Session 3 Summary: Orbit Feedback

Workshop on Ambient Ground Motion and Vibration Suppression for Low Emittance Storage Rings GM2017
12/13/2017

MMS System Design, Initial Results and Experiments with Orbit Feedback (Nick Sereno ANL)

Commissioning the Fast Orbit Feedback System at SSRF (Bocheng Jiang SINAP)

Preliminary Design and Performance Analysis of the FOFB System of HEPS (Dapeng Jin IHEP)

Estimation of the Orbit Feedback Performance for HEPS (Zhe Duan IHEP)

MMS System Talk Summary

- At ANL/APS we have developed capacitive and hydrostatic MMS systems that:
  - **RF and X-ray BPM movement relative to the floor (horizontal and vertical motion)**
  - **Vertical tilt of the floor at the bpms (vertical motion only)**
- Initial data from the MMS looked interesting but we wanted to do experiments to see how to use it to correct for long term mechanical movement of bpms up to 7 days
- Logging MMS and rf bpm data over a week using a local square matrix at rf bpms to correct exactly at the ID upstream and downstream rf bpms showed:
  - One predict position changes at the GRID X-ray bpm that agree well with GRID measurements corrected for mechanical movement
  - In the frequency domain remaining errors can be modeled as 1/f noise
- The least squares fit analysis showed a similar result using the same data
- Obtained similar results in the horizontal plane where there is only capacitive mechanical motion measurements
- *Main conclusion is that from these experiments, correction of bpm readings for underlying mechanical motion of the bpm vacuum chamber and floor can improve the raw bpm readings for long term drift relative to an absolute position reference*
- Open questions –
  - Can one use AC capacitive motion information?
  - Systematic errors for HS system for > 20 m long systems

Commissioning the FOFB System at SSRF (Bocheng Jiang SINAP)

- Commissioned coupled fast and slow orbit feedback systems
- Meets 10 % beam size up to 100 Hz requirements
- Uses low strength air-core fast correctors and 5 kHz sampling rate
- Resets FOFB every 17 seconds due to saturation of fast correctors
- See uncorrected beam motion due to gap changes similar to what APS saw in the early days
- May be improved using faster update rate for slow correction with your FOFB reset scheme
- Future upgrades might consider increasing closed loop bandwidth beyond 100 Hz (VME/reflective memory hardware is obsolete)
  - Air core fast correctors have bandwidth out to 1000 Hz
  - Libera filter latency is quite large but for few hundred Hz closed loop bandwith is still likely ok
  - Check and improve if nessary power supply small signal bandwidth (might need to be much bigger than fast corrector bandwidth for good amplitude and phase response to 1 kHz)
  - Increase sampling rate beyond 5 kHz
  - Check other latencies in the system and model system performance

Preliminary Design and Performance Analysis of the FOFB System of HEPS (Dapeng Jin IHEP)

- FPGA based design with distributed controllers around the ring
- Uses state of the art Xilinx Ultrascale FPGA
- Early design goal is to minimize latency in the system
- Parallel data transmission to power supply controllers
- Nice identification of latencies in the system
- Modelled errors due to vibration and power supply ripple
- Nice feedback system model using initial model of vibration sources
- Likley can achieve 500 Hz CL bandwidth as reported (what we initially achieved in initial upgrade feedback controller experiment at APS)
- Continue refining the model as new information becomes available to inform the design of the system
- Our experience is FPGAs require specialized knowledge by experts...might consider DSP solution

Estimation of the Orbit Feedback Performance for HEPS (Zhe Duan IHEP)

- Simulated orbit feedback in the limit of low frequencies
- Vibration of multipoles on a girder are correlated, girder to girder motion uncorrelated
- Computed amplification factors, assumed 0.1 μm rms vibration for quadrupoles and bpms (uncorrelated)
- Discussion -
  - PSD description of the transfer function equation is fine since s or z in the transfer functions convert to frequency with the appropriate formula
  - Just need to convert to PSD units
  - Vadim Sajaev (APS) assumed $1/f^2$ dependence on vibration from measurements and an average interpretation of data with is more pessimistic than higher order dependencies so less orbit attenuation at low frequencies
  - In subsequent work, he continues to refine his model to include other parts of the spectrum with other frequency dependence (instead of just $1/f^2$)
  - Not sure if there is a simple scaling of orbit attenuation at low frequency
  - In my talk, 1/f noise of electronics should be included which ultimately could dominate

Some Thoughts for Consideration

- Fast correctors to correct AC motion
  - Two fast correctors/sector can correct both AC position and angle at ID source points
  - Avoid large DC correction with the usually weaker fast correctors
  - Reasonable slow corrector position control in the arcs
- Xray or photon bpms best for correcting long term pointing stability
- Carefully evaluate rf bpm performance for low charge/current conditions during initial machine commissioning
- Investigate more elaborate state space model of the controller + feedback system other than PI
  - Goal is to increase orbit attenuation at frequencies where it is most beneficial based on the machine beam motion spectrum (BMS)
  - Orbit feedback simulations take as input the BMS based on the transfer function model presented in other talks
  - Benchmark simulations using measured BMS for existing machines
  - May be able to get better than the standard factor of three open vs closed loop rms over given bandwidth (algorithm development)

Some Thoughts for Consideration cont.

- System latency has a large negative impact on closed loop bandwidth
  - Make sure to include in FOFB simulations latency for bpm FIR/IIR filters
  - Reduce latency as much as possible for fast corector power supply, magnet and vacuum chamber (eddy current effects, power supply controller electronics)
  - 1 kHz is a nice goal but maybe not necessary since beam motion is small at higher frequencies (on the other hand modern FPGA/DSP based feedback systems allow for very large amounts of data to be quickly transmitted and processed up to nearly turn-by-turn)
- Hardware considerations for feedback controller:
  - FPGA, DSP, combination of both?
  - What is your institutions expertise?
  - Maintain the system over long period of time?
  - Cost and difficulty of future upgrades?
  - Ease of algorithm testing and implementation

General Requirements for Orbit Positioning and Stability for Diagnostics and Orbit Feedback Systems

- Commissioning -
  - Obtain first turn trajectory, close the orbit, store and perform bpm offset/orbit/tune/optics correction *under low charge/current conditions*
- ID steering
  - Put photon beam on user target within a fraction of the beam size
  - Recover the orbit within a fraction of the beam size at each ID after shutdown
- Recover the orbit close to the magnetic centers of the multipoles
- Maintain a stable beam trajectory -
  - Long term drift > 100 seconds to 7 days
  - Maintain AC beam motion to 10% of the beam size
- Ultimately the definitions of beam drift and AC motion “noise” depend on the details of the user experiment – *keep users special stability needs in mind*