LINEAR LATTICE ERRORS AT THE ESRF:
MODELING AND CORRECTION

A. Franchi, L. Farvacque, T. Perron

SUMMARY:

- Which errors and why correct them.

- Special focus on beta beating and coupling correction using RDTs

-Correction sequence and resulting vertical emittance.

-Vertical dispersion description and correction.

ERRORS DESCRIPTION:

ERROR OBSERVED	SOURCE	CONSEQUENCES
Closed orbit errors	Magnet misalignments	Integer stop band enhanced Feed down in multipoles magnets.
focussing errors	Quad strength or length errors. H offset in sextupoles.	Half integer stop band enhanced. Beta beating
Coupling	Tilted quads, vertical offset in sextupoles.	Coupling resonances enhanced. Source of vertical emittance
Vertical dispersion	Coupling, closed orbit errors, dipole tilts	Source of vertical emittance

BETA BEATING AND COUPLING CORRECTION:

sequence:

Partial response matrix measurement (16*2 steerers⇒224*2 BPM)

⇓

The difference between measurement and perfect machine model is fitted by adjusting the strength and introducing a tilt on each of the 256 quads.

⇓

Resonance Driving Terms (RDTs) at the BPM locations are calculated from the fitted errors.

⇓

The RDTs are then minimised using the correctors installed on the machine:

- 32 normal quads.
- 64 skew quads.

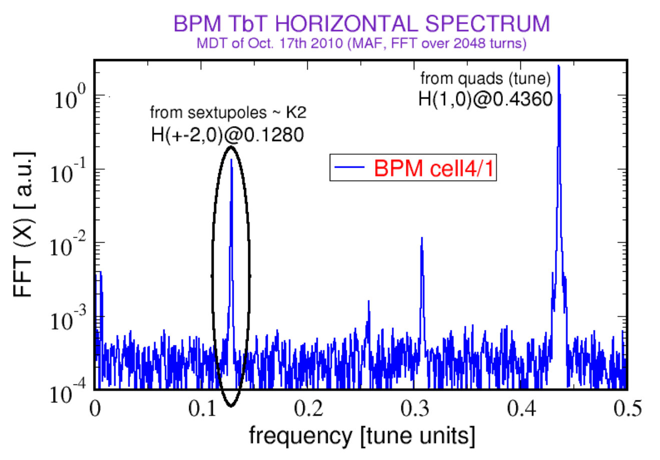
This process allows to correct the real machine but also to create a numerical model to perform simulations on a realistic lattice.

RDT DESCRIPTION:

[R. Bartolini and F. Schmidt, Part. Accel. 59, 93(1998)]
[A. Franchi and al, Phys. Rev. ST Accel. Beams 14, 034002]

Example for the coupling correction:

RDT describes the impact of a resonance at a given position. Each RDT is proportional to a specific secondary line measured in the spectrum of turn by turn data.



The RDT due to a skew quad,for the coupling resonances $\nu_x+\nu_y=n$ and $\nu_x-\nu_y=n$ is given by:

$$f_{\substack{1001\\1010}} = \frac{\sum_{w}^{W} J_{w,1}\sqrt{\beta_x^w \beta_y^w}\, e^{i(\Delta\phi_{w,x}\mp\Delta\phi_{w,y})}}{4(1-e^{2\pi i(Q_u \mp Q_v)})}$$

Skew quad gradient Tune Phase advances

It is possible to build a matrix system of the type:

$$\begin{pmatrix} f_{1001\ bpm\ 1} \\ f_{1001\ bpm\ 2} \\ \cdots \\ f_{1010\ bpm\ 1} \\ f_{1010\ bpm\ 2} \\ \cdots \end{pmatrix} = M \times \begin{pmatrix} J_1 \\ J_2 \\ \cdots \end{pmatrix}$$

For n BPMs and m skew gradient contributions, the matrix M is of size 2n x m.

RDT DESCRIPTION (2):

Using this matrix formalism, the RDTs arising from skew quad errors can be calculated and minimised using the skew quad correctors.

Skew quad correctors are also used to correct vertical dispersion. The final setting is given by solving a linear system containing both corrections with different weights.

Let Dy be the vertical dispersion measured at the BPMs, f_{1001} and f_{1010} The RDTs calculated from the measured skew errors.
The system to be inverted to find the skew correctors settings J_c is given by:

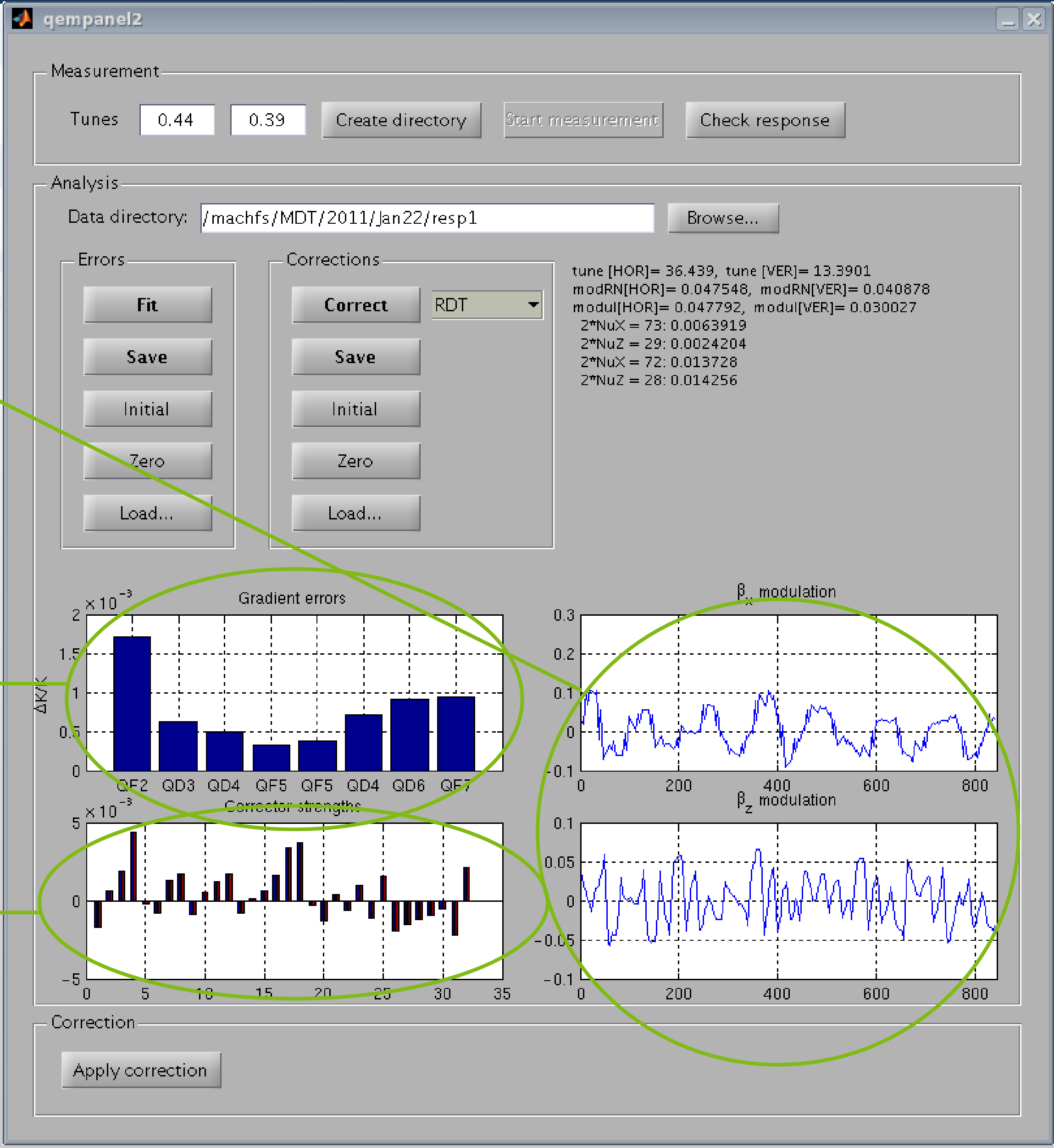
M is the matrix mentioned above with n more lines describing the effect of skew correctors on V-dispersion measured on the BPMs.

Weights a1 and a2 are adjusted to reach best vertical emittance

$$\boxed{\begin{pmatrix} a_1\vec{f}_{1001} \\ a_1\vec{f}_{1010} \\ a_2\vec{D}_y \end{pmatrix}_{\text{meas}} = -\mathbf{M}\vec{J}_c,}$$

NORMAL QUAD CORRECTION

Beta Beating (peak)
10-20% uncorrected
~5% corrected



Tunes 0.44 0.39

Data directory: /machfs/MDT/2011/Jan22/resp1

RDT

```
tune [HOR]= 36.439,  tune [VER]= 13.3901
modRN[HOR]= 0.047548,  modRN[VER]= 0.040878
modul[HOR]= 0.047792,  modul[VER]= 0.030027
 2*NuX = 73: 0.0063919
 2*NuZ = 29: 0.0024204
 2*NuX = 72: 0.013728
 2*NuZ = 28: 0.014256
```

Quad gradient errors

Normal quad correctors

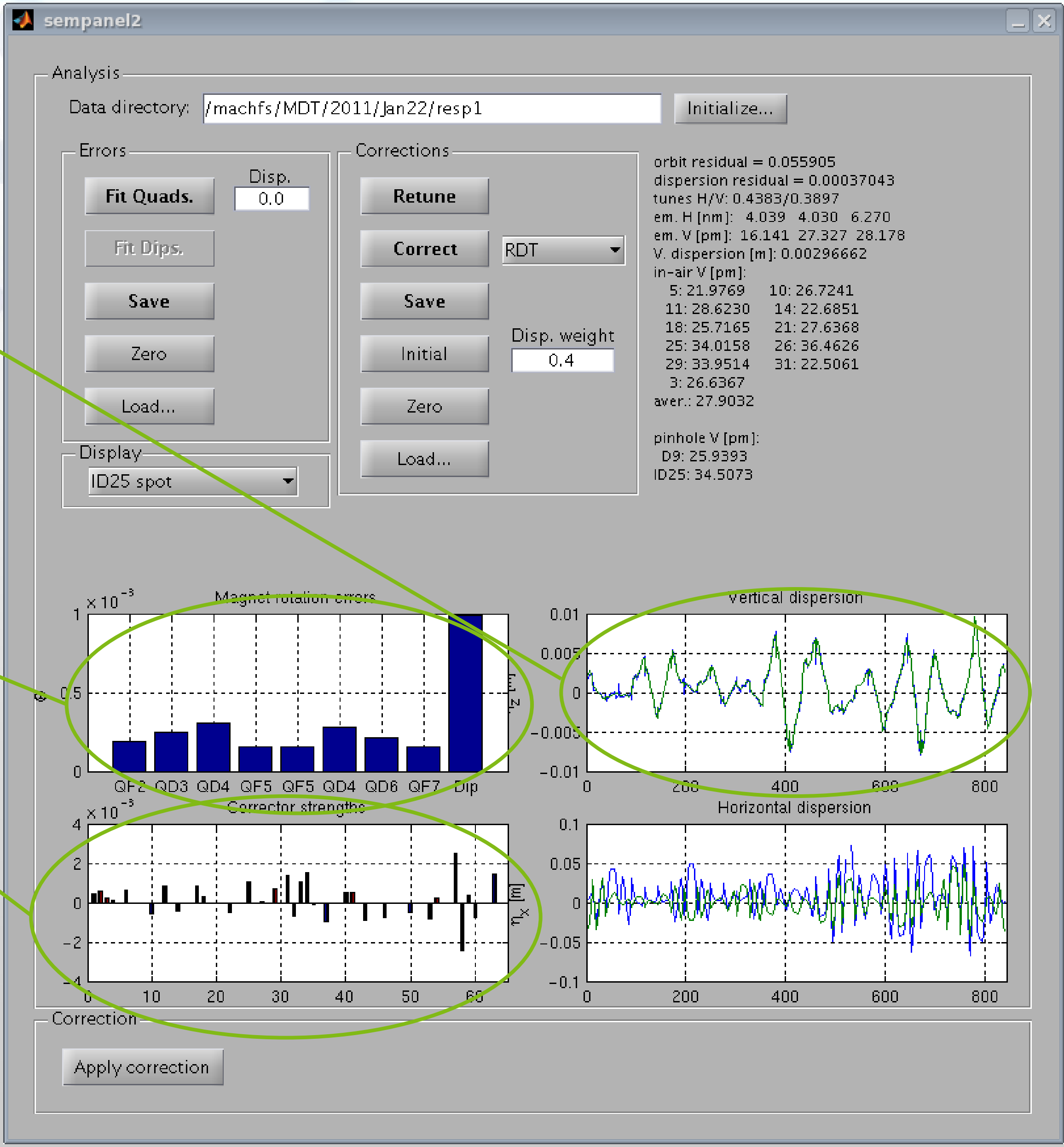
SKEW QUAD CORRECTIONS

V dispersion measurement and fit by dipoles rotation
Initial: ~7mm (RMS)
Corrected: ~1-2mm (RMS)

Magnet rotation error model. Unrealistic dipole rotations are needed to fit vertical dispersion

Skew correctors setting

Thanks to RDT algorithm vertical emittance is decreased to 3-4pm (down from 20-30 pm until 2010)



sempanel2

Analysis

Data directory: /machfs/MDT/2011/Jan22/resp1

Errors — Disp.: 0.0

Corrections — RDT — Disp. weight: 0.4

Display: ID25 spot

```
orbit residual = 0.055905
dispersion residual = 0.00037043
tunes H/V: 0.4383/0.3897
em. H [nm]:  4.039  4.030  6.270
em. V [pm]: 16.141  27.327  28.178
V. dispersion [m]: 0.00296662
in-air V [pm]:
   5: 21.9769     10: 26.7241
  11: 28.6230     14: 22.6851
  18: 25.7165     21: 27.6368
  25: 34.0158     26: 36.4626
  29: 33.9514     31: 22.5061
   3: 26.6367
aver.: 27.9032

pinhole V [pm]:
 D9: 25.9393
ID25: 34.5073
```

VERTICAL DISPERSION DESCRIPTION (1):

On many machines, ESRF included, V dispersion has been measured far above predictions.

At ESRF we choose to use dipole tilts to simulate V dispersion. It led to unrealistic dipole tilt angles.

Nevertheless once measured, correction schemes numerically calculated are efficient even if the error model is inconsistent.

We could describe the source of spurious vertical dispersion as being linked to closed orbit errors combined with chromaticity.

VERTICAL DISPERSION DESCRIPTION (2):

The formula giving the closed orbit at location S resulting from a kick at location S0 is given by:

K	kick strength (rad)
ν	tune
$\psi_s - \psi_{s0}$	Phase advance between observer and kick(rad)

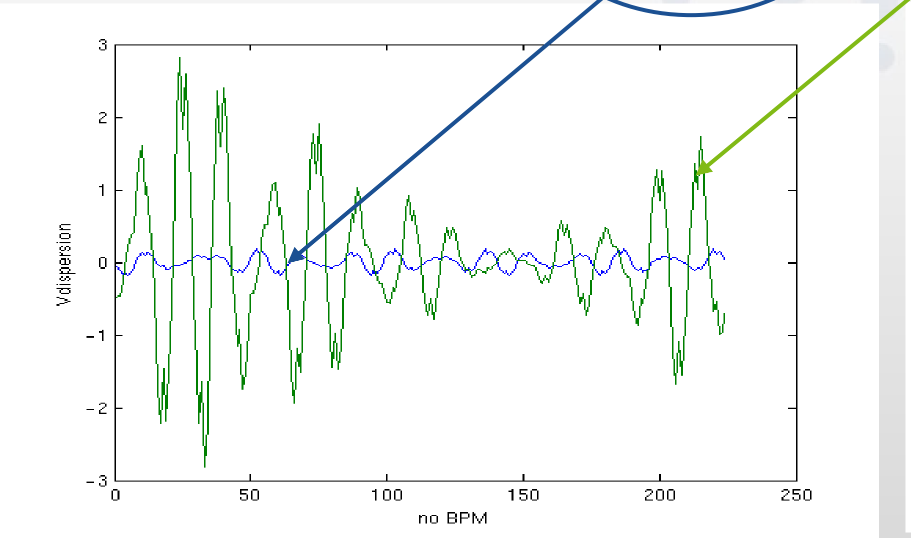
$$\boxed{X(s) \propto k \times \frac{\cos\left(\pi \times \nu - \left|\psi_s - \psi_{s0}\right|\right)}{\sin(\pi \times \nu)}}$$

In this expression two quantities depend on the energy: The kick strength, but also the tune. The variation of the tune relative to energy is given by the chromaticity.

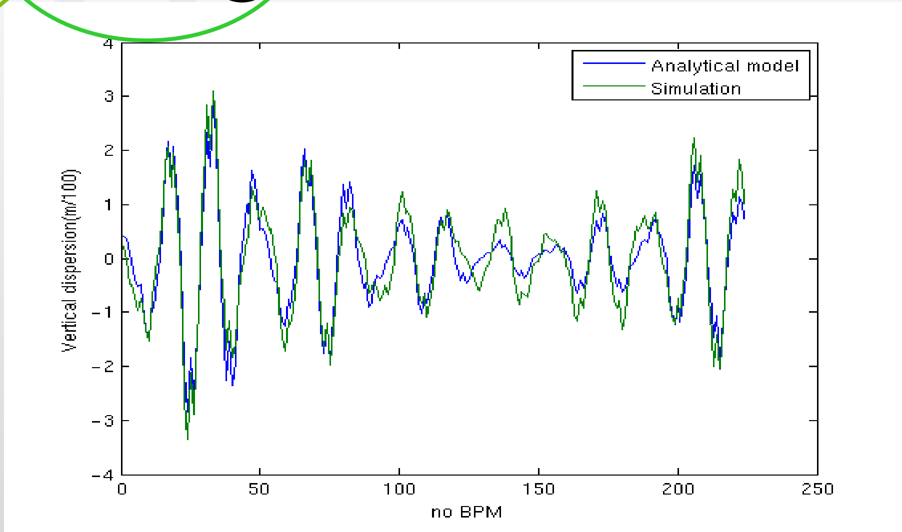
VERTICAL DISPERSION DESCRIPTION (3):

$$\boxed{\frac{dx(s)}{dE} = \frac{dx(s)}{dk}\times\frac{dk}{dE} + \frac{dx(s)}{d\nu}\times\frac{d\nu}{dE}}$$

Chromaticity



Example for ζv=0.4



Correlation between analytical model and simulation.

By convention, tilting a dipole in MADX or AT does not produce vertical closed orbit errors. It explains why we had to introduce unrealistic dipole tilts in our model to reproduce the vertical dispersion measured.

CORRECTION:

The part linked to chromaticity is the dominant one for the ESRF operation case.

Following this model, vertical steerers have a strong impact on dispersion, the effect is amplified by chromaticity.

↓

It should be possible to use the vertical steerers to correct the dispersion in the same way we correct the orbit.

Orbit is corrected using “steerer to orbit” response matrices.
The goal is to use “steerer to orbit&dispersion” response matrices to correct both orbit and dispersion at the same time.
Looking into literature we found that this correction scheme had already been applied on many machines.

CORRECTION RESULTS:

Using the steerers to correct dispersion should release the skew quad correctors and have them only correct coupling.

On an other hand, using steerers to correct V dispersion requires to release constrains on the vertical orbit.

Experiment VS simulations:

	Initial	**After correction measure/simulation**
Orbit RMS (µm)	**60**	**150/125**
Dispersion RMS (mm)	**12**	**1.6/1.3**

The correlation with simulation is good, nevertheless, the constrains on the closed orbit are too tight to allow a drastic reduction of the vertical dispersion.

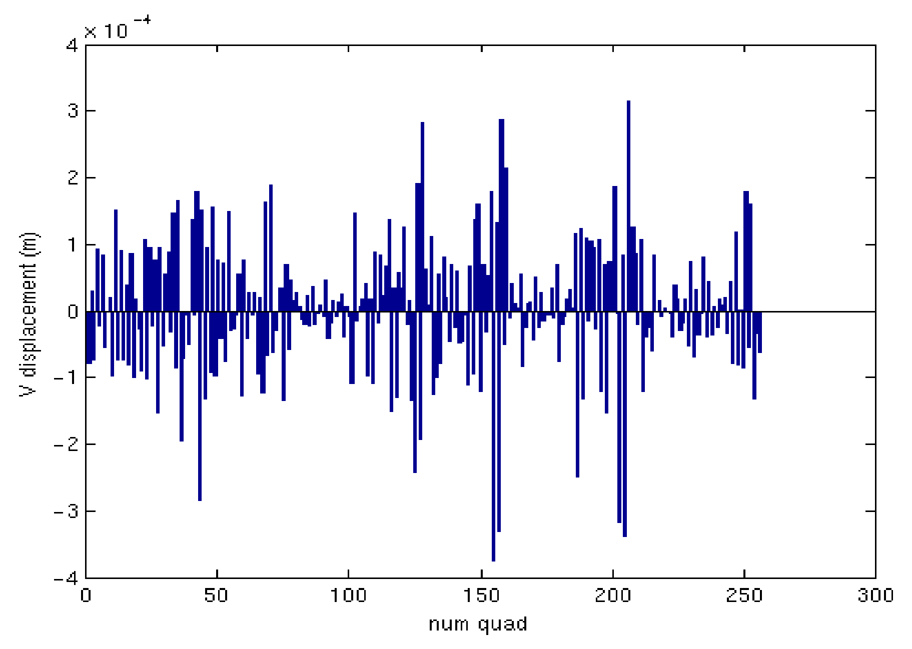
This correction scheme was unable to help to further reduce vertical emittance.

WAS IT COMPLETELY USELESS???

Not really:

-We still highlighted a second solution to reduce vertical dispersion which is to work at zero chromaticity (need of a fast feedback).

-We can now construct a more realistic model for simulations where vertical dispersion is fitted via quadrupoles misalignments.



Rms displacement=100µm
with 125 vectors over 256 used for SVD

CONCLUSIONS

The ESRF correction scheme for beta beating, coupling and vertical dispersion has been described. Thanks to the new low noise BPMs (Libera) and to the RDT formalism, vertical emittance could be reduced to 3-4 pm during beam delivery.

For ultra low vertical emittance, vertical dispersion is of importance. The vertical emittance link to close orbit errors has been explained and possible cure explored. Unfortunately we where unsuccessful to further reduce emittance.

Nevertheless it helped building a more realistic model for simulations and understand the source of vertical dispersion.

Acknowledgements:
F. Ewald and K. Scheidt for the diagnostics involved.