Mechanically Induced Influences on the Storage Ring Beam

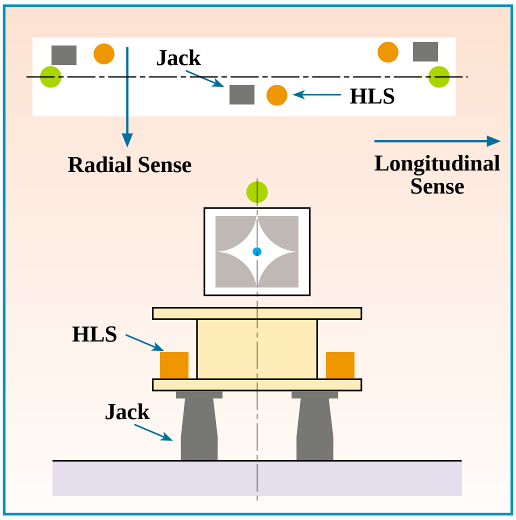
D. Martin[1] and L. Farvacque[2]

1 ESRF, Technical Services Division
2 ESRF, Machine Division

Magnet alignment errors are responsible for different types of perturbations in the ESRF storage ring.
The main effects are:
• Quadrupole magnet positioning errors inducing closed orbit distortions,
• Quadrupole tilt error inducing emittance coupling into the vertical plane.
These perturbations are normally compensated by magnetic correctors (horizontal or vertical steerers, skew quadrupole corrector magnets). Thanks to the good initial alignment of the machine, these correctors are used at a small fraction of their nominal strength. Alternatively the remote controlled motorised jacks supporting the magnet girders can also be used to minimise some of the misalignment errors:
• Vertical quadrupole positioning
• Quadrupole tilt (though this motion is correlated with an undesired horizontal displacement of the magnets).
The interest of correcting mechanically these errors may be:
• The analysis of the correction gives indications on the residual errors (amplitude, distribution) after the alignment of the machine,
• Ensuring a certain level of correction could permit the reduction of the strength of the magnetic correctors and at the same time improve their resolution. This would be beneficial for the fine adjustment of the beam position.
Several experiments have been performed recently to check these two correction procedures.

The remote control of the jacks, together with the Hydrostatic Levelling System (HLS), which cross-checks the effective girder displacement, enable these tests to be performed with the tunnel closed and with 5 mA of stored beam. The net advantage is that the effect (beneficial or not) of the girder displacements on the electron beam is assessed on-line. This beam-based alignment technique is a long awaited dream of accelerator physicists around the world. The different experiments were performed within a few hours and the girder's position and beam trajectory were put back at the end of the tests.

Fig. 1: position of the HLS and jacks on a typical storage ring girder.



Control of Girder Movements

Figure 1 shows the position of the HLS and jacks on the G10, G20 and G30 girders. Longitudinal tilt motion is a rotation about the middle jack on a girder in the sense of the travel of the beam. Radial tilt motion is about the center of the girder in the sense perpendicular to the beam travel. Vertical movements are made on the G10, G20 and G30 girders.
Jack movements are calculated from longitudinal and radial tilt values issued from calculations of beam parameters. These tilt values are translated into movements for the three jacks under each girder. Corresponding expected HLS readings at the jack positions are also calculated and used as a control for these movements. The difference between the jack movement and the expected HLS reading is the precision of the movement. In practice, the HLS readings must be processed to eliminate the wave effect due to the motion of water in the pipes, and the possible discontinuities in the readings created by blockages in the water system.
For a 40 μm peak movement of the jacks, the residual standard deviation is 1.3 μm which represents both the precision of the 288 jack movements and the natural evolution in time of the storage ring girders.

Vertical Beam Closed Orbit Distortion

Calibration of girder displacements

Eighteen jacks were moved independently by 10 μm. The motion was checked by deducing the displacement from the beam position readings on the electron Beam Position Monitors (BPM) all around the storage ring. There is an agreement of better than 1 μm between the requested jack movement, the HLS readings and the beam response.

Closed orbit correction using girder displacements

The response matrix of the vertical closed orbit to girder motion was computed for the theoretical machine. In simulation analysis, it was confirmed that pure longitudinal rotation of girders was more efficient than pure translation. It was therefore decided to correct the machine using only girder rotations. The correction method was exactly the same as the one used for magnetic steerers (SVD method).
The procedure used in the test was:
• Start from a perfectly corrected machine,
• Reduce the number of steerer correction vectors so that the vertical orbit blows up significantly (z_{rms} < 300 μm),
• Measure the vertical closed orbit and compute the mechanical correction,
• Apply the mechanical correction,
• iterate.
The results were obtained after four

Table 1

	Nb. vectors left on steerers	rms. orbit before movements (μm)	rms. orbit after movements (μm)	rms. steerer strength (mA)
1st iteration	32	269	191	76
last iteration	3	493	215	21

iterations (see Table 1).
Figure 2 shows the displacements corresponding to this partial alignment: The full cancellation of the steerer currents could not be tested because of lack of time, but should be straightforward. The rather large residual orbit is due to the choice of a limited number of correction vectors to avoid too large movements of girders.

HORIZONTAL/VERTICAL EMITTANCE COUPLING

The horizontal/vertical betatron coupling is responsible for the major part of the vertical emittance of the storage ring. It is defined as the ratio *k* of the vertical to the horizontal beam emittances:

$$\varepsilon_z = k\, \varepsilon_x$$

In a perfect machine coupling does not exist. It is a result of magnet imperfections and alignment tilt errors. Since the brilliance is inversely proportional to the coupling, its reduction is a way of optimising the performance. This is usually done by powering skew quadrupole correctors. Alternatively, coupling can be varied by tilting girders in the radial sense. The horizontal displacement linked to the tilts also induced undesired horizontal closed orbit distortions which were corrected by the standard orbit correction system.

Calibration of a harmonic tilt

The coupling is mainly sensitive to the excitation of the resonance close to the betatron tune difference ($\nu_x - \nu_z = 25$ in the case of the 4 nm lattice). So a systematic transverse tilt was applied to the girders on a corrected machine, according to this 25th harmonic:
The value of the peak angle was varied between 0 and 1 mrad and the coupling was measured using the pinhole camera. The results show a large deviation (factor 2 to 3) from the prediction of the theoretical model. This discrepancy is not understood at this point.

Correction of the main harmonic with the storage ring girders

This was applied on the low βz optics for which the tune difference is ν_x-ν_z = 22. A harmonic 22 tilt was applied to a machine without corrections and was varied experimentally to cancel the excitation of the coupling resonance:

rms tilt angle (mrad rms)	Phase (°)	Coupling
0	0	34 %
0.21	19	4.5 %

The residual coupling value is similar to what can be obtained with magnetic correction of a single resonance. However, the rms tilt value of 0.21 mrad (see Figure 3) introduced in the machine is very large. It cannot represent the compensation of a residual harmonic component with such an amplitude in the girder alignment. It probably compensates another coupling source (individual positioning of magnets on girders, magnetic tilt angle,…).

CONCLUSION

Several experiments have been carried out using high precision jacks installed under the SR girders relating mechanical motion to vertical closed orbit and coupling:
• the calibration of the translation of one girder,
• the complete correction of the machine by movements made to imitate the action of the steerers,
• the calibration of a harmonic excitation of a coupling resonance as a function of girder tilts,
• the compensation of the main coupling resonance.

The correction of coupling shows a sensitivity of the machine much higher than predicted and movements larger that what could be derived from alignment tolerances.

The correction applied for the vertical closed orbit agrees perfectly with the modelling and results in motions compatible with the residual alignment errors. This may be applied for the next machine realignment (performed with beam after the next winter shutdown) and could allow a further reduction of the rms vertical closed orbit errors. It could also allow the achievement of a low rms orbit (~ 200 μm) without any magnetic correction which would be a record for such a high focusing storage ring. ■

Fig. 2: Girder displacement after correction.

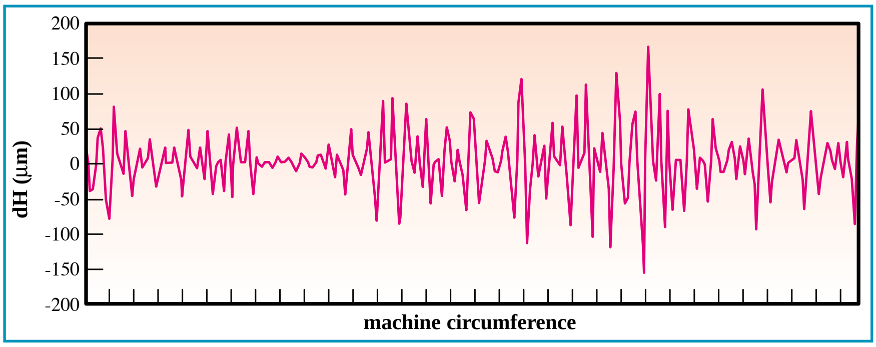


Fig. 3: Tilt movements used for coupling correction.