

MEASUREMENT AND CORRECTION OF THE CLOSED ORBIT IN THE STORAGE RING ADONE

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Abstract

The storage ring Adone has been recently equipped with a new beam position detecting system consisting of 21 electrostatic pick-up monitors. Absolute accuracy is <0.2 mm with respect to the center of the nearby quadrupole. Reproducibility is within 0.025 mm. The position measurements are used to correct the closed orbit distortion by a least squares minimization.

Introduction

Adone is a first generation e^+e^- 1.5 GeV storage ring with lattice periodicity 12; focusing in both planes is performed by quadrupole doublets at both ends of bending magnets.

Operating point options are at betatron wavenumbers $Q_x \approx 3.15$ or $Q_x \approx 5.15$, $Q_z \approx 3.15$.

Orbit length is 105 m. The RF harmonic number is 18, corresponding to 51.411 MHz. The injection system allows for operation with 1, 3 or 18 bunches. Bunch length is dominated under most operating conditions by anomalous lengthening with values ranging from 20 to 60 cm (4σ). Typical transverse dimensions are 6 mm horizontal and <2 mm vertical (4σ). Total average current ranges between 30 and 100 mA.

In 1986 most of the vacuum chamber has been renovated and beam position monitors (BPM) installed.

Monitor description

The only suitable location to install BPMs was in the center of 21 out of the 24 quadrupole doublets. The available space between the quadrupoles is about 15 cm, preventing the use of flanged units; furthermore in the same region a vacuum pump port must be accommodated. These constraints have led to the design depicted schematically in Fig. 1: the BPM is integral part of the quadrupole vacuum chamber, which in turn is referenced to the magnet axis by means of supporting arms.

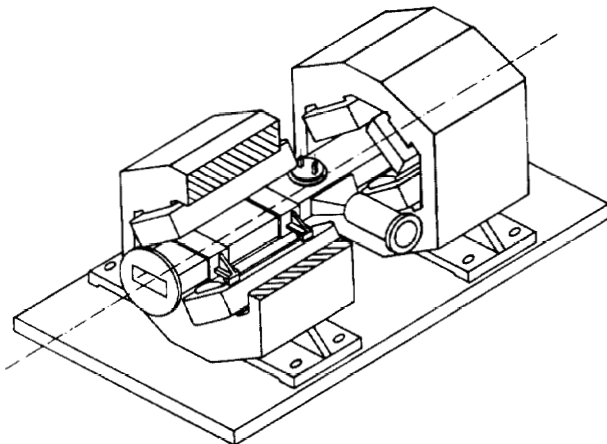


Fig. 1 - View of the BPM assembly.

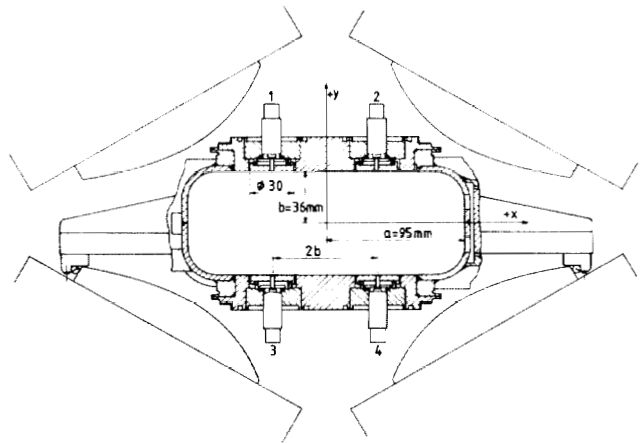


Fig. 2 - Transverse section of a BPM.

Fig. 2 shows a transverse section of the monitor along with the positioning arms in the quadrupole. The BPM is the usual 4-buttons 'electrostatic' monitor type with circular electrodes of radius $r = 15$ mm mounted flush with the approximately rectangular (sides $2a = 190$ mm and $2b = 72$ mm) vacuum chamber. The electrode centers are symmetrically located at the corners of a square of side $2b$.

The BPM center coincides with the quadrupole axis within ± 0.2 mm.

Calibration

Under the assumption of a relativistic bunch much longer than the button the voltage induced at the i -th electrode (see Fig. 2) is¹:

$$(1) V_i = \frac{2i(t)}{c a C} \int_{x_i-r}^{x_i+r} f_i(x, x_0, y_0) \sqrt{r^2 - (x-x_i)^2} dx$$

with $i(t)$ bunch current, c speed of light, C button capacitance to ground, x_i button center position, (x_0, y_0) beam position and

$$f_i(x, x_0, y_0) = \sum_{m=1}^{\infty} \frac{\sin[\alpha_m(x_0+a)] \sin[\alpha_m(x+a)] \sinh[\alpha_m(b-s_i y_0)]}{\sinh(2\alpha_m b)}$$

with $s_i = -1$ ($i=1,2$), $s_i=1$ ($i=3,4$), and $\alpha_m = m\pi/2a$.

By measuring the induced voltages one can in principle deduce the beam position (x_0, y_0) .

Prior to the installation in Adone all monitors have been calibrated. The TEM field generated in the coaxial system of a wire inside the vacuum chamber simulates the beam electric field. A thin wire carrying fast current pulses is stretched in the monitor by means of a bow support driven by stepping motors. The vacuum chamber is supported by reference blocks simulating the quadrupole geometry.

The calibration procedure consists of two measurement sets: first, a small area $3 \times 3 \text{ mm}^2$ is scanned with a 0.5 mm step to precisely determine the monitor electrical center and to detect possible asymmetries. Then, a scan of a larger area to get an experimental position fit is performed.

The calibration measurements are in excellent agreement with those numerically evaluated from (1).

The skew differences method² is adopted to deduce the position from the electrode voltages. We write (see Fig. 3a):

$$(2) \quad U = (1/2) [(V_2 - V_3)/(V_2 + V_3) - (V_1 - V_4)/(V_1 + V_4)]$$

$$V = (1/2) [(V_2 - V_3)/(V_2 + V_3) + (V_1 - V_4)/(V_1 + V_4)]$$

$$(3) \quad x_0 = k_x(x_o, y_o) U - x_{os}$$

$$y_0 = k_y(x_o, y_o) V - y_{os}$$

where (x_{os}, y_{os}) is the monitor offset. k_x and k_y have the dimensions of a length and are fitted to the calibration data by a polynomial in x_o, y_o . The implicit equations (3) are solved by a recursive method. The result of the reconstruction is shown in Fig. 3b.

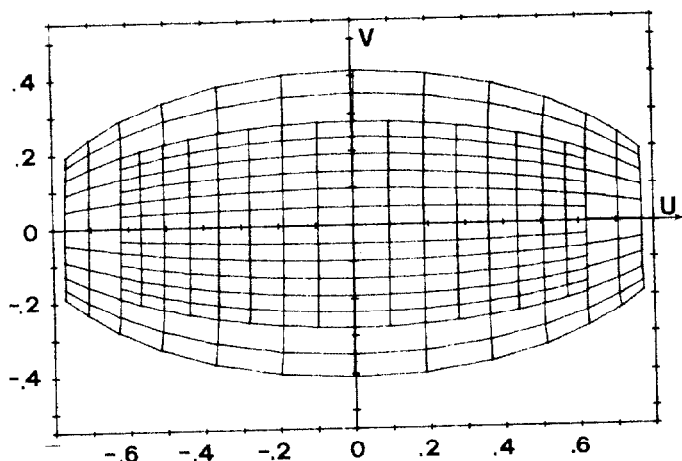


Fig. 3a - Nomograph of measured U and V, as defined in (2). Horizontal lines are drawn at constant y_0 and vertical ones at constant x_0 . Distance between lines: 2.5 mm inner grid; 5 mm outer grid.

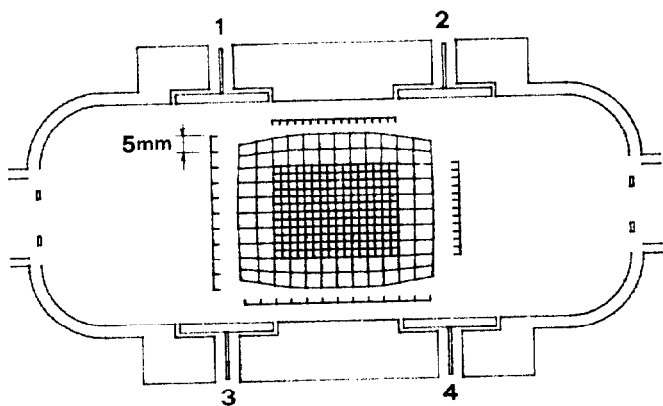


Fig. 3b - Results of the position reconstruction algorithm. Lines should ideally lie 2.5 and 5 mm far away from each other in the inner grid and in the outer grid, respectively.

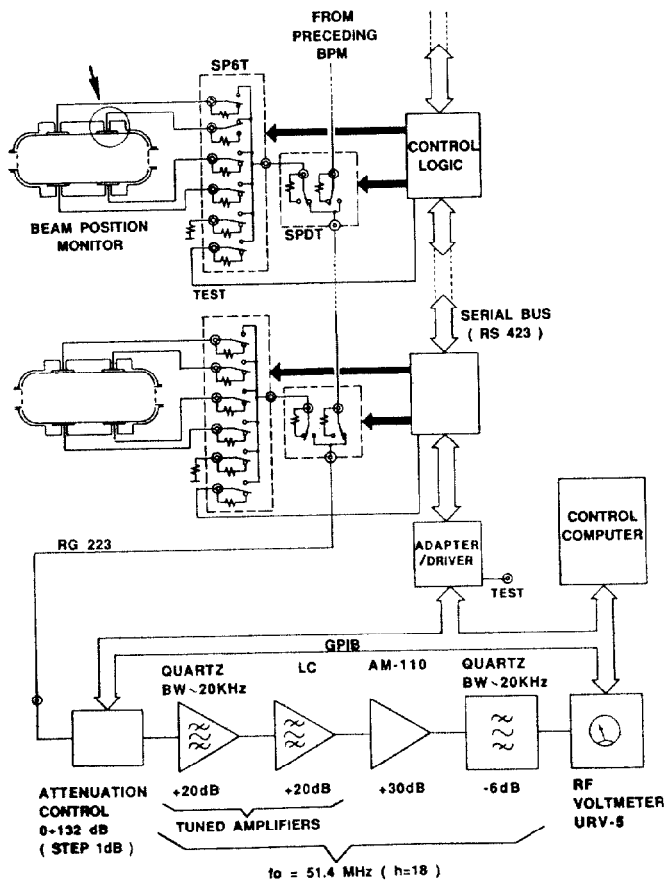


Fig. 4 - Block diagram of the measurement system.

Measurement system

Fig. 4 shows a schematic block diagram of the acquisition system.

The bunch current frequency spectrum in any operating condition has always a component at the 18th harmonic of the revolution frequency. We use a narrow-band system tuned to this frequency to measure the voltages (sinusoidal amplitude is about $100 \mu\text{V}/\langle\text{mA}\rangle$ regardless of the number of bunches).

Custom-made narrowband quartz filters (bandwidth $\sim 20 \text{ KHz}$) are used to filter-out noise. The equivalent noise input voltage is $< 0.2 \mu\text{V rms}$ yielding a good S/N ratio even at very low current. The sinusoidal voltage output is measured by a $4\frac{1}{2}$ digits micro-processor controlled RF voltmeter.

The position measurement reproducibility is $\sim 3 \mu\text{m rms}$ at the calibration bench; with actual beam it is $\sim 25 \mu\text{m rms}$ horizontal and $\sim 10 \mu\text{m rms}$ vertical.

Every button is sequentially connected to the measuring detector by means of an RF distributed multiplexer ($-3\text{dB BW } 300 \text{ MHz}$). The use of double commutation ensures an insulation $>120 \text{ dB}$.

In the idle position the buttons are terminated into 50 Ohm resistors.

Orbit correction

The closed orbit data are obtained by the measured voltages according to the reconstruction algorithm outlined above.

Data are checked for consistency and, should the case occur, an alert message indicating poor S/N ratio or possible relay malfunction is issued at the operator console.

Horizontal correctors are backleg windings in the 12 bending magnets. Vertical correctors are additional dipole windings in 12 D quadrupoles, where the vertical β -function approaches its maximum value. The typical working point of the machine being near betatron wavenumber of 3 in both planes, 4 correctors per betatron wavelength are therefore available.

The Least Squares Method³ (LSQM) has been chosen to correct the closed orbit distortion. This method proves to be particularly easy to use when different lattice configurations and working points are used in the ring operation. It minimizes the rms displacements at the monitor positions with angular kicks δ whose values are determined by the constraint that the sum

$$S = \sum_{i=1}^N (z_i + z_{i0})^2 + K \sum_{j=1}^M \delta_j^2$$

be a minimum (z_{i0} = measured position of the beam at the i -th BPM before the correction, z_i = displacement created by correctors, N, M = number of monitors and correctors respectively). The factor K has been introduced to allow for a reduction in required corrector strengths if current limits are exceeded⁴.

The result of the correction for the vertical plane is shown in Fig. 5. There is a reduction factor of ~ 10 in the measured beam position.

The LSQM tends to compensate monitor position errors; the compensation can in principle be total if $N=M$. Since monitor displacements can, at least in part, be hidden by this correction method, the estimated overall accuracy of the corrected orbit is ± 0.5 mm with respect to the quadrupole axes.

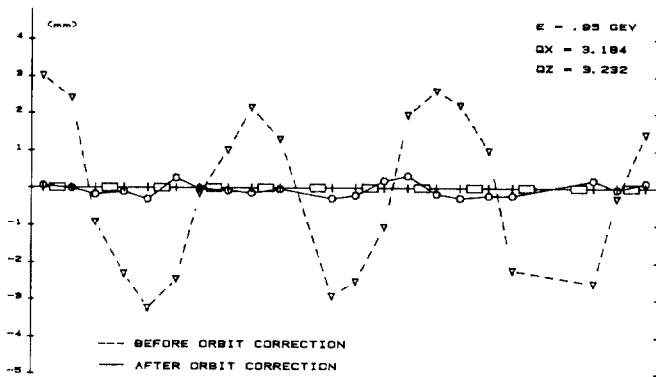


Fig. 5 - Example of vertical orbit correction.

Localized orbit bumps

Beam steering is often required to optimize the performance of the experimental beam lines. Steering of the beam at a given point in one plane requires 4 correctors.

In absence of any constraint on the total orbit length L , a set of N horizontal angular kicks δ_k at points where the dispersion function is η_k , creates a relative orbit lengthening:

$$\frac{\Delta L}{L} = \frac{1}{L} \sum_{k=1}^N \eta_k \delta_k$$

The total orbit length being constrained by the synchronism condition with RF frequency, the energy of the beam is forced to change, in order to compensate the orbit lengthening. In the vertical plane the effect is of second order, negligible in all practical cases.

The energy variation can of course be compensated by changing the RF frequency according to $\Delta f/f = -\Delta L/L$.

Fig. 6 shows an example of localized horizontal bump before and after such RF correction. The points are all at the same distance from those measured before this correction, because the dispersion is the same in all BPMs. The solid line is the beam path calculated with the theoretical machine model with localized angular perturbations.

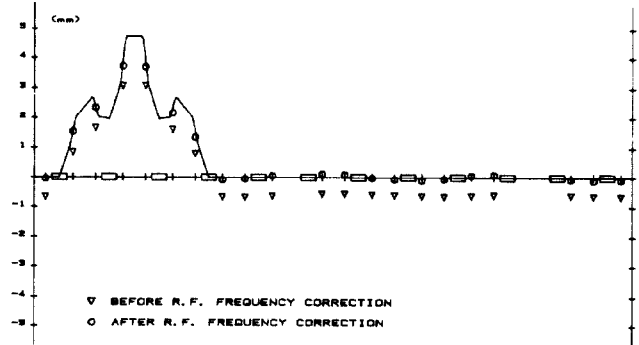


Fig. 6 - Example of horizontal localized bump.

Acknowledgements

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References

1. J.H. Cupérus, "Monitoring of particle beams at high frequencies" NIM Vol.145 (1977) pp.219-231.
2. J. Borer, C. Bovet, "Computer response of four pick-up buttons in an elliptical vacuum chamber" LEP Note 461 (1983).
3. A.S. King, M.J. Lee, P.L. Morton, "Closed orbit correction in SPEAR" SLAC-PUB-1203 (1973).
4. Y. Baconnier, "Contribution a l'étude de l'orbite fermée" CERN 65-35 (1965).