NLC Damping Rings Beam Loading and Gap Transients

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Introduction

- Beam loading and Gap Transients Present Challenges for the NLC damping rings.
- Simulate RF conditions to determine stability and operation with RF feedback and gap transients.
Topics of Discussion

- Direct RF feedback is useful in reducing the effects of heavy beam loading.
  - None of the rings is unstable without RF feedback, but each is uncomfortably close to it.
- The bunch gaps produce voltage transients which act on the bunches to generate phase variations along the trains. These may be suppressed using the klystron power.
Direct RF Feedback

- Widely used and simple to implement.
- Gain limited by loop delay (waveguide, cable, klystron delay). 1 μs is assumed.
- Requires slight klystron power overhead to provide the modulation driven by the gap transient propagating through the feedback.
  - Predamping Ring: 4.5%
  - Main Rings: 2%
- Reduces Robinson damping.
- Longitudinal aperture is increased.
- $Y^* = \frac{Y}{(1+H)}$, $Y=IB/I_0$, $I_0=V/R$. $H$: feedback gain.
Gap Transients

- Lead to energy variation in linac if uncorrected.

- Key parameters for these gap transients:
  - Cavity fill time = 1.7μs.
  - Revolution period = ~700-950ns.
  - # gaps = 2-3.
  - Gap Duration = 60-90ns.
Gap Transients (cont.)

- For the main rings, the transient with direct RF Feedback is essentially the same as without direct feedback. It is approximately linear.
  - The stability benefit of the feedback warrants its use.
Suppressing the Gap Transients

- The vector diagram shows what is required to restore the cavity field when the beam gap arrives:
  - Rotate and change the generator vector according to:
    - if $IG \cos(\psi) > I_0$ --> reduce and rotate
    - if $IG \cos(\psi) < I_0$ --> increase and rotate
  - With sufficient power and bandwidth in carrying out this operation the transients are eliminated.
Vector Diagram of Cavity Components
(optimal detuning)

\[ IT = IB + IG \]
Suppressing the Gap Transients (cont.)

- Main Rings need no extra power to suppress.
- Predamping Ring requires large increase:
  - \(~1\text{MW for nominal power of } ~550\text{kW}\)
    - Probably not practical
Realistic Considerations

- Finite klystron bandwidth limits the effectiveness of this approach.
- Provide an inverse system that shapes the klystron pulse to obtain a more ideal response. Use an adaptive group delay equalizer.
- Ring period, digital sample rate, and klystron bandwidth all affect this approach.
Adaptive Inverse

Cascade an adaptive inverse of the klystron which produces a (more) ideal pulse out of the klystron. The output is delayed and therefore the input should be provided earlier to accommodate this.
Pulse Response through 10 MHz klystron

Ampl.

turns

-0.2 0.2 0.4 0.6 0.8 1.0 1.2

9 9.1 9.2 9.3 9.4 9.5 9.6 9.7 9.8 9.9 10

ideal uncompensated klystron compensated klystron
Phase Transient: vNLodelta

3rd order butterworth, L=40, del=16

Bunch charge profile
Realistic Considerations (cont.)

- What klystron bandwidth is necessary to effectively carry out the inverse?
  - Important in specifying the klystron.

- What digital equalizer length and sample rate is adequate?
  - Is the filter length compatible with the revolution period?
Eliminating the Transient via the Ring Frequency

- If the ring operates at a slightly higher frequency, a train leaving the ring and possessing a phase variation lands at exactly uniform phase in the linac. No Gap Transient is observed outside the ring.
  ➢ For the main ring transient the ring RF must be approximately 40kHz greater than 714 MHz.
Eliminating the Transient via the Ring Frequency (cont.)
Eliminating the Transient via the Ring Frequency (cont.)

- Requires complex timing and synchronization with only specific instants allowed for injection and extraction such that the ring and linac RF cycles are approximately aligned.
  - Optimal ring frequency varies with current (as does the transient).
Summary

- Direct RF feedback is useful for the NLC damping rings.
- Gap Transients may be suppressed; but more study is needed.