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Status of Beam Stabilisation at ESRF

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Slow orbit control

Installation of mechanical damping links

Fast orbit control

E.S.R.F Parameters

	H	V
Energy	6 GeV	
circumference	844.39 m	
emittances	4.0 nm	30 pm

Stability criterion

Emittance growth 20%

Fraction of beam size 10%

Fraction of divergence 10%

Reference: middle of a high-β straight section:

	H	V
β-function	35.1	2.5
Beam size	380 μm	9 μm
Required stability	38 μm	0.9 μm

Slow orbit control

BPMs

- 224 BPMs for a tune of 36.44 / 14.39

- Resolution: 1 μm with averaging

  6 x 10ms samples, spaced in opposite phase for 7Hz, main perturbation. The corresponding error on beam stability (for β_{BPM} = 20m) is:

	H	V
emittance growth	0.73%	8%
fraction of beam size	0.36%	4%
fraction of divergence	0.36%	4%

  This is not negligible in the vertical plane. Using a global correction method improves this number by eliminating uncorrelated errors.

- Offset calibration

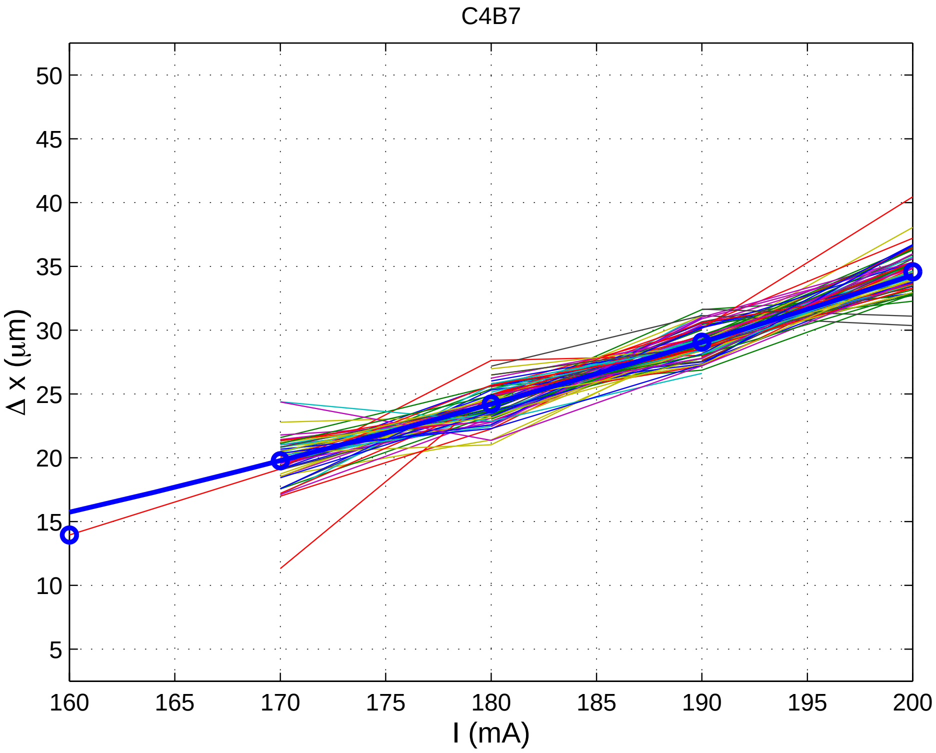
  Performed by varying the current in the quadrupole supporting each BPM. Resolution: 20 μm

  Periodic update necessary because of:

  - Ageing (cables…)
  - Replacement of multiplexors

❖ Calibration of drifts with beam intensity

Calibration using statistics on beam with a permanent smooth orbit correction: the real beam motion induced by possible magnet displacement is mostly corrected, while the uncorrelated BPM drifts are not. Very slow motion is eliminated.



BPM drift with beam intensity (4 weeks)

The process can be iterated.

The drift depends on the fillin pattern

The drift is shared between

- mechanics (thermal displacement)
- electronics (differential saturation)

Periodic update is also necessary to take into account:

- Ageing
- Replacement of multiplexors

Steerers

96 steerers in each plane

Combined function correctors using additional coils on sextupole yokes.

15-bit DAC

The resolution was improved by reducing the full range by a factor 4.

	H	V
Range (mrad)	0.66	0.41
Resolution (mrad)	$4.1\ 10^{-6}$	$2.6\ 10^{-6}$

Consequently, the errors made when setting a global correction (96 random errors) are:

	H	V
Emittance growth	0.24%	1.52%
Fraction of beam size	0.12%	0.76%
Fraction of divergence	0.12%	0.76%

For resolution errors, the BPMs are now slightly dominating.

Correction method

Global correction by SVD method applied every 30 s.

Using measured response matrices.

Using a limited number of Eigen vectors to limit the sensitivity to BPM drift and resolution errors.

Target: zero orbit (no "golden orbit" definition).

Horizontally:

- 224 BPMS + constraint on steerers: $\sum I = 0$
- 96 steerers + RF frequency

  This is to avoid any influence of orbit control on beam energy.

Vertically

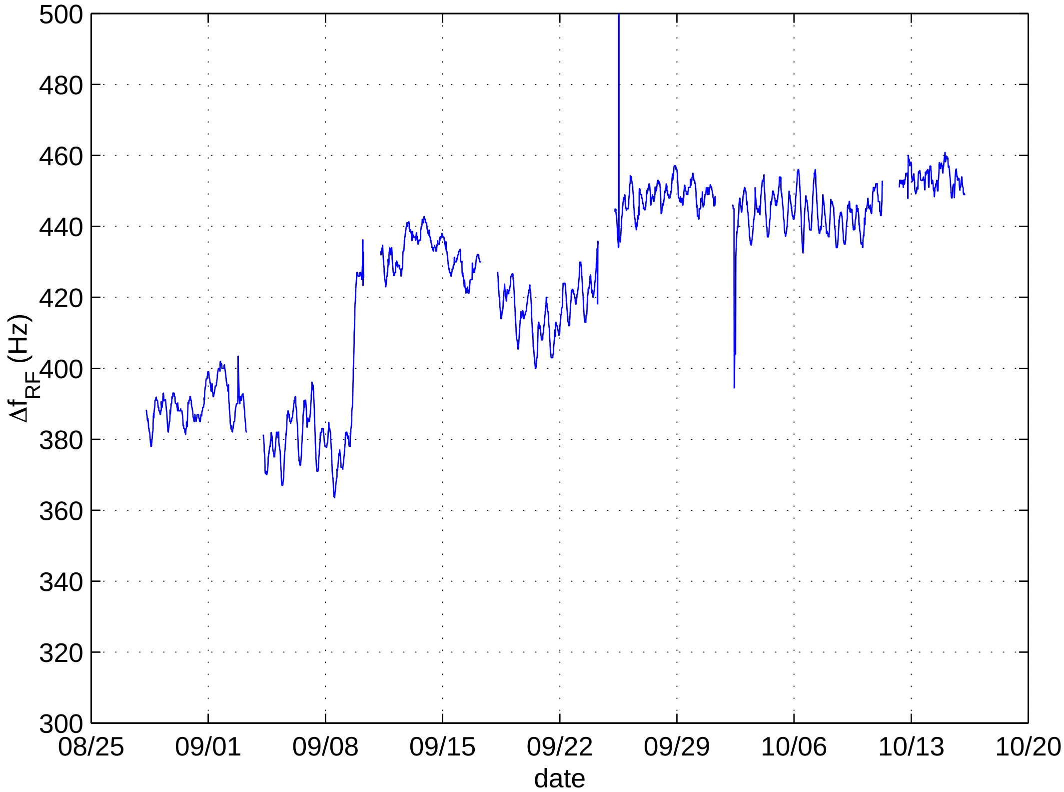
- 224 BPMs
- 96 vertical steerers

The choice of the optimum number of Eigen vectors is based on an estimate of the amplitude of BPM drifts.

Control

- Electron BPMs: as we have much more BPMs than steerers, we can have "independent" monitors.
- Pinhole cameras
- X-BPMs:

Influence of RF frequency control:



Evolution on the RF frequency over 1 run

- Daily evolution: without correction, ± 10Hz would give ΔE/E=±1.5 10-4
- Slow fluctuation

Long term performance

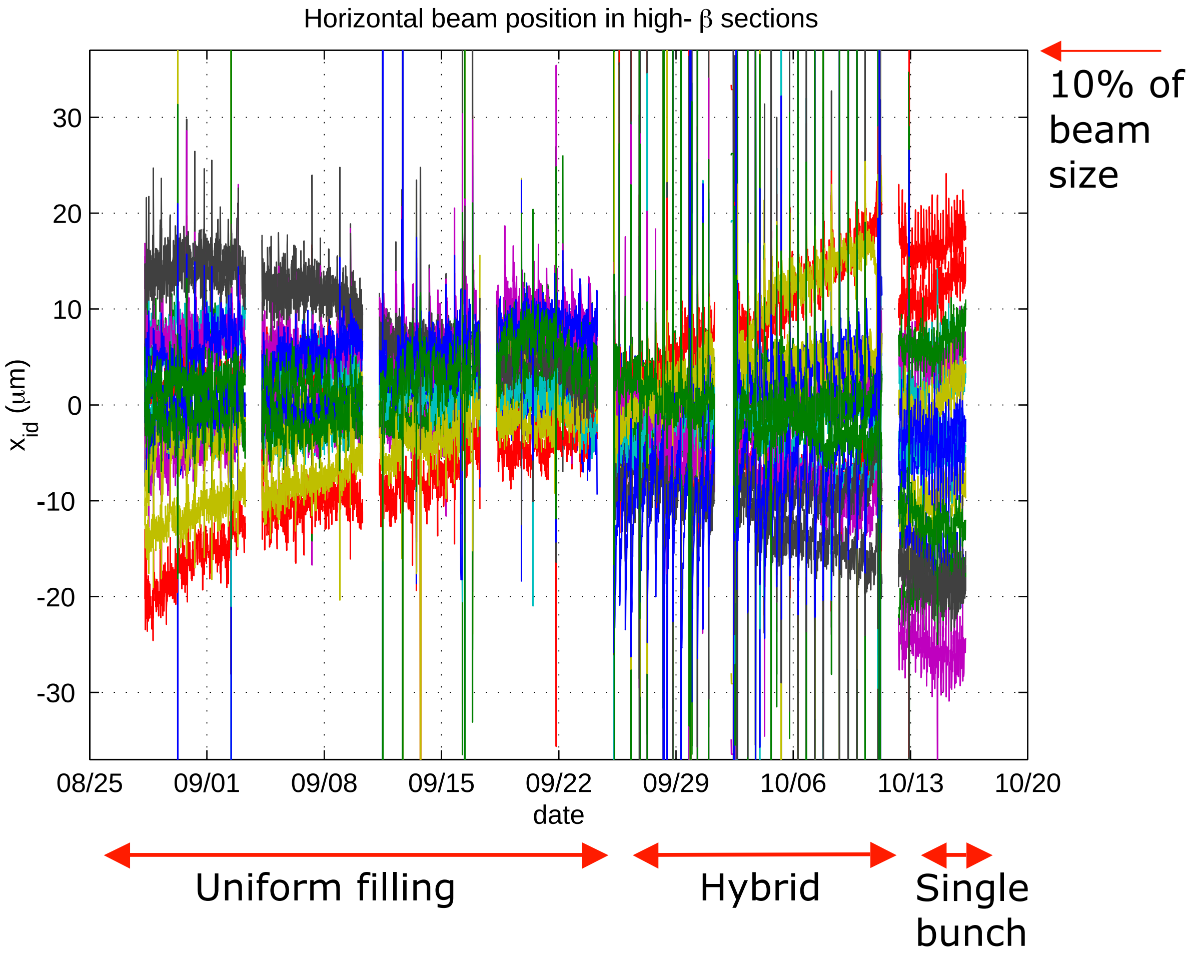
Data taken over a full run: 7 weeks.

The values are averaged over slices of 15 minutes.

The beam position is computed in the middle of straight sections.

All 16 sections superimposed

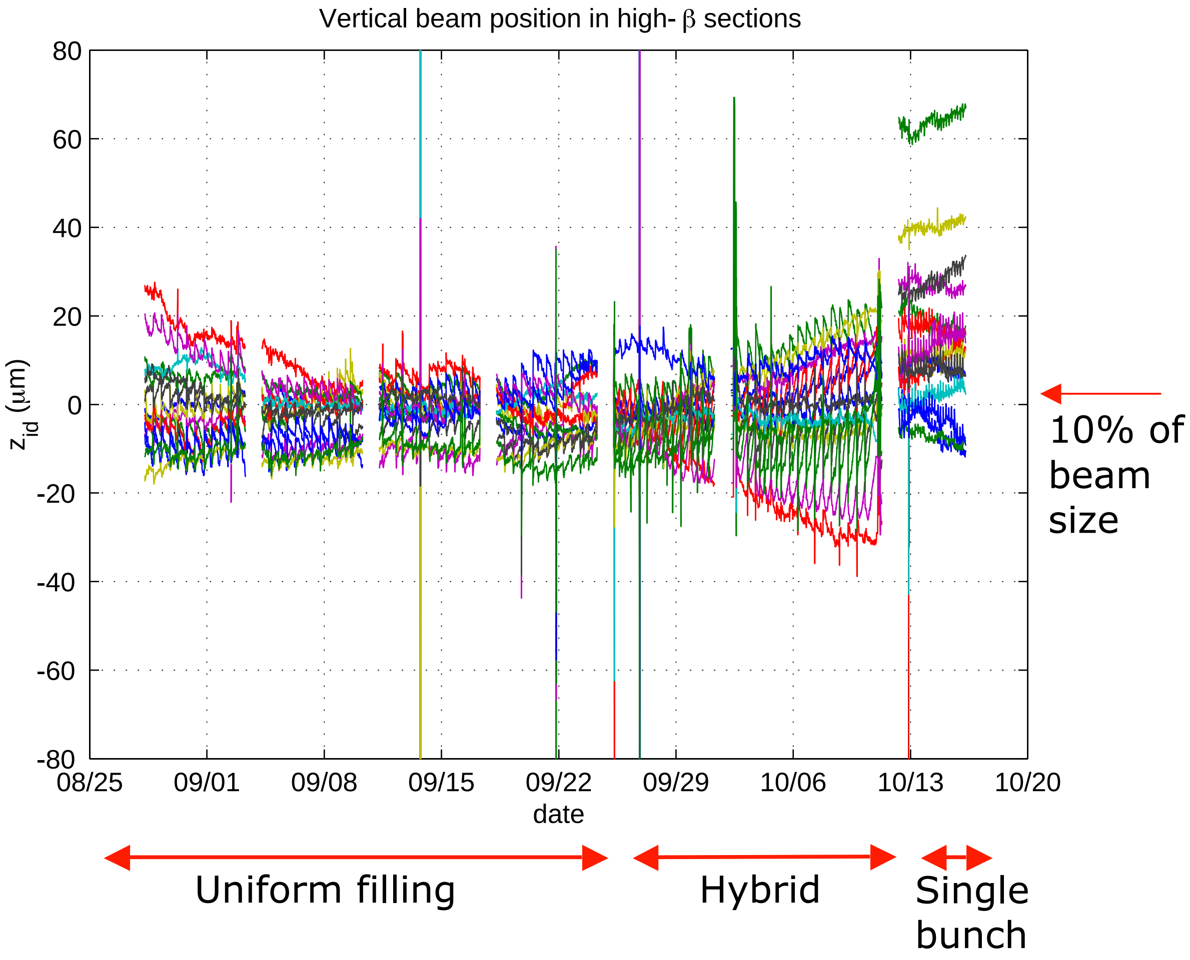
Horizontal



Horizontal beam motion
in the middle of high-β straight sections
(β_x = 35.1 m, σ_x = 380 μm)

- 10% of horizontal beam size achieved over 6 weeks
- visible influence of the filling pattern

Vertical



Vertical beam motion
in the middle of high-β straight sections
(β_z = 2.5 m, σ_z = 9 µm)

- 10% of beam size are exceeded
- influence of the filling pattern
- problem of referential: the ground itself is not an absolute reference in that range.

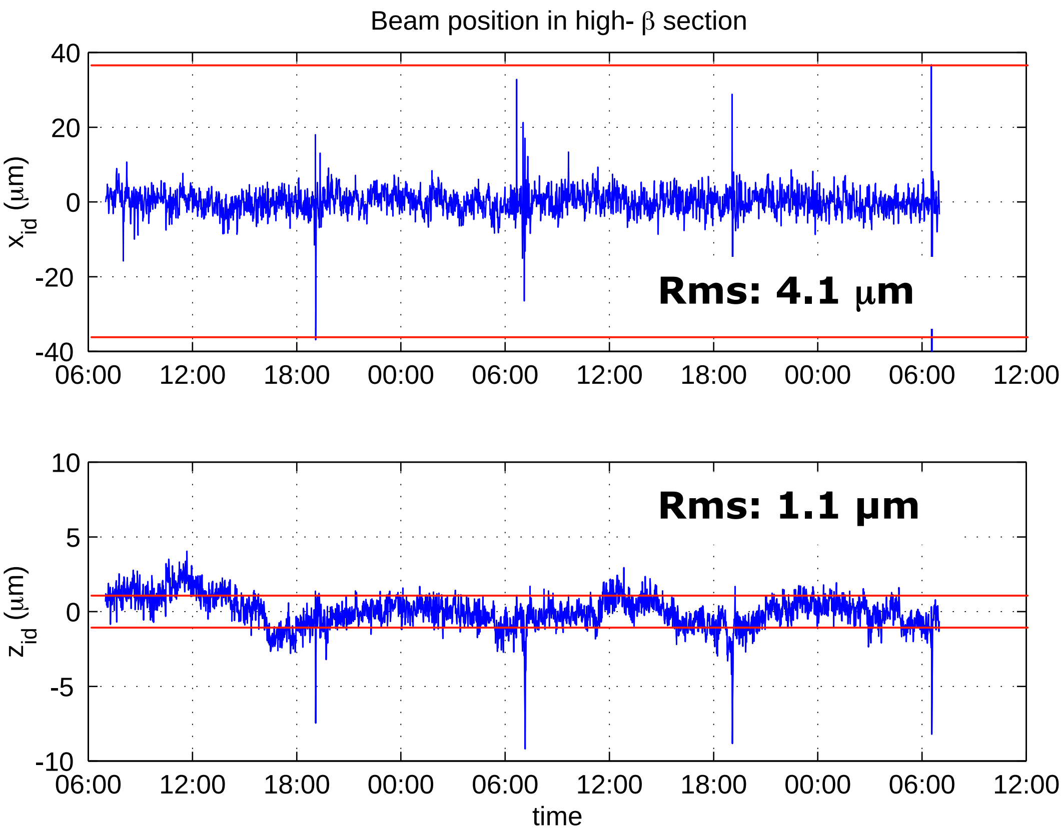
Medium term stability

The beam position is computed in the middle of straight sections.

The position sampled every minute.

Integration over 60 ms.

2 days, uniform filling.

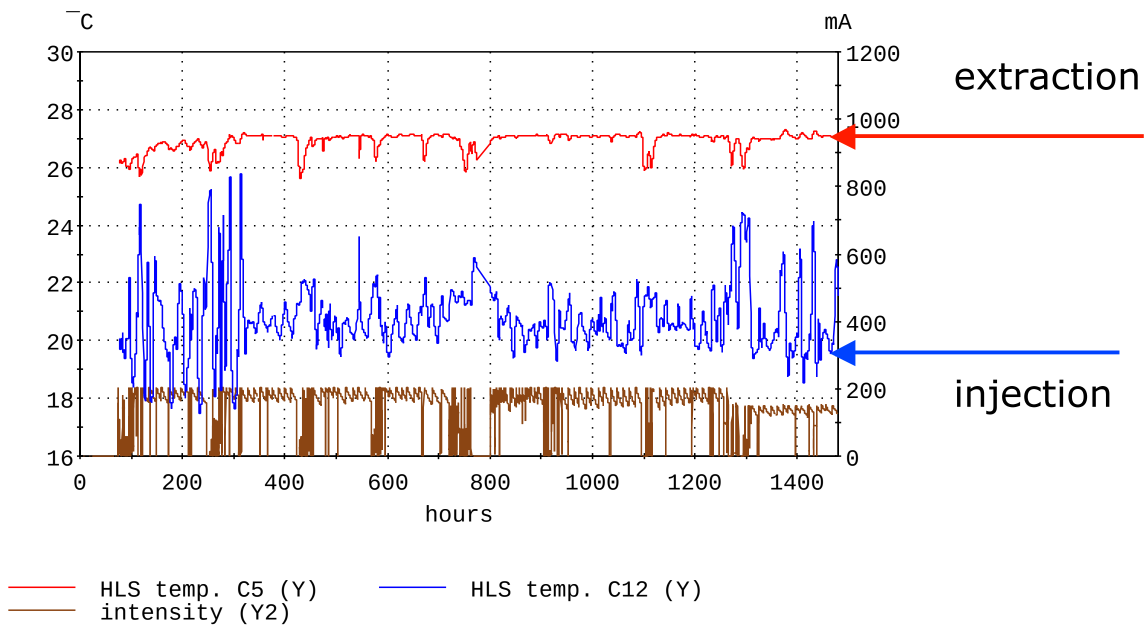


Beam motion in the middle of a high-β straight section
(β_x = 35.1 m, σ_x = 380 μm)
(β_z = 2.5 m, σ_z = 9 μm)

Example of bad behaviour: Air temperature control in the tunnel

The tunnel is split in 4 quadrants, cooled air is injected at one end of each quadrant and extracted at the other end.

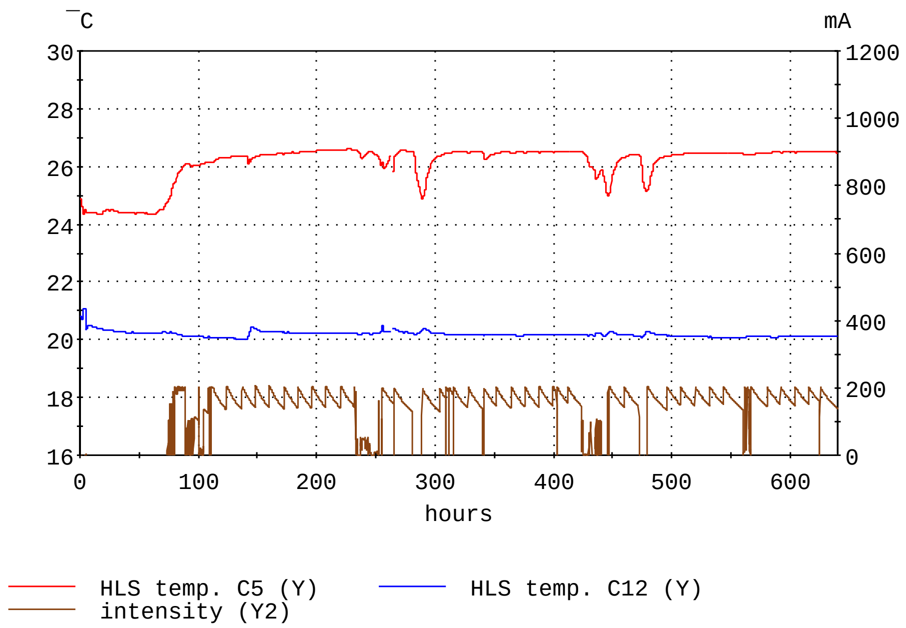
Initially, the regulation sensor was near the extraction end



Before modification

We see very large oscillations of the temperature of injected air (very long delay in the regulation loop).

The regulation sensor was then moved to the injection end



After modification

Improvement on long-term stability
Faster stabilization after shutdown

Conclusion

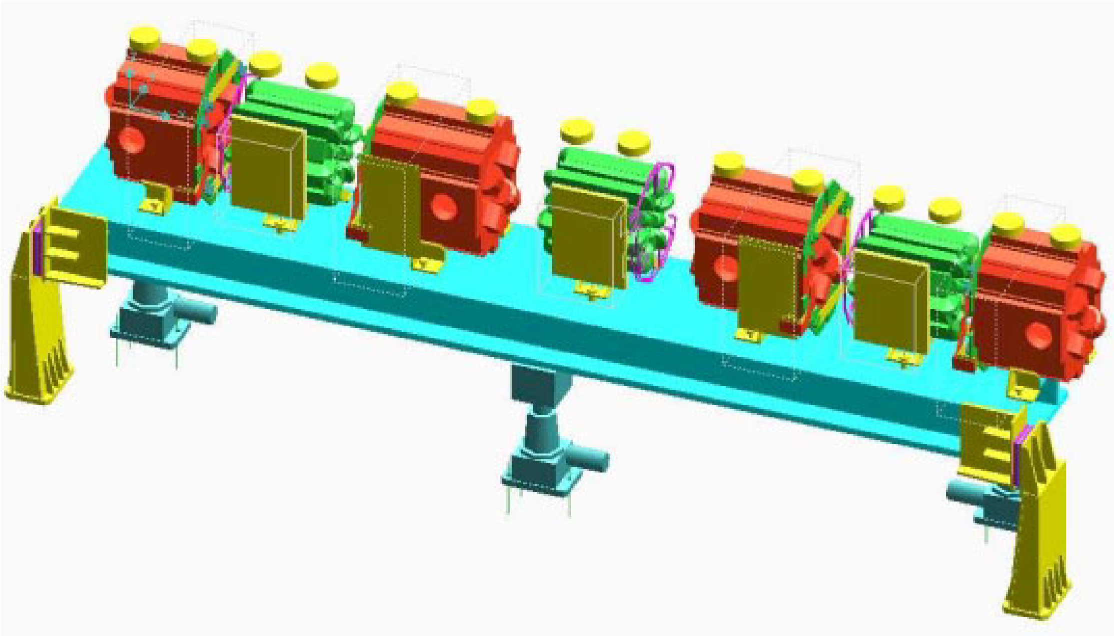
❖ Unfortunately, with this method of ventilation, we cannot avoid a large temperature gradient along the section, varying with:

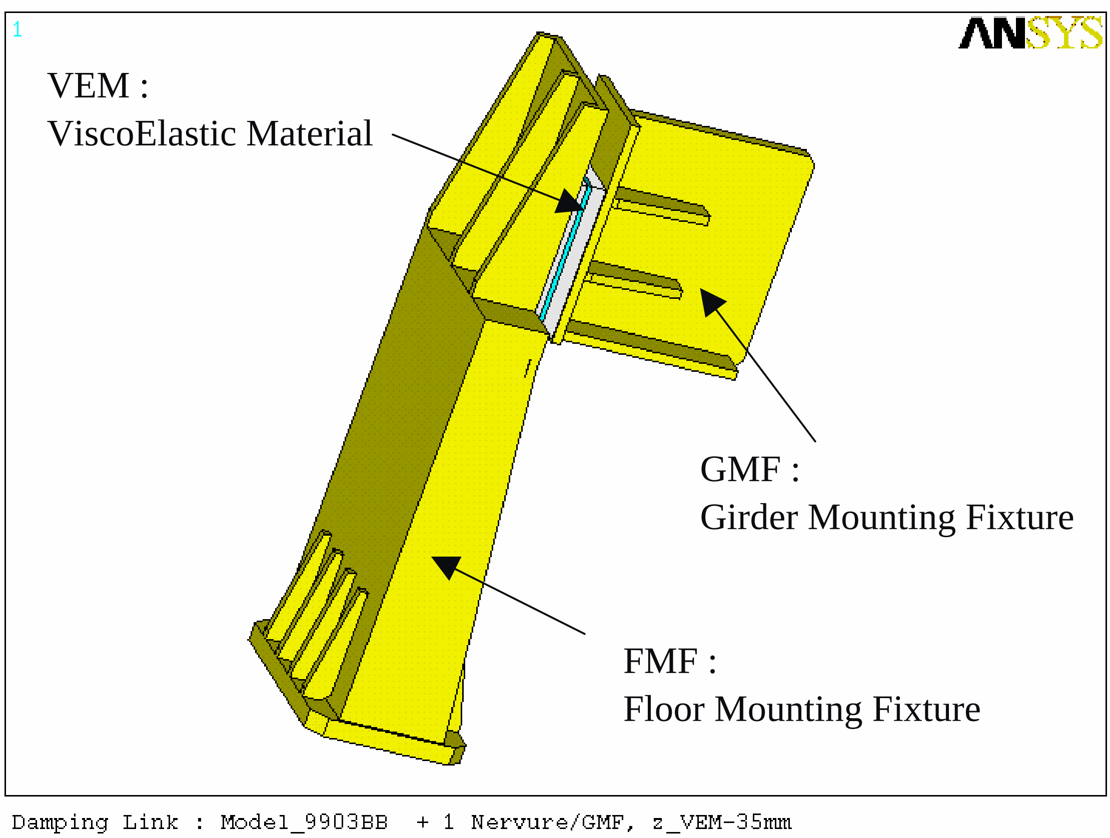
- Magnet powering
- Stored beam

❖ However, the way the regulation is done has a strong influence.

Installation of damping links

Design

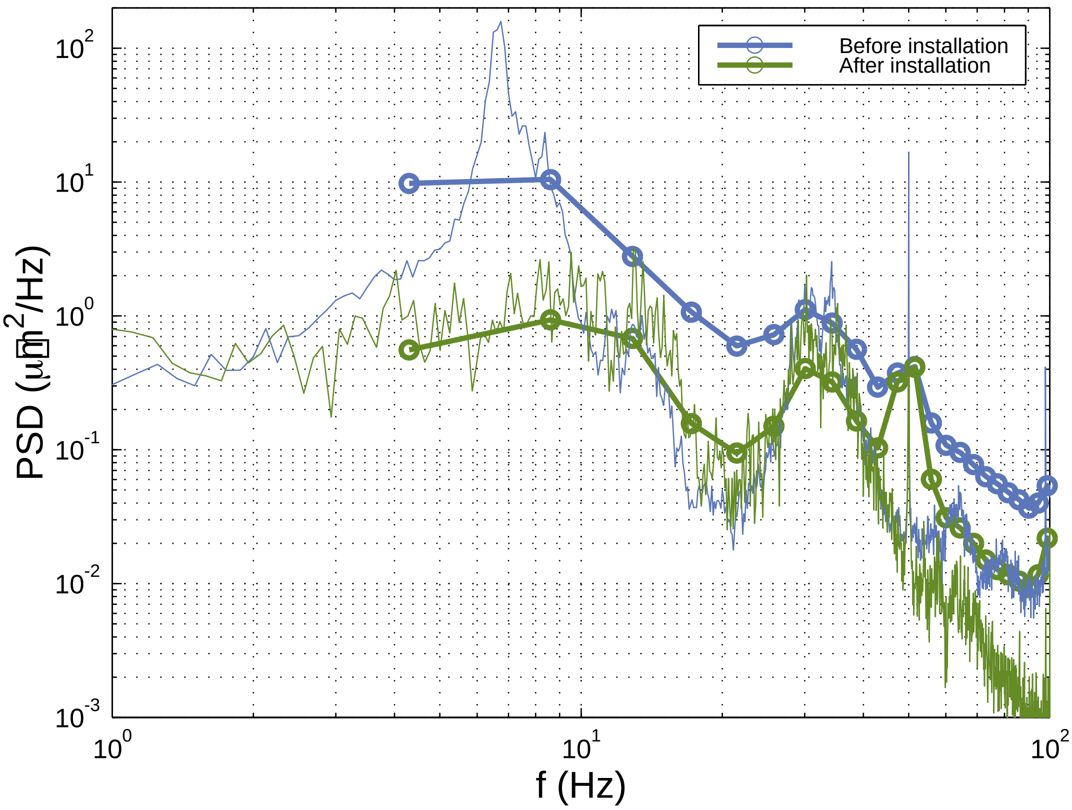




Performance

horizontal plane

Measurement with feedback BPMs



Single-side PSD of horizontal beam motion

Fast orbit control

BPMS

Dedicated BPMs, located at the end of straight sections

- Higher sensitivity (larger buttons, smaller vertical aperture).
- Dedicated electronics: low noise. Resolution 20 nm/√Hz
- Beam intensity range: 5 mA to 200 mA
- Multiplexed system, sampling frequency 4.4 kHz
- We do not care about long term stability, drifts

Steerers

- Air coils, located et the end of straight sections (around bellows)
- bandwidth limited by the vacuum chamber.
- Range: 40 μrad

System

- Digital, DSP based system
- The loop runs at 4.4 kHz
- Bandwidth 0.1 - 200 Hz. We eliminate the DC component. The decoupling between slow control and feedback is made by in the frequency domain.

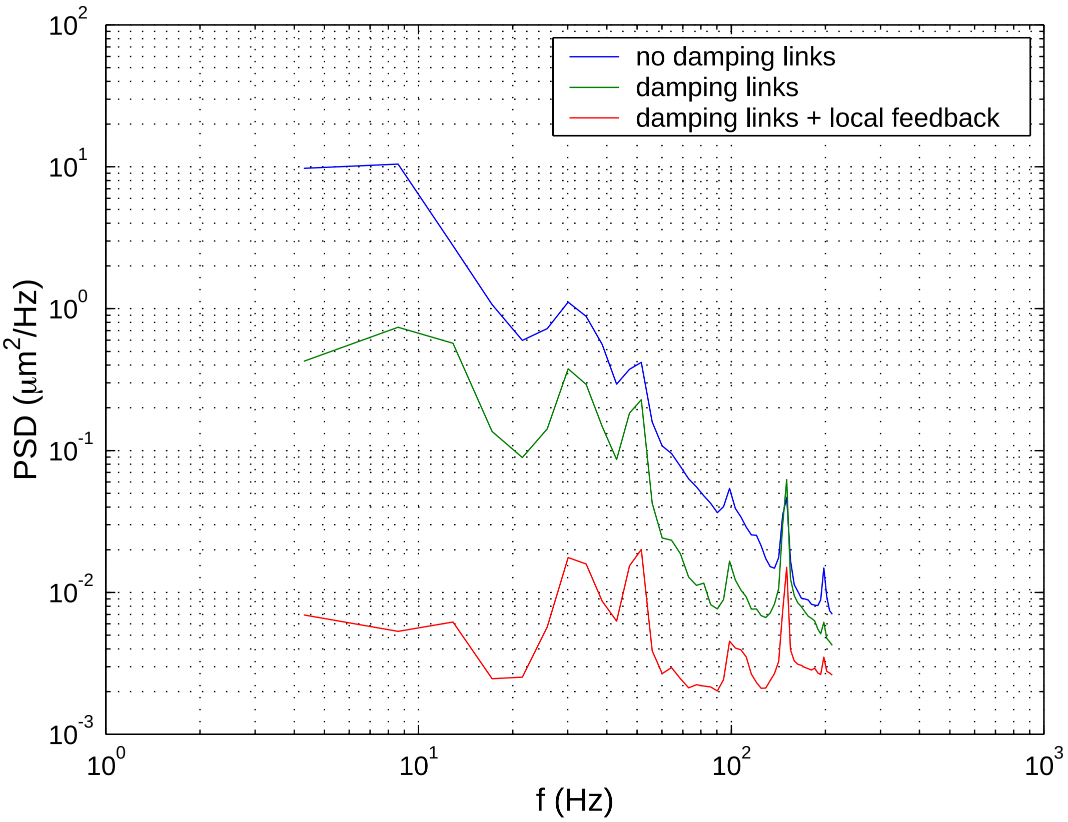
Control

BPMs: 4.4kHz sampling, 1024 points archived per sample

- Frequency resolution 4.3 Hz
- Bandwidth 200Hz

Performance
Horizontal plane

❖ 4 independent local horizontal feedbacks using 2 BPMs and 4 kickers (closed bumps)



Horizontal beam motion in high-β straight sections

\+ Very efficient

— Limited control: no independent BPM

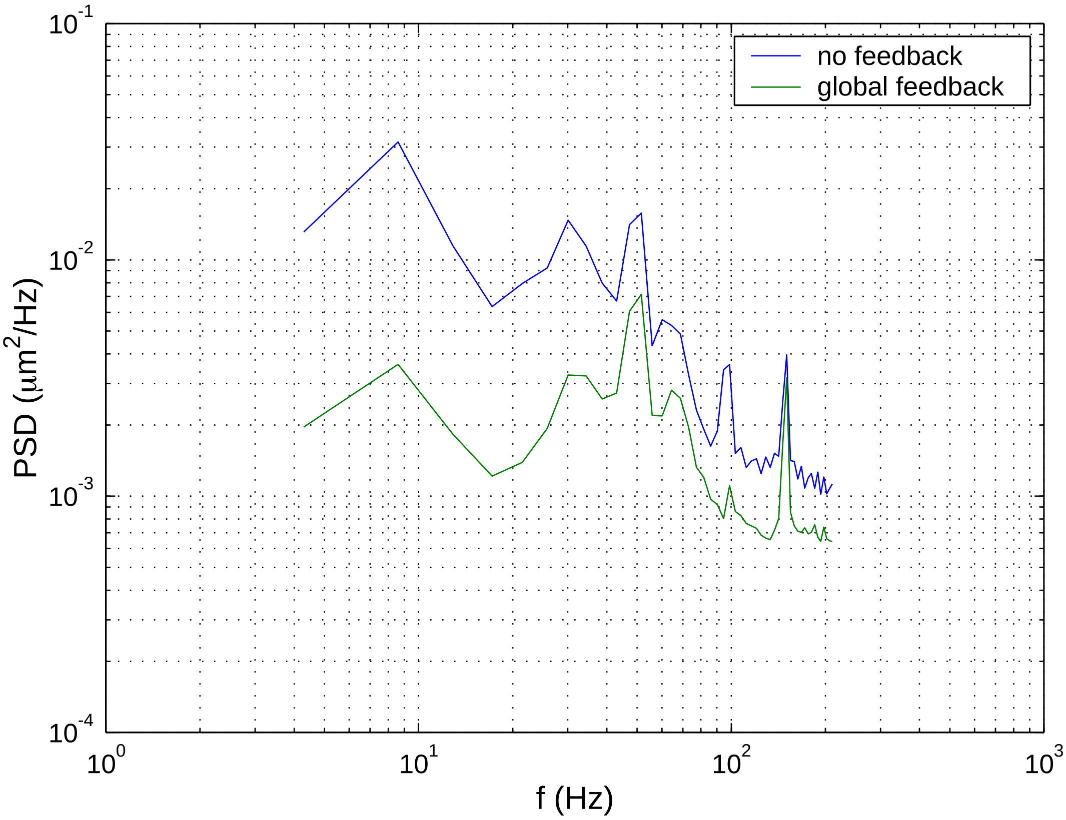
— No fault tolerance: any failure causes the feedback to stop

— Cannot be generalised (crosstalk)

— Matching (lever arm / β-function) not optimal

Vertical plane

- Global vertical feedback
- 16 BPMs, 16 steerers
- SVD algorithm, PID applied to correction Eigen vectors.



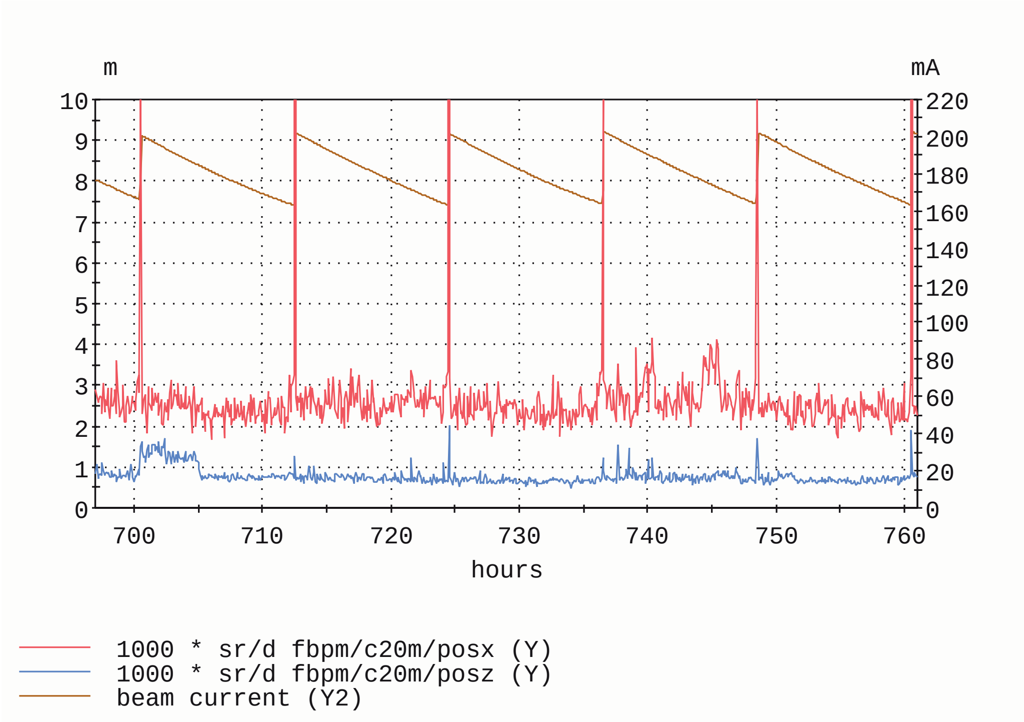
Vertical beam motion in high-β straight sections

— Limited efficiency: After improvements of H/V coupling and addition of damping links, the vertical motion is so small that the feedback efficiency is limited by the noise level.

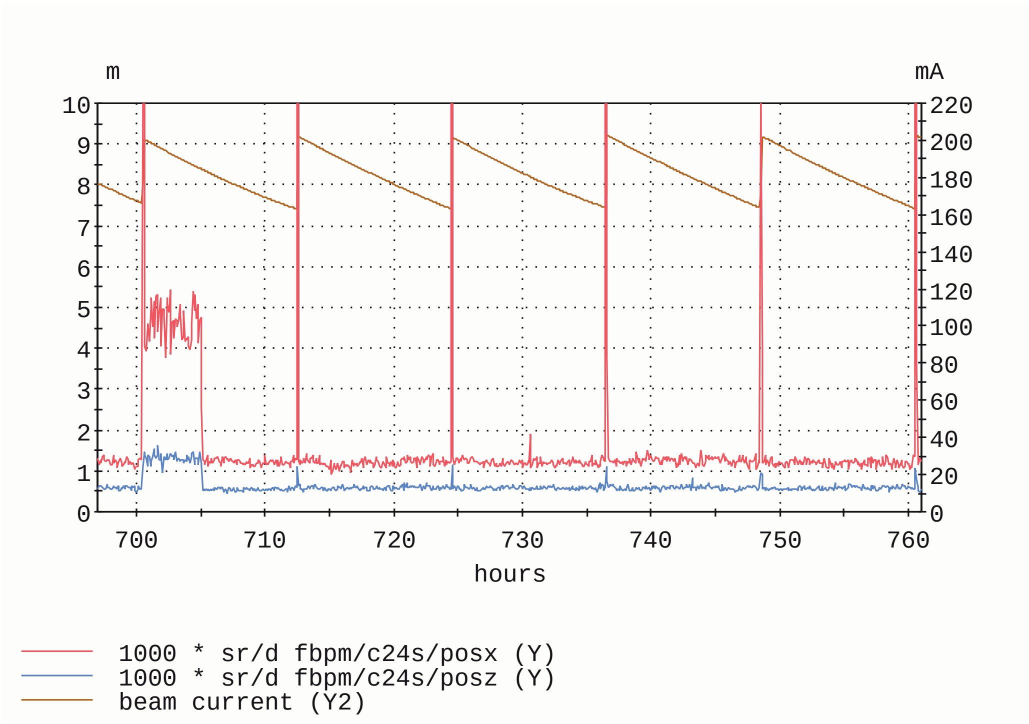
\+ We have a number of independent BPMs that can monitor the performance

\+ Runs well in case on BPM or steerer failure

Time domain



Section without feedback



section with feedback

Limitations:

- The bandwidth is limited by the steerer design: eddy currents in the vacuum chamber.
- The noise level is limited by the BPMs (multiplexing technology)

New developments

Replacement of all the horizontal local feedbacks by a global feedback.

- using 32 BPMs and 32 steerers (higher horizontal tune).
- Higher above the noise level (efficiency should be better)
- New hardware for the digital part.

Expected gain:

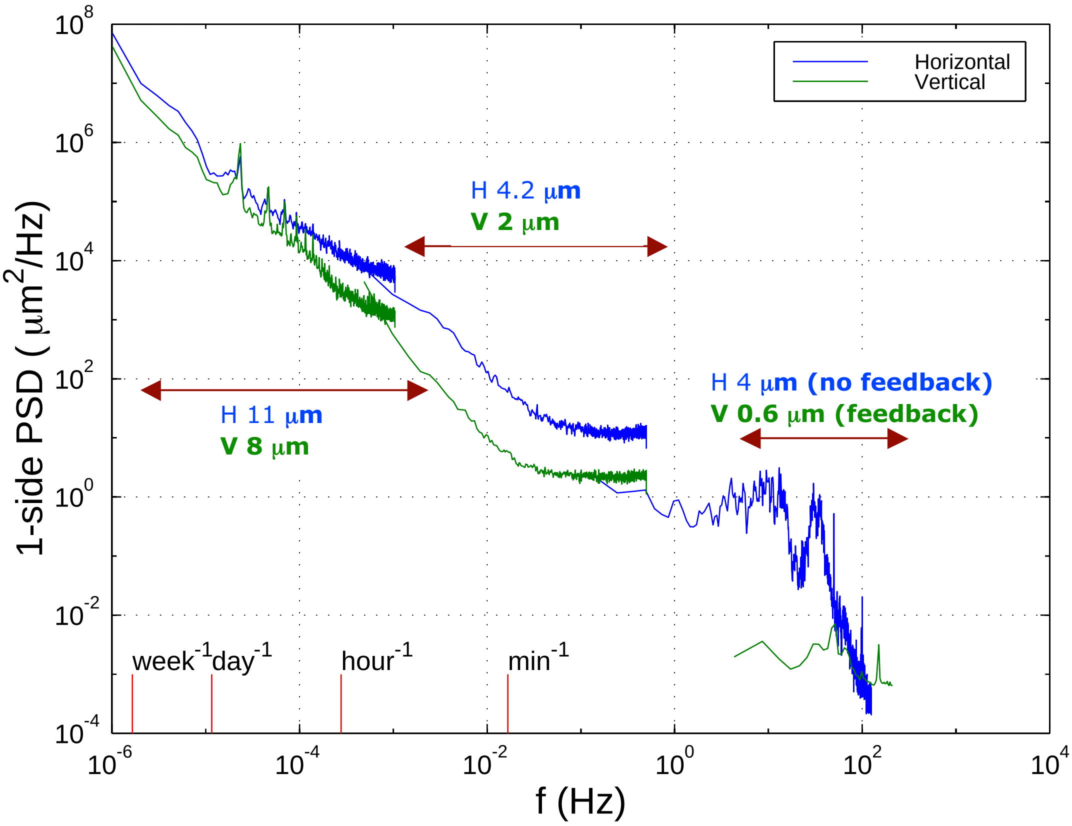
- Beneficial everywhere around the machine
- High reliability: can work with missing BPMs and steerers

Performance summary

The broadband PSD can be plotted using several diagnostics:

- Low frequency: standard BPM archived in the history database and averaged over slices of 8 minutes.
- Medium frequency: live reading of standard BPMs: 1Hz sampling frequency
- High frequency: statistics on fast BPMs: 4.4 kHz sampling frequency

Frequency domain



Beam motion on straight section BPMS
(β_x = 35.4 m, β_z = 6.2 m)
(σ_x = 360 μm, σ_z = 15 μm)

Caution

Data at low frequency assume that the monitors are "fixed points"

Time domain

r.m.s. beam position on straight section BPMs

Horizontal (β_x = 35.4 m)

	4-12 Hz	4-200 Hz
no damping links (μm)	10	12
with damping links (μm)	2.7	4
damping links+feedback (μm)	0.28	1

Vertical (β_z = 6.2 m)

	4-12 Hz	4-200 Hz
no damping links (μm)		
with damping links (μm)	0.5	1
damping links+feedback (μm)	0.17	0.6

Conclusion

The combination of slow control and mechanical damping brings the vibration level to an acceptable level (less than 10% of beam size). However some users require a much better stability. This can be achieved by feedback.

Reaching the micron range requires the combination of all the available approaches.

The amplitude of very slow motion is still dominant.