{C^-}}$$

Figure 1 shows a cylindrical pick-up station.

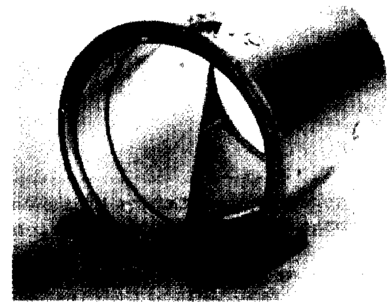
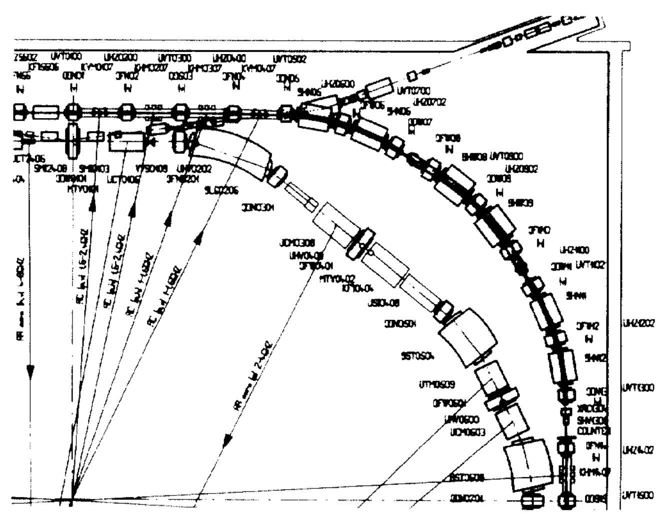


Fig. 1 -

The correcting system consists of 28 horizontally focusing quadrupoles and 28 vertically focusing quadrupoles for horizontal and vertical corrections, respectively, which may be transversely displaced using motorized jacks. In addition, the 24 bending magnets might also be considered for horizontal correction. Here, the correction is achieved by shimming the dipoles, which corresponds to downstream or upstream longitudinal displacement along the central orbit.

The quadrupoles are shared out into seven families depending on their characteristics. Some of them have sextupole components built in. The dipoles are also divided in two families. Due to injection constraints, two special quadrupoles and one special dipole have been designed. A quadrant of the ring is shown in Fig. 2.



* Outer ring: Antiproton Collector
Inner ring: Antiproton Accumulator

Fig. 2 -

The Correction of Closed Orbits

The closed orbit is corrected by means of the "least square" method, where the squares of the orbit distortion are minimized by choosing the most effective correctors. In the Antiproton Collector, the dipole corrector fields are provided by moving quadrupoles (upwards, downwards or sideway) a distance Δz, or for the horizontal plane only, by moving dipoles (upstream or downstream) along the central orbit a distance Δz. The orbit corrections act on central orbit. Thus the horizontal orbit vector to be considered for correction is

$$Z = Z_m - D(\Delta p/p)$$

where D is the dispersion at each pick-up and Z_m the measured closed orbit.

The residual vector R due to the action of correctors is

$$R = Z + A\,\Delta\psi\ ,$$

A being the matrix describing the distortion of reference orbit at each pick-up location due to unit kick at corrector position. The requested kick vector is found by minimizing the square norm of residual vector at each iteration, that is

$$\frac{d\|R\|^2}{d\,\Delta\psi} = 0\ .$$

Solving the previous system of equations leads to the set of corrections

$$\Delta\psi = -(A^tA)^{-1}A^tZ\ .$$

The computational procedure uses the MICADO [3] method. Its main feature is that it requires only a small number of correctors. It also has the capability of ignoring pick-ups and correctors, and allows the user to consider or ignore the presence of previous magnet displacements. At each new iteration, MICADO keeps all correctors retained from the previous iterations but their strengths are recomputed. This drawback has been overcome with the MINIMO [4] method which scan at each iteration all possible combinations of correctors. However, this technique is of exponential complexity and required waste amount of time to execute even moderate size corrections. Consequently, it must be run off-line.

The mode of operation of the orbit correction software, called ORBCOR, is semi on-line, as the orbit data are consecutively measured and analyzed by the program which calculates the necessary kick at each of the best correctors [5]. The results are then displayed for appropriate action at any convenient time. The ORBCOR software allows also the users to perform local orbit alterations (bumps) and to simulate the effect of displacing magnets.

Local Orbit Correction where Dispersion is Zero

There are two long and two short straight sections with zero dispersion in the Antiproton Collector ring, which are used for stochastic coolings and injection/ejection purposes.

Closed orbit corrections (called TRIM correction) are possible in these regions thanks to a special power supply installed on dipoles, with the additional constraint of keeping constant the total length of the closed orbit.

The orbit deformation is calculated at each horizontal pick-up where the dispersion is zero.

$$\Delta q(s) = \frac{\sqrt{\beta_H(s)}}{2\sin\pi Q}\int_S^{S+C}\sqrt{\beta_H(\sigma)}\,\cos(-\pi Q+\mu(\sigma)-\mu(s))\left(\frac{\Delta I}{I}\right)\frac{1}{\rho}\,d\sigma\ .$$

At the nominal current, the magnetic field B is proportional to the current I. The TRIM correction is derived from

$$TRIM = \frac{1}{\Delta q(0)}\,\frac{\sum_{i=1}^{n} x_i/\Delta q_i}{\sum_{i=1}^{n} 1/\Delta q_i^2}$$

where x_i is measured at horizontal orbit position.

Table 1 shows the measured orbits and the weighted mean orbit deformation (TRIM) in the zero dispersion regions.

Table 1

1988-03-15-21:30:45 AC CLOSED ORBIT DISTORTIONS IN MM

HORIZONTAL POSITIONS				VERTICAL POSITIONS			
PU 2	2.8	PU 30	.1	PU 1	-1.9	PU 29	-2.6
PU 4	6.3	PU 32	-4.6	PU 3	-1.7	PU 31	2.0
PU 6	3.6	PU 34	-7.1	PU 5	2.0	PU 33	.5
PU 7	-3.5	PU 35	-4.0	PU 7	1.0	PU 35	1.2
PU 9	-6.8	PU 37	-2.6	PU 9	.8	PU 37	-2.8
PU 11	-8.1	PU 39	.4	PU 11	-.9	PU 39	-3.9
PU 12	-5.9	PU 40	.3	PU 13	.4	PU 41	1.7
PU 14	3.2	PU 42	-2.8	PU 15	.4	PU 43	5.3
PU 16	6.4	PU 44	-2.7	PU 17	2.8	PU 45	-.3
PU 18	.5	PU 46	-1.4	PU 19	-.6	PU 47	-3.7
PU 19	-4.4	PU 47	-1.3	PU 21	-.6	PU 49	-1.4
PU 21	-8.1	PU 49	-3.1	PU 23	3.3	PU 51	1.9
PU 23	-5.8	PU 51	-.9	PU 25	2.1	PU 53	2.5
PU 24	-1.2	PU 52	-6.3	PU 27	-1.4	PU 55	0
PU 26	4.9	PU 54	-3.4				
PU 28	5.0	PU 56	-4.0	Ip BUNCHED=	.834 E10		

DP/P (FROM FREQUENCY)= -.2 E-3 MEAS FREQUENCY =1588.474 kHZ
DP/P (FROM PU AVERAGE)= -2.1 E-3 TRIM = 1.2 mm

Results

Figures 3 and 4 show the horizontal and vertical closed orbits measured on March 1988. ORBCOR software was used on the horizontal orbit, predicting the decrease of the rms and peak-to-peak values from 3.5 mm and 12.0 mm to 1.1 mm and 4.6 mm moving inwards and outwards four quadrupoles. After implementing the correction, the closed orbit was measured with a rms and peak-to-peak values of 1.3 mm and 5.1 mm, respectively. The resulting orbit is shown in Fig. 5.

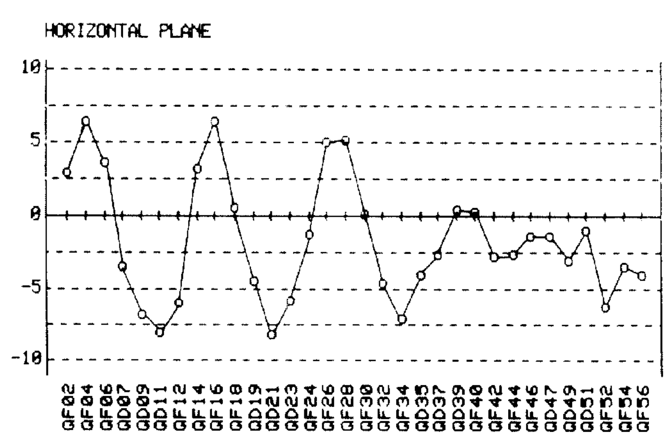


Fig. 3

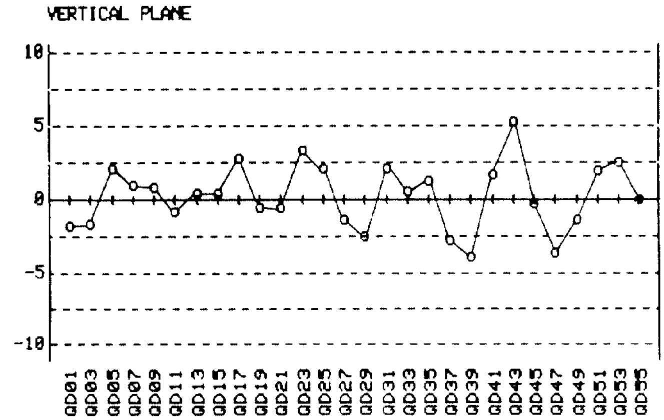


Fig. 4

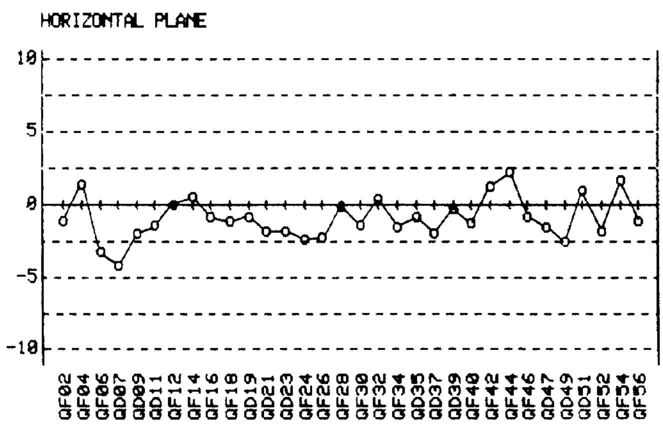


Fig. 5

Considering horizontal orbit correction by means of dipoles as an alternative would have led to the final rms value of 1.8 mm and peak-to-peak value of 7.8 mm displacing longitudinally (shimming) four magnets. Considering both quadrupoles and dipoles as correctors, ORBCOR proposed the same setting as for pure quadrupole correction. The results are summarized in Table 2.

Table 2

Quadrupoles		Dipoles	
Name	Transverse displacement	Name	Longitudinal Displacement
QFN04	-1.7 mm	BHN05	-7.9 mm
QFN26	-0.6 mm	BHN06	-21.4 mm
QFN28	-1.2 mm	BHN34	9.2 mm
QFN54	0.7 mm	BHW51	-5.1 mm
rms = 1.1 mm ptp = 4.6 mm		rms = 1.8 mm ptp = 7.8 mm	

* Positive value means outwards quadrupole displacement and downstream dipole displacement (or shimming).

The results achieved show that the closed orbit correcting systems are efficient and reliable.

References

[1] E. Bozoki, OBCOR, The New Orbit Correction System of the PS Complex, CERN/PS 85-57 (PSR), 1985.

[2] M. Le Gras, Mesure de la position du faisceau dans ACOL, PS/BR Note 87-3, 1987.

[3] B. Autin, Y. Marti, Closed Orbit Correction of A.C. Machines Using a Small Number of Magnets, CERN ISR-MA/73-17, 1973.

[4] T. Risselada, An Improved Version of the Orbit Correction Program OBCOR, CERN/PS/87-90 (PSR), 1987.

[5] M. Martini, L. Rinolfi, Closed Orbit Correction in the AA Complex, CERN/PS/87-79 (OP), 1987.