Orbit Stability and Stability Control

NSLS-II ASAC Review

October 8, 2007

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Outline

1. Long term ground motion and orbit correction
2. Calculation on the performance showing vibration problem can be solved by fast feedback
3. Requirement on power supply strength
4. Requirement on temperature stability and thermal expansion of BPM support

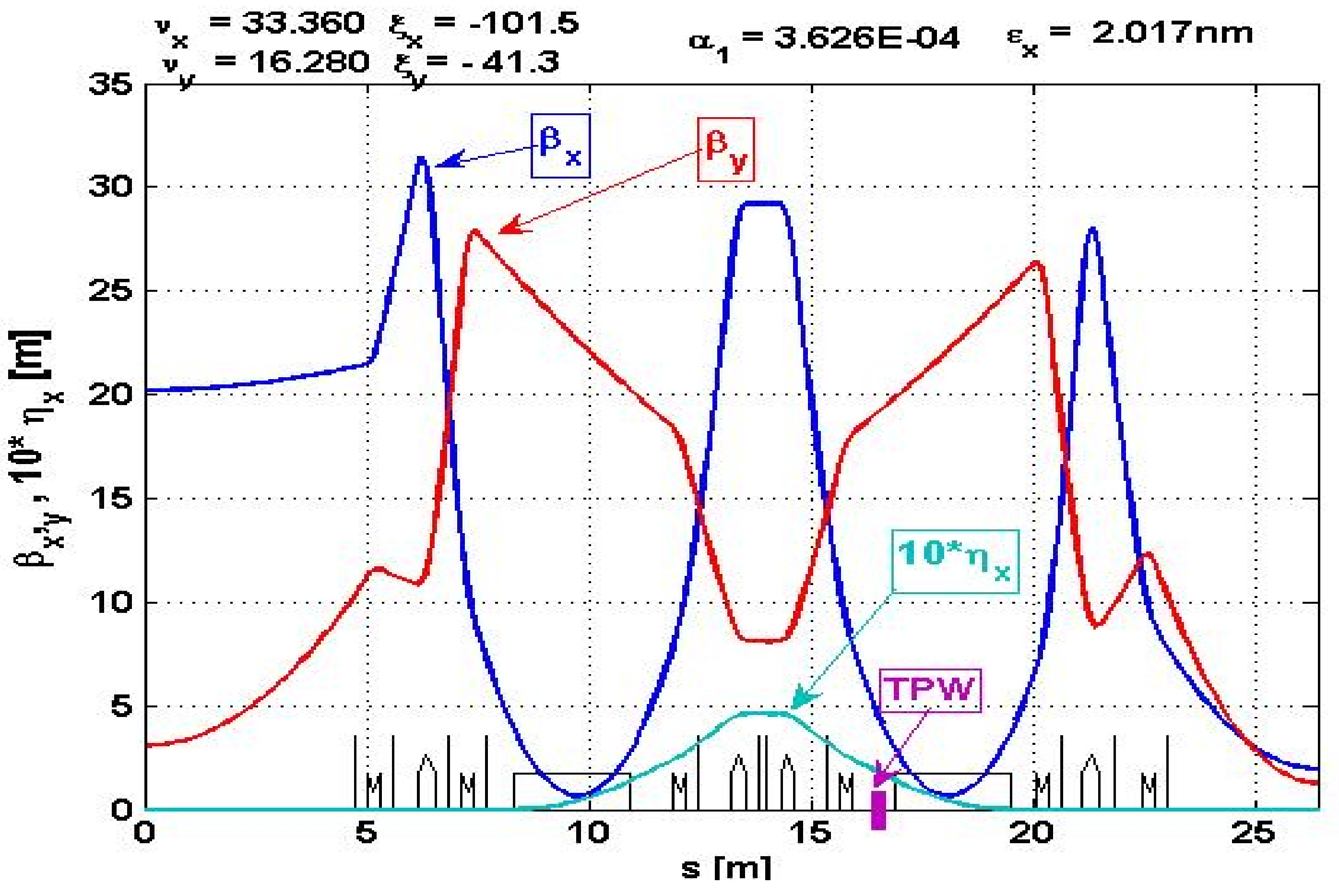
Goal

Beam stability requirement based on 10% beam size

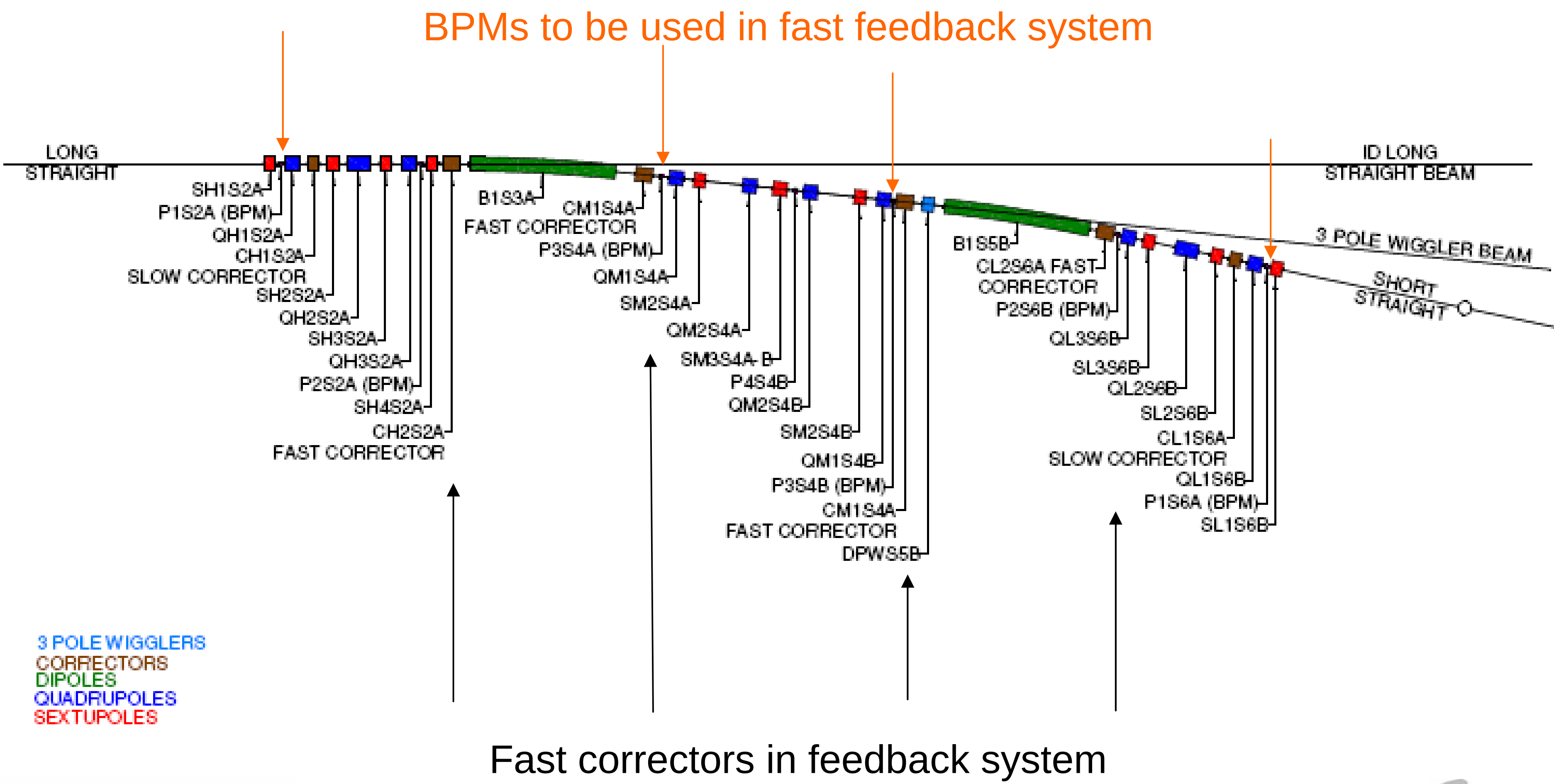
The minimum beam size is 2.7 μm at β =1.2m ,

assuming $\epsilon_y = 0.1$nm/4π.

Machine model used in feedback system performance calculation



BMPs and Dipole Correctors in the design



Orbit feedback system calculation: BPM vibration and noise errors are included

BPM signals without feedback

$$y_{0j} = \Delta y_{Bj} + \sum_i \frac{\sqrt{\beta_j \beta_i}}{2\sin \pi\nu} \cos(\pi\nu - |\varphi_i - \varphi_j|)(Kl)_i \Delta y_{Qi}$$

- y_{0j}: BPM output signal
- Δy_{Bj}: BPM motion+noise
- $(Kl)_i$: Quad strength
- Δy_{Qi}: Quad motion

BPM signal is used to calculate the corrector trim kick strength and the orbit movement with feedback:

$$y(s) = \sum_i \frac{\sqrt{\beta(s)\beta_i}}{2\sin \pi\nu} \cos(\pi\nu - |\varphi_i - \varphi(s)|)(kl)_i \Delta y_{Qi} + \sum_k \frac{\sqrt{\beta(s)\beta_k}}{2\sin \pi\nu} \cos(\pi\nu - |\varphi_i - \varphi(s)|)\theta_k$$

- $y(s)$: Beam position
- θ_k: Trim kick strength

Response Matrix

In matrix form:

$$y = R\theta$$

As a simplest approximation, we take:

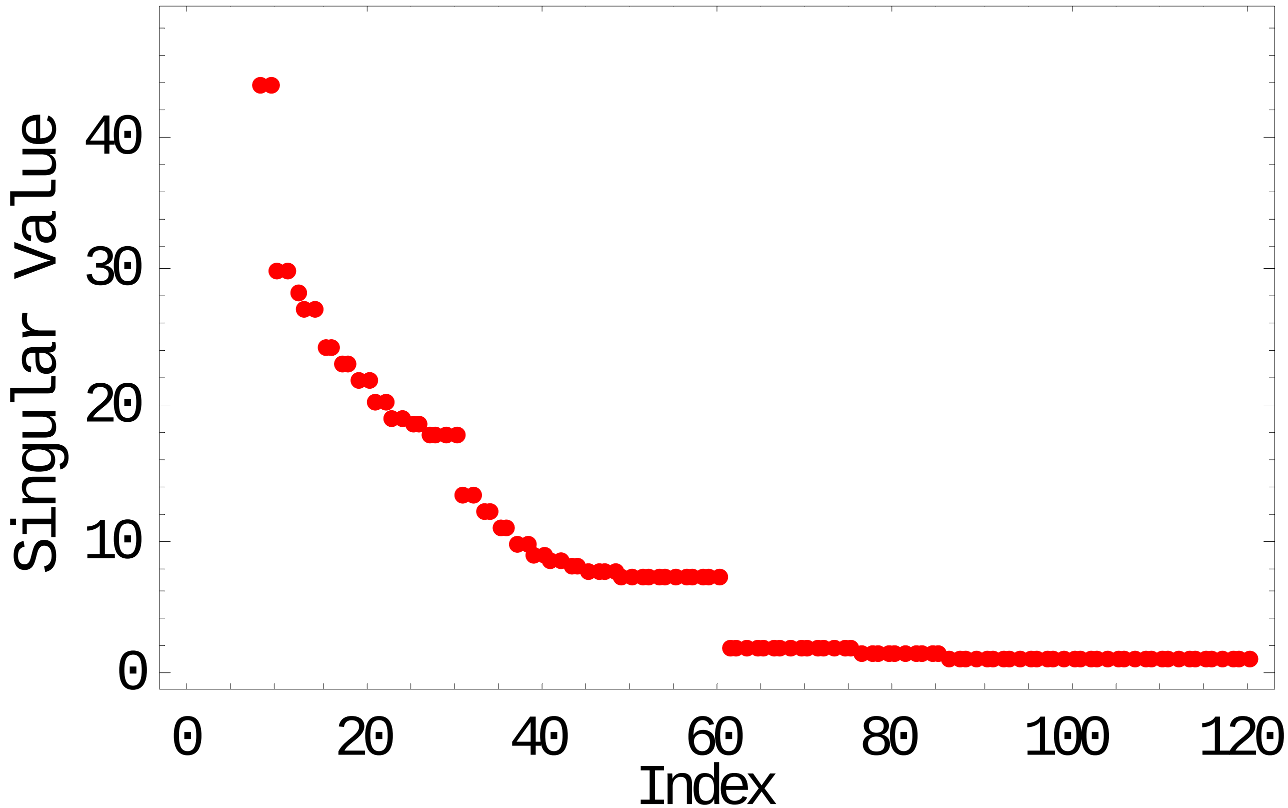
$$y_j = \sum_k \frac{\sqrt{\beta_j \beta_k}}{2\sin \pi\nu} \cos(\pi\nu - |\varphi_k - \varphi_j|)\theta_k$$

Frequency response of dipole correctors and vacuum chamber eddy current T(ω): (T(0)≡1)

$$\theta = T(\omega)C$$

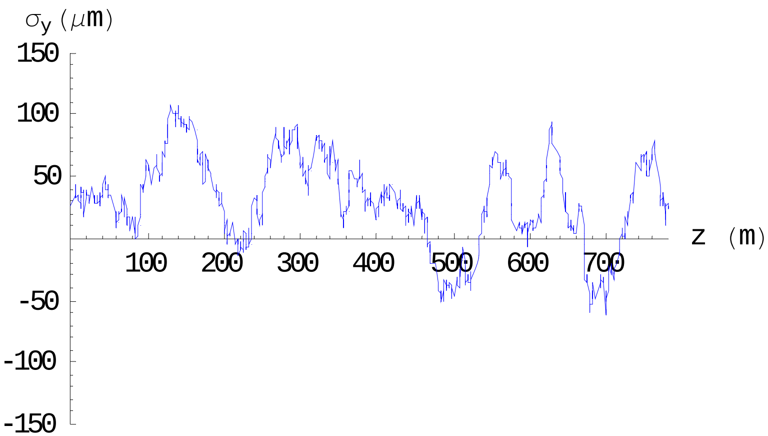
Singular value spectrum and selection of singular values used in feedback

$$R = UW\tilde{V}$$

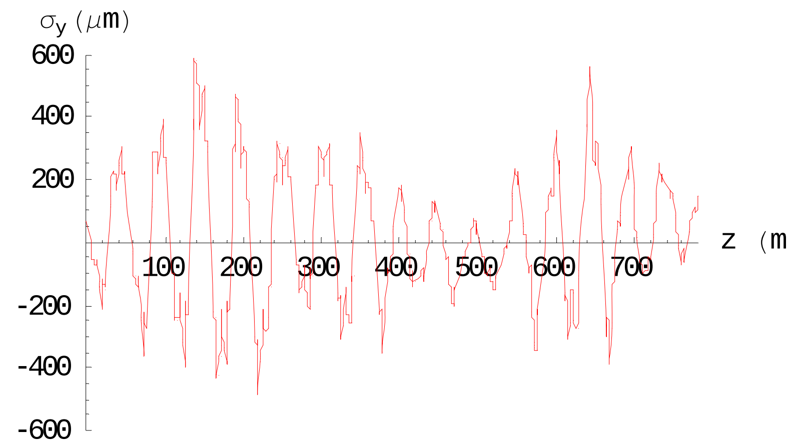


Long Term Ground Motion and Orbit Correction

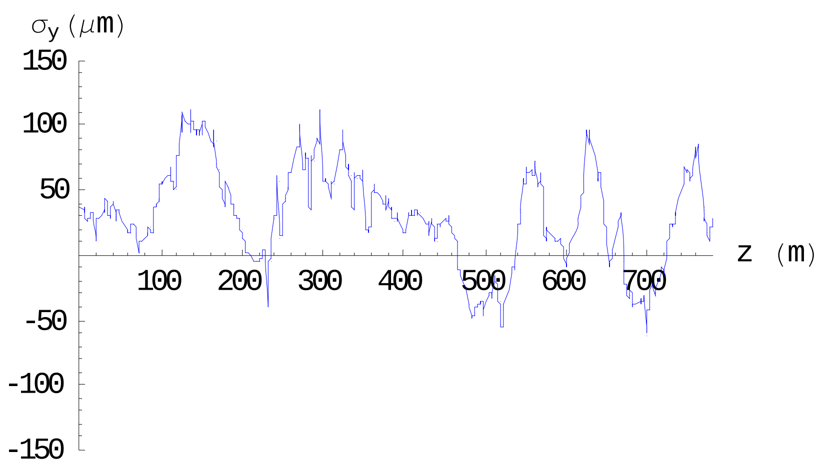
ground motion modeled on ATL law in half year with $A \cong 3\times10^{-18}$ m2/m/s



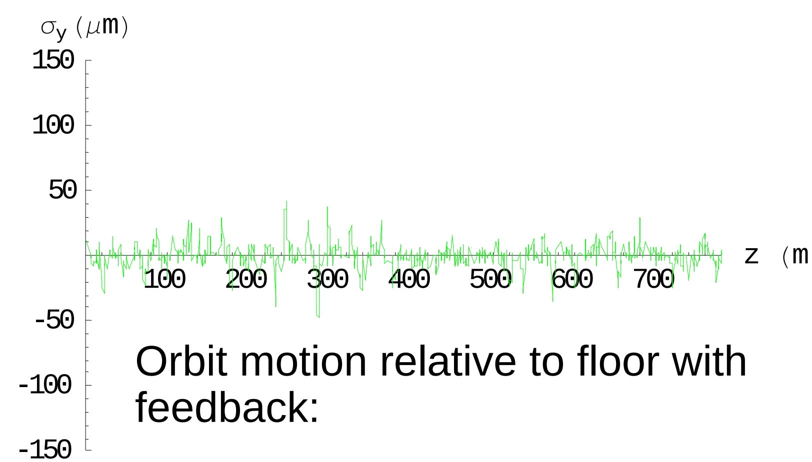
Floor motion Max=107 μm RMS=36 μm



Orbit motion without feedback, Max=600μm



Orbit motion follows the floor with feedback



Orbit motion relative to floor with feedback:

Max=48 μm, RMS=10 μm

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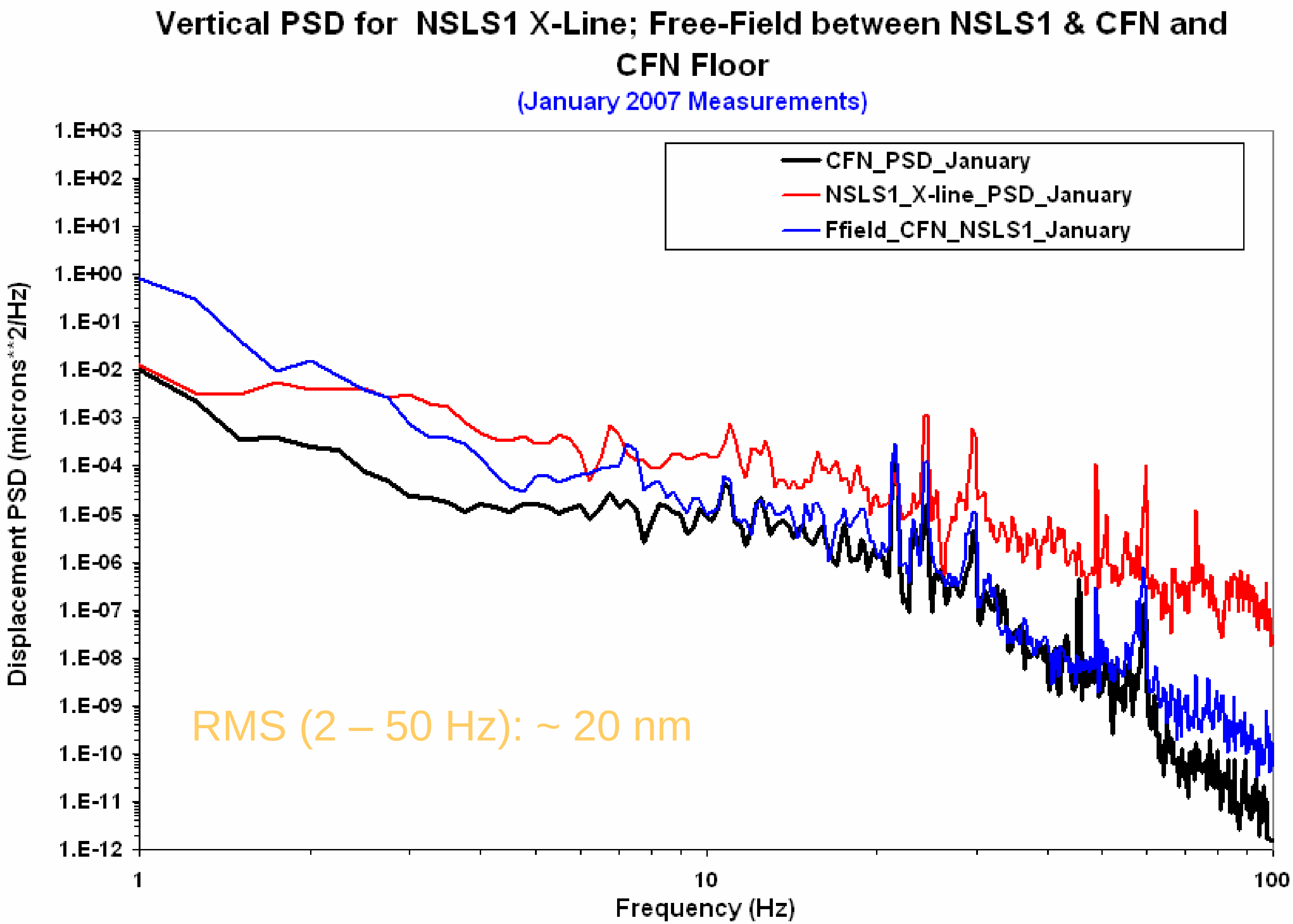
Approximation considered in calculation

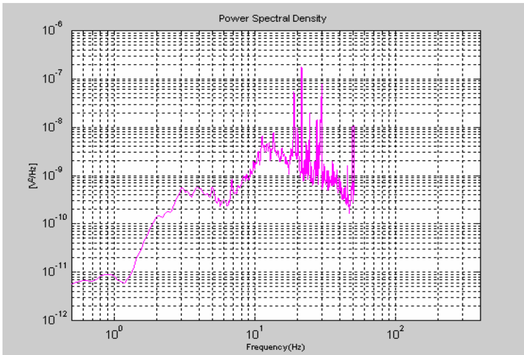
- Quads motion is considered dominant noise source
- BPM motion contribution dominates the residual orbit motion when feedback is on
- Corrector noise is assumed made sufficiently small
- Other sources are neglected. For example, contribution from sextupoles is found to be negligible.
- Frequency response of correctors including the effect of eddy current in the vacuum chamber is considered flat within the feedback bandwidth

Ground Motion

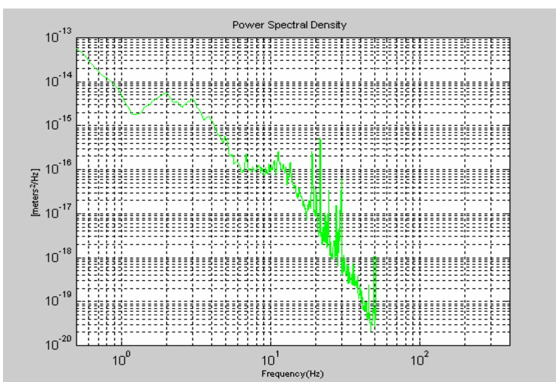


N. Simos

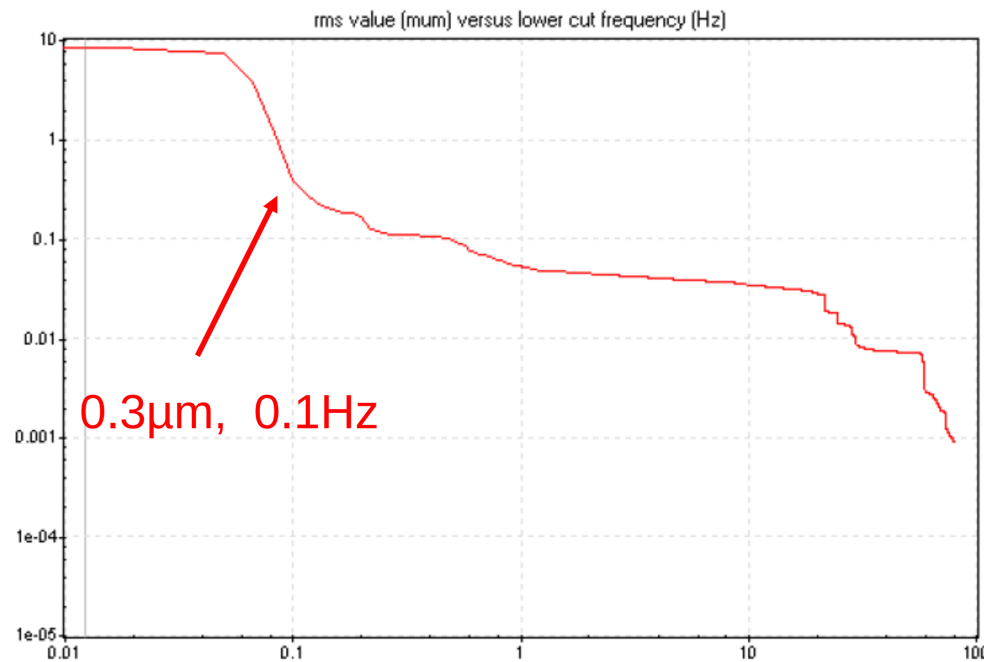
DESY Seismic Sensors shows 0.04μm @>1 Hz



Signal Analyzer reading in PSD (V^2/Hz)



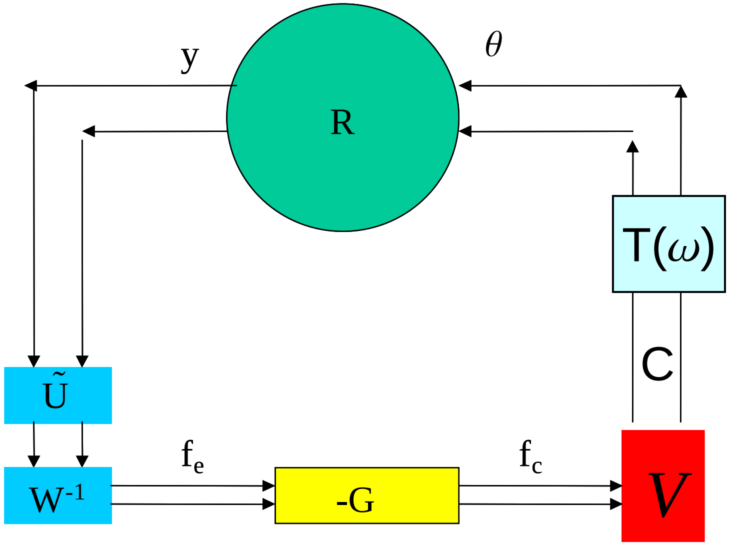
Signal Analyzer reading in PSD (V^2/Hz) converted to m^2/Hz



Graph of displacement
On UV ring floor near door

Effect of feedback

$$R = UW\tilde{V}$$



Without feedback:

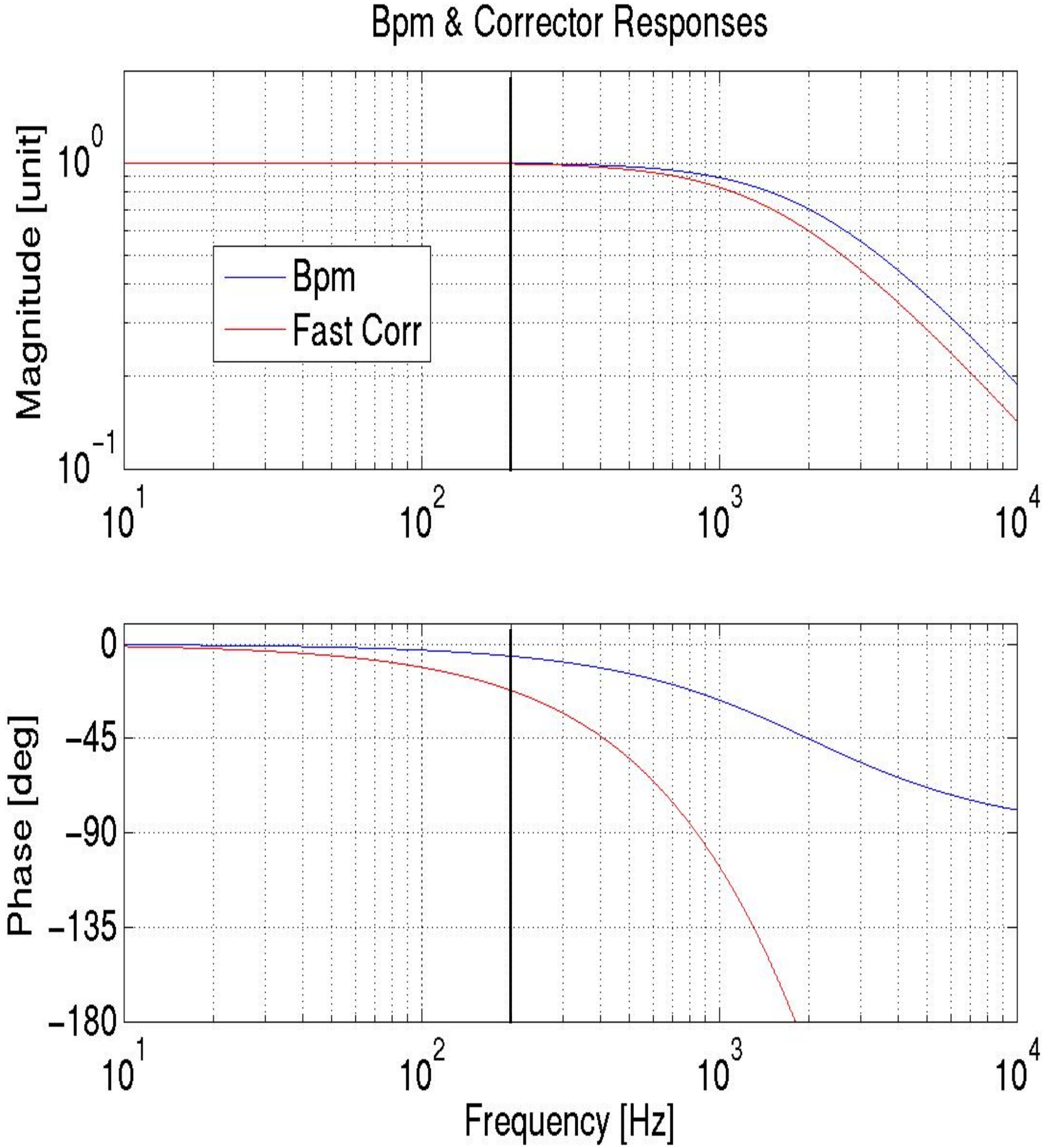
$$f_e = W^{-1}\tilde{U}y_{noise}$$

With feedback:

$$f_e = \frac{1}{1+TG}W^{-1}\tilde{U}y_{noise}$$

- If G is a large positive number, with feedback loops on, the error signal is reduced by a factor of 1+G at DC (T(0)=1).
- At higher frequency, TG is a complex number and has to be designed to avoid oscillation.
- Assume all the correctors have the same frequency response

BPM / Fast Corrector – Responses



BPM Response

One pole low pass filter @ 2KHz

Fast Corrector Response

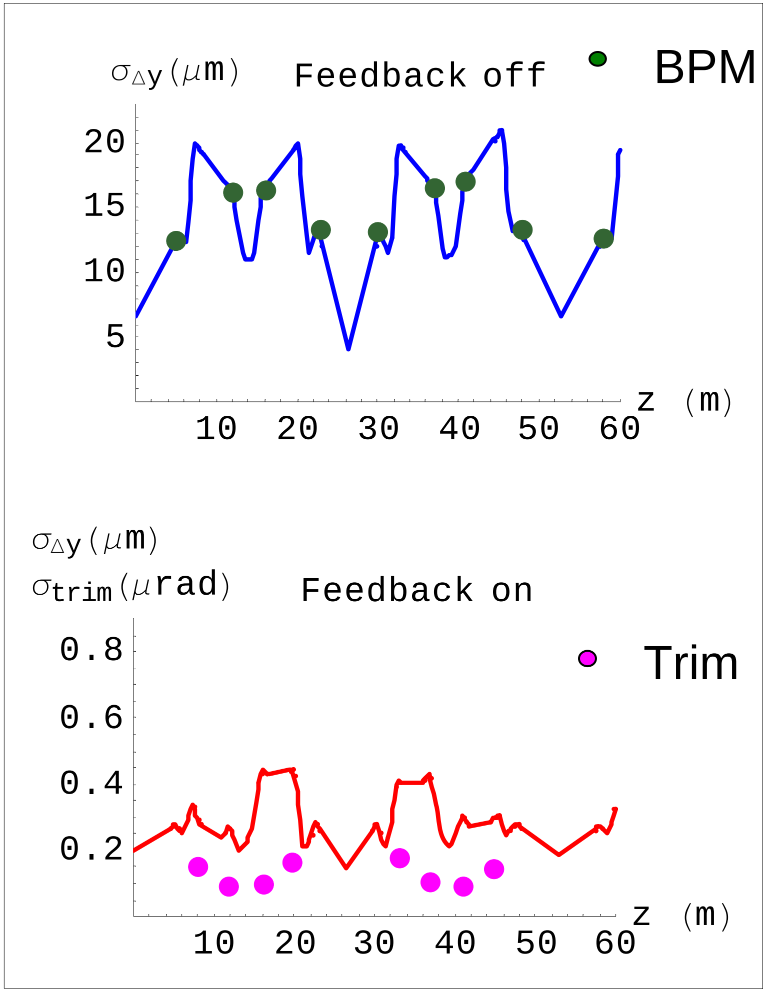
One pole low pass filter @ 1.5 KHz
Delay ζ = 0.2 ms

BPM & Fast Corrector Combined Phase Contribution

@ 100 Hz = 15°
@ 200 Hz = 27
@ 300 Hz = 45
@ 400 Hz = 57
@ 500 Hz = 70

We take $T(\omega) \approx 1$ When f<200Hz

Amplification factor with and without feedback system on

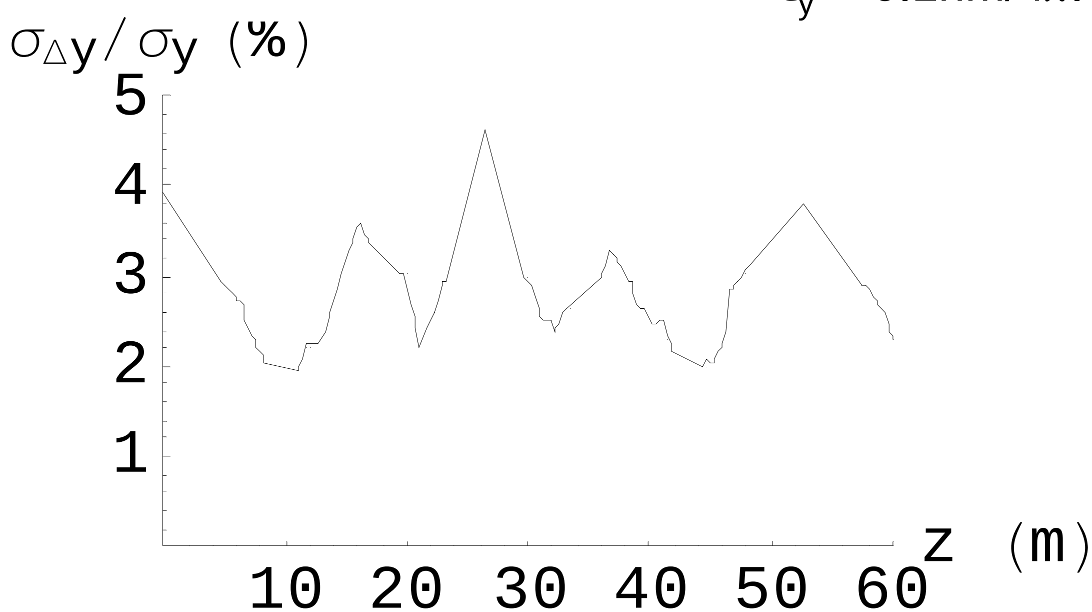


- Assuming 0.2 micron random vibration of quads and BPMs
- Assuming 0.2 micron electronic BPM noise
- The residual beam motion at center of short straight section is 0.14 micron RMS
- The calculation uses 4 correctors next to sections of stainless vacuum chamber for each half superperiod.
- 60 singular values used out of 120
- Required trim strength is 0.2 μrad
- Introducing 0.2 micron random vibration in all the sextupoles does not change result

Ratio of Orbit Motion over Beam Size

Ratio of vertical beam motion over beam size with the feedback system on shows the stability is satisfied. The calculation uses 4 correctors next to sections of stainless vacuum chamber for each half superperiod

$\epsilon_y = 0.1\text{nm}/4\pi.$



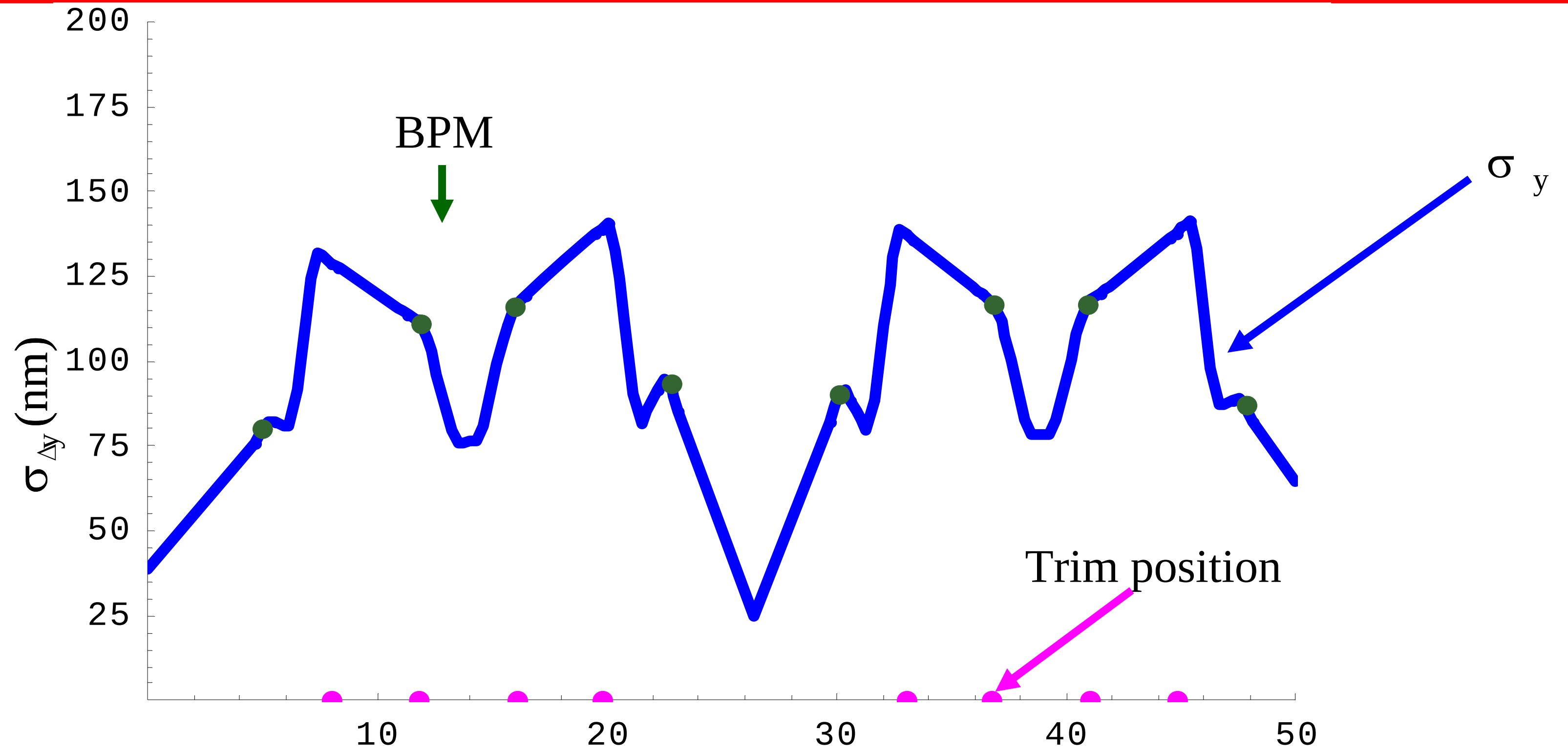
↑ 9.3 m straight

↑ 6.6 m straight

If we design the BPM support in short straight sections such that temperature change of 0.1˚C causes 0.3μ motion, the beam motion will be less than10% of beam size there.

Tolerance on Vertical Trim Power Supply Resolution

Orbit motion due to trim power supply noise of 1 nrad rms



- If we require beam motion due to the trim noise at the beam waist where β_y=1.2m is less than 100nm, the RMS trim noise should be less than 4 nrad.
- The last digit should be less than 4 nrad/0.29 = 12 nrad

Summary of Requirements

- Power Supply Specification:

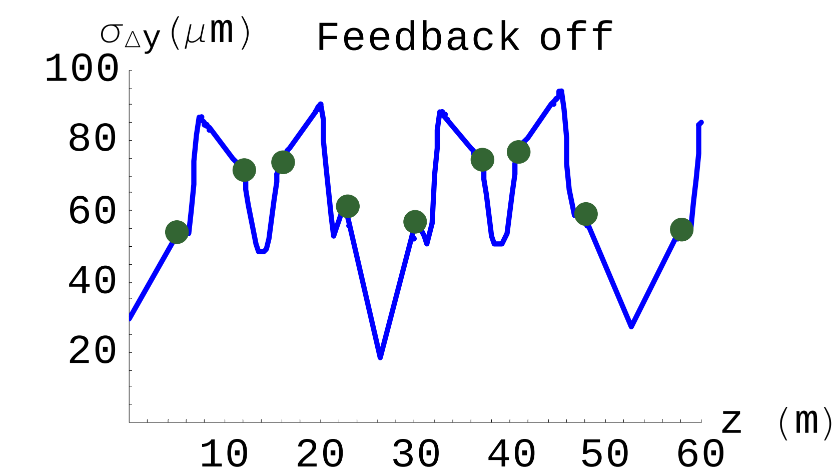
Frequency	Strength - RMS
< 5 Hz	800 μrad
20 Hz	100 μrad
100 Hz	10 μrad
1000 Hz	1 μrad

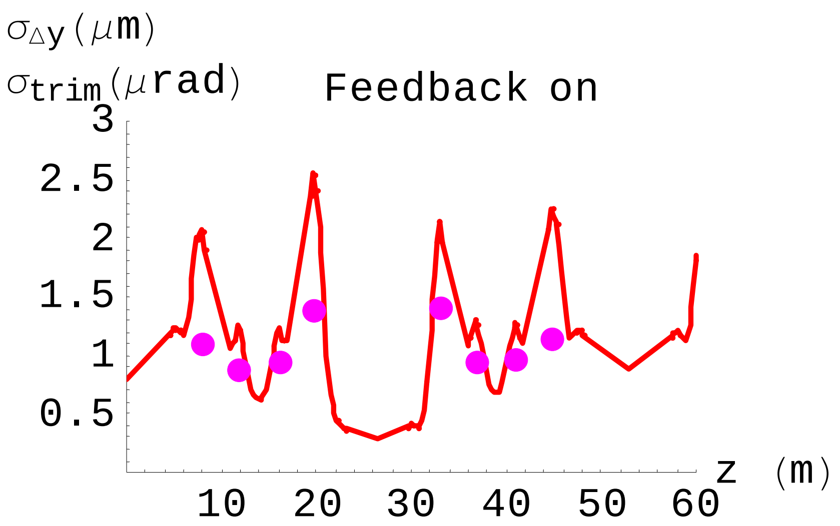
Resolution of last bit: 0.01 μrad

Noise Level : 0.003 urad (~ 4 ppm of 800 μrad)

- We plan special BPM supports in short straight sections to reduce temperature dependence to <0.1μ for 0.1˚C change.
- All trims (magnet, power supply, vacuum chamber Eddy current included) assumed to have same frequency response with bandwidth 60-100Hz.

Specially designed BPM support at 6.6m straights to reduce temperature dependence





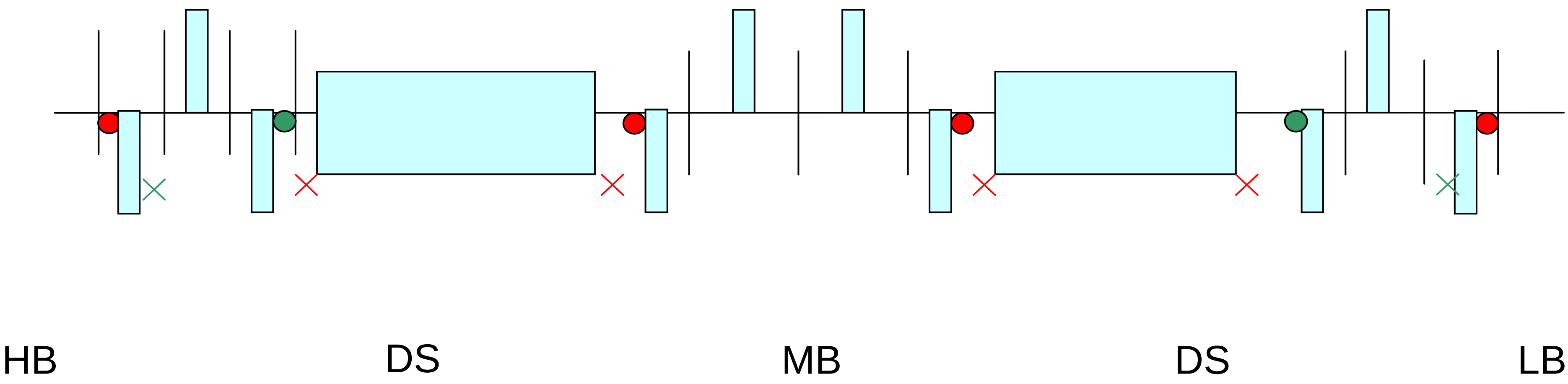
- Assuming 1.2 μ mrandom motion of quads and BPMs
- BPMs in the short straight move 0.2 μm
- Residual at center of short straight <0.3 μm

Conclusion

- Fast feedback system can satisfy the 10% beam size stabilization goal
- 4 correctors 4 BPM system is sufficient, but it is easy to add more BPMs
- Specially designed BPM supports at the ends of short straight sections can solve the thermal expansion issue

Backup slides

Feedback BPMs and trims in One Super-period



BPM in feedback system

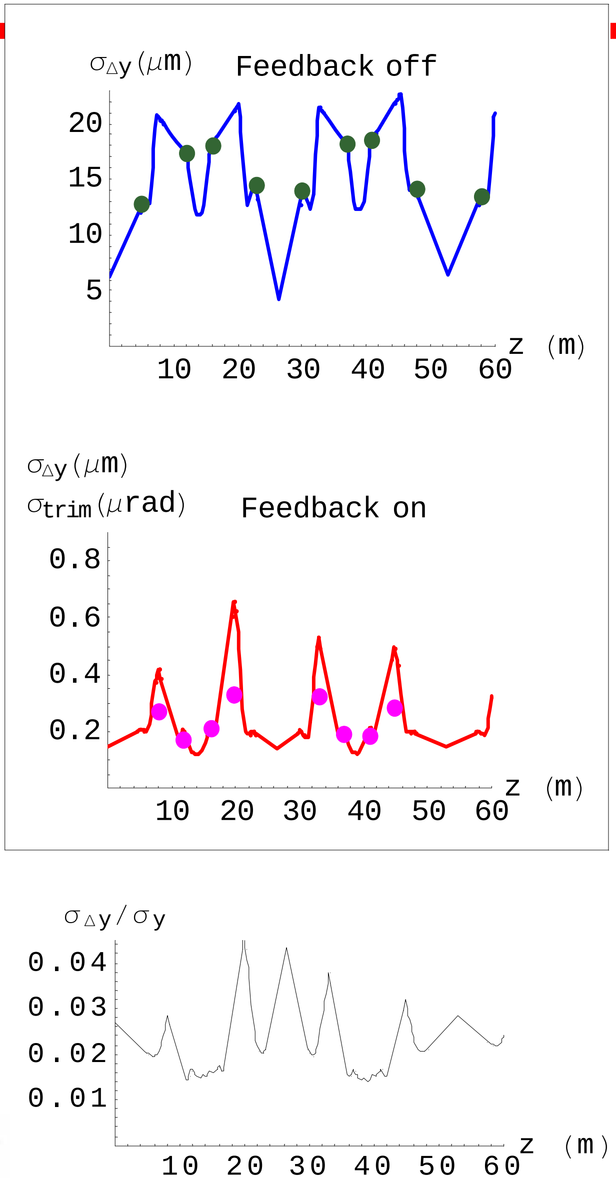
Trim in feedback

quad

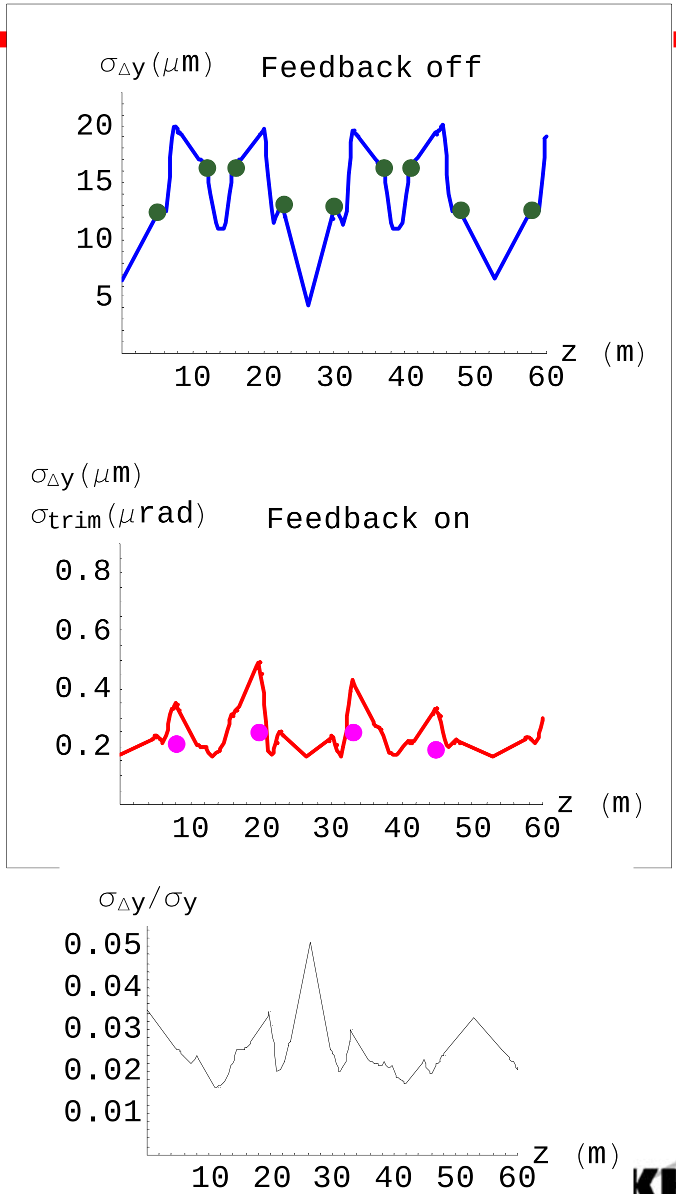
dipole

Sextupole

4 trims system compared with 2 trims

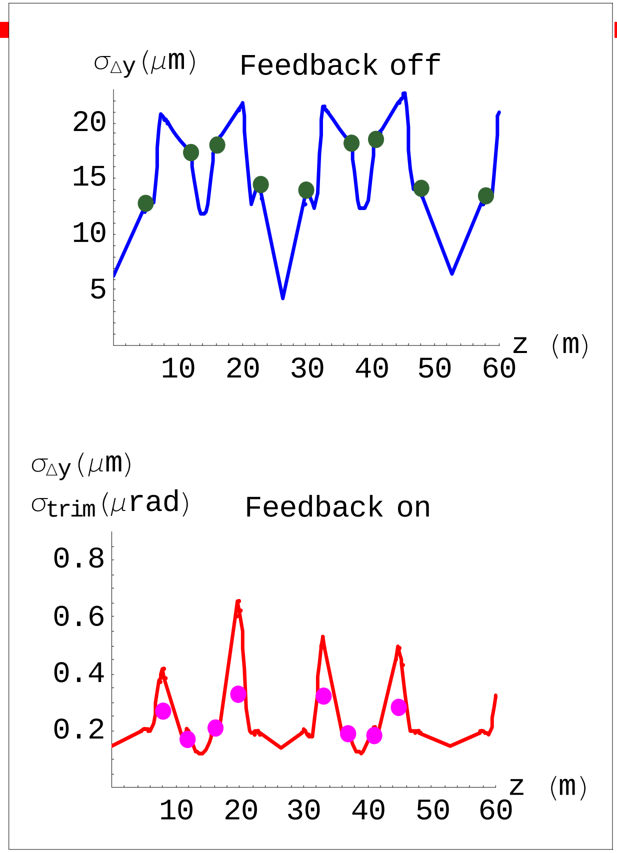


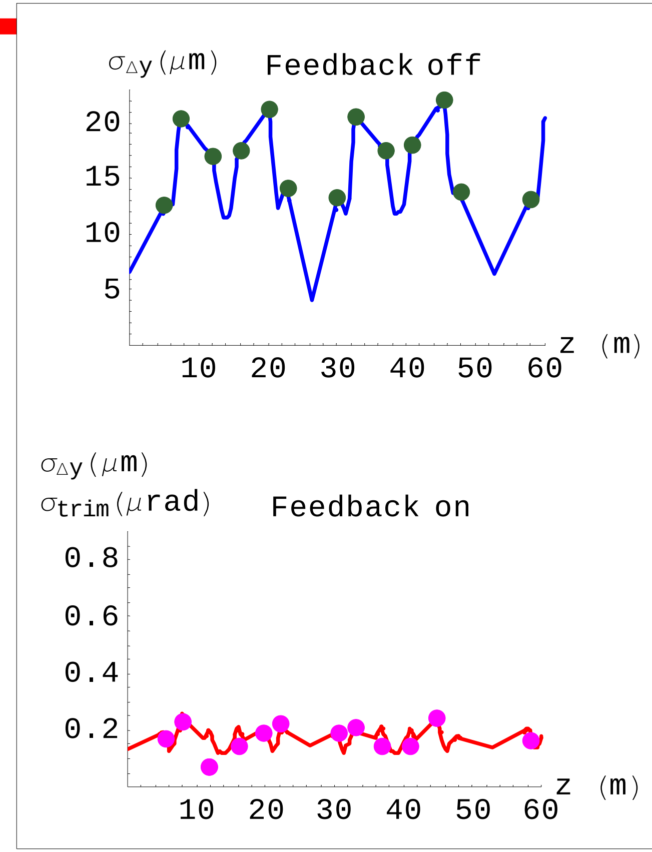
4 trims

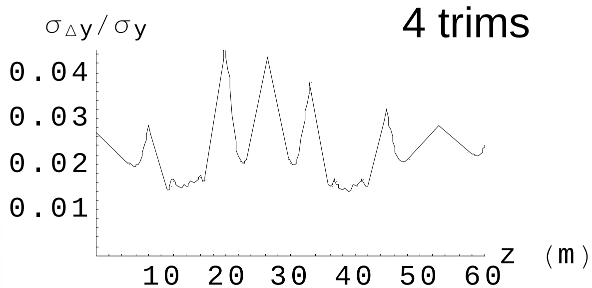


2 trims

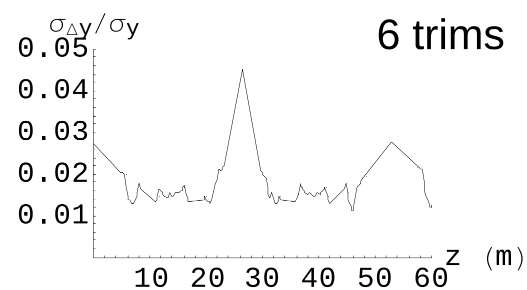
4 trims system compared with 6 trims





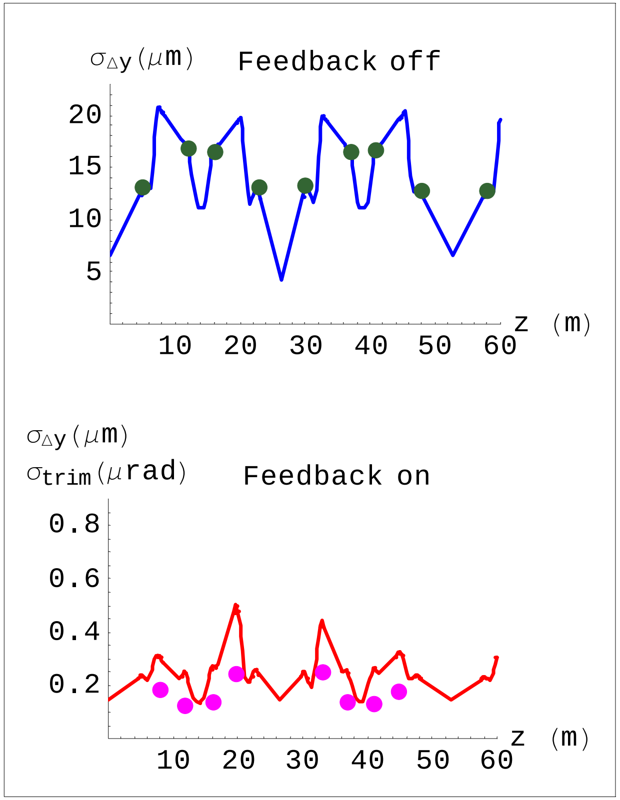


4 trims

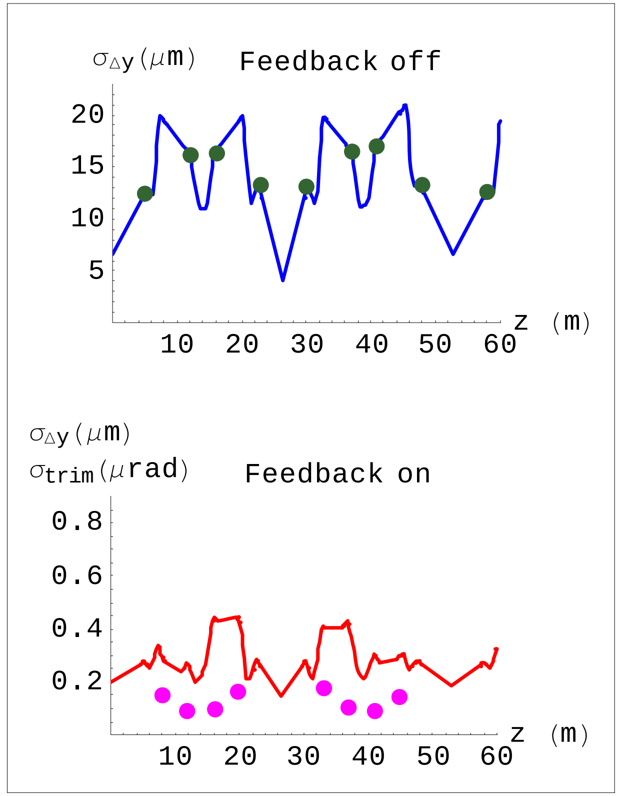


6 trims

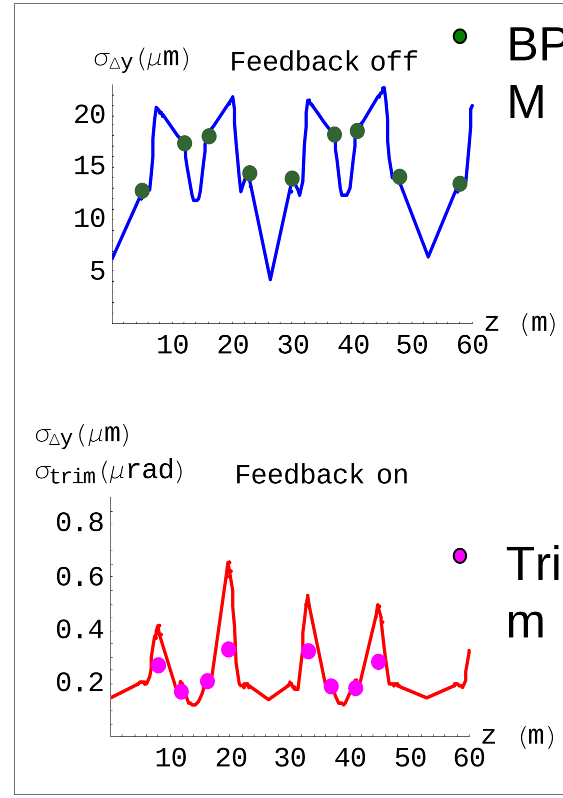
Result of using 80 singular values instead of 120



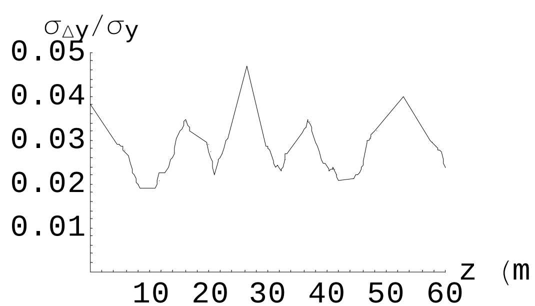
80

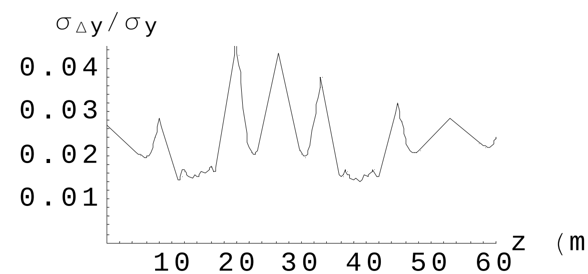


60



120





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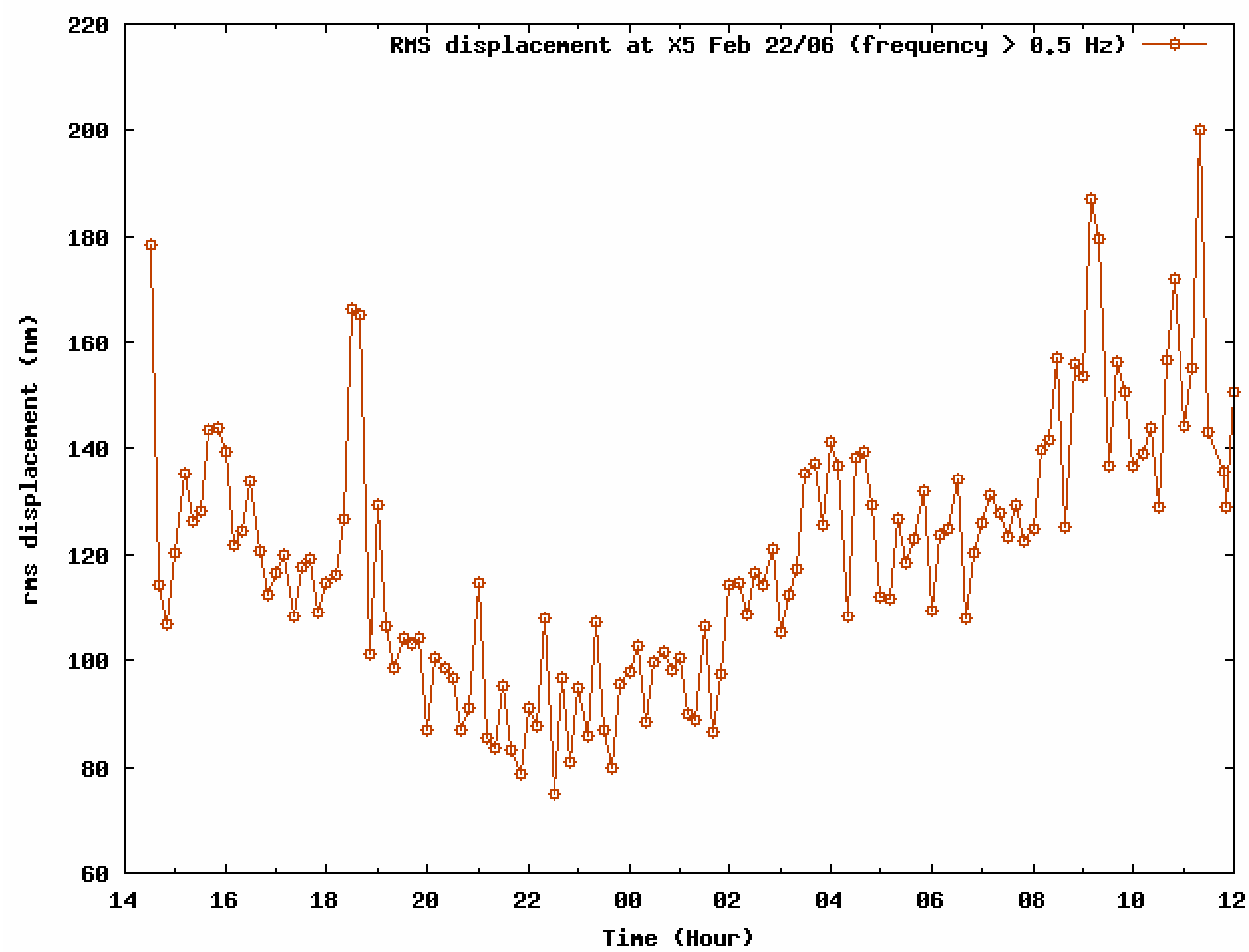
Local feedback

- Global is sufficient
- We have provisions for local with fast trim at ends of ID.

Stability of combined slow and fast feedback systems

- One system serves both as fast and slow feedback, works well.

DESY seismic sensor data at X5 Feb. 22-23 (frequency >0.5 Hz)



The vertical misalignment around the RHIC ring (the difference of the two measurement in 1997 and 2002), Vadim Ptitcin, (7/2004)