Orbit Stabilization at ATF2

Andrea Latina (CERN)

Many thanks to Juergen Pfingstner from whom I borrowed several slides

18th ATF2 Project Meeting – Feb 24-26, 2015 – LAPP, Annecy

Introduction and context

- Ground motion, vibrations and drifts, affect the beam quality and harm the beam stability
- Trajectory Orbit Feedback can typically correct frequencies less than a fraction of the repetition frequency, higher frequencies remain uncorrected
- Intra-train feedbacks can help at the IP, but when the intra-bunch spacing is very short (e.g. CLIC, 0.5 ns), global orbit distortions remain uncorrected (banana effects)
- Active and passive stabilization of the components might be considered (CLIC), but its large mechanical setup (hundreds of tons of concrete) limits its applicability to specific systems (e.g. the final doublet)
- Novel idea: use Ground motion sensors to anticipate and counteract the induced misalignments via feed-forward loops. Quite a large project: split into two parts:
  - first, the prediction of the ground motion effect on the beam orbit
  - second, the correction of the predicted orbit changes

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **17,** 122801 (2014)

Mitigation of ground motion effects in linear accelerators via feed-forward control

J. Pfingstner, K. Artoos, C. Charrondiere, St. Janssens,[†] M. Patecki,[‡] Y. Renier,[*]
D. Schulte, and R. Tomás
European Organization for Nuclear Research (CERN), Geneva 23, CH-1211, Switzerland

A. Jeremie
LAPP, Université de Savoie, 9 Chemin de Bellevue, 74941 Annecy-le-Vieux, France

K. Kubo, S. Kuroda, T. Naito, T. Okugi, T. Tauchi, and N. Terunuma
High Energy Accelerator Research Organisation (KEK) and School of High Energy Accelerator Science, Graduate University for Advanced Studies (SOKENDAI), 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan
(Received 24 September 2014; published 4 December 2014)

Ground motion is a severe problem for many particle accelerators, since it excites beam oscillations, which decrease the beam quality and create beam-beam offset (at colliders). Orbit feedback systems can only compensate ground motion effects at frequencies significantly smaller than the beam repetition rate. In

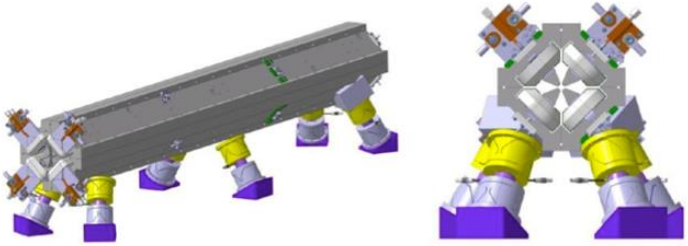
Ground motion effects and mitigation schemes

- Ground motion effects:
  - Problem for performance of future linear colliders.
  - Misaligned quadrupoles create beam oscillations.
  - Mitigation methods are necessary.

- Orbit feedback systems and transverse damping systems:
  - Very efficient for frequencies significantly below the beam (train) repetition rate $f_{R.}$
  - Higher frequencies cannot be suppressed.
  - f_R is small at linear colliders: 5 Hz (ILC), 50 Hz (CLIC).

- Intra-train feedback systems:
  - Very efficient for ILC.
  - Not sufficient for CLIC, due to the very short bunch spacing.
  - Also no spatially distributed corrections possible.

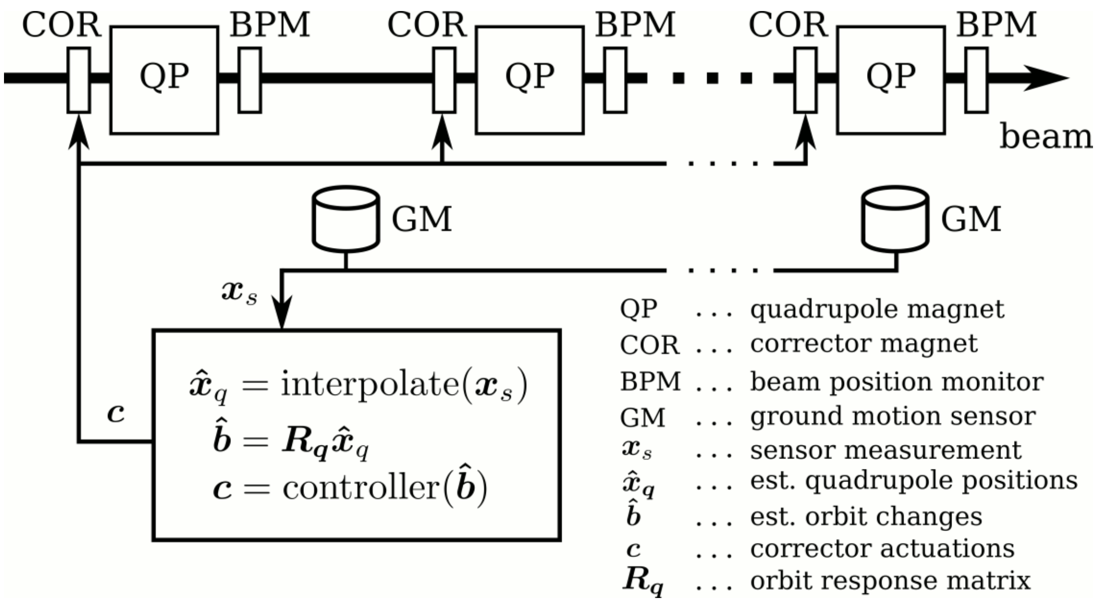
- Active and passive stabilisation systems:
  - Baseline for CLIC.
  - Relative costly.
  - Complex integration.



K. Artoos et al.

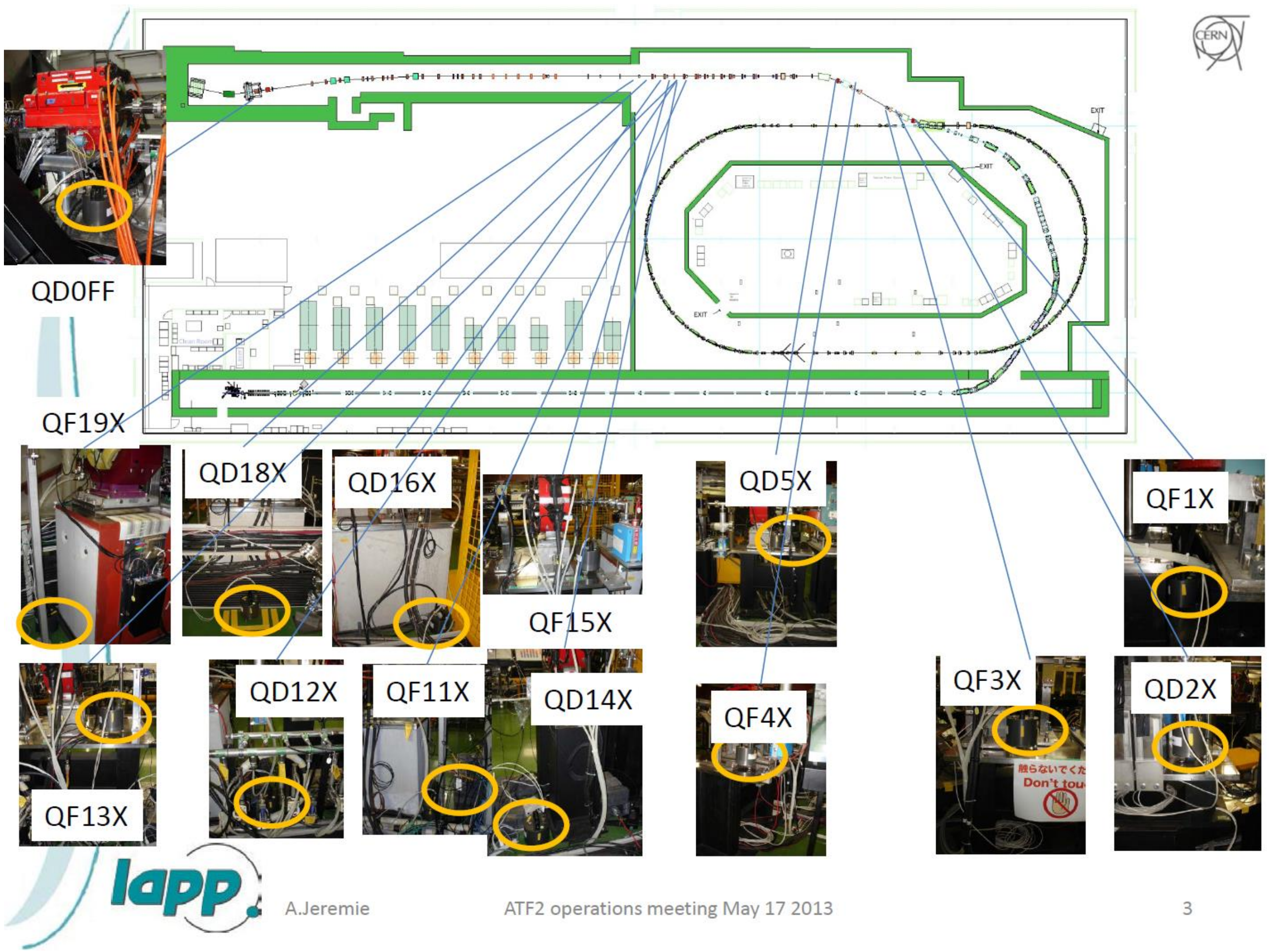
Ground motion mitigation via feed-forward control

- Concept is similar to an orbit feedback system.
- But ground motion measurements are used to predict the orbit changes.
- Orbit offsets are already corrected before the beam train arrives (feed-forward vs. feedback).



- Advantages:
  1. System is faster than orbit feedback systems.
  2. It is cheaper and easier to implement than stabilisation systems.
  3. It is also efficient, when the bunch spacing is very short and when the beam oscillations have to cured distributed along the machine (CLIC).

Experimental setup at ATF2

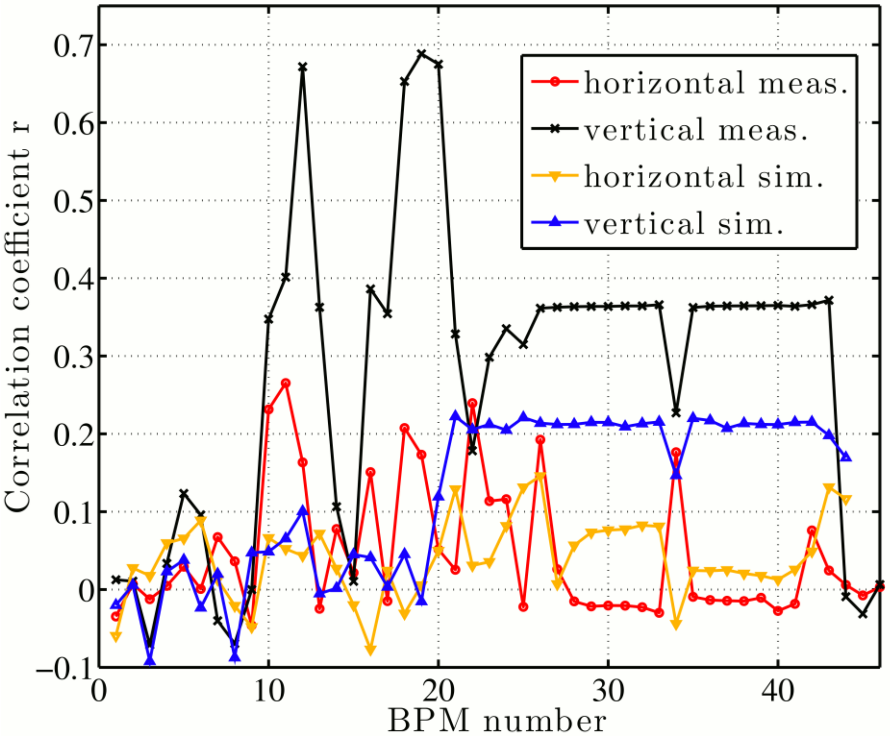


- 14 vibration sensors have been installed.
- National Instruments data acquisition hardware.
- Synchronisation signals for BPM and ground motion data are formed.

Y. Renier

Experimental results at ATF2

- Full demonstration split into two parts:
  1. Prediction of orbit change due to ground motion measurements.
  2. Correction of the predicted changes (future work).
- Measure: correlation coefficient *r* computed from the measured orbit changes (BPMs) and the predictions.

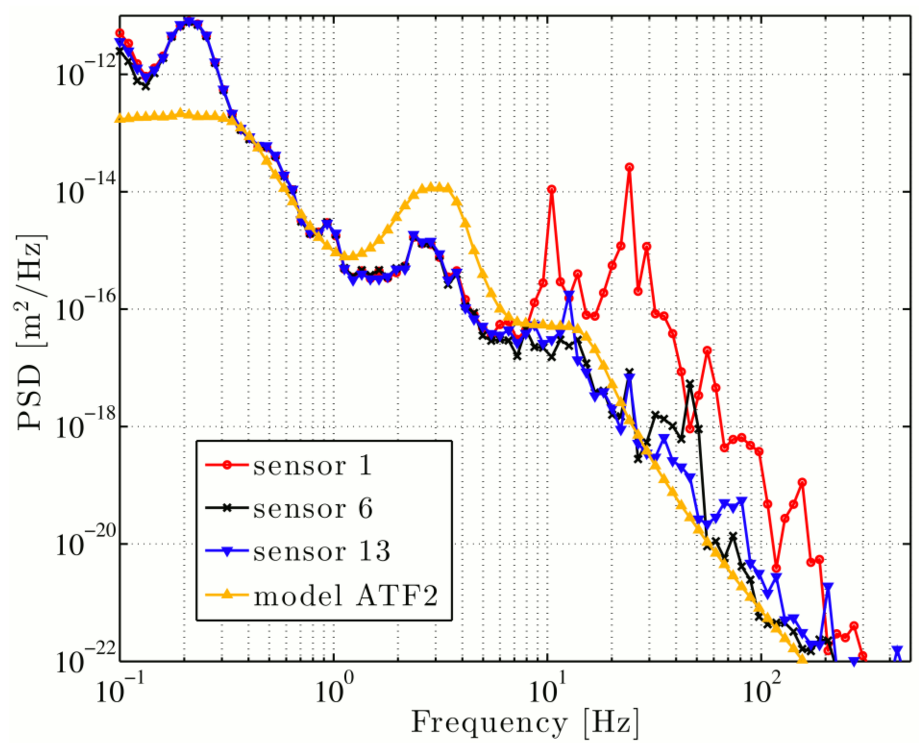


- Results:
  1. High correlations observed: *r* up to 0.7 in the vertical direction.
  2. Prediction of orbit changes due to seismometer measurements was successful.

J. Pfingstner

Ground motion analysis

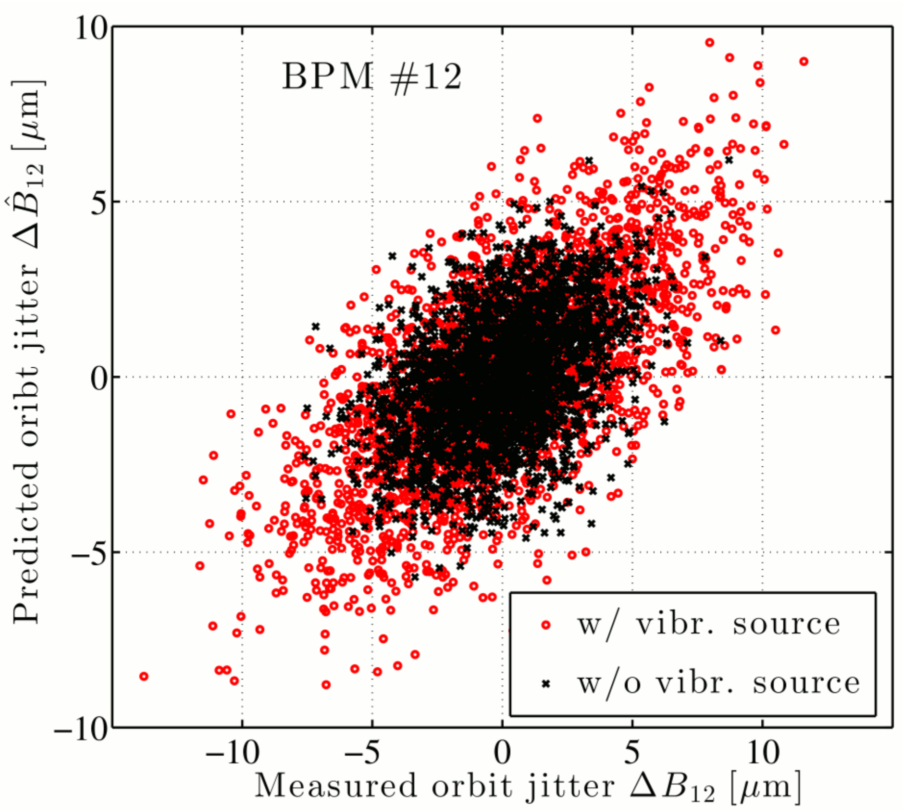
- Simulation forecast: only a small fraction of the orbit jitter at ATF2 is due to ground motion.
- Small *r* was expected, which is in contradiction to measurement results.
- Explanation of discrepancy: strongly increased vibrations measured by sensor 1.
- Local vibrations source with frequencies from 10 Hz to 100 Hz.



J. Pfingstner

Orbit jitter reduction

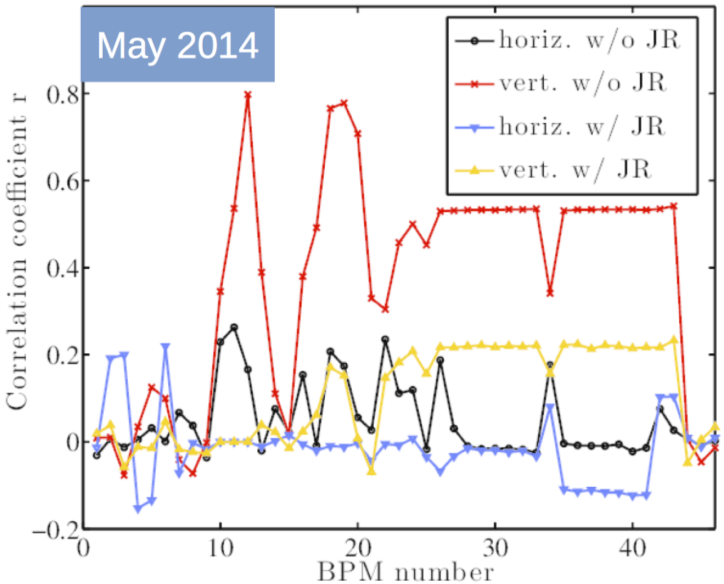
- Beamline around sensor 1 has been inspected.
- Two vibration sources (water cooling pipes) could be identified.
- After the removal of the two sources, the RMS orbit jitter was reduced by a factor 1.4.
- This corresponds to halving the excitation power.

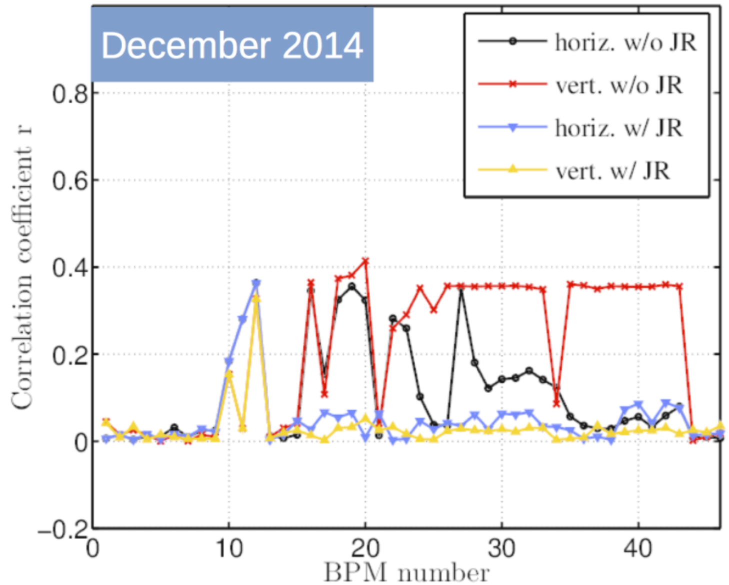


J. Pfingstner

Update on GM measurements

Correlation coefficient along the beamline (May and December comparison)





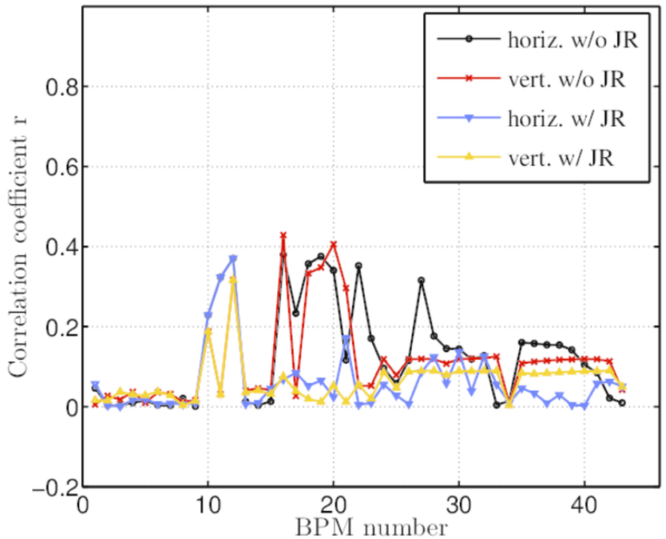
- $10\beta_x 1\beta_y$ optics (β_x= 40mm, β_y=100µm);
- BPMs #10,11,12 are used for jitter reduction (JR);
- In May there was a vibration source downstream from BPMs #10,11,12 (next to QD10X, QF11X, QD12X);

- This vibration source was removed (maybe during the OTRs investigation?);
- The only source left is upstream from BPMs #10,11,12;
- In May sensors #1,2,3 were installed on the top of QPs, in Dec next to Qps
- More horizontal correlation in Dec. (S11?)

M. Patecki

Update on GM measurements

Correlation coefficient for $0.5\beta_y^*$ (50 μm)



- Horizontal correlation higher for $0.5\beta_y$* optics;
- Vertical correlation lower for $0.5\beta_y$* optics;
- However, vertical correlation is still present for after jitter reduction (JR);
- Further investigation is needed...

- We observe important differences between putting the sensor on the quadrupole and another position;
- It may be a reason of small correlation;
- **There is a strong justification of placing the sensors on the top of the quadrupoles;**

M. Patecki

Conclusions on the ground-motion measurement

- Ground motion mitigation via feed-forward control is designed to suppress ground vibrations of high frequencies.

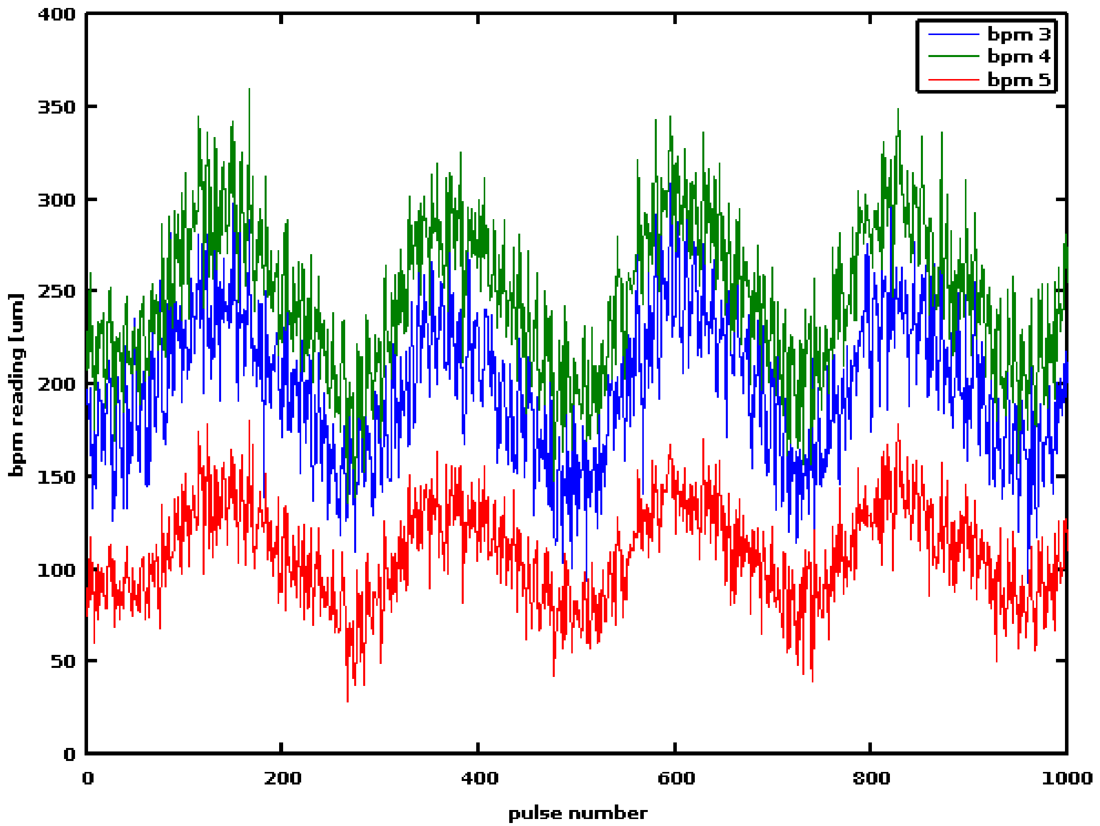
- It has significant advantages compared to existing methods (cost, speed, distributed correction)

- The prediction of ground motion has been successfully performed at ATF2.
  - The predicted beam oscillations were much higher than expected and originated from one local vibration source (water cooling pipe).

- After removing the source the beam jitter was reduced by a factor of 1.4.
  - However, only correlation from one localised source was observed. Without the data of the corresponding sensors, the correlation is much lower than predicted by simulations.

Slow drifts and incoming angle and position offsets

Observed periodic slow drift, during one run in December. Later removed by the ATF2 team.



An incoming offset and angle (even if not drifting) will induce emittance growth. This should be counteracted as early as possible. Fit of the incoming angle and position offsets must be performed and countermeasures must be taken.

Summary

Ground motion mitigation via feed-forward control is designed to suppress ground vibrations of frequencies higher than those covered by trajectory orbit feedbacks:

- Correlations between orbit measurements and ground motion have indeed been seen
- Should we consider to test phase 2 of the the GM project?

Jitter: amplified by large beta functions, need keep it small

- Intra-bunch feedback should help (second bunch beam size measurement)

Beam-based techniques and data analysis tools can be envisaged to estimate and counteract the impact of slow drifts and jitter (noise) on the orbit

Additional BBA methods can be envisaged to improve orbit stability (e.g. DFS removes energy dependence from the orbit, WFS removes charge dependence)