DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

Frascati, February 14, 1997

Note: **L-26**

HARMONIC CLOSED ORBIT CORRECTION IN THE DAΦNE ACCUMULATOR RING

S. Guiducci, M.R. Masullo

1. Introduction

An harmonic method to correct the closed orbit proposed by M. Bassetti [1] has been applied to the DAΦNE Accumulator ring. The peculiarity of this method is that, with a proper choice of the harmonics, a correction independent on the monitor errors and with a quite low corrector strength is achievable. In Section 2 the computer program used to calculate the correction is described. Section 3 refers to measurements and corrections of the closed orbit in the DAΦNE Accumulator ring which show the effectiveness of this method in presence of offsets of the beam position monitors. In Section 4 the dispersion function obtained by closed orbit measurements is reported. The orbit analysis program and related input and output files are described in more detail in Appendix.

2. Computer code description

An off-line Fortran code has been written to apply the harmonic correction method, described in Ref. 1 to the measured accumulator closed orbit.

At present the data were read from an external input file, but the inclusion of this method for the orbit correction in the Control System it is foreseen .

In this section we summarize the method and give a basic description of the code.

The closed orbit, read at the monitor locations, is Fourier transformed retaining only a given number of harmonics M.

The Fourier expansion of the closed orbit (horizontal or vertical) measured at H monitors, in Courant-Snyder variables η and ϕ, is:

$$\eta_i = \frac{x_i}{\sqrt{\beta_i}} = \frac{a_0}{2} + \sum_{m=1}^{\infty}\left[a_m \cos(m\phi_i) + b_m \sin(m\phi_i)\right]; \qquad i = 1,...H \qquad (1)$$

The number M of harmonics and their index can be chosen in the input data with the condition:

$$2M \leq H$$

The correction is performed only in one plane at each time (horizontal or vertical), chosen in the data. The program gives in the output the reconstructed orbit, the measured one and their difference together with the relative rms values.

Then the intensities of the correctors which reproduce the same Fourier coefficients for the M harmonics are calculated. A solution can be found only if the number N of correctors is:

$$N \geq 2M$$

The program calculates the difference between the measured orbit and the one due to correctors, which is the closed orbit expected after correction.

This method, as explained in [1], minimizes the strength of the correctors; therefore increasing the number of correctors decreases their strength and the correction becomes more distributed and gives better results.

With this method the goodness of the correction depends on the optimal choice of the harmonics to correct. The optimum choice depends on the machine periodicity, on the number and distribution of the monitors and correctors, on the magnitude of the monitors errors with respect to the monitors readings and so on.

In the following section we describe the procedure, made in several steps, adopted successfully to correct the orbit in the DAΦNE Accumulator ring; below we give some general considerations on the use of the method.

First of all the Fourier spectrum can be calculated with a maximum number of harmonics allowed by the number of monitors, i.e. $M < H/2$, choosing the harmonics nearest to the Q value on both sides.

The harmonics to be corrected are chosen from the aspect of the Fourier spectrum, keeping in mind that the spectrum of the closed orbit is resonant with the betatron tune, while that of the monitor errors should be nearly flat, as due to a noise. Therefore if the monitors errors are negligible with respect to the measured orbit the spectrum is sharply peaked on the harmonic nearest to the Q value; when the errors get larger all the harmonics increase and the peak tends to disappear.

A possible strategy is to adopt an iterative procedure: as a first approximation correct only one harmonic, the one nearest to the Q value, and then try to check the goodness of the correction and, if necessary, correct more harmonics.

3. Closed orbit measurements and correction

The data analyzed in this section were recorded during the Accumulator shifts performed, between November '96 and January '97, by the DAΦNE Team. The on-line acquisition of the closed orbit was performed by a high level program [2] and the data transferred to the main ALPHA computer.

The model of the Accumulator lattice used for the orbit analysis is described in Ref. [3] with the field index n, the fringing length b, and the quadrupole constant C_1 given below:

$$n = .450495\ , \quad b = .11253\ , \quad C_1 = 9.1286 \times 10^{-3}$$

The horizontal and vertical closed orbit measured in the DAΦNE Accumulator ring during November shifts is described in Table I and shown in Fig. 1.

TABLE I - Measured closed orbit before correction

File name - Date	reforb 1/12/96	reforb 1/12/96
Correctors	off	off
Energy (GeV)	.504	.504
RF frequency (MHz)	368.39 *	368.39 *
Q_x	3.103	3.103
Q_y	1.176	1.176
H/V	H	V
x_{rms} (mm)	1.63	3.73
x_{max} (mm)	-4.08	-5.95

* *Here, as in the following, we report the value of the RF frequency set by the master generator, which corresponds to the DAΦNE RF one. The Accumulator RF frequency, generated by the timing electronics, is five times lower .*

The Fourier spectrum of the orbit in both planes is shown in Fig. 2. The amplitude ρ_m is defined as:

$$\rho_m = \sqrt{\langle\beta\rangle}\sqrt{a_m^2 + b_m^2}$$

where <β> is the mean value of the β function over the ring.

The vertical orbit has a sharp peak at the harmonic m=1, which is the integer of the Q_y value, as we expect for a closed orbit due to alignment errors of the magnetic elements and with small monitor errors.

On the contrary the horizontal orbit is not peaked on m=3 (the integer of Q_x) and all the harmonics are within a factor two from the third: this is typical of a measure with monitor errors of the same order of magnitude of the orbit due to magnet alignment errors.

It has been decided to correct the vertical orbit by moving two quadrupoles and to perform further measurements before correcting the horizontal orbit.

To correct the vertical orbit two quadrupoles have been displaced as listed below:

QUAA2002	Δy = -.3 mm (down)
QUAA4002	Δy = .1 mm. (up)

To check the goodness of the correction we have measured the orbit for two different tune values. In fact, if the closed orbit is corrected it does not change with the tune.

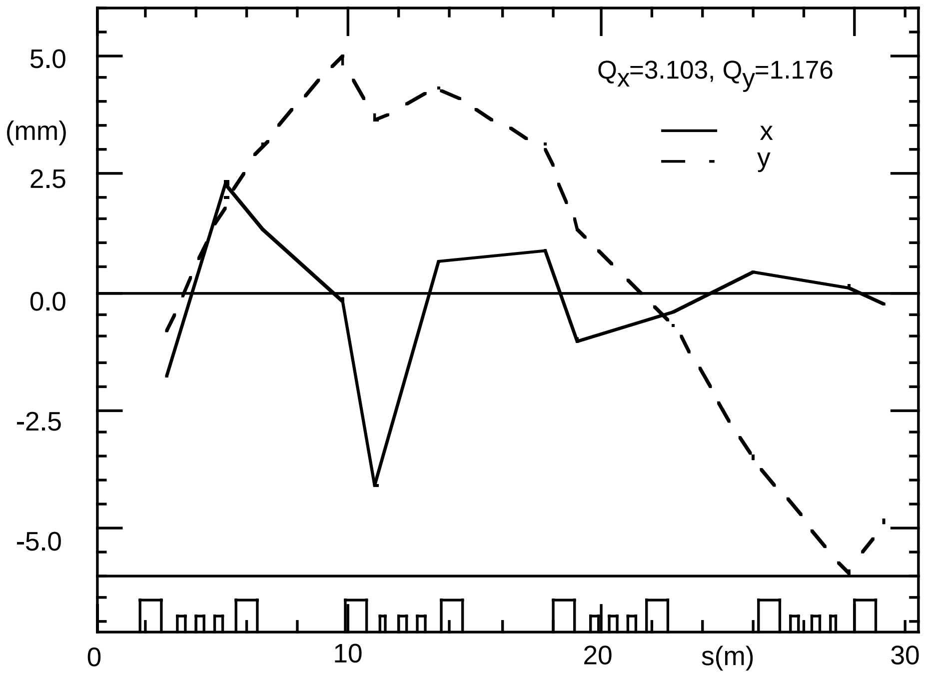

Fig. 1 - Measured closed orbit , before correction (reforb), in both planes.

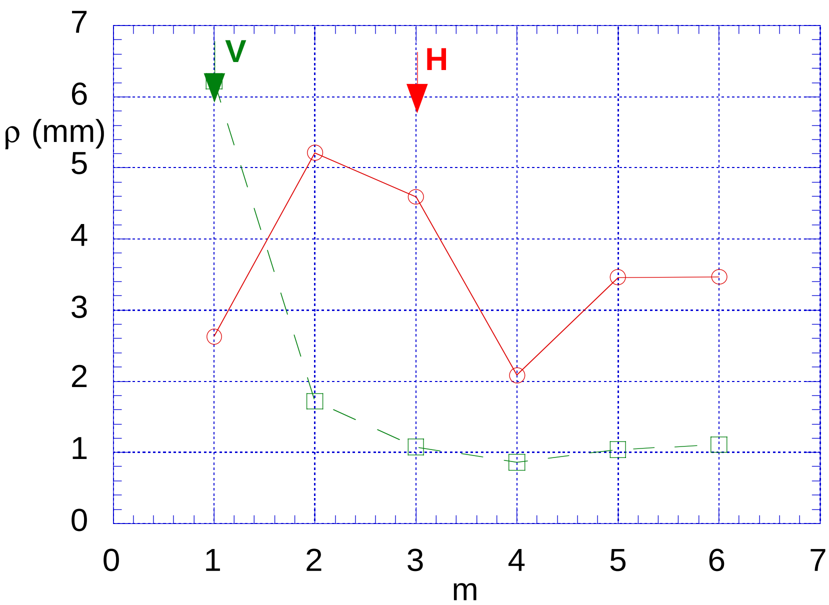

Fig. 2 - Fourier spectrum of 'reforb' in both planes.

After the displacement of the quadrupoles (December shifts) the orbit has been measured, in each plane, for two different values of the tune: the plots of the two orbits are shown in Figs. 3 and 4 for the x and y plane respectively and the parameters are listed in Table II.

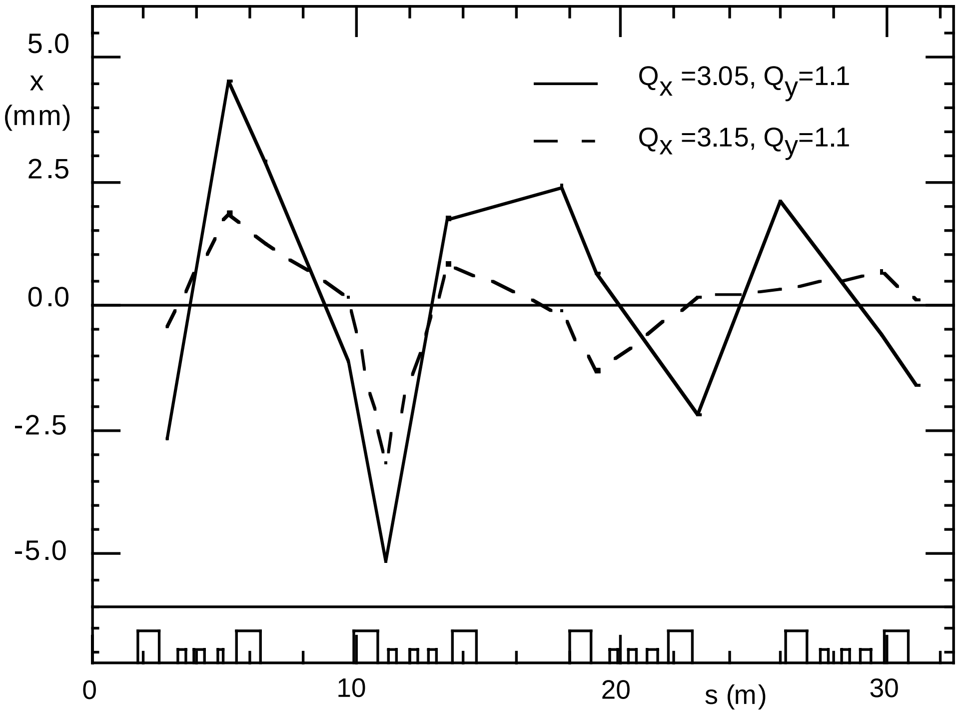

Fig. 3 - Horizontal closed orbit at two different tunes
(after quadrupole displacement, correctors off)

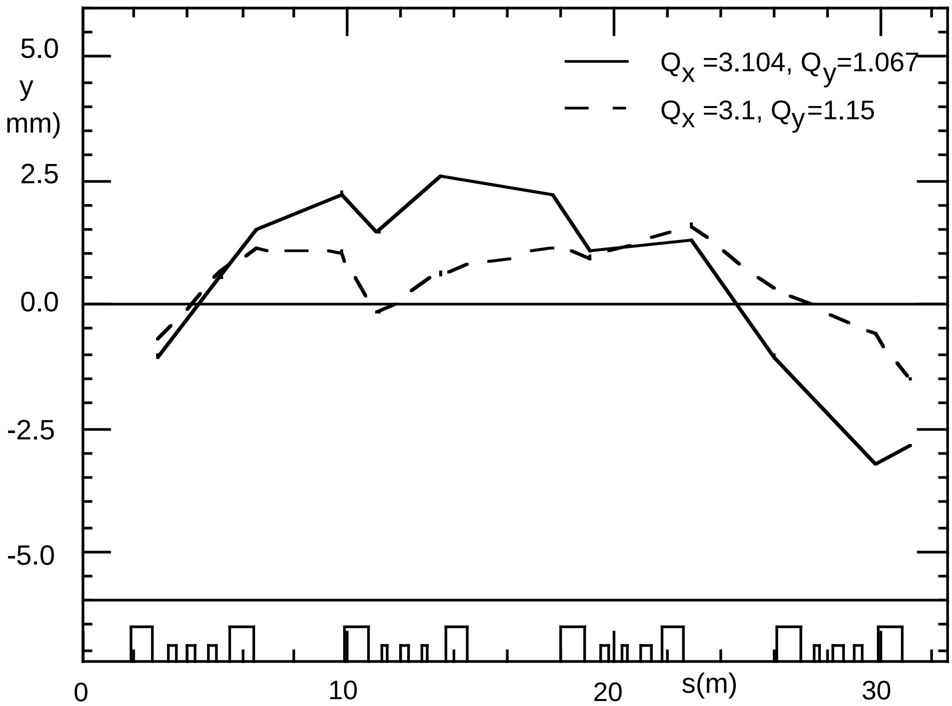

Fig. 4 - Vertical closed orbit at two different tunes
(after quadrupole displacement, correctors off).

Table II - Orbits at different tunes after quadrupole displacement

File name	orb3.15a	orb3.15a	orb1.15a	orb1.05a
Date	22/12/96	22/12/96	22/12/96	22/12/96
Correctors	off	off	off	off
Energy (GeV)	.511	.511	.511	.511
RF frequency (MHz)	368.369 *	368.369 *	368.369 *	368.390 *
Q_x	3.15	3.05	3.10	3.104
Q_y	1.1	1.1	1.15	1.067
H/V	H	H	V	V
x_{rms} (mm)	1.29	2.70	1.01	2.02
x_{max} (mm)	-3.14	-5.41	1.57	-3.25

The difference between the closed orbit at two tunes (smaller than 3 mm in both planes, see Figs. 3, 4) shows that the closed orbit can be reduced by a further correction.

We have used the harmonic correction method to calculate the corrector strengths for the two orbits at the tune value nearest to the integer (Q_x = 3.05, Q_y = 1.067), which is the most sensitive to the alignment errors.

To eliminate the monitor errors we cut the Fourier spectrum of the orbit and correct only the harmonic nearest to the tune value (m=3 for the horizontal, m=1 for the vertical). All the correctors are used in both planes; the strengths, listed in Table III, are very small.

Table III - Correctors strengths saved as 'ORBITA CORRETTA'

Name	δ_x (mrad)	I_x (A)	δ_y (mrad)	I_y (A)
CHVA1001	-.062	-.328	.023	.121
CHVA1002	-.015	-.002	-.009	.011
CHVA2001	.048	.251	-.044	-.229
CHVA3001	-.050	-.264	-.055	-.286
CHVA3002	.062	.328	-.023	-.119
CHVA4001	-.006	.019	.021	.017
CHVA4002	-.047	-.249	.044	.229
CHVA4003	.038	.198	.061	.323
δrms	.049		.042	

During January shifts, the value of the RF frequency corresponding to the central orbit has been determined:

$$f_0=368.375 \text{ MHz}$$

and all the following orbits have been measured at this frequency.

After correction we have measured again the orbits at two tunes (Figs. 5,6 and Table IV). As shown in the figures they are nearly coincident. This means that the closed orbit due to alignment errors has been corrected and the residual shown in Figs. 5 and 6 is the offset of the beam position monitors.

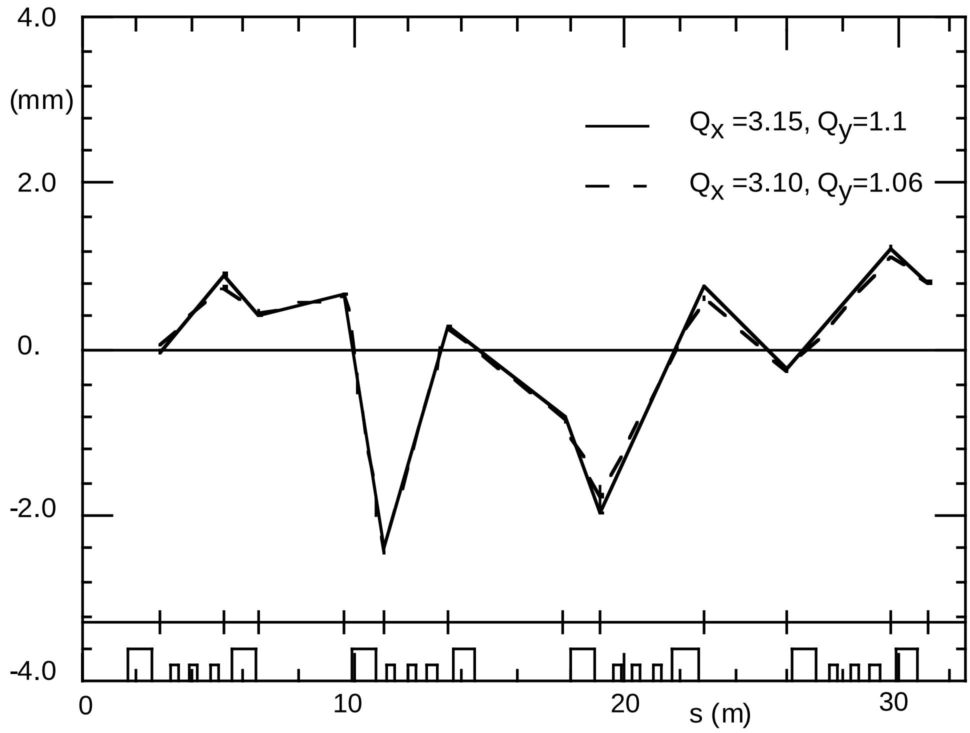

Fig. 5 - Horizontal closed orbit at different tunes after correction

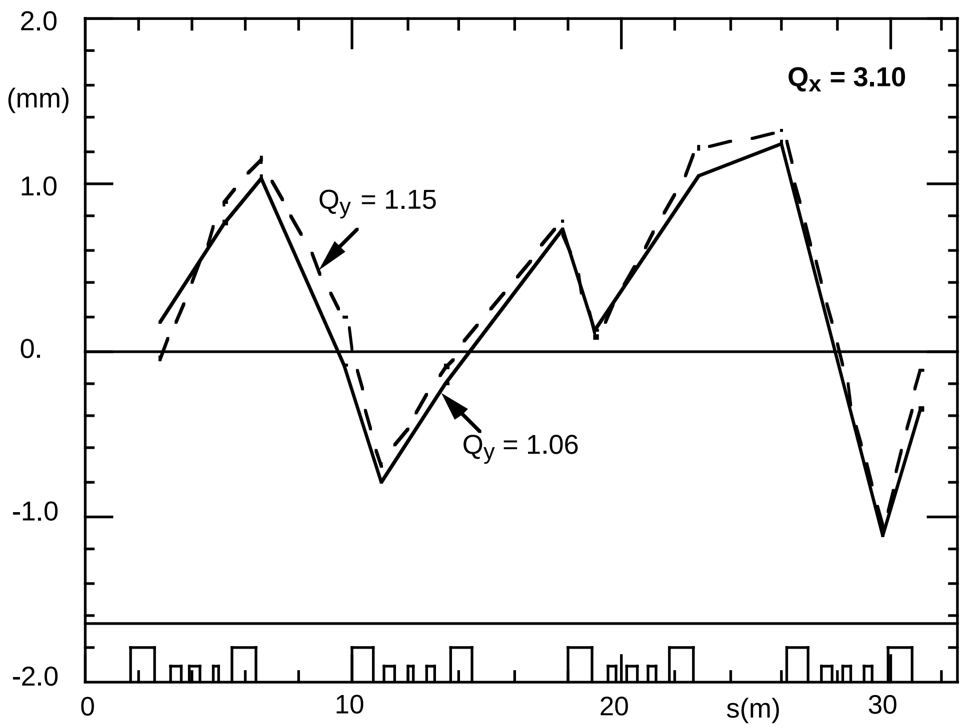

Fig. 6 - Vertical closed orbit at different tunes after correction.

Table IV - Orbits at different tunes after correction

File name	ACH12	ACH10	ACH10	ACH11
Date	30/01/97	30/01/97	30/01/97	30/01/97
Correctors	on	on	on	on
Energy (GeV)	.511	.511	.511	.511
RF frequency (MHz)	368.375 *	368.375 *	368.375 *	368.375 *
Q_x	3.15	3.104	3.104	3.104
Q_y	1.1	1.067	1.067	1.15
H/V	H	H	V	V
x_{rms} (mm)	1.15	1.10	.79	.83
x_{max} (mm)	-2.38	-2.45	1.25	1.31

The Fourier spectrum, in both planes, of one of these orbits (ACH10 - Q_x = 3.1, Q_y = 1.06) is shown in Fig. 7.

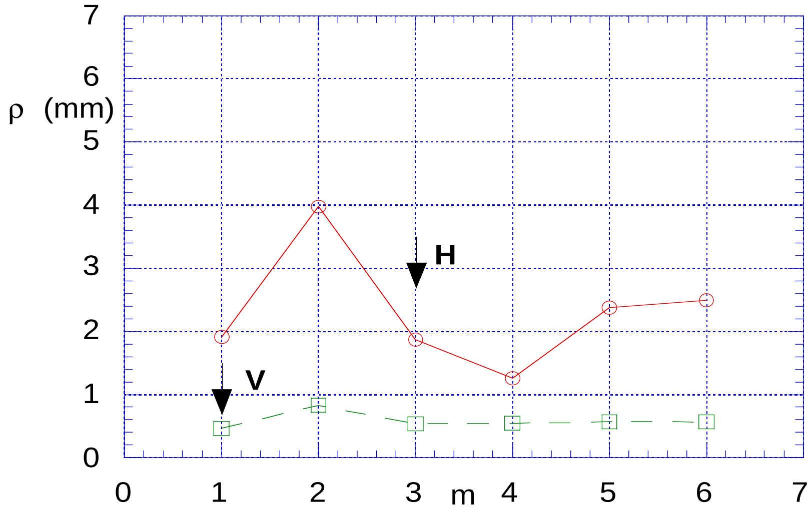

Fig. 7 - Fourier spectrum of the closed orbit after correction in both planes (H,V)

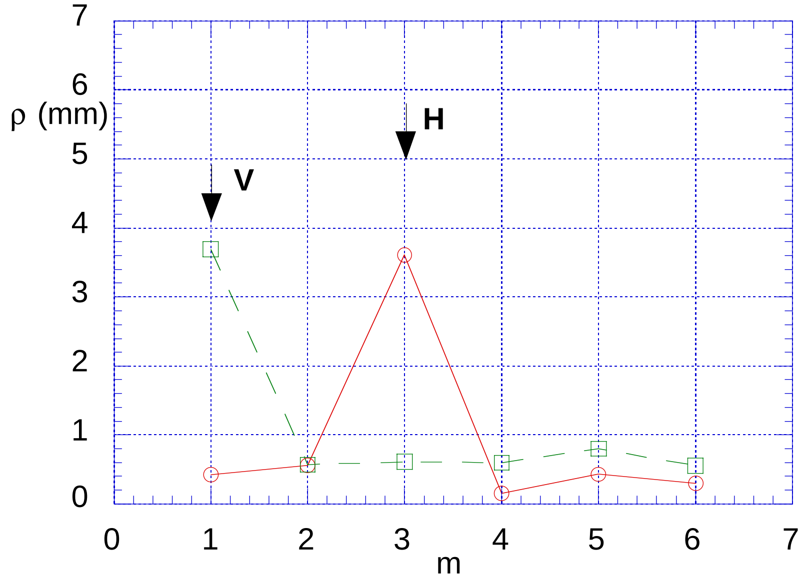

Fig. 8 - Fourier spectrum of a measured orbit after subtraction of the monitor offsets.

This spectrum is essentially due to the offset of the beam position monitors: the harmonic nearest to the tune value is of the same order of the others. The offset is quite larger in the horizontal plane than in the vertical one, in particular the 5th and 8th monitors (BPSA2001, BPBA3001) show an offset of 2 mm.

For comparison we have subtracted the orbit due to monitors offset (ACH10) from the one before correction (orb3.05a) and then calculated the Fourier spectrum (see Fig. 8), which has a sharp peak for m = 3 in the horizontal plane and m=1 in the vertical, as expected.

4. Measurement of the dispersion function

The dispersion function has been measured at all the monitors by measuring the closed orbit at three different frequencies: the central one f_0 and the central one plus or minus Δf:

$$f_0 = 368.375 \text{ MHz}$$
$$\Delta f = .050 \text{ MHz.}$$

The three orbits are shown in Fig. 9 and the set of the magnetic elements is given in Table V. Fig. 10 shows the dispersion function calculated from the machine model [3] (solid line) and that obtained by the difference between the orbits at $\pm\Delta f$ and the one at f_0.

Table V - Set of the magnetic elements for the dispersion measurement

File names: ACH12, ACH13, ACH14 - Date 30/01/97					
		I (A)			I (A)
Dipole		594.05	Quadrupole:	QF1	250.3
Sextupole	SF	182.5		QD	269.6
	SD	149.6		QF2	248.4

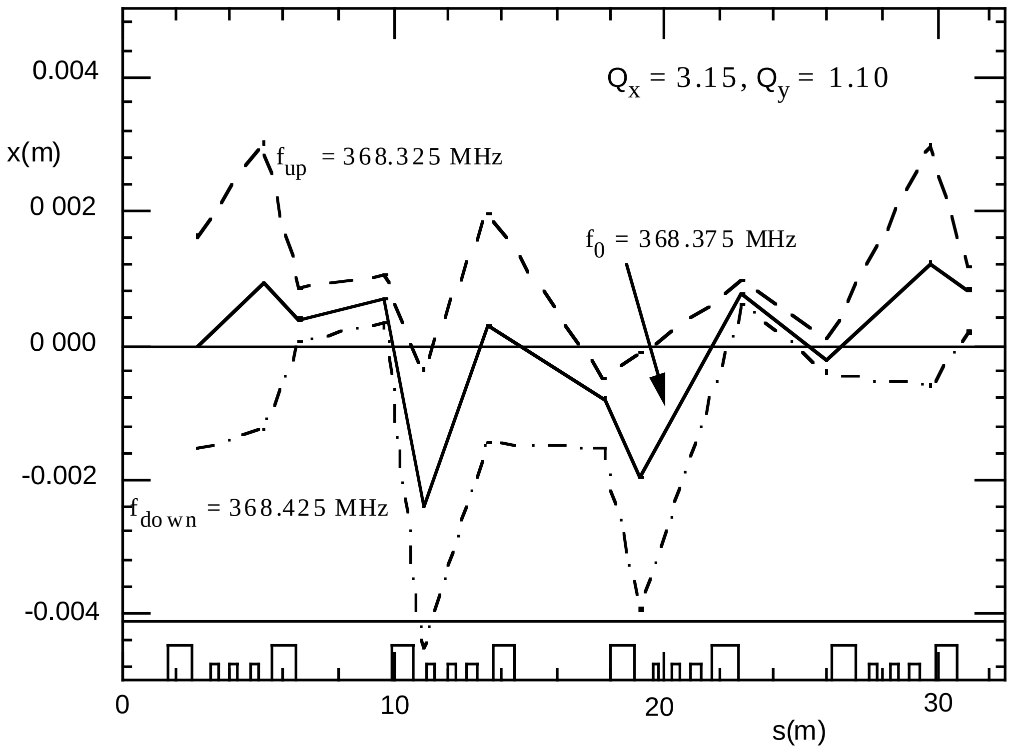

Fig. 9 - Orbits measured at different RF frequencies.

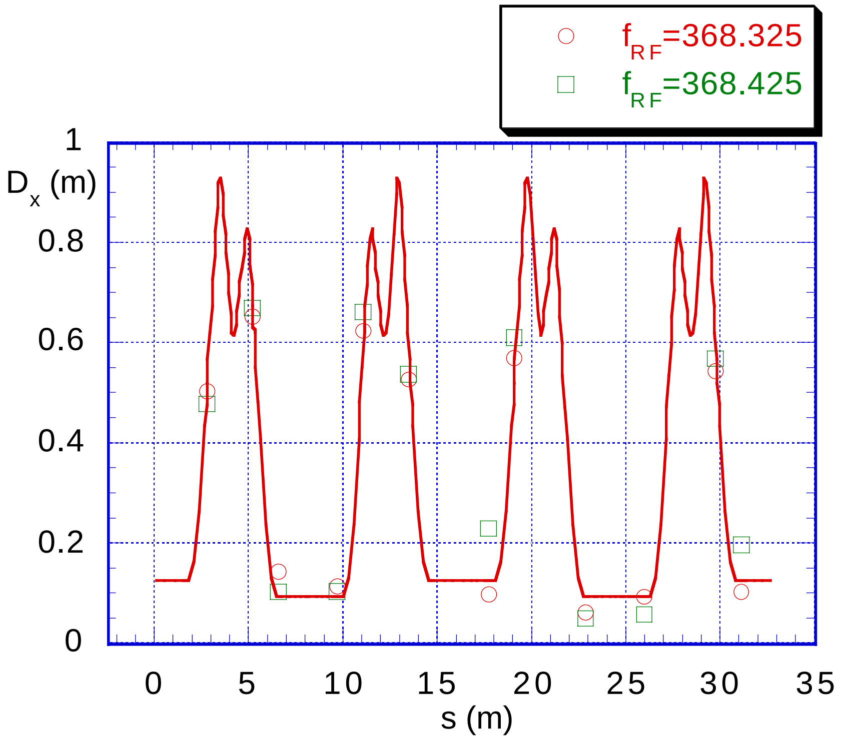

Fig. 10 - Dispersion function calculated (solid line) and measured (dots).

References

[1] M. Bassetti, S. Guiducci: "Harmonic closed orbit correction with the Lagrange multipliers method", in progress.

[2] G. Di Pirro, C. Milardi: "GETORBIT - Orbit acquisition program for the Control System", to be published.

[3] M.E. Biagini, M. Preger: "Accumulator modelling" DAΦNE Technical Note L-25 (1997).

APPENDIX

Program description

The program is based on the following steps:

a) Reading of the orbit measurements at the H beam position monitors .
In both transverse planes, the measured orbit is read from a file produced by the control system which contains the azimuth positions, the x and y values, at the beam position monitors.

b) Calculation of the *2M* coefficients a_m, b_m of the Fourier expansion of the closed orbit with *M* harmonics.
The *2M* coefficients of the orbit Fourier transformation are found by minimizing, at each monitor, the difference between the measured orbit and that one reproduced by retaining M harmonics and not an infinite number in the Fourier expansion.

c) Orbit reconstruction by means of the Fourier expansion using the *2M* coefficients previously found.

d) Calculation of the minimum corrector intensities which reproduce the *2M* Fourier coefficients of the measured orbit expansion.

In order to reproduce with the correctors the *M* harmonics of the measured orbit, the coefficients of the harmonic expansion of the corrector orbit are calculated.

The correction is obtained by minimizing the correctors strengths by means of the Lagrange multipliers method with the constraint of obtaining the same Fourier coefficients of the *M* harmonics for the measured and the correctors orbit.

For the Fourier expansion of the measured closed orbit and of the correctors one the $\beta_{x,y}$ and the betatron phase advance, $\nu_{x,y}$, at the monitors and correctors are required as shown in equation (1). Those input data are read from two files produced running NOLISY with the appropriate Accumulator model file.

The printout of the angles and currents of the correctors (the calibration of the DAΦNE Accumulator correctors is included in this version of the program) is shown in the output together with the orbit produced by the correctors and its difference with respect to the measured one.

A top-draw file with the plot of the measured and of the corrected orbit (i.e. the difference between the measured orbit and the orbit produced by the correctors) is produced.

As an option it is also possible to make a plot of the orbit produced by corrector strengths read by an external file.

Another option is the possibility to make the plot of the correctors orbit (either for the calculated strengths , either for those read by a file) in all the elements of the ring. In this case a NOLISY type file with the parameters of the elements is needed as input.