Mechanical Collimation System Development for the NLC

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Collimator Damage

• Full beam will destroy any solid object at nominal LINAC beta functions (10um spot size).
  – ~10 MW average power
  – ~$10^{10}$e⁻/pulse, $10^{12}$e⁻/train (NLC),
  – Even a single bunch will damage

• Large beta functions -> increase spot size
  – Tight alignment tolerances
  – Wakefield problems
Collimation

- Use "Spoiler / Absorber" scheme
- Thin (~1 radiation length) spoiler
  - Increases transverse momentum spread
- Thick absorber downstream
  - Absorbs high beam power, but low density
- **Critical damage problems are on spoiler.**
Spoiler Materials

- Damage typically caused by thermal fracture
- Carbon (glassy or graphite) has best damage threshold (in calculation). $\sim<10^{16}\text{e}^-/\text{cm}^2$
  - Poor conductivity -> resistive wake problems
  - Diamond?
- Beryllium $\sim2.5\times10^{15}\text{e}^-/\text{cm}^2$
  - Some concerns about toxicity
    (may be less serious than radiation hazard)
- Titanium similar to Beryllium
- None will survive full beam
Indestructible Spoilers?

- Use high power lasers for collimation:
  - Laser power requirements (wildly) impractical with current technology.

- Liquid metal jets:
  - No known way to obtain micron level surface stability

- Nonlinear magnetic collimation
  - Very useful idea, but can't do entire job
  - Too much like "accelerator physics" to discuss here
  - Will be used for NLC (in addition)

No clear solution (Yet)
Spoiler Schemes

- Must assume that occasionally the Machine Protection System will fail

- Can design "Consumable" spoiler to remain usable after some number of damage events.
  - Not too difficult: NLC baseline design

- Alternately design "Repairable" spoiler which can be continuously repaired after damage.
  - In- vacuum spoiler factory.
  - Difficult: Requires exotic technology
Consumable Spoiler

After damage is detected, wheels are rotated to new location

Wheels referenced to central frame (with BPM) for stability
Composite Spoiler Jaws

- Would like collimation (spoiling) depth to change abruptly as a function of R.
- For wakefields would like surface to change gradually as a function of R.
- Use Composite Copper Beryllium spoiler.
- Be is "invisible" to the beam.
Prototype Unit

Real mechanicals, but rotors are Aluminum, not Be/Cu

Gap 0-700 microns
stability: 0.5 um / C

Rotation: causes 7um gap variation due to out of round support wheels: easy to fix

Prototype Be/Cu bond
Repairable Spoilers

• Since we can't make an indestructible collimator, we design one we can continuously repair in vacuum.

• Several crazy ideas considered, finally selected:

• Use a solid wheel rotating in a pool of liquid metal. Liquid metal freezes onto the wheel and serves as the spoiler surface. After damage the surface is reformed on each rotation.
Solidifying Metal Spoiler

Horizontal Collimator

Vertical Concept

Liquid Metal

Bearing

Drive Motor

Low MP liquid (indium?)

Temperature Control

Pump
Materials Compatibility

• Liquid metal needs to adhere to the substrate, but not dissolve it.
  – Note: solder on copper doesn't work - solder dissolves copper.

• After lots of "Alchemy" found:
  – Substrate: Niobium
  – Smoothing Roller: Molybdenum
  – Liquid metal: Tin
    • vapor pressure at melting
    $< 10^{-11}$ Torr
Solidifying Metal Spoiler
Prototype Performance

- Vacuum good (10^{-8} Torr), limited by pump.
- Problems with bearings in UHV and at high temperature.
  - Switching to SiN bearings will probably fix this.
    - Work well in initial test
- Works with a thin (~100 micron?) coat formed by surface tension.
- Thicker coat (>3 mm) works briefly, but soon (~ 1 minute) Tin solidifies in the wrong places.
Thick Coating: Problems

Tin builds up on sides of roller
Possible Fix for "Thick Coat"

Tin collects on cool part of wheel

Cooling through shaft

Heat added to liquid Tin pot

Tin frozen on cool surface

Tin does not freeze on warmer areas

Cooling through shaft

Heat added to liquid Tin pot
Collimation Mechanical System Status

- NLC baseline has passive survival for energy collimation and consumable spoilers for position collimation
- Prototype consumable spoiler meets most requirements, remaining problems appear easy to fix
  - Damage detection system required
- Solidifying metal repairable spoiler is under development