Crab cavity RF noise mitigation

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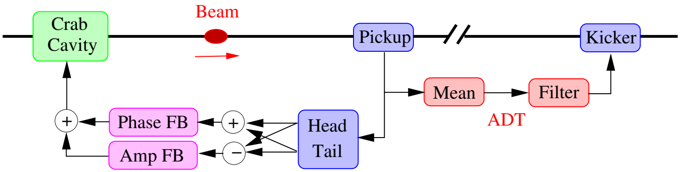
Introduction

- Philippe has already presented our studies on the expected transverse emittance growth rates due to crab cavity RF noise.
- A noise spectrum similar to the LHC main RF cavities would lead to unreasonably high growth rates.
- Due to the different components though (tetrodes vs klystrons) and improved technology (RF demodulators), we believe that a growth rate in the order of 4.6% per hour is realistic (3.7% due to amplitude noise, 0.9% due to phase noise).
- (*) These estimates are assuming the worst case β^* for the duration of the fill, ie. the growth rates will only reach these levels at the end of the fill. More details from L. Medina, R. Tomas.
- We investigated a dedicated feedback system which would mitigate RF noise injected by the crab cavities to achieve even lower growth rates.
- Presented initial results last year, but have many more details now.

Crab Cavity RF Noise Feedback

- The system would mitigate RF noise injected by the crab cavities.
- It would use the same pickup as the ADT, but rather than just averaging the transverse position over the bunch, it will estimate the position of both the head and tail of the bunch.
    - The sum of these positions will provide the centroid shift (phase noise), whereas their difference the bunch tilt (amplitude noise).
- It will then act directly on the cavity reference (amplitude and phase) to reduce the effects of RF noise

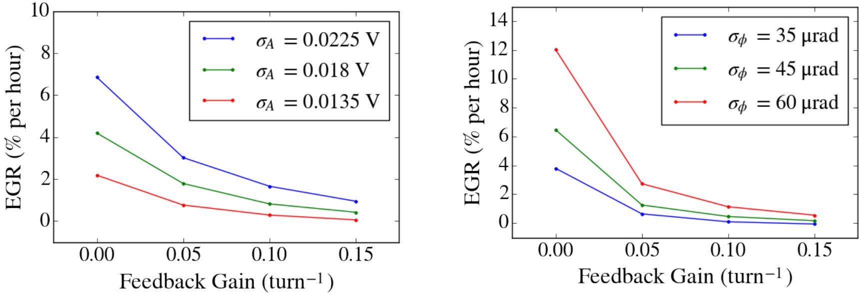


Simulations of the proposed feedback

- The potential system performance was evaluated through simulations.
- The limitations imposed by the system delay, tune spread, and pickup measurement noise were first investigated.
- These studies were conducted with modified versions of HEADTAIL (single-bunch simulations).
- Assumption: the β at the pickup location is the same as the β at the crab cavity location.

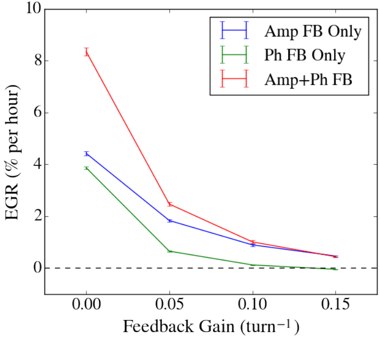
Emittance growth rate reduction

- An ideal system (no delay, no measurement noise) shows the potential for significant emittance growth rate reduction.



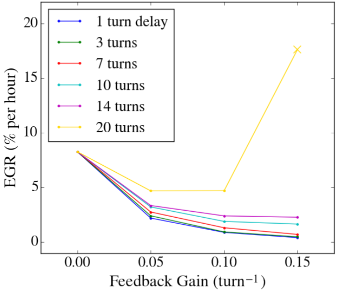
Emittance growth rate reduction

- Amplitude and phase feedback systems are independent: the emittance reduction is additive.



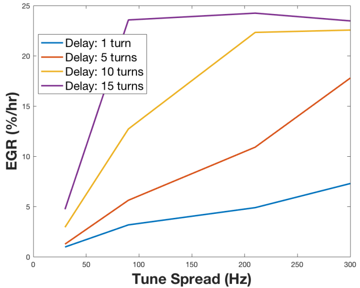
Effects of delay and phase advance

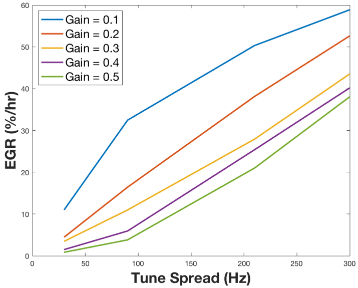
- The system will have a delay of a couple of turns (2?). The figure below shows the performance as a function of delay. No significant performance loss is expected due to the low system bandwidth.
- On the other hand, the phase advance between crab cavity and pickup is critical in the presence of delay. Since we can't change the phase advance, we instead changed the tune in the simulations, so that a momentum kick at the CC translates to the peak position excursion at the pickup.
- For the actual implementation, 2 pickups at 90° phase difference would be optimal and reduce the sensitivity on location with respect to the CC



Effects of betatron spread

- The system performance does depend on the betatron spread.
- The higher the tune spread, the quicker the bunch decoheres.
- The performance reduction is highly dependent on the system delay.

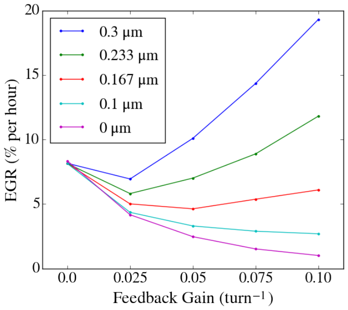


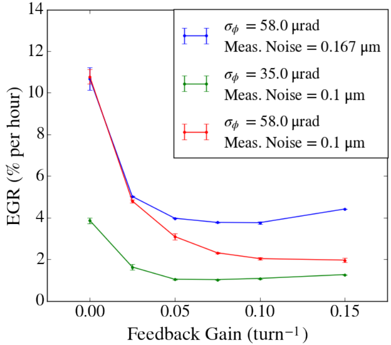


Delay of 2 turns.

Measurement noise

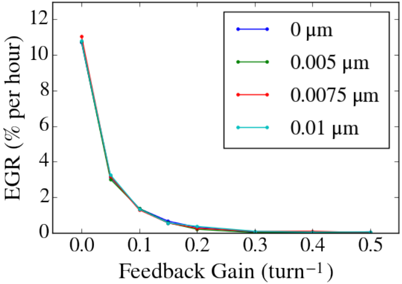
- The introduction of measurement noise reduced the system's performance as expected.
- For low gains the performance is dominated by the RF noise, whereas for high gains by the measurement noise.





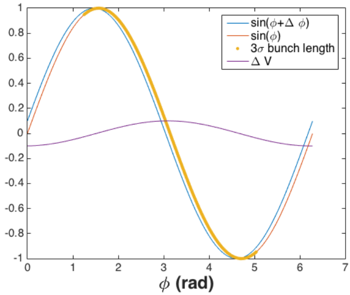
Measurement noise

- The bunches respond to the CC noise on the betatron sidebands only, and, as the CC noise is narrow-band it will excite low-order coupled-bunch modes only.
- The feedback input (estimate of centroid shift and bunch tilt) can then be filtered over ≈400 bunches, thus leading to a measurement noise level of about 7.5 nm.
- As a result, we don't anticipate any performance reduction due to measurement noise, assuming that the β at the pickup location is the same as the β at the crab cavity location.



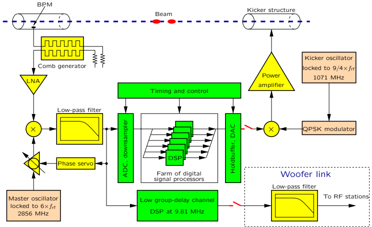
Complementing the ADT

- A CC voltage phase error leads to a voltage error proportional to a cosine.
- The proposed feedback can perfectly cancel the cosine error.
- The ADT cannot act within a bunch. It gives a rectangular kick proportional to the average value over the bunch $\rightarrow$ it actually *increases* the noise effect at the longitudinal tails (Damper action is less efficient)



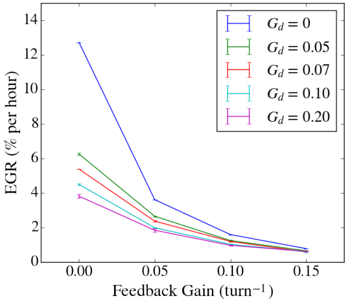
Complementing the ADT

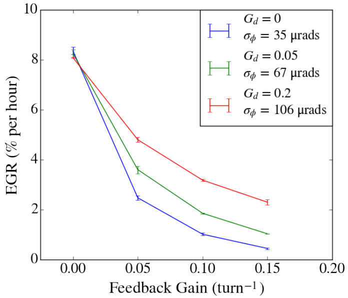
- Advantage vs. Damper: It would allow us to act on BOTH phase and amplitude noise; we can act on both dipole and head-tail motion. More efficient action on phase noise too.
- Limitation vs. Damper: the achievable bandwidth is the closed loop CC BW (≈100 kHz)
- BUT this is not an issue for crab cavity noise mitigation, because we are acting on noise injected by the same loop and therefore also limited to the 100 kHz BW. We only need to counteract low-order transverse modes.
- With the two systems working together we will get the best of both worlds: a fast bunch-by-bunch system (ADT), and an "intra-bunch" feedback system able to act on amplitude noise (through the crab cavities).
- A similar technique was used at PEP-II, where longitudinal instabilities were corrected by a broadband longitudinal feedback system together with woofer channel acting on the cavity reference.



Superposition with Damper

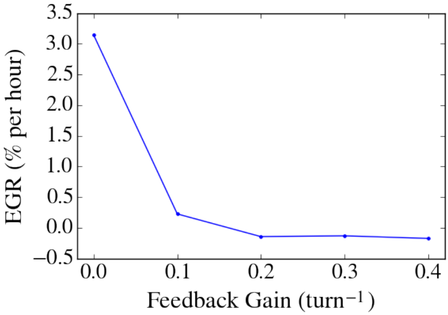
- In an ideal situation with a very short bunch length (σ_z = 0.75 cm), the damper and feedback system are interchangeable and combine linearly.
- With the nominal bunch length, there is a higher loss of performance in the presence of the damper.
- When used together, as the damper gain increases, the effectiveness of both systems *together* is slightly reduced.
- This could potentially be addressed by reducing ADT gain at low-order modes.





HiLumi LHC parameters

- Using our target crab cavity RF noise levels, the expected measurement noise levels, the nominal ADT gain, the anticipated delay, and the planned tune spread, we get very promising results with the proposed feedback system.



Conclusions

- We have investigated a CC RF noise feedback acting directly on the crab cavities.
- This proposed system can significantly reduce the RF noise induced emittance growth rate.
- The expected delay, tune spread (*), and measurement noise do not seem to be limiting the performance.
- Coordination with the damper could provide even better results.
- The proposed feedback system could also act on *low-order* dipole and head-tail transverse motion of any source.

Acknowledgments

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Thank you for your attention!

References

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