RF MD: Cavity Voltage Phase Modulation

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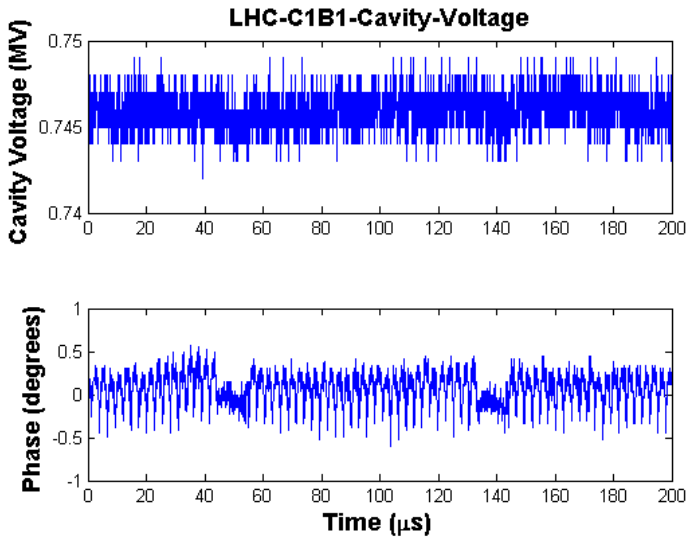
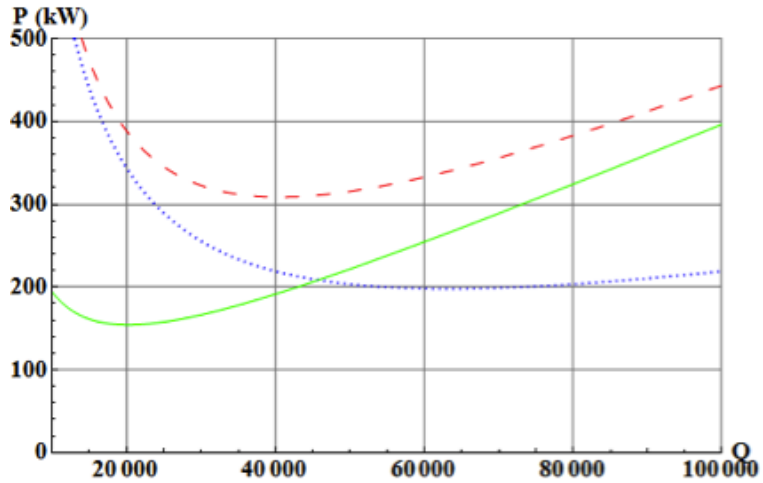
Background

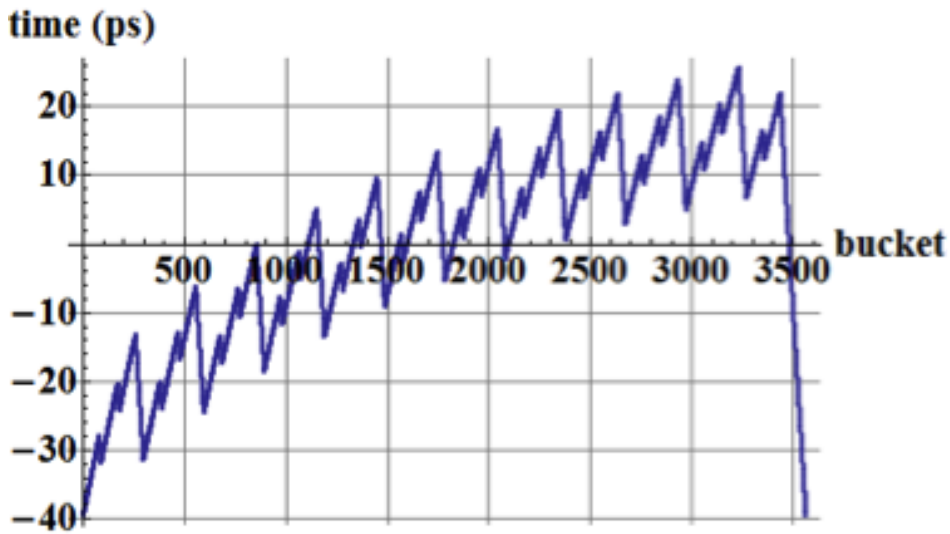
- RF/LLRF currently setup for extremely stable RF voltage (minimize transient beam loading effects). Less than 1° RF phase modulation (7 ps)
- To continue this way, we would need at least 200 kW of klystron forward power at nominal intensity
  - Klystrons saturate at 200 kW with present DC parameters (ultimately 300 kW). Sufficient margin necessary for reliable operation, additional RF manipulations etc.
  - The present scheme cannot be extended beyond nominal. Graphs for 1.15e11 ppb, 25 ns, 7 TeV, 1.7e11 ppb, 25 ns, 450 GeV, 1.7e11 ppb, 25 ns, 7 TeV





Solution

- For beam currents above nominal (and possibly earlier), we will accept the cavity phase modulation by the beam in physics (transient beam loading), but keep the strong RF/OTFB for loop and beam stability
- To achieve this, we have to adapt the voltage set point for each bunch
  - Method proposed by D. Boussard for the LHC in 1991! [1]
  - More details in IPAC '12 paper [2]
- Up to 65 ps peak to peak displacement over a turn in physics (for ultimate beam, 25 ns spacing) compared to 1.25 ns bunch length
  - Even smaller shift of collision point in IP1, IP5 due to symmetry
- More significant phase modulation at 450 GeV $\rightarrow$ fill with current scheme, switch over during Pre-Ramp.
  - Lower voltage at injection $\rightarrow$ more power available for transient beam loading compensation

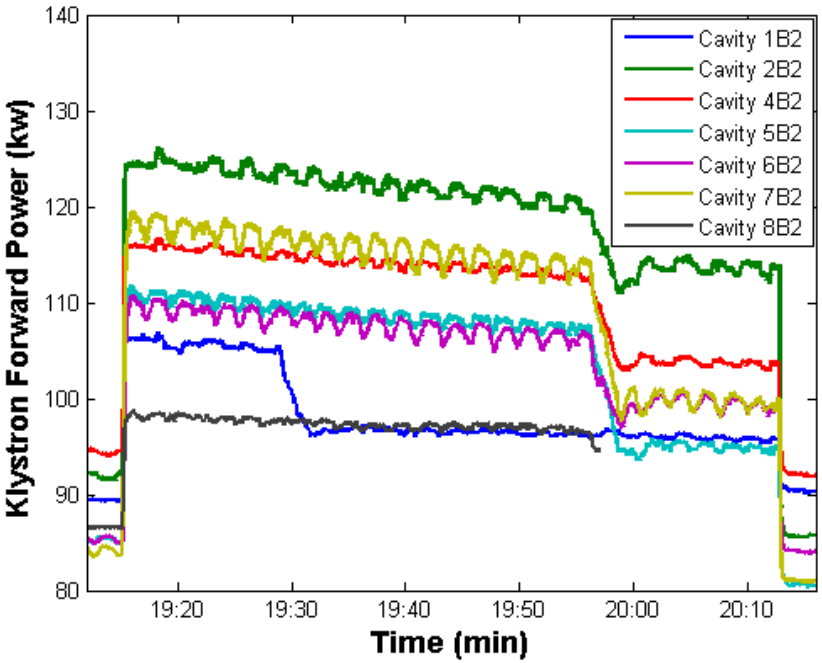


MD Details

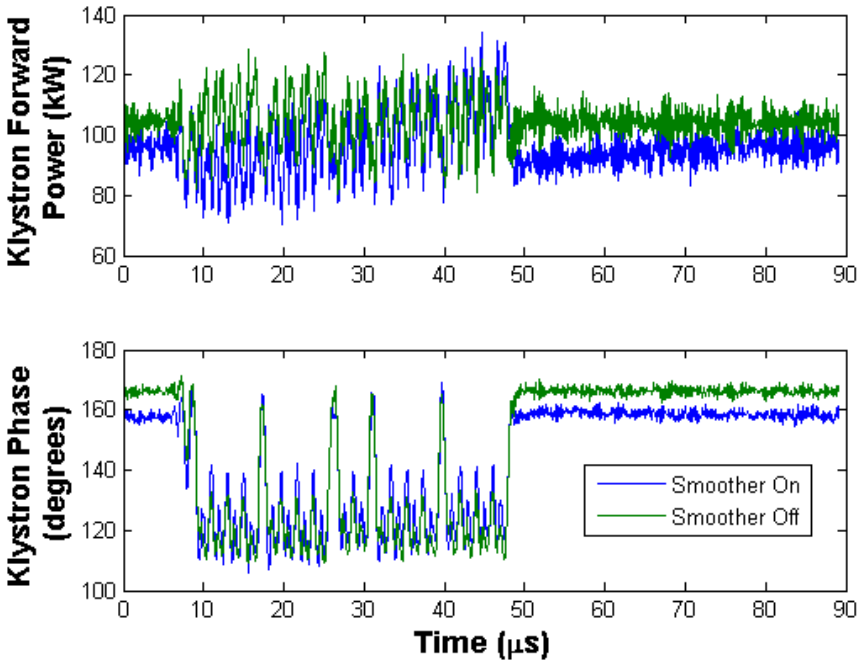
- During MD block #2, we tested the algorithm to adjust the voltage set point adaptation over a turn (“feedforward" algorithm)
- This initial test provided useful and promising results, but was performed using Matlab to calculate each iteration (20 seconds!)
- With the knowledge from the previous MD, firmware has been developed and extensively tested in simulations between MD blocks #2 and #3
- The firmware allows us to update the correction every turn (5-6 orders of magnitude faster)
- Due to beam dump system problems the MD was limited to beam 2 and a total time of only 1.5 hours
- Algorithm tested with 150 and 654 bunches in the machine

MD Results

- A significant reduction in average klystron forward power was achieved (10-15 kW)
- Due to the shortened MD time and reduced gain for observation purposes, the algorithm did not reach the final value in the available time. As a result, the peak klystron power reduction did not reach the desired levels. Nonetheless, we expect good results with the nominal algorithm settings



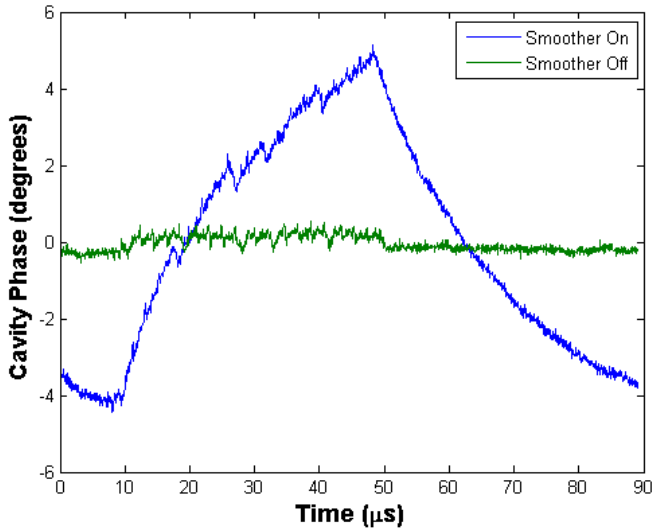
Average Klystron forward power. 6+144 bunches.



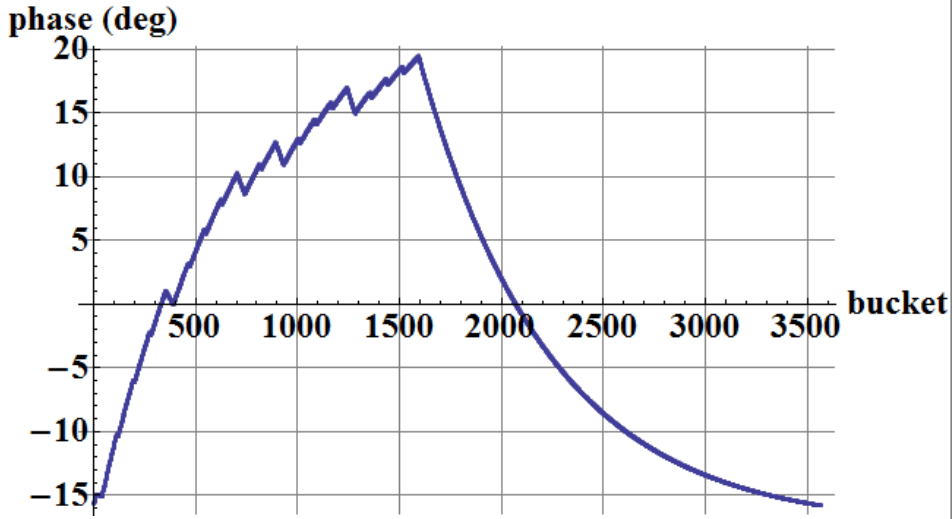
Klystron forward power over a turn, 654 bunches.

MD Results

- The cavity phase modulation reached approximately a quarter of the theoretically estimated value of 35° for the half-full ring case (highest phase modulation)
  - The structures though are very similar → gaps/batches can be clearly identified
- This 240 ps modulation is still small compared to the 1.3 ns long bunch and will be symmetric for IPs 1 and 5
- The settings of the algorithm will be optimized using the MD results and an operational version will be tested and deployed soon (operational development or MD Block #4)



Cavity phase over a turn, 654 bunches.



Estimated cavity phase modulation for 654 bunches.

References

[1] D. Boussard, “RF Power Requirements for a High Intensity Proton Collider", CERN-SL-91-16-RFS, 1991

[2] P. Baudrenghien, T. Mastoridis, “Proposal for an RF Roadmap Towards Ultimate Intensity in the LHC", Proceedings of Third International Particle Accelerator Conference 2012, New Orleans, Louisiana, USA, 20 - 25 May 2012.