Local chromaticity measurement using the response matrix fit at the APS

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Motivation

- During part of 2007 and the beginning of 2008 APS operated with unusually short lifetime
- An extensive investigation led us to believe that the sextupole symmetry was broken (see poster TH6PFP004 tomorrow)
- In order to confirm it, we performed local chromaticity measurement using the response matrix fit
  - Local chromaticity is the dependence of local betatron phase shift on rf frequency
  - We used response matrix measurement and fit performed on different rf frequencies to get local betatron phases
- Data were taken in November 2007 but not analyzed until after the reversed sextupole was found by visually inspecting the power supplies

Response matrix fit at APS

- Response matrix fit is used routinely for lattice correction after fill pattern and lattice changes
- To save time, we use 27 correctors in each plane (out of 320) and all 400 BPMs in each plane. We vary all 400 quadrupoles and we use quadrupole strength constraints.
- We don't fit energy changes due to corrector excitations – instead, we calculate orbits with fixed path length
- The fitting program and GUI is written in Tcl/tk and uses `elegant`[1] for orbit calculations and SDDS toolkit[2] for data processing

[1] M. Borland, APS-LS 287, 2000
[2] M. Borland et al., Proc. of PAC 2003

Measurements

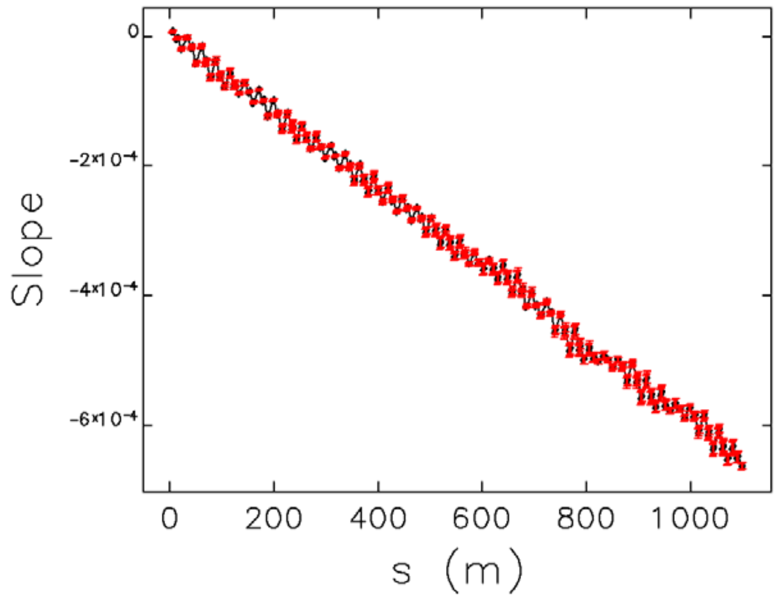
- Response matrix was measured for a set of three rf frequencies: -300 Hz, 0 Hz, and +300 Hz
- We used fill pattern with the longest lifetime – 324-bunch fill pattern; and sextupoles from the fill pattern with highest chromaticity – +11 in both planes

- The measurement processing consisted of two steps
  - Perform a response matrix fit for each measurement; the result of which is the Twiss file with beta functions and phases
  - Analyze betatron changes across these Twiss files to calculate local phase slope with rf frequency

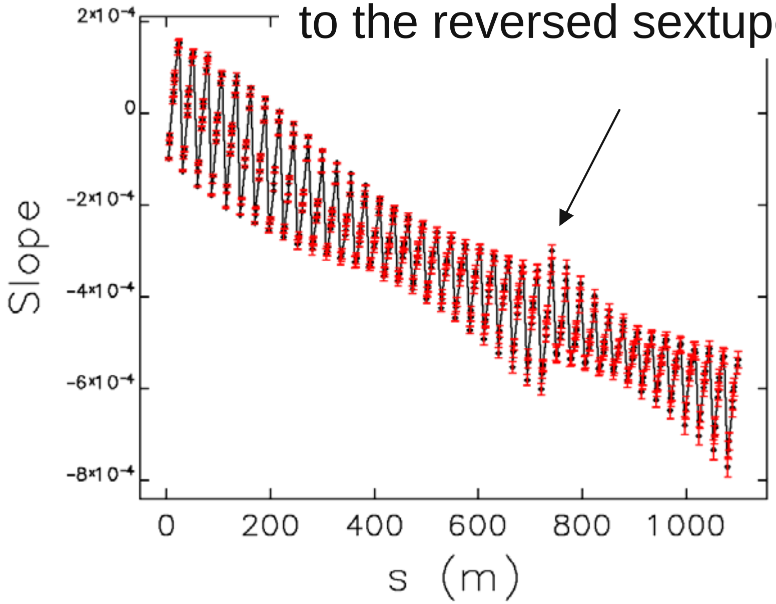
Betatron phase slope with rf frequency

- For each longitudinal point, betatron phases corresponding to different rf frequencies were collected and straight line fit was performed

- Horizontal (left) and vertical (right) betatron phase slopes

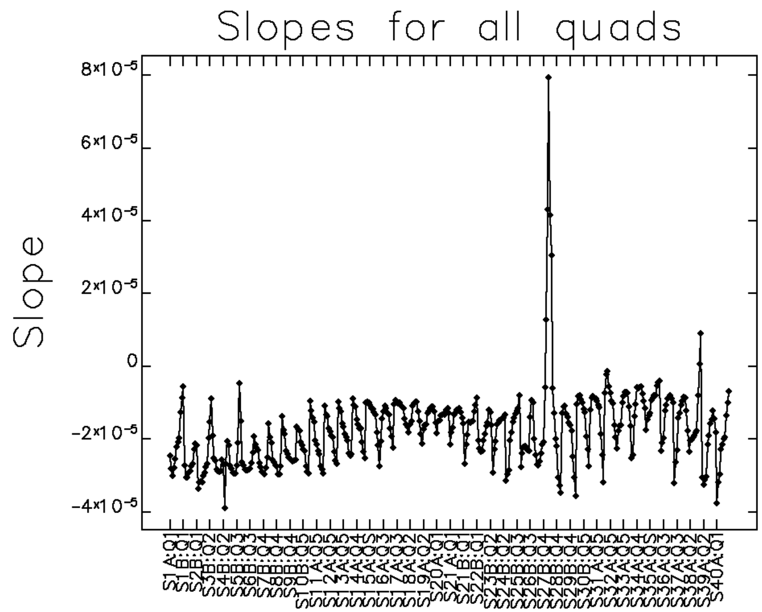


Phase jump corresponding to the reversed sextupole



Finding exact location

- To localize chromatic perturbation, we calculated the phase difference between each point on the previous plots and a point exactly one sector in front of it

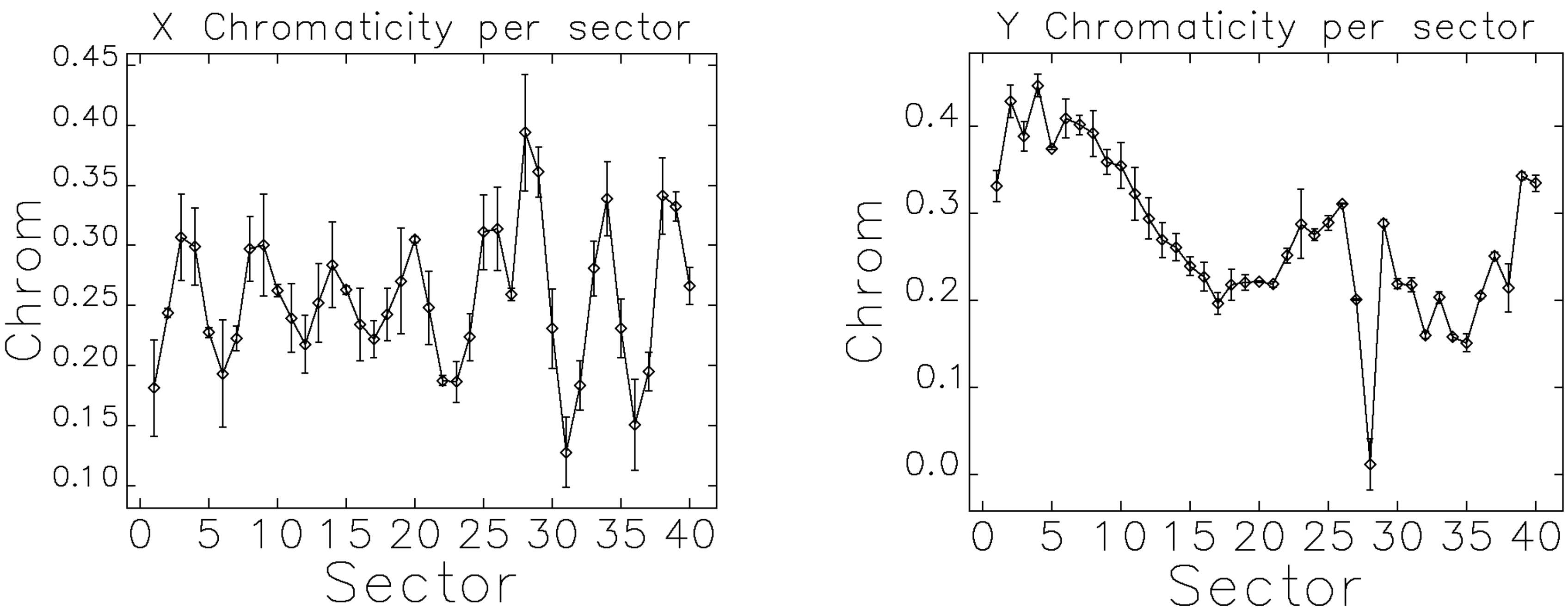


- The first step of the spike corresponds to the S27B:Q3 quad; the reversed sextupole was located right in front of it

Local chromaticity

- Local chromaticity can be calculated from the local phase slopes:

$$C_z = -\frac{1}{2\pi} f_{rf} \cdot \alpha_c \cdot \frac{d\psi_z}{df_{rf}},$$



Improving the sensitivity of the method

- A reversed sextupole is a big perturbation and is easy to find
- We performed a measurement of local chromaticity with the K2 value of one sextupole intentionally reduced by 5 $1/m^3$
- We performed 5 measurements in the same ±300 Hz range (±0.3% energy error – maximum possible range)
- Same analysis of phase advances described earlier did not identify the location of the test sextupole

Other processing methods

- Fit phase-slope curve using a small number of quadrupoles (1 or 2 per sector):
  - Avoids quadrupole ambiguity problem
  - Phase-slope curve is too noisy to find a small perturbation
  - This method worked for local impedance measurement
- Use artificial quadrupoles at sextupole locations
  - First, the response matrix fit is performed on nominal rf frequency using real quadrupoles to achieve the best fit accuracy
  - For off-momentum measurements, the fit performed varying only artificial quads at the location of sextupoles
  - Because the sextupoles are located everywhere, we had to use many quadrupoles, and this method suffered from the quad ambiguity problem
- Both methods did not locate the test sextupole

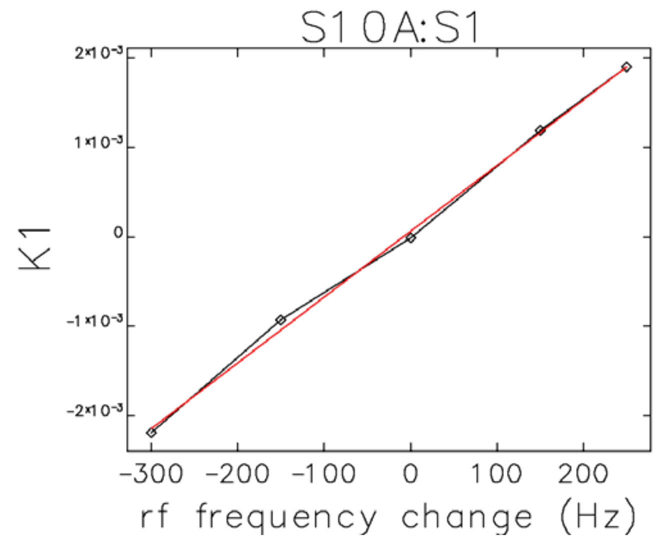
Other processing methods

- The best result was achieved when we improved the second approach:
  - For each off-momentum measurement, we performed a fit on the orbit distorted due to rf frequency change (it was done by varying path length of an artificial drift-space element[1])
  - In this case the existing sextupoles of the lattice take care of the focusing changes due to orbit change – therefore, in an ideal case, artificial quads at sextupole locations should give zero focusing errors
  - Non-zero focusing errors in the fit correspond to additional focusing that is not represented by existing sextupoles
  - Number of quadrupoles in the fit can be reduced to avoid the ambiguity problem (we used 120 quads, or 3 per sector)

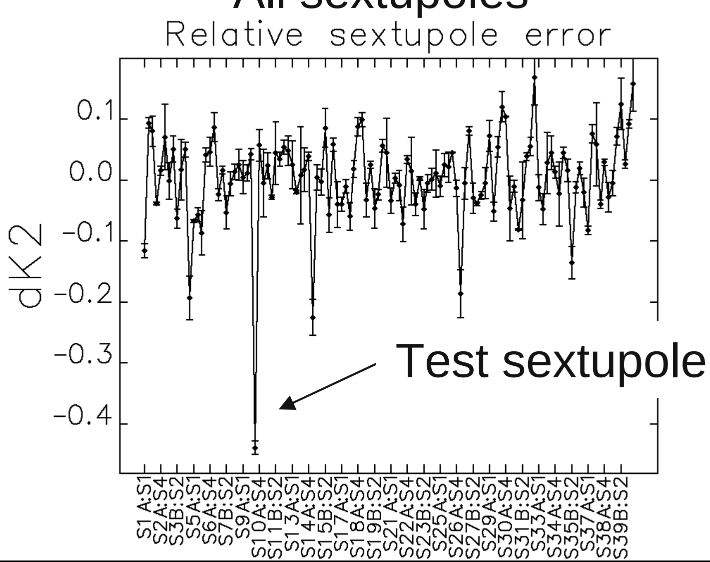
[1] M. Borland, private communications

Measurement processing

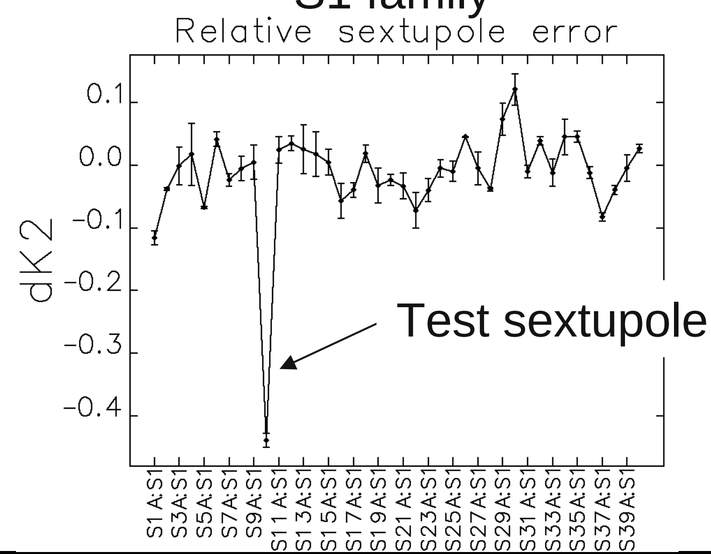
- The response matrix fit is performed for each measurement which results in five sets of quadrupole K1 values
- For each quad, a K1 slope with rf frequency is calculated (plot to the right)
- Relative K2 errors are calculated from the slopes



All sextupoles



S1 family



Conclusions

- We have implemented local chromaticity measurement using a response matrix fit at different rf frequencies
- We have used this method to diagnose a sextupole mistakenly connected with the wrong polarity
  - The data was not analyzed until the problem was solved by other means
  - But we have shown that the method can be used in the future for sextupole diagnostics
- We have looked at several processing methods and found one that provides for the best sensitivity

- Thanks to L. Emery and M. Borland for useful discussions