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ORBIT CORRECTION ANALYSIS FOR DAΦNE LATTICE

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INTRODUCTION

In this note we will discuss the effects of magnetic field imperfections and alignment errors in the DAΦNE main ring[1] on the closed orbit and on some parameters of crucial importance for our machine, like β at interaction point, dispersion and coupling coefficient. We will also look for a corrector configuration capable of reducing the effects of the errors. Furthermore we want to understand if it will be necessary or not a pick-up system capable of reading single turn signals.

Before going into the description of the performed analysis, let us spend some words about the start-up of the machine. Because the machine is small, at the beginning it is unnecessary to correct chromaticity (and so no sextupoles are introduced) if we operate with a low current value, under the "head-tail" instability limit. So, first of all, after the reading of the closed orbit amplitude, it is possible to perform a first disalignment correction, which leaves a residual distortion in any case. In this situation we can turn on the sextupoles, and we can operate the machine with an higher current value. At this point, one has to find out a new correction scheme in order to minimize the residual closed orbit amplitude and the corrector strength.

This working philosophy naturally brings to divide the error analysis into two parts: the first one is dedicated to the study of the sensitivity of the lattice, without sextupoles, to imperfections and to control if after the injection the beam remains inside the physical aperture of the machine; the second one, with the complete lattice, is dedicated to the research of an efficient corrector scheme.

The program MAD[2] has been used to simulate and correct orbit distortions. Misalignments due to displacements along the transverse coordinates ($\Delta x, \Delta y$)and to rotation in the horizontal (bending) plane ($\Delta\Theta$) and field errors ($\Delta B/B$) have been assigned to all the optical elements according to gaussian distributions of errors. For each set of given errors 10 different machines have been simulated by changing the error distribution. All the monitors and the correctors, distributed along the lattice, have zero length and are positioned on one side of the magnetic elements.

For each simulation, the program finds the closed orbit and produces a table of the orbit readings at the monitor positions. Starting from this table, the correction is, then, computed by using "the n most efficient correctors" method, which introduces in the scheme a corrector at a time, choosing at each step the one that gives the smallest residual distortion at monitor positions[3]. Some studies are currently under way in order to implement an harmonic correction method[4].

LATTICE SENSIVITY TO IMPERFECTIONS

In the first part, errors have been assigned to all the magnetic elements except to the wigglers, which will be analyzed separately in another note. The sextupoles are not included, as mentioned before.

The monitor arrangements have been chosen according to the high beta locations and to the phase advance between the elements (see Figs.1a,b and 2a,b). In our case we put three or four of them per betatron wavelength plus some more in critical regions: in the low-β and near the separators in order to record the angle and the position of the outcoming beams.

The monitor distribution (M01), used in this first part of the investigation and shown in Fig. 3, includes 36 elements (28 Horizontal and Ver-tical, plus 4V, plus 4H). Starting from a magnetic structure with a typical set of errors included (see Table I)[5], the effect of increasing each kind of error has been analyzed separately. The maximum and the rms values of the orbit distortions obtained by averaging over the 10 machines are reported in Table I and shown in Fig. 4.

TABLE I

Starting rms errors:	$\Delta x = \Delta y = .1$ mm $\Delta\Theta = .5$ mrad - $\Delta B/B = 5. \times 10^{-4}$ M01:28HV, 4V,4H			
variable err.	Xrms (mm)	Xmax (mm)	Yrms (mm)	Ymax (mm)
$\Delta y=\Delta x = .1$ mm $\Delta y=\Delta x = .2$ mm $\Delta y=\Delta x = .4$ mm	8.098±3.418 9.867±4.283 15.45±8.178	17.77±6.491 21.66±7.744 33.74±16.45	5.671±3.568 11.42±7.169 23.28±14.57	14.97±8.927 30.06±17.88 61.11±36.08
$\Delta\Theta = .5$ mrad $\Delta\Theta = 1.$ mrad $\Delta\Theta = 2.$ mrad	8.098±3.418 8.469±4.747 10.799±7.02	17.77±6.491 18.47±9.139 22.87±13.79	5.671±3.568 5.687±3.579 5.735±3.611	14.97±8.927 15.035±8.96 15.19±9.053
$\Delta B/B= 5\ (\times 10^{-4})$ $\Delta B/B= 8\ (\times 10^{-4})$ $\Delta B/B=10\ (\times 10^{-4})$	8.098±3.418 12.533±5.05 15.07±6.476	17.77±6.491 26.503±.9.62 32.46±12.09	5.671±3.568 5.682±3.64 5.699±3.698	14.97±8.927 14.976±9.13 15.002±9.73

From the Table I, one can see that the particle orbit remains within the physical aperture of the accelerator (± 4 cm), even in the case of $\Delta x = \Delta y = .2$ mm; for the case $\Delta x = \Delta y = .4$ mm the maximum vertical displacement is too high(6.1 cm). The higher value in the V plane reflects the fact that the β-functions are larger in this plane respect to the horizontal one.The results show that it is not necessary to correct the orbit on a single turn basis and therefore the pick-up system can be designed to read the signal of the accumulated beam. Anyway few pick-ups, capable of reading the single turn signal, are required at the injection.

The results of the TableI show that magnetic element displacements give big contributions to closed orbit distortions in both transverse planes. For these planes we have calculated the so called *amplification factor* P,[6] taking into account only quadrupole displacements:

$$\mathbf{P_x} = \frac{\langle x_{co} \rangle}{\Delta x} = 19.55 \quad ; \qquad \mathbf{P_y} = \frac{\langle y_{co} \rangle}{\Delta y} = 46.62$$

where $\langle x_{co} \rangle$ is the rms of the expectation value of the amplitude closed orbit distortion given by

$$\langle x_{co} \rangle = \frac{\sqrt{\beta_x}\ \Delta x}{2\sqrt{2}\sin \pi Q_x} \left[\Sigma_i K_i^2 l_i^2 \beta_i \right]^{1/2}$$

for a displacement Δx; an equivalent relation holds for the other plane. The higher contribution to P_y comes from the strong low-β quadrupoles and from the high β_y value in that region. The P_x, P_y reported are calculated using for β_x, β_y the mean values coming from the whole lattice. Comparing the closed orbit values obtained from these parameters with the results of Table I, one can see that in the vertical plane the bigger contribution to the residual orbit comes from the magnet displacements, meanwhile in the horizontal plane also the field error, due expecially to the bending magnets, gives a great contribution.

In order to have an idea of the required corrector strength (αX, αY) a correction scheme (C01) for the "starting" set of errors has been carried out over10 machines. The Fig. 3 shows the corrector arrangement (32 H and 21V), chosen with the same criteria as monitors, meanwhile in Table II some optical parameters, before and after correction, are reported together with the unperturbed values. The correction done shows that the rms value of c.o. is easily reduced of a factor 100 in x and a factor 80 in y and the corrector strength (αXmax, αYmax) is under 1.2 mrad.

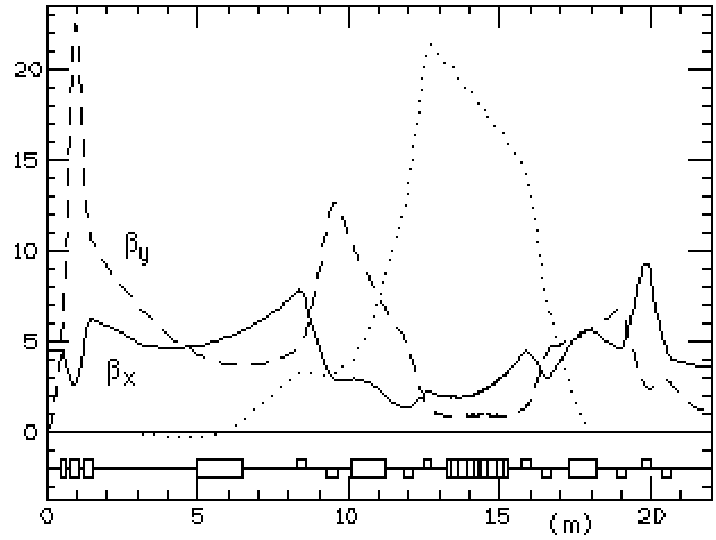
The obtained data show that the orbit distortions can be eliminated and that it is reasonable to make the correction by just moving the single magnetic elements.

TABLE II

before correction		after correction **(C01)**
Xrms (mm)	8.098±3.418	.093±.019
Xmax (mm)	17.775±6.491	.543±.135
Yrms (mm)	5.671±3.568	.073±.026
Ymax (mm)	14.972±8.927	.386±.141
αXrms (mrad)	0.	.379±.069
αXmax (mrad)	0.	1.156±.343
αYrms (mrad)	0.	.149±.048
αYmax (mrad)	0.	.463±.223

a)

half short machine



b)

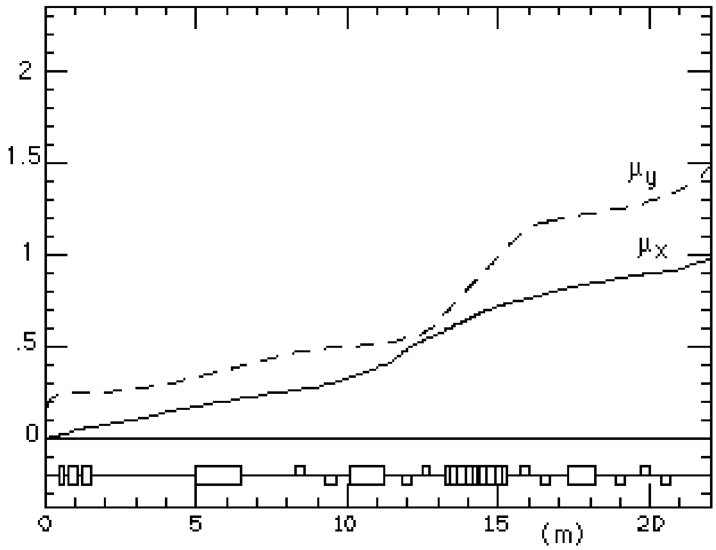
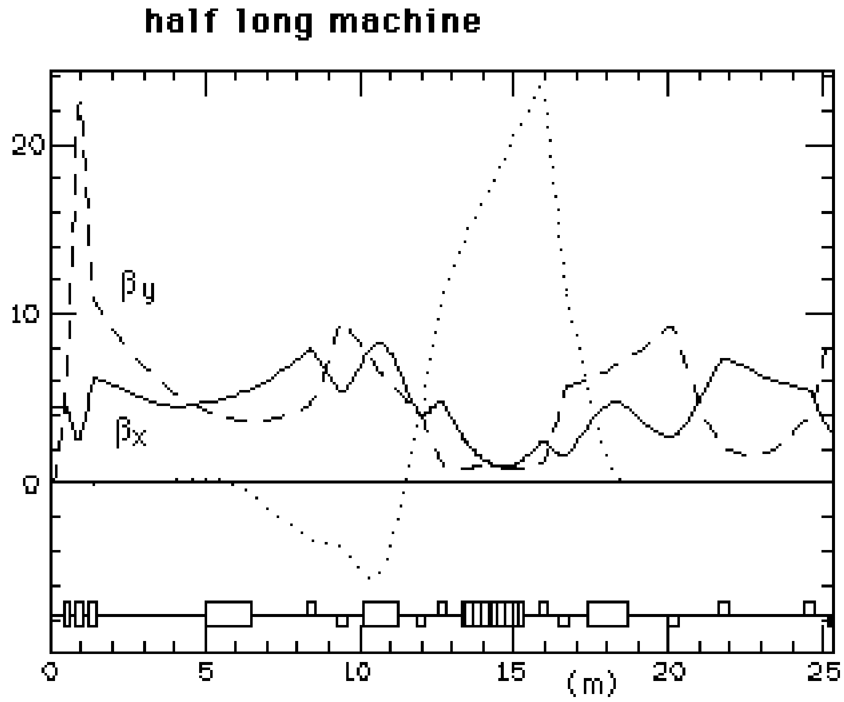


Fig. 1 - Half short machine.

a)



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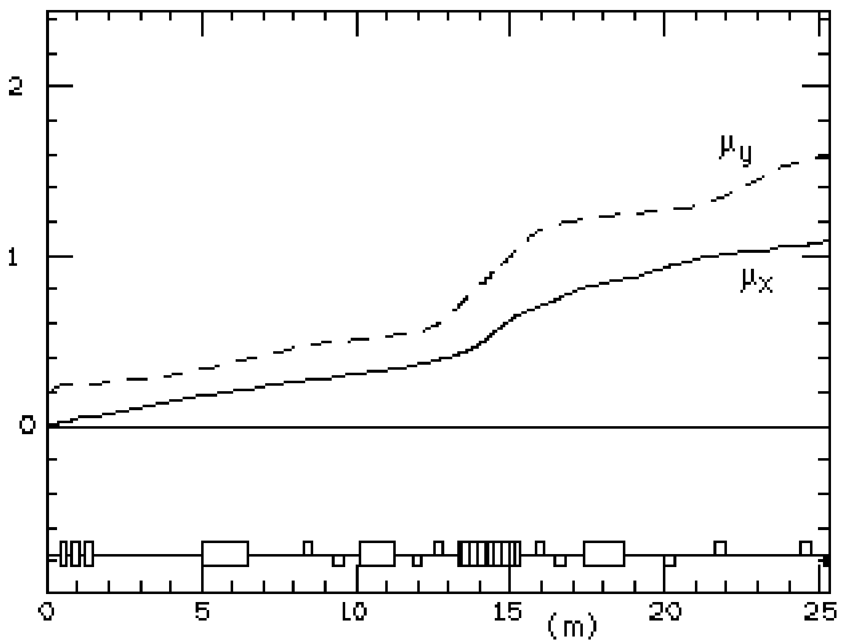


Fig. 2 - Half long machine.

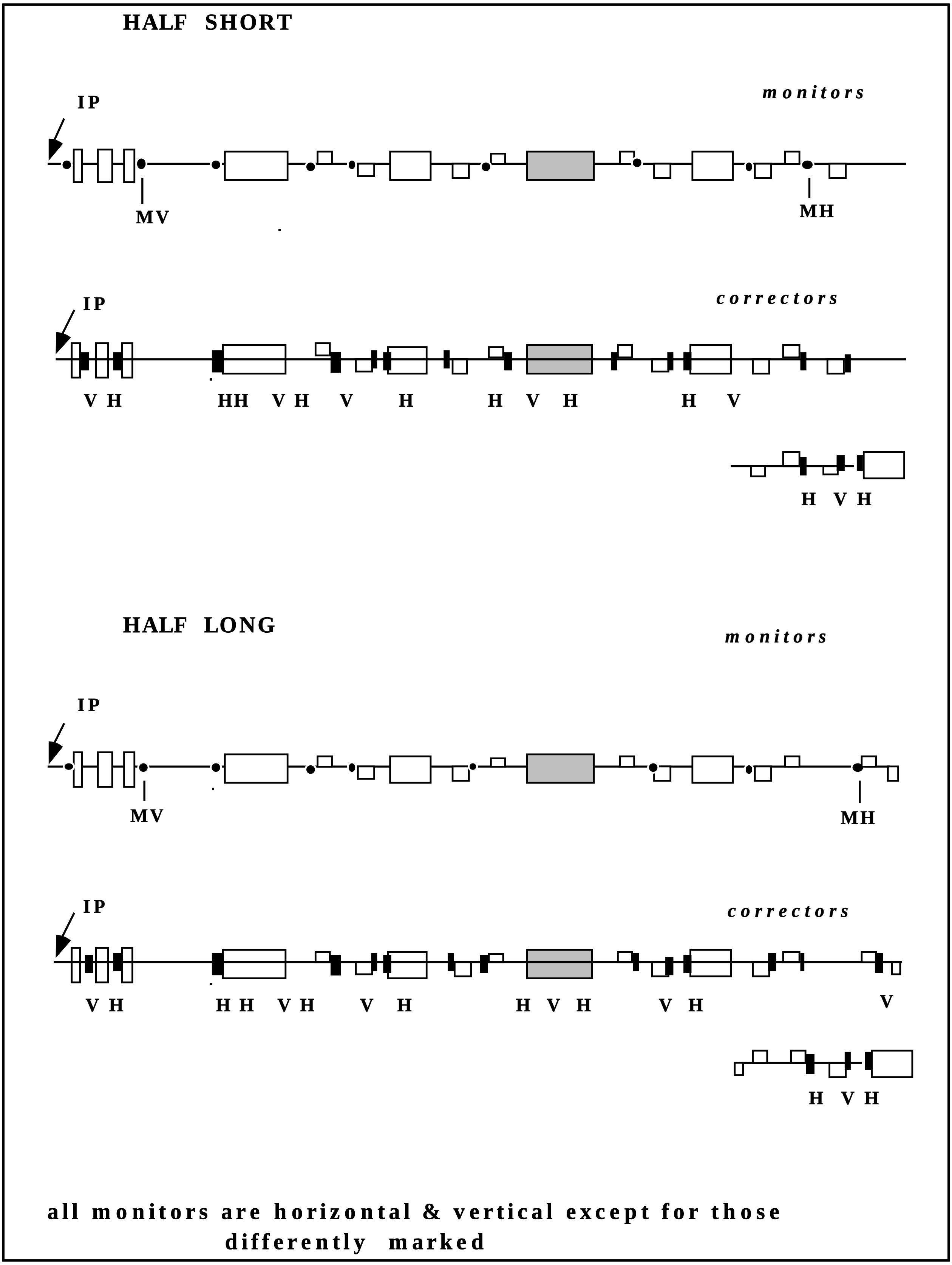


Fig. 3 - Monitor arrangement M01/28HV, 4V, 4H
Correctors C01/32H, 21V.

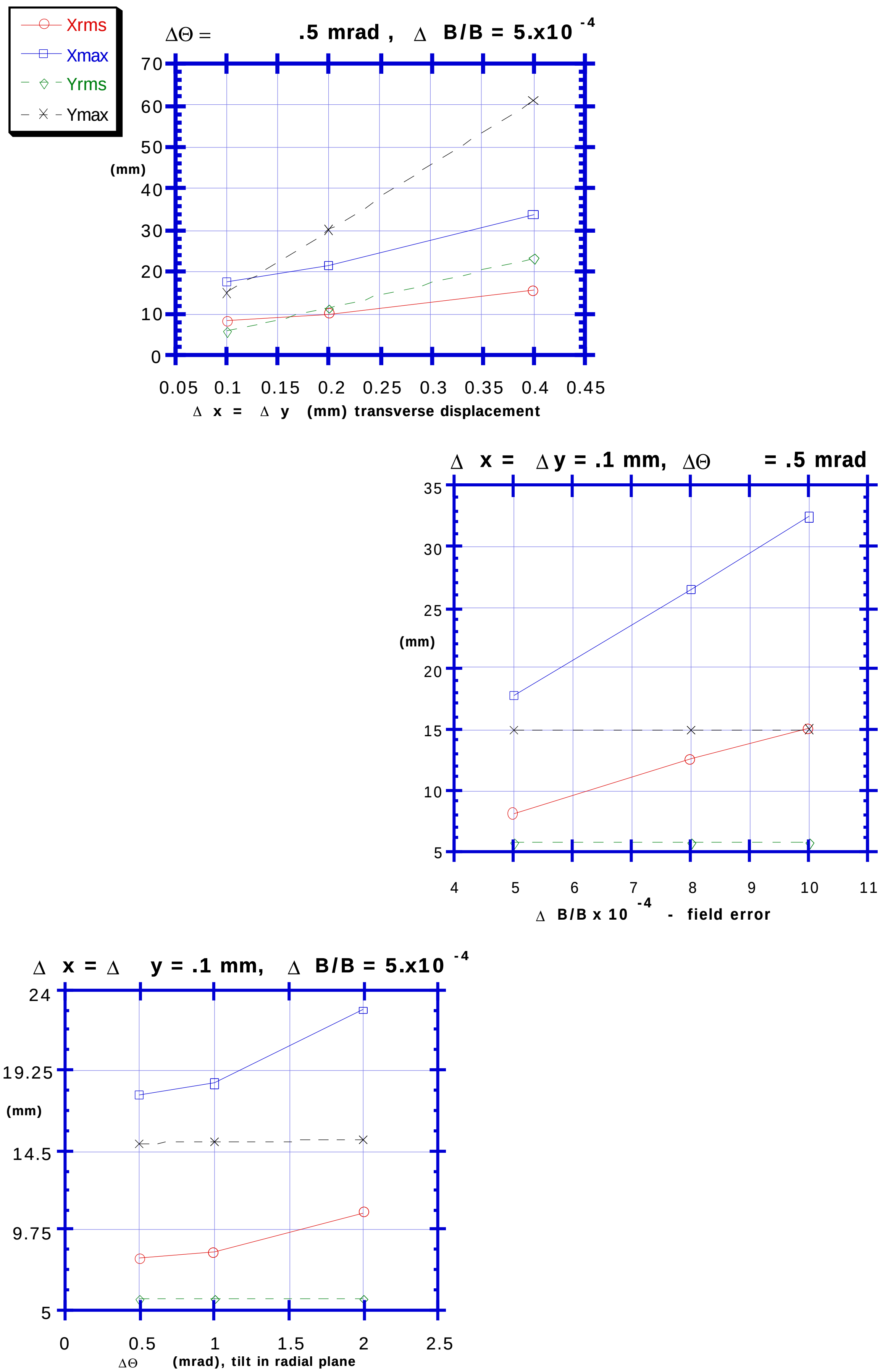


Fig. 4 - Orbit distortion before correction as function of the 3 kinds of error.

COMPLETE LATTICE - Corrector and Monitor configurations analysis.

After this "magnet adjusting" it is then possible to turn the sextupoles on, and to carry out a new study with smaller errors comparable to the residual displacement, which comes from the previous correction. No errors in the low-β quadrupoles are considered, because the correction of this region, with the smaller residual errors, will be separately and carefully studied taking into account the narrow space existing between optical elements for correctors and for monitors and the presence of the two beams inside the same quadrupoles.

In order to find an efficient corrector scheme, different monitor and corrector configurations have been studied. Fig. 5 shows an arrangement of monitors (M02) and correctors (C01) located at each quadrupole; the former elements are used for readings in both transverse planes, the latter act only in one plane (monitors: 45HV, correctors: 32H, 21V). Correctors are also put near each bending magnet to control the bend angle. In Table III the results for two different set of errors are reported together with the unperturbed values. The error sets used are:

1)	$\Delta x = \Delta y = .1$ mm $\Delta\Theta = .175$ mrad $\Delta B/B = 5\times10^{-4}$	2)	$\Delta x = \Delta y = .2$ mm $\Delta\Theta = .25$ mrad $\Delta B/B = 8\times10^{-4}$

From now on the first set of errors will be called standard[7], because it is the ensemble of minimum values permitted. With the second set of errors 10 machines over 20 are unstable.

TABLE III

M02:45 HV, **C01**: 32 H, 21 V	initial data (no errors)	$\Delta x=\Delta y=.1$mm, $\Delta\Theta=.175$ mrad $\Delta B/B=5\times10^{-4}$	$\Delta x=\Delta y=.2$mm, $\Delta\Theta=.25$ mrad $\Delta B/B=8\times10^{-4}$
Xrms (mm)	0	.054±.013	.100±.032
Xmax (mm)	0	.3487±.1123	.594±.132
Yrms (mm)	0	.023±.004	.045±.010
Ymax (mm)	0	.094±.016	.162±.041
DXrms (m)	0.9809	.981±.002	.981±.006
DXmax (m)	2.339	2.347±.008	2.351±.017
DYrms (m)	0	.016±.009	.026±.019
DYmax (m)	0	.039±.019	.064±.042
αXrms (mrad)		.309±.068	.499±.104
αXmax (mrad)		.916±.303	1.514±.409
αYrms (mrad)		.072±.013	.1354±.027
αYmax (mrad)		.174±.034	.332±.0801
Qx	4.1202	4.121±.001	4.121±.003
Qy	6.102	6.102±.003	6.101±.006
β_X (m)@ IP	4.5	4.51±.029	4.514±.041
β_Y (m)@ IP	0.045	.0454±.0009	.0454±.0013

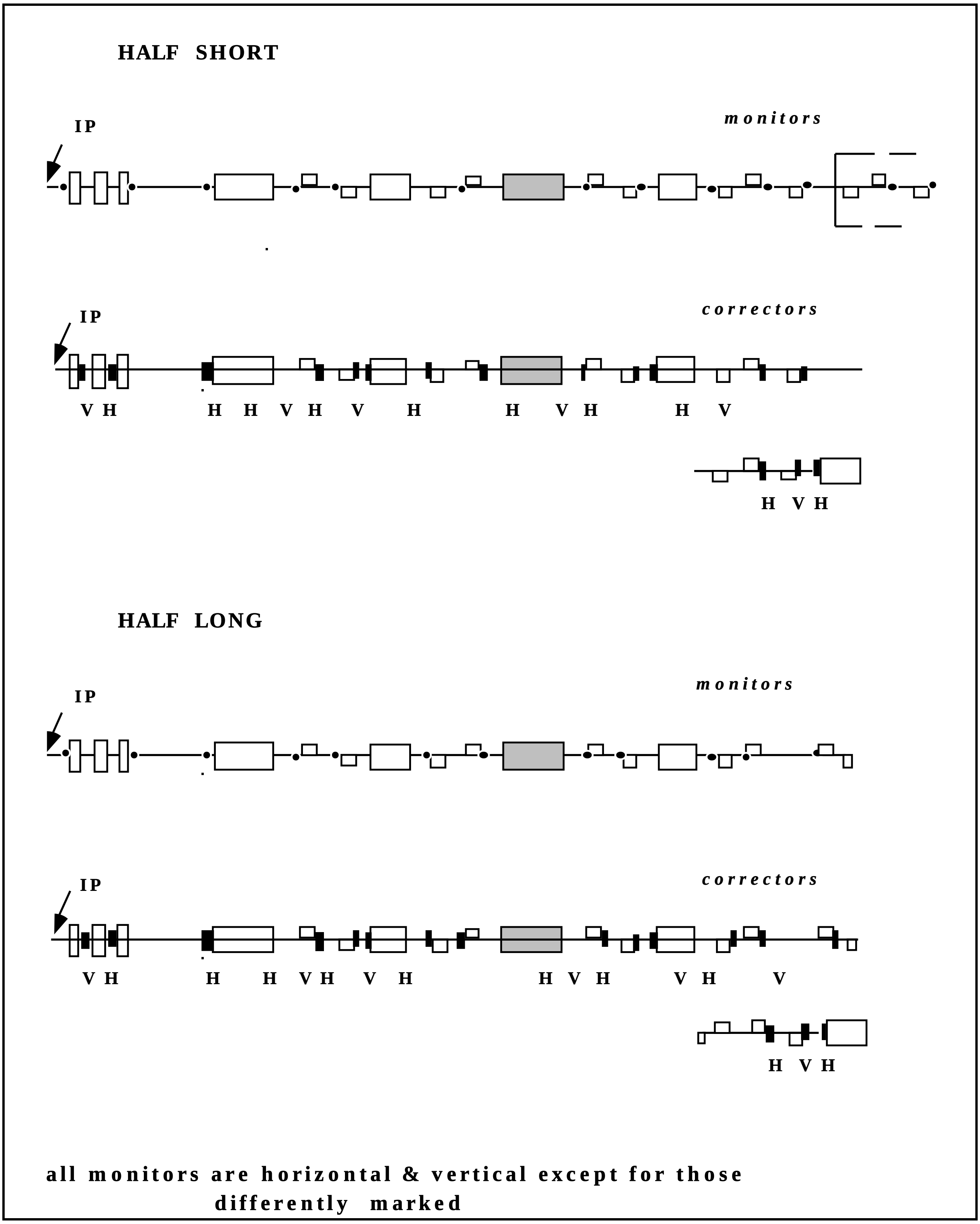


Fig. 5 - Monitor arrangement M02/45HV
Correctors C01/32H, 21V.

A second correction scheme has been carried out changing the monitor arrangement (M03) but leaving unchanged the correctors one (see Fig. 6). In this case the number of monitors is reduced by putting one of them for each couple of quadrupoles in the regions where the β functions are separated (28HV, 4V, 4H). The results of this correction, averaged over 10 machines, are reported in Table IV for the standard set of errors.
The values are still good for the vertical plane, but in the horizontal the residual *Xmax* is too high with a big error (4.05±4.19 mm).

TABLE IV

M03: 28HV,4V,4H - C01: 32H, 21V $\Delta x=\Delta y=.1$ mm, $\Delta\Theta=.175$ mrad, $\Delta B/B=5.\times10^{-4}$ after correction	
Xrms (mm)	.5153±.5143
Xmax (mm)	4.052±4.188
Yrms (mm)	.1405±.0902
Ymax (mm)	.6546±.3643
DXrms (m)	.9775±.0097
DXmax (m)	2.3782±.0547
DYrms (m)	.0268±.0305
DYmax (m)	.066±.078
Qx	4.1216±.0068
Qy	6.0985±.0119
β_X (m)	4.5977±.1873
β_Y (m)	.0426±.0058

The successive studies, performed on different monitor configurations and for one machine each time, have put in evidence some crucial points:

- the central arc region is very critical especially in the horizontal, probably because of the higher β_x value and the high number of quads.
- the two monitors after the septum are necessary to control the beam in position and in angle.

This analysis brought to the monitor configuration (M04) shown in Fig. 7 (24HV, 8H, 4V). For this arrangement the correction has been looked for simulating different error sets. Table V shows the values of some optical parameters (mean values over 10 stable machines) for the following sets:

A	B	C
$\Delta x = \Delta y = .1$ mm	$\Delta x = \Delta y = .15$ mm	$\Delta x = \Delta y = .2$ mm
$\Delta\Theta = .175$ mrad	$\Delta\Theta = .2$ mrad	$\Delta\Theta = .25$ mrad
$\Delta B/B = 5\times10^{-4}$	$\Delta B/B = 7\times10^{-4}$	$\Delta B/B = 8\times10^{-4}$

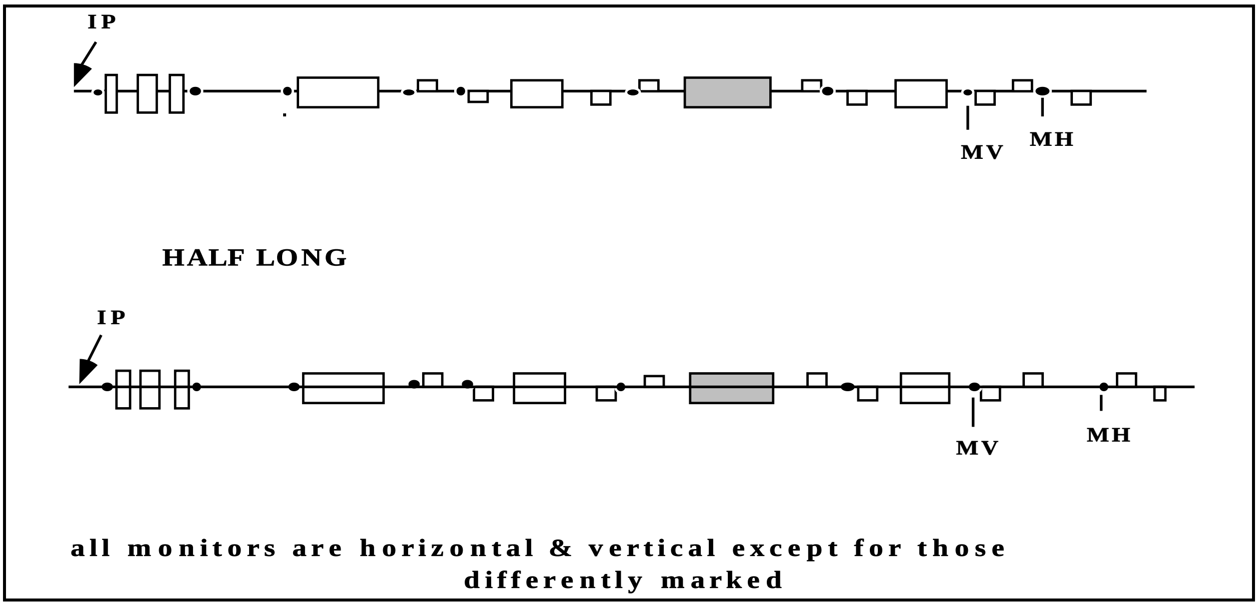


Fig. 6 - Monitor arrangement M03/28HV, 4V, 4H.

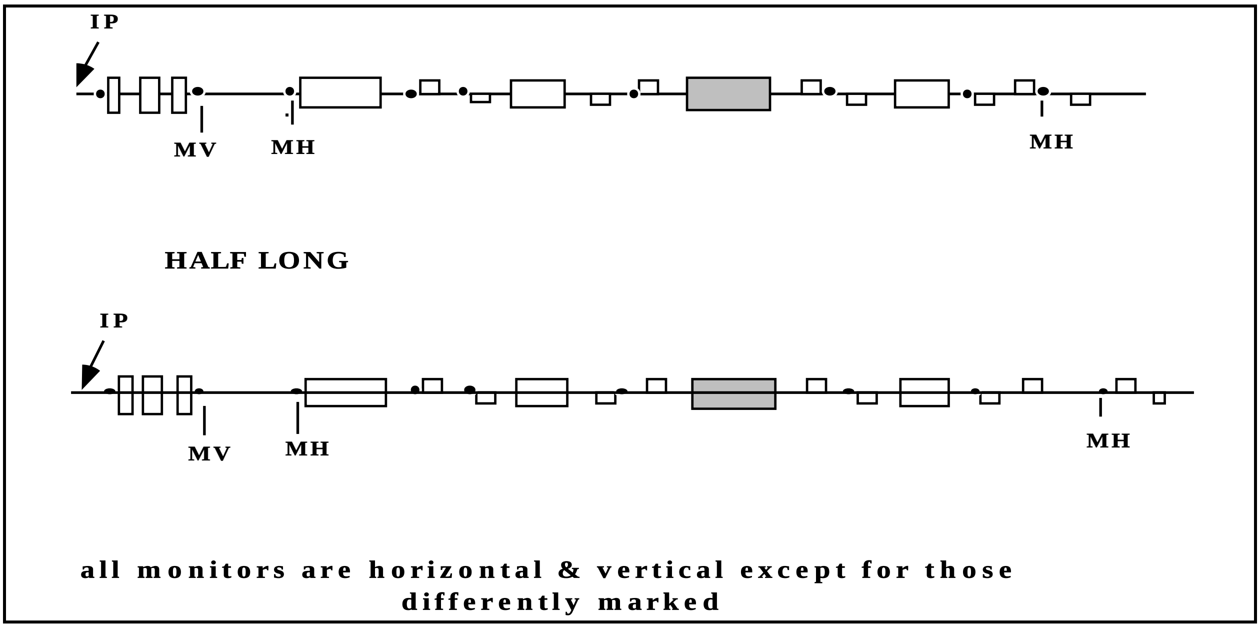


Fig. 7 - Monitor arrangement M04/24HV, 4V, 4H.

TABLE V

M04:24HV,8H,4V - **C01**:32H, 21V			
	$\Delta x=\Delta y=.1$mm, $\Delta\Theta=.175$ mrad, $\Delta B/B=5.x\ 10^{-4}$	$\Delta x=\Delta y=.15$mm, $\Delta\Theta=.2$ mrad, $\Delta B/B=7.x\ 10^{-4}$	$\Delta x=\Delta y=.2$mm, $\Delta\Theta=.25$ mrad, $\Delta B/B=8.x\ 10^{-4}$
Xrms (mm)	.072±.022	.104±.029	.139±.029
Xmax (mm)	.406±.151	.575±.211	.808±.275
Yrms (mm)	.097±.062	.208±.185	.183±.087
Ymax (mm)	.532±.346	1.141±1.041	1.008±.471
DXrms (m)	.973±.002	.973±.003	.978±.006
DXmax (m)	2.35±.009	2.348±.012	2.362±.019
DYrms (m)	.014±.006	.023±.009	.028±.018
DYmax (m)	.035±.015	.059±.024	.068±.040
α Xrms (mrad)	.341±.087	.480±.123	.599±.117
α Xmax (mrad)	1.02±.382	1.496±.516	1.987±.634
α Yrms (mrad)	.073±.013	.117±.029	.148±.028
α Ymax (mrad)	.170±.048	.312±.102	.395±.143
Qx	4.121±.001	4.121±.001	4.119±.002
Qy	6.102±.003	6.101±.004	6.104±.006
β_X(m)@ IP	4.510±.033	4.502±.050	4.507±.084
β_Y (m)@ IP	.0455±.0008	.0456±.0013	.0458±.0015

For case *A* one machine over 11 is unstable, for *B* four machines over 14 and finally for *C* twelve machines over 22.

In all the studied cases, the residual orbit distortion is less than .3 mm rms and 2 mm peak (better in H plane) and furthermore the corrector strength is less than 2 mrad (hardware specification limit). In Fig. 8 the residual orbit values (rms and maximum) for both planes are shown as function of increasing magnets displacement, values averaged over 10 machines. The residual orbit amplitudes are low for the three cases, but the number of unstable machines increases from 1 over 11 to 4 over 14.

It has to be noticed that the vertical residual values are always worse than the horizontal ones, showing the critical machine sensitivity in this plane. Furthermore the effect of monitor position errors has been studied. In Fig. 9 the residual rms and maximum orbit values are reported as a function of monitor errors for one chosen machine.

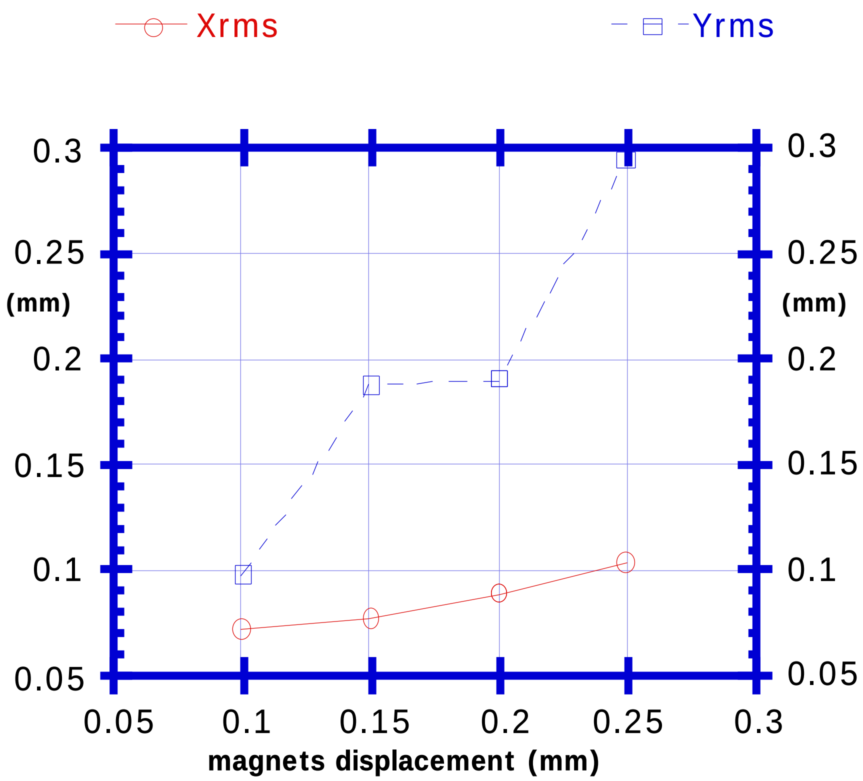
Tables VIa and VIb contain a complete list of optical parameters after correction relative to results of Figs. 8 and 9.

TABLE VI a

M04: 24HV,4V,8H - **C01:**32H, 21V **$\Delta\Theta$ =.175 mrad, $\Delta B/B=5.x10^{-4}$** average over 10 machines changing the magnets displacement			
	$\Delta x=\Delta y=.15$ mm	**$\Delta x=\Delta y=.2$ mm**	**$\Delta x=\Delta y=.25$ mm**
Xrms (mm)	.0766±.0220	.0892±.0253	.1038±.0277
Xmax (mm)	.4001±.1404	.4861±.1975	.5767±.2088
Yrms (mm)	.188±.1105	.1905±.1424	.2941±.2133
Ymax (mm)	1.0288±.6277	1.0435±.7878	1.617±1.1869
DXrms (m)	.9744±.0039	.9737±.0049	.9747±.0065
DXmax (m)	2.3527±.0131	2.3519±.0166	2.3546±.0204
DYrms (m)	.02751±.0144	.0361±.0182	.047±.023
DYmax (m)	.0642±.0308	.087±.039	.111±.0517
Qx	4.1207±.0017	4.1211±.0021	4.1212±.0025
Qy	6.1028±.0039	6.1014±.0046	6.1017±.0058
β_X (m)@ IP	4.5062±.0363	4.5009±.0478	4.5091±.0762
β_Y(m)@ IP	.0455±.0008	.0456±.0009	.0453±.0012

TABLE VI b

$\Delta x=\Delta y=.1$ mm, $\Delta\Theta$=.175 mrad, $\Delta B/B=5\ x10^{-4}$ correction for the same machine for different monitor errors						
monitor errors (mm)	**dx=.1 dy=.1**	**dx=.2 dy=.2**	**dx=.3 dy=.3**	**dx=.4 dy=.4**	**dx=.6 dy=.6**	**dx=.8 dy=.8**
Xrms (mm)	.184	.331	.484	.638	.949	1.260
Xmax (mm)	.841	1.161	1.479	2.026	3.151	4.272
Yrms (mm)	.153	.377	.386	.506	.881	.972
Ymax (mm)	.521	1.561	1.302	1.733	2.893	3.453
DXrms (m)	.982	.986	.991	.996	1.02	1.026
DXmax (m)	2.365	2.383	2.402	2.423	2.49	2.524
DYrms (m)	.0104	.0196	.036	.0499	.111	.109
DYmax (m)	.0244	.048	.086	.1204	.293	.269
α Xrms (mrad)	.433	.580	.763	.962	1.377	1.804
α Xmax (mrad)	1.530	1.755	1.979	2.243	3.619	4.995
α Yrms (mrad)	.1650	.302	.429	.568	.844	1.128
α Ymax (mrad)	.4266	.834	1.239	1.641	2.4402	3.231
Qx	4.117	4.115	4.114	4.112	4.1098	4.107
Qy	6.108	6.11	6.111	6.113	6.1173	6.1198
β_X (m)@ IP	4.638	4.682	4.725	4.771	4.862	4.974
β_Y (m)@ IP	.044	.044	.044	.044	.0435	.044



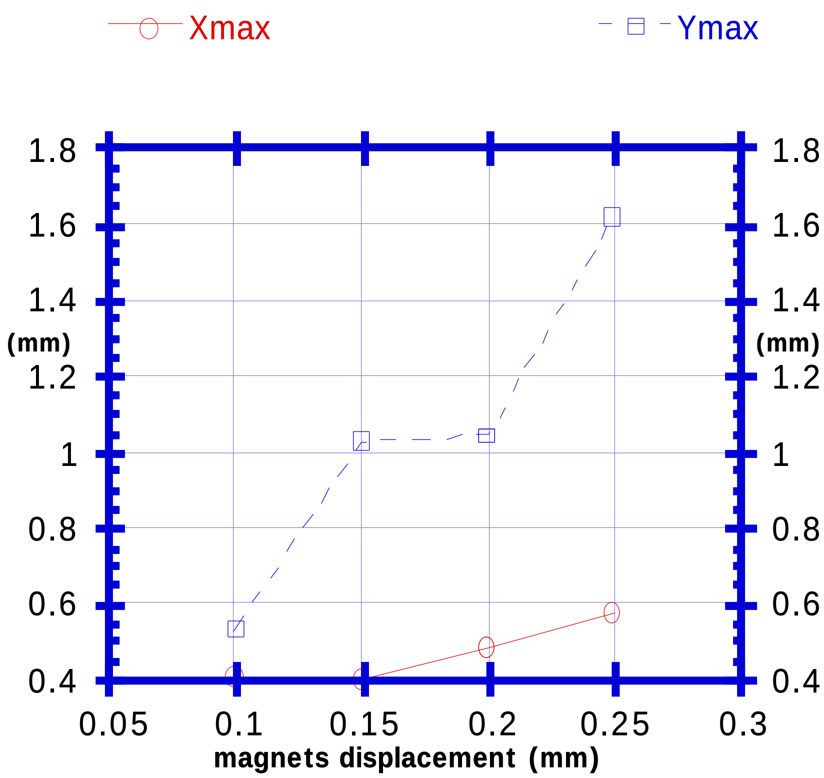


Fig. 8 - Residual closed orbit distortions as function of magnet displacement (rms and maximum values).

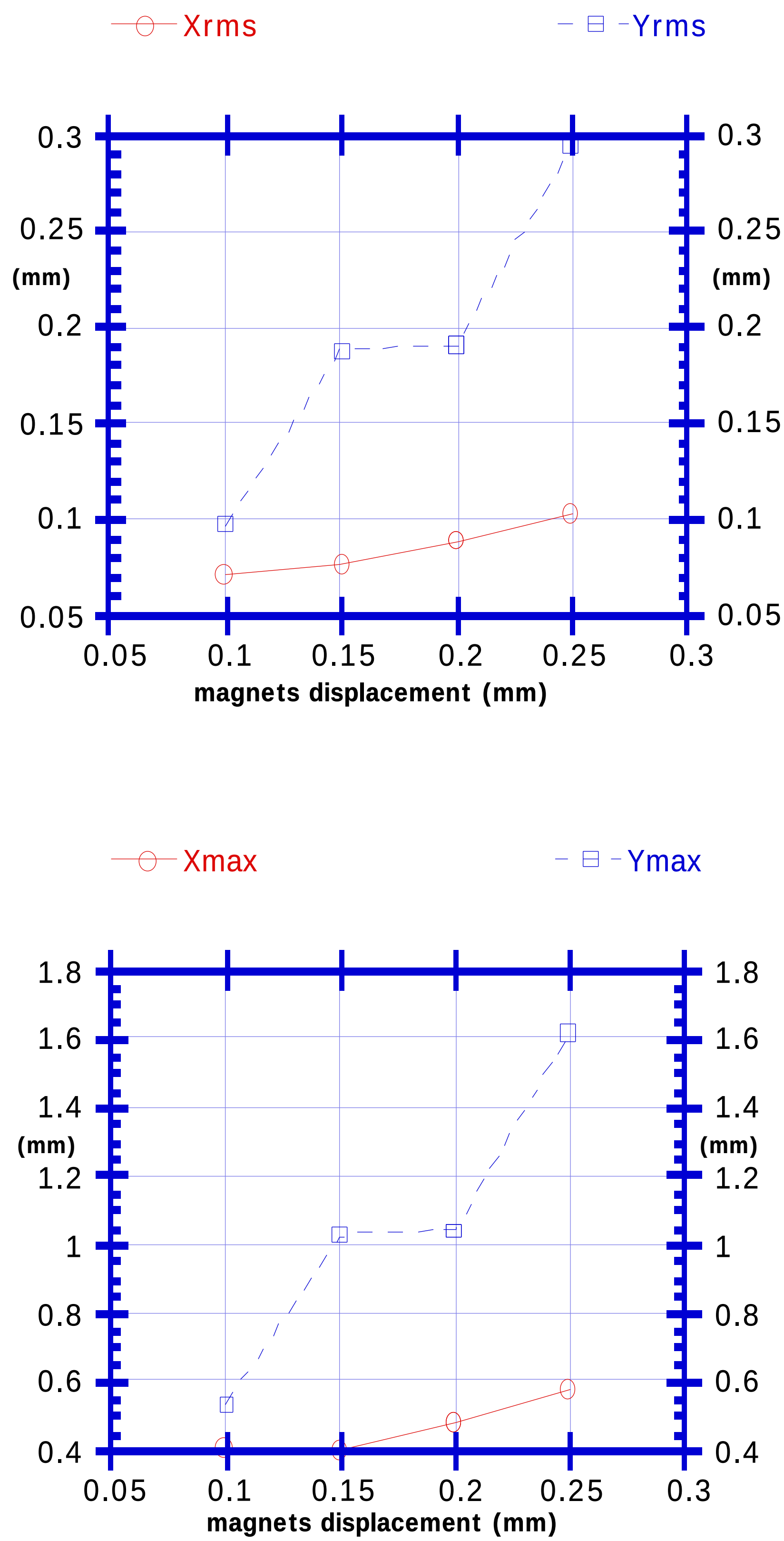


Fig. 9 - Residual closed orbit distortions as function of monitor displacement (rms and maximum values).

In the subsequent analysis we have eliminated the monitors and the correctors from the low-β region because, putting no errors in the local quads, the correction was redundant in this zone. Fig. 10 shows the new monitor (M05) and corrector (C02) used scheme (mon.: 20HV, 8H; corr.: 28H, 17V).

Using the standard error set, correction has been performed for 10 machines. Results are shown in Table VII together with the values before correction. It has to be noticed from table values that the contribution to the total vertical dispersion due to the low-beta region is negligible. Roughly doubling the three kinds of introduced errors, the correction can be still carried on with a residual distortion of 1.3 mm peak value and reasonable corrector strengths. Table VIII contains these data and those obtained increasing only the magnet displacements ($\Delta x=\Delta y=.25$ mm).

TABLE VII

$\Delta x=\Delta y=.1$ mm, $\Delta\Theta=.175$ mrad, $\Delta B/B=5\times10^{-4}$ **M05**: 20HV,8H - **C02**:28H,17V	**initial data**	**before correction**	**after correction**
Xrms (mm)	0	7.349 ± 2.394	.074±.022
Xmax (mm)	0	15.757 ±4.551	.406±.150
Yrms (mm)	0	1.368 ± .622	.133±.157
Ymax (mm)	0	3.682 ± 1.701	.687±.867
DXrms (m)	0.9809	1.138 ± .129	1.000±.003
DXmax (m)	2.339	2.649 ± .272	2.348±.009
DYrms (m)	0	.141 ± .075	.015±.007
DYmax (m)	0	.376 ± .179	.037±.015
α Xrms (mrad)			.364±.093
α Xmax (mrad)			1.023±.381
α Yrms (mrad)			.088±.021
α Ymax (mrad)			.196±.0782
Qx	4.1202	4.130 ± .015	4.121±.001
Qy	6.102	6.118 ± .031	6.102±.003
β_X (m)@ IP	4.5	4.617 ± .927	4.510±.034
β_Y (m)@ IP	0.045	.0567 ± .0114	.0455±.0008
DXrms (m)@ IP	0		-.0045±.012
DYrms (m)@ IP	0		.0001±.0016

For the standard errors set, Fig. 11 shows the plot of the closed orbit distortions (rms and maximum values) at monitor locations along the whole lattice in both planes before and after correction.

The histograms of Figs.12a,b are the distributions of the rms orbit distortions, in x and y, before and after correction evaluated for10 machines.

Also for this arrangement the effect of monitor displacement has been studied. In Table IX the optical parameter values, after correction, are listed for different errors from .1 mm to .4 mm compared with the case without monitor errors (average over 5 machines).

TABLE VIII

M05:20HV,8H - **C02**:28H, 17V			
	$\Delta x=\Delta y=.1$mm, $\Delta\Theta=.175$ mrad, $\Delta B/B=5.x\ 10^{-4}$	$\Delta x=\Delta y=.2$mm, $\Delta\Theta=.25$ mrad, $\Delta B/B=8.x\ 10^{-4}$	$\Delta x=\Delta y=.25$mm, $\Delta\Theta=.175$ mrad, $\Delta B/B=5.x\ 10^{-4}$
Xrms (mm)	.074±.022	.143±.030	.106±.028
Xmax (mm)	.406±.150	.808±.276	.579±.208
Yrms (mm)	.133±.157	.233±.135	.260±.137
Ymax (mm)	.687±.867	1.208±.751	1.361±.744
DXrms (m)	1.000±.003	1.005±.007	1.001±.007
DXmax (m)	2.348±.009	2.362±.019	2.354±.021
DYrms (m)	.015±.007	.029±.017	.044±.024
DYmax (m)	.037±.015	.073±.039	.108±.056
α Xrms (mrad)	.364±.093	.640±.125	.430±.101
α Xmax (mrad)	1.023±.381	1.987±.636	1.182±.470
α Yrms (mrad)	.088±.021	.172±.029	.21637±.037
α Ymax (mrad)	.196±.078	.429±.130	.522±.145
Qx	4.121±.001	4.119±.002	4.121±.003
Qy	6.102±.003	6.104±.006	6.102±.006
β_X (m)@ IP	4.510±.034	4.508±.084	4.511±.075
β_Y (m)@ IP	.0455±.0008	.0458±.0015	.0453±.0012

TABLE IX

M05: 20HV,8H - **C02**:28H,17V $\Delta x=\Delta y=.1$ mm, $\Delta\Theta=.175$ mrad, $\Delta B/B=5\ x10^{-4}$ correction for the same machine for different monitor errors **monitor errors (mm)**					
	no monitor errors	**dx=.1 dy=.1**	**dx=.2 dy=.2**	**dx=.3 dy=.3**	**dx=.4 dy=.4**
Xrms (mm)	.074±.022	0.165±.025	.304±.049	.444±.072	.588±.096
Xmax (mm)	.406±.150	.700±.186	1.376±.417	2.054±.647	2.73±.874
Yrms (mm)	.133±.157	.237±.134	.376±.095	.515±.056	.669±.069
Ymax (mm)	.687±.867	1.039±.765	1.607±.434	2.027±.421	2.643±.553
DXrms (m)	1.000±.003	1.002±.007	1.003±.268	1.004±.016	1.006±.021
DXmax (m)	2.348±.009	2.356±.017	2.363±.024	2.372±.034	2.382±.044
DYrms (m)	.015±.007	.040±.019	.074±.036	.110±.059	.154±.089
DYmax (m)	.037±.015	.106±.051	.196±.089	.292±.145	.402±.221
α Xrms (mrad)	.364±.093	.430±.058	.572±.103	.723±.143	.899±.199
α Xmax (mrad)	1.023±.381	1.166±.284	1.449±.313	1.893±.470	2.399±.673
α Yrms (mrad)	.088±.021	.148±.028	.243±.048	.335±.073	.434±.103
α Ymax (mrad)	.196±.078	.333±.053	.568±.112	.784±.172	1.020±.246
Qx	4.121±.001	4.120±.002	4.121±.003	4.121±.004	4.122±.006
Qy	6.102±.003	6.102±.007	6.102±.011	6.101±.015	6.100±.019
β_X (m)@IP	4.510±.033	4.522±.929	4.522±.137	4.520±.179	4.518±.221
β_Y (m)@ IP	.0455±.0008	.0446±.0011	.0446±.0011	.0444±.0011	.0444±.0015

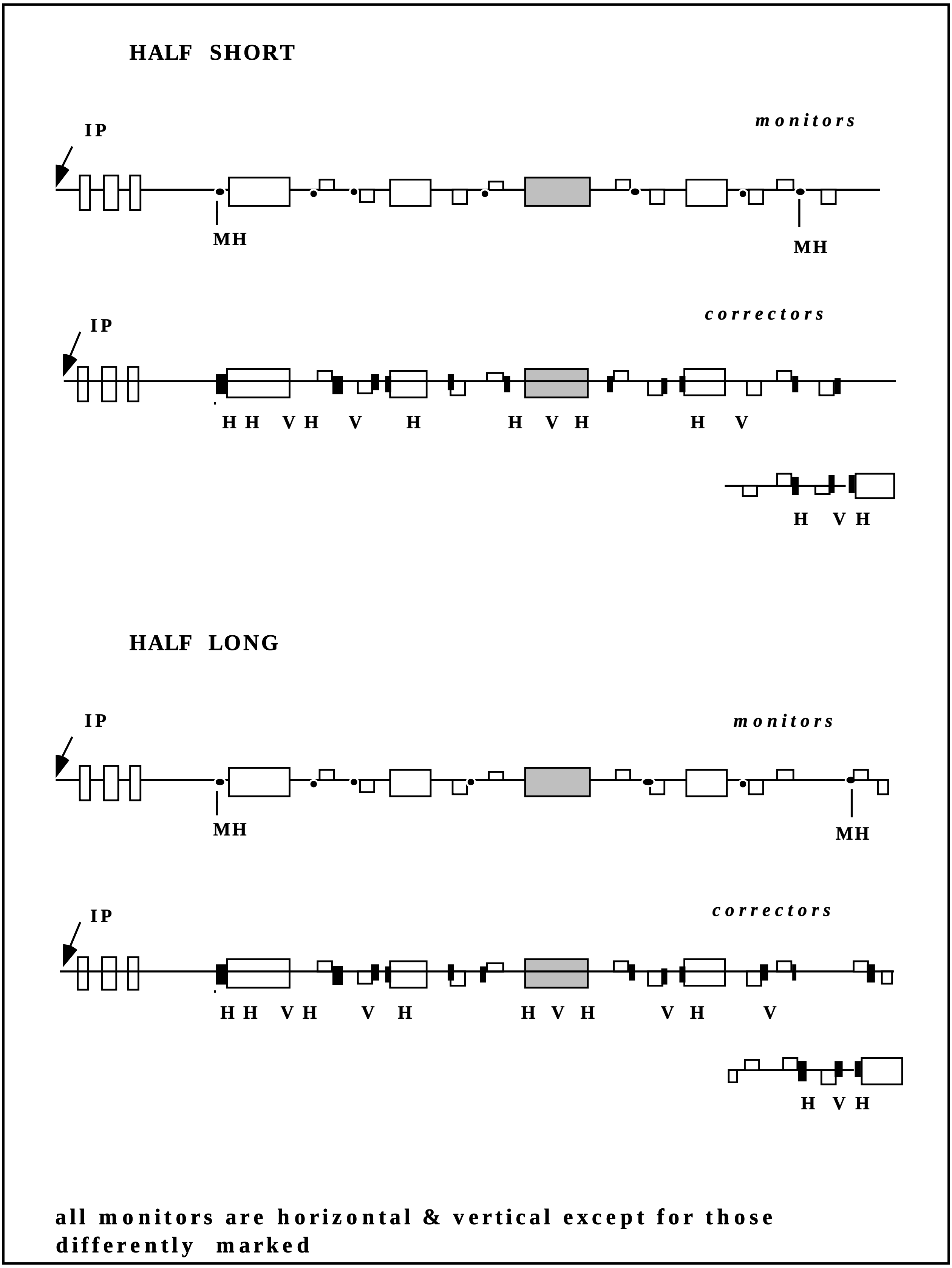


Fig. 10 - Monitor arrangement M05/20HV, 8H
Correctors C02/28H, 17V.

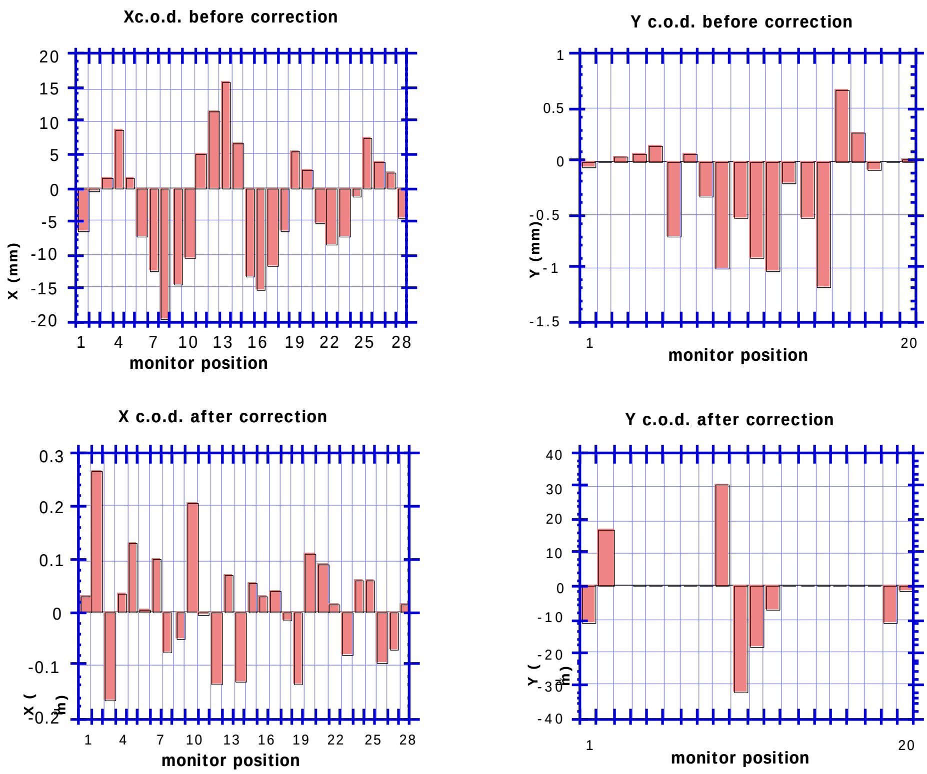
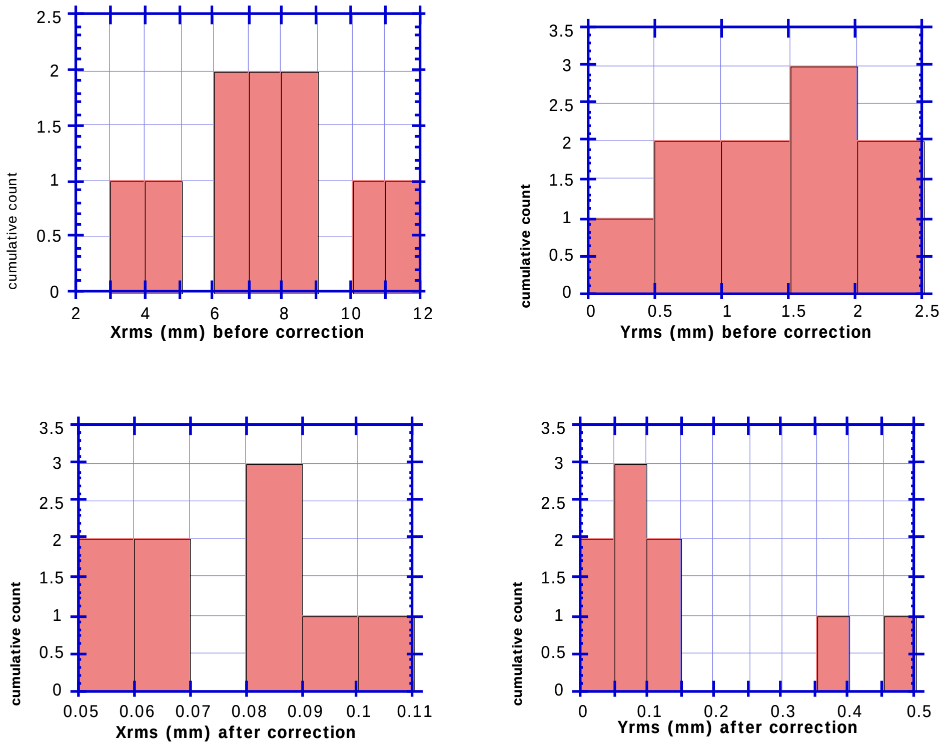


Fig. 11- Closed orbit distortions before and after correction at monitor locations along the whole machine.



(a) **(b)**

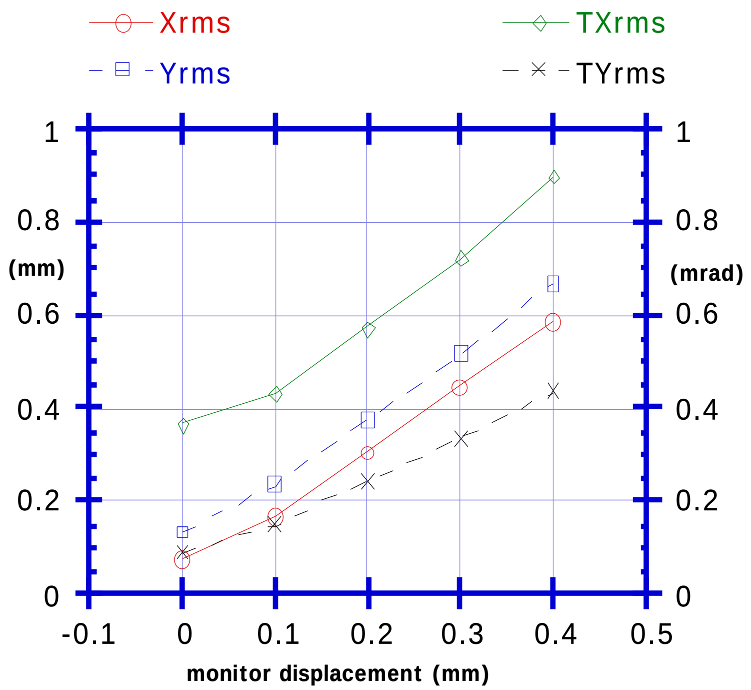
Fig. 12 - Histograms of the rms values of the closed orbit distortion before and after correction, calculated for 10 machines, in both transverse plane.

Figs.13 a,b show rms and peak residual displacements and corrector strength as function of this error. From the obtained values one can see that, even with large monitor errors (.4 mm), the particles are well inside the beam-pipe and that, by increasing the monitor displacement, the behaviour in horizontal plane becomes worse than in the vertical and stronger correctors are required. Moreover the presence of these errors has a bigger influence on the residual distortion peak values than on the rms results.

Finally in Fig. 14 a different corrector scheme (C03) is shown (24H, 17V), meanwhile the results of the correction carried on are listed in Table X in comparison with the previous case performed with the same errors set and the same 10 machines. The Table shows that reducing correctors is still possible where quad doublets are present. This arrangement contains 4 horizontal correctors less than the previous one.

TABLE X

M05: 20HV,8H $\Delta x=\Delta y=.1$ mm, $\Delta Q=.175$ mrad, $\Delta B/B=5\times10^{-4}$		
	C02:28H,17V	**C03:24H,17V**
Xrms (mm)	.074±.022	.085±.027
Xmax (mm)	.406±.150	.454±.159
Yrms (mm)	.133±.157	.126±.138
Ymax (mm)	.687±.867	.646±.764
DXrms (m)	1.000±.003	1.006±.003
DXmax (m)	2.348±.009	2.348±.009
DYrms (m)	.015±.007	.014±.007
DYmax (m)	.037±.015	.035±.017
α Xrms (mrad)	.364±.093	.409±.117
α Xmax (mrad)	1.023±.381	1.081±.415
α Yrms (mrad)	.088±.021	.085±.021
α Ymax (mrad)	.196±.078	.190±.079
Qx	4.121±.001	4.121±.001
Qy	6.102±.003	6.101±.002
β_X (m)@ IP	4.510±.034	4.508±.029
β_Y (m)@ IP	.0455±.0008	.0453±.0006



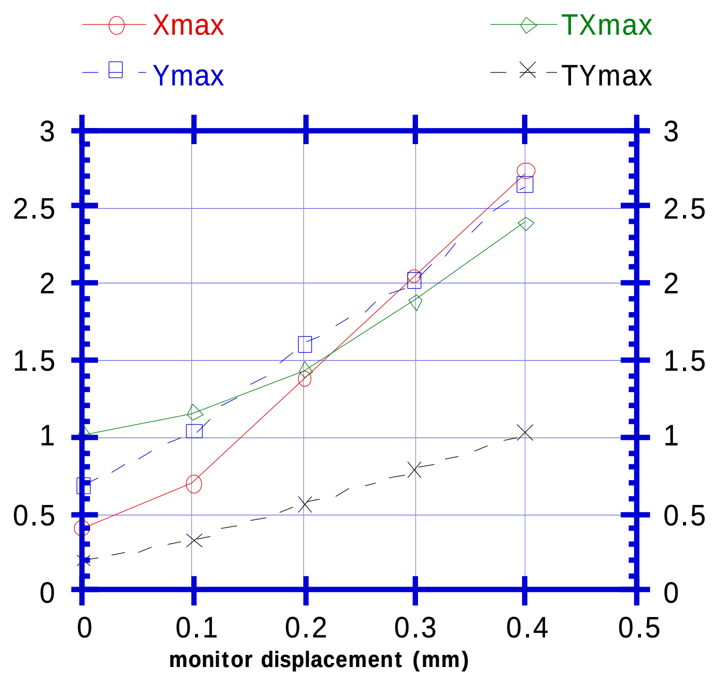


Fig. 13 - a) Rms values of the orbit residual distortion and corrector strength as function of monitor displacement; b) Max values.

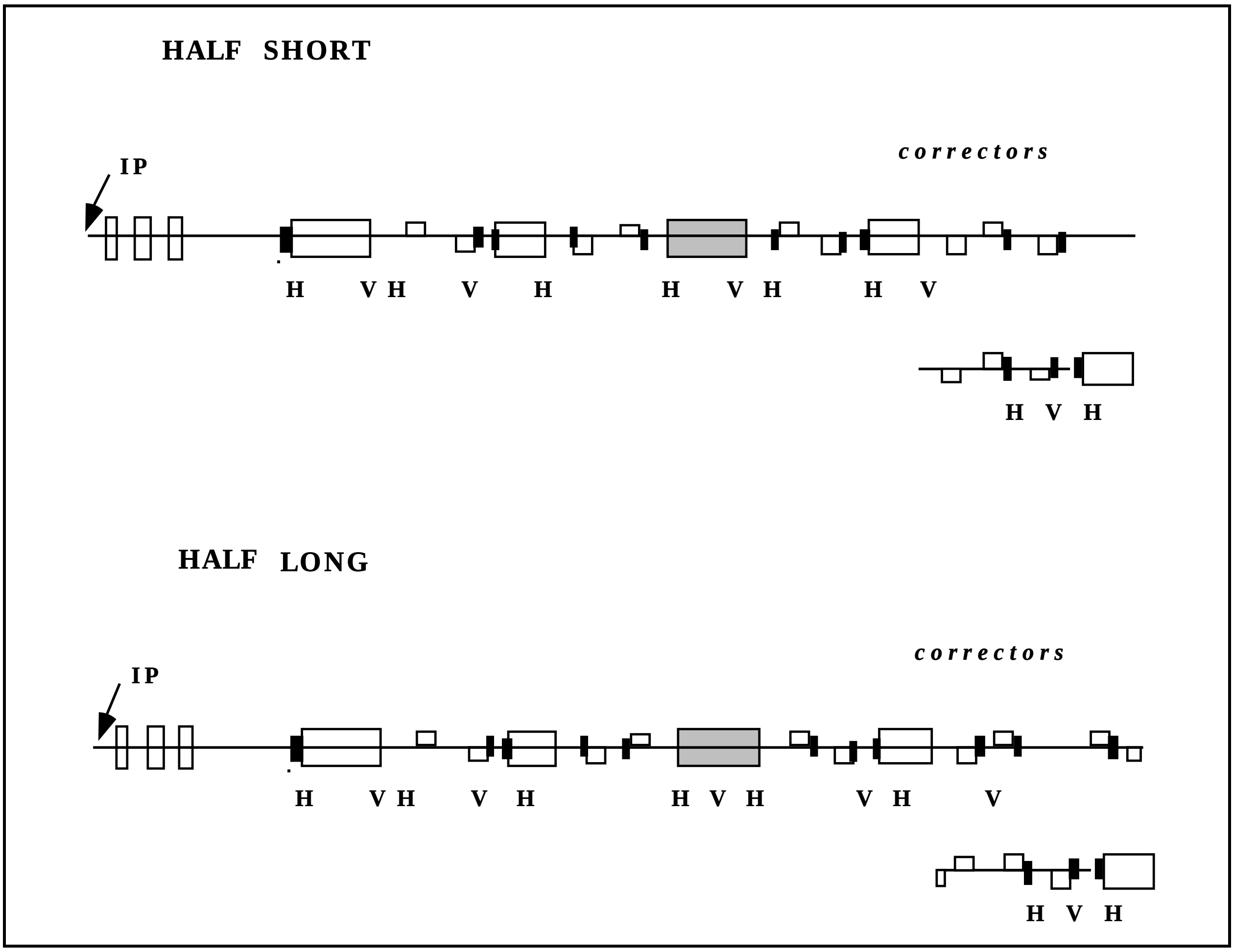


Fig. 14 - Correctors C03/24H, 17V.

From the whole performed analysis we can conclude that for this lattice it is possible to correct alignment and field errors, even with monitor errors, keeping the corrector strength at a quite low value (~ 1 mrad). The residual closed orbit displacement is very small in the two transverse planes and, more important, the paramenters of interest, like the β's @ IP, are changed not so much in order to have still the same requested luminosity.

Finally, the variation of the coupling, k, between the horizontal and the vertical motion has been calculated using a different program, PETROC. The correction has been performed starting with the standard set of errors and using the corrector configuration called "C02" before.

Table XI shows the results obtained after correction without and with monitor errors ($\Delta x=\Delta y= .1$ mm) .

TABLE XI

M05: 20HV,8H - **C02:** 28H,17V $\Delta x = \Delta y = .1$ mm, $\Delta\Theta = .175$ mrad, $\Delta B/B = 5 \times 10^{-4}$		
	without monitor errors	monitor errors $\Delta x = \Delta y = .1$ mm
Xrms (mm)	.119± .047	.207±.075
Xmax (mm)	.408±.132	.614±.247
Yrms (mm)	.252±.135	.246±.105
Ymax (mm)	.909±.402	1.026±.446
αXrms (mrad)	.227±..069	.286±.044
αXmax (mrad)	.677±.364	.742±.308
αYrms (mrad)	.117±.036	.135±.05
αYmax (mrad)	.243±.094	.278±.122
k ($\times 10^{-2}$)	2.69±4.08	3.069±3.124

Some differences between the MAD and the PETROC results are due the different algorithms used in the programs and to the different statistics involved.

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