Risks for Linear Collider Damping Rings

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We consider a number of technical risks:

- The risks are:
  - Poor acceptance leads to poor injection efficiency
  - Vertical emittance is larger than specification
  - Extracted beam has large transverse jitter
  - Rise/fall times of kickers are longer than specified
  - Kickers have large ripple on “flat top”
  - Beam is affected by stray fields
  - Electron cloud causes beam instability in the positron ring
  - Ions cause beam instability in the electron ring
  - Vacuum chamber impedance causes beam instability

- For each risk, we consider:
  - The reason for the concern
  - The severity (luminosity scaling)
  - The stage of the project the problem will be detected
  - The consequence (how hard is it to correct the problem?)

1. Acceptance

- High injected beam power (60 kW warm, 225kW cold)
- Physical and dynamic aperture limitations
  - More difficult for large positron beam
- Dynamic aperture limitations from multipoles and wiggler
- Comparable requirements to 3rd Generation Light Sources
  - …but driven by injection rather than lifetime issues
- Wigglers are of particular concern
  - 67 m in warm LC main damping rings
  - 420 m in cold LC positron damping ring

1. Acceptance

- Reason for Concern (Beam Physics)
  - Warm and cold:
    Best theory indicates a problem, no data to the contrary
  - Present lattice designs probably have insufficient aperture
  - Still some development needed in modeling wiggler dynamics
  - Useful data from CESR-c etc., but all rings are unique

- Severity
  - Warm and cold:
    Effect on parameter is linear
  - Reduction in current (from source, or through collimation)
  - Assume problems are with positrons only

- Detection
  - Warm: *Not detected until engineering and design*
  - Cold: *Not detected until facility pre-ops*
  - Possible to prototype and test warm DR wiggler

- Consequence
  - Warm and cold:
    Alternate design available, would need new plan or minor rework
  - Nonlinear correctors (e.g. SPEAR 2 BL11…)

2. Coupling

- Magnet misalignments in the damping rings will generate vertical emittance that must be reduced to below the specified value by beam based alignment and coupling correction methods.

- Typically, the sensitivities are such that once the emittance is corrected to the specified value, relative motion between the beam and the sextupoles (for example) of a few tens of microns will double the vertical emittance.

- The sensitivities are a function of the lattice design, the required vertical emittance, and the number of magnets in the lattice.

- Although the alignment sensitivity is a consideration in the lattice design, other design requirements limit what can be done in practice to make the vertical emittance less sensitive to magnet misalignments.

2. Coupling

- Reason for Concern (Beam Physics)
  - Warm: *Understood theory and data indicate no problem*
  - Cold: *Best theory indicates a problem, no data to the contrary*
  - Theory based on calculated sensitivities (*not* correction simulations)
  - Specified emittance for warm LC has been achieved, cold has not

- Severity
  - Warm and cold: *Effect on parameter is less than linear*
  - Emittance is diluted between DR and IP
  - Luminosity varies as square root of the emittance at the IP

- Detection
  - Warm and cold: *Not detected until facility pre-ops*
  - Limited conclusions can be drawn from simulations…

- Consequence
  - Warm and cold:
    Alternate design available, would need new plan or minor rework
  - Most likely problems resulting from poor diagnostics performance
  - …upgrade BPMs for example

3. Vertical Jitter

- Vertical beam jitter can be the result of vertical vibration of the quadrupoles, beam instability driven by long-range wake fields, or jitter from the extraction kickers and septa acting in the vertical plane through some rotation of the magnet around the beam axis.

- For both warm and cold LC technology, the specification on vertical beam jitter on extraction from the damping ring is that the jitter should be less than 10% of the vertical beam size [ref: Design Considerations].

- The vertical jitter can be suppressed by:
  - careful design, construction of the main lattice magnets and supports
  - design of the vacuum chamber to reduce long-range wake fields
  - use of fast orbit feedback within the damping ring
  - careful alignment of the extraction kickers and septa.

- In addition there is the possibility of using fast feedback acting across an appropriate part of the beamline between the damping ring and main linac.

3. Vertical Jitter

- Reason for Concern (Engineering/Design)
  - Warm: *Tested R&D design*
    Cold: *Engineering feasible, but untested design*
  - SLS close to warm LC specification
  - Some extrapolation (factor of 2) required to cold LC specification

- Severity
  - Warm and cold: *Effect on parameter is less than linear*
  - Emittance is diluted between DR and IP
  - Luminosity varies as square root of the emittance at the IP

- Detection
  - Warm and cold: *Not detected until facility pre-ops*

- Consequence
  - Warm and cold:
    Alternate design available, would need new plan or minor rework
  - Improve magnet supports, feedback systems…

4. Kickers

- For the warm LC, entire bunch trains are injected/extracted at once
  - Field integral 0.017 T-m
  - 65 ns rise/fall time
  - Flat-top (to ±0.05%) of 270 ns
- The most challenging parameter looks to be the stability of the flat-top, though most of the variation is likely to be systematic, which allows the possibility of feed forward correction to be used.
- The effect of some residual field from the trailing edge of the kicker pulse acting on the following bunch train will be mitigated by the fact that these bunches will remain in the ring for some 4.6 damping times (in the horizontal plane) before themselves being extracted.
- In the cold LC, bunches are injected and extracted individually, with the last bunch being extracted 17 turns later than the first bunch
  - Field integral 0.01 T-m
  - 20 ns rise/fall time
  - Pulse-to-pulse stability is ±0.07%
- The variation between pulses is likely to be more random than systematic.
- Since the bunch following each kicker pulse is extracted some number of turns later, any bunch that sees a residual kick from the extraction of the immediately preceding bunch will have an emittance growth resulting from beam filamentation.

4. Kickers

- Reason for Concern (Engineering/Design)
  - Warm and cold: *Engineering feasible, but untested design*
- Severity
  - Warm and cold: *Effect on parameter is less than linear*
  - Increase in (horizontal) jitter
  - Reduced number of bunches/pulse
    - but might be able to increase charge
- Detection
  - Warm and cold: *Detected by R&D*
- Consequence
  - Warm and cold: *More R&D would be needed*

5. Stray Fields

- The cold LC damping ring is sensitive to stray fields because of the large beta functions in the straight sections make the beam sensitive to the steering effects of fields of only a few μT.
- The dispersion generated by these weak fields can lead to an increase in the vertical emittance of the extracted beam.
- The fields may come from a number of sources, including the main linac klystrons.
- Magnetic shielding is ineffective for μT fields, and it is likely to be difficult to control all the sources of stray field over the 7.5 km of tunnel the straight sections will share with other systems.
- The warm LC is less likely to suffer from this effect because of the different lattice design, and the fact that the damping rings are separated from pulsed power systems.

5. Stray Fields

- Reason for Concern (Beam Physics)
  - Warm: *Understood theory and data indicate no problem*
  - Cold: *Best theory indicates a problem, no data to the contrary*

- Severity
  - Warm and cold: *Effect on parameter is less than linear*
  - Emittance is diluted between DR and IP
  - Luminosity varies as square root of the emittance at the IP

- Detection
  - Warm and cold: *Not detected until facility pre-ops*
  - Difficult to predict presence and behavior of weak fields

- Consequence
  - Warm and cold:
    Alternate design available, would need new plan or minor rework
  - Compensate dispersion effects increase by (adaptive) feed-forward

6. Electron Cloud

- *Some preamble:*
  What is electron cloud, solenoids at B-factories…

- The important parameters for the electron cloud are:
  - bunch charge
  - bunch spacing
  - peak secondary electron yield (SEY) of the chamber wall

- Bunches in the warm LC damping rings have a much shorter separation than in the cold LC damping rings, and the problem is expected to be more severe in the warm LC.

- However, electrons can be trapped in magnetic fields, and disperse more slowly between bunches than in field-free regions; this effect may lead to a build-up of electron cloud in the long wiggler of the cold LC positron damping ring.

6. Electron Cloud

- Reason for Concern (Beam Physics)
  - Warm and cold: *Poor or ambiguous data indicate problem*
  - Simulation codes predict a problem, but these codes are not always in good agreement with the limited data available

- Severity
  - Warm: *Effect on parameter is linear*
  - Cold: *Effect on parameter is less than linear*
  - Emittance increase
  - Current limitation

- Detection
  - Warm and cold: *Not detected until facility pre-ops*
  - Can't rely on simulation codes
  - Behavior of low SEY coatings is highly variable

- Consequence
  - Warm and cold:
    Alternate design available, would need new plan or minor rework
  - If proposed solution is not sufficient, additional data collected will allow specification for reworking parts of the vacuum chamber

7. Ions

- Ion trapping in the electron damping rings can be avoided by including a clearing gap in the stored bunch train.
- The injection/extraction gaps in the warm LC electron damping ring are effective for this purpose, and a gap can be incorporated in the cold LC electron damping ring without significant difficulty.
- However, ions can still accumulate during the passage of a single bunch train.
- In the straight sections of the cold LC electron damping ring, simulations suggest that at a vacuum pressure of 10^{-9} torr ions will cause a tune shift of 0.28 by the end of the bunch train, which is unacceptable; a vacuum pressure as low as 10^{-10} torr may be needed in the straights.
- Ions in both the warm and cold LC electron damping rings can lead to coherent oscillations along the bunch train (a fast ion instability) with growth times of the order 100 μs at pressures of 10^{-9} torr.

7. Ions

- Reason for Concern (Beam Physics)
  - Warm and cold:
    Best theory indicates a problem, no data to the contrary
  - Simulation codes predict a problem, but the complex effects involved are difficult to model with confidence
  - DRs will operate in regimes that are not well explored

- Severity
  - Warm and cold: *Effect on parameter is less than linear*
  - Emittance increase (diluted between DR and IP)
  - Current limitation?

- Detection
  - Warm and cold: *Not detected until facility pre-ops*

- Consequence
  - Warm and cold:
    Alternate design available, would need new plan or minor rework
  - Upgrade to vacuum system

8. Impedance

- Microwave instability can result from a vacuum chamber impedance that is too large.
- If this instability appears as a “bursting” mode, with large fluctuations in bunch dimensions along a bunch train or between pulses, machine tuning and operation can be made very difficult.

8. Impedance

- Reason for Concern (Beam Physics)
  - Warm: *Understood theory and data indicate no problem*
  - Cold: *Best theory indicates a problem, no data to the contrary*
  - Plenty of margin in warm design, impedance in known regime
  - Cold LC DRs need impedance an order of magnitude lower than warm

- Severity
  - Warm and cold: *Effect on parameter is quadratic or steeper*
  - Will need to reduce current to stay below threshold
  - Positron and electron rings equally affected

- Detection
  - Warm and cold: *Not detected until project engineering and design*
  - Usually some discrepancy between predicted and measured impedance values, but can allow some margin in design
  - Detailed engineering design of vacuum chamber components needed before confident prediction of impedance can be made

- Consequence
  - Warm and cold:
    Alternate design available, would need new plan or minor rework
  - Could identify and fix problematic components