Accelerator Test Facility – KEK/ATF

Status
Goal: prototype injector for JLC/NLC

ATF is the only test facility with ~NLC emittance
Emittance

- NLC spec: 3e-6 3e-8 m-rad
- ATF achieved: 5e-6 5e-8 (5e-6 <2e-8 expected)

- Single bunch; 1.28 GeV; 8e9 ppb (NLC: 1.98 GeV; 8e9)

• What are important emittance effects?
  - ring dispersion / coupling correction
  - intra-beam scattering
  - extraction line optical aberration correction
  - instrument validity
ATF Status

- ATF operates 20 weeks/year for a 4 1/3 day block /week
- Users get about ½ time
- Stability is critical for ~10pm emittance
- Typical beam sizes are 50 x 8μm
- BPM resolution single shot is ~15μm
- Beam pulse rate is 1.5 Hz

- Precise measurements require long periods of checking/setup
Collective effects

- cause either coherent instability or incoherent emittance growth
  - Potential well distortion
  - “Microwave” instability
    - Bane of SLC operation –
      - worse with ‘strong’ but still a problem with ‘weak’
    - Intra-beam scattering
      - Key topic of ATF work
      - more studied at proton machines
      - probable dominant single bunch emittance driver for NLC
Intra-beam scattering

- Similar to synchrotron radiation \(\rightarrow\) growth rate = damping rate at eq.
  - collisions involve energy exchange between particles
  - beam temperature in rest frame: 7000:35:1 \((x, y, z)\)
  - EXCEPT: SR from bends only; IBS everywhere

\[
\frac{\langle H \rangle_{bends}}{\langle H \rangle} = 1.6 = \frac{(\varepsilon_y - \varepsilon_{y0})/\varepsilon_{y0}}{(\varepsilon_x - \varepsilon_{x0})/\varepsilon_{x0}}
\]

- (for emittance generated through residual dispersion vv coupling)
  - \(H\) is the dispersion invariant

\[
H = \left[ \eta^2 + (\beta \eta' + \alpha \eta)^2 \right] / \beta
\]
Intra-beam scattering – theory

- small transfer approx. of Touschek lifetime
  - (limitation in SR sources and well understood)
- Bjorken&Mtingwa + Piwinski
  - $x - y$ coupling and microwave related $\sigma_z$ distortion not included
- Magnitude
  - overall scale factor usually used (protons…, ALS)
- Tail generation – (should be important for downstream users)
  - cut-off parameter introduced
    - reduces computed ‘rms’ emittance by 30%
Normal cell of ATF arc.
'Design' optics with Wiggler: /users/kuroda/sad/atf/dr4

\[ H_x = \frac{\eta_x^2 - (\beta_x \eta_x + \alpha \eta_x)^2}{\beta_x} \]

Note that it is constant out of beam.

Hx of optics without wiggler is shown in ATFB2-15.

Average H over arc cell 0.00291096 m
Average H over dipole 0.00123668 m
Average H over lattice 0.00193846 m
Evidence for IBS at ATF

- Vertical still large – no effect on x and E
- Vertical damped – increase in x and E
- minimum at 70ms
- damping times (x, y, z):
  - 17/27/20 ms

\[ \begin{align*}
N &= 1.6 \pm 0.8 \times 10^9 \\
N &= 4.8 \pm 0.8 \times 10^9 \\
N &= 8.0 \pm 0.8 \times 10^9 \\
\end{align*} \]
ATF emittance results

- Growth ratio is well measured
- Actual growth itself is poorly understood
- Observed energy spread/horizontal emittance growth indicates a 5x smaller vertical emittance than observed
- Table of emittance measurements: (e-9/e-11 x/y; not normalized)

\[
\begin{array}{|c|c|c|c|c|c|}
\hline
& e_{x0} & e_x & e_{y0} & e_y & r \\
\hline
\text{wires} & 1 & 1.85 & 1 & 3 & 2.35 \\
" & 1.1 & 2.2 & 1.7 & 4 & 1.35 \\
" & 1.1 & 2.2 & 0.7 & 2.8 & 3.00 \\
\text{l wire} & 1.1 & 2.2 & 0.7 & 1.9 & 1.71 \\
\hline
\end{array}
\]

\[
r = \frac{(\varepsilon_y - \varepsilon_{y0})}{\varepsilon_{y0}} / \frac{(\varepsilon_x - \varepsilon_{x0})}{\varepsilon_{x0}}
\]

- IBS: $1 < r < 1.6$
Constraints on measurement/optical errors from estimate of $r$

- for example – a coupled mixture as would be generated by a skew quad
  \[ \epsilon_{ymeas} = \epsilon_{yreal} + k\epsilon_x \]  
  \[ (k \text{ independent of I}) \]

- only makes sense if:
  \[ \frac{\epsilon_y}{\epsilon_{y0}} < \frac{\epsilon_x}{\epsilon_{x0}} \]

- not so for 00/01 data
Techniques for measuring emittance at ATF

- wires
  - extraction line
  - few micron beam size resolution
  - 2-3 micron beam jitter
  - control of eta to few mm
- laserwire – in the ring…
- energy spread – extraction line optics
- SR monitor
Extraction line optics

- Advantage:
  - very large dispersion allows energy spread measurement more accurately than any other SR ring
- Disadvantage:
  - very large dispersion
    - drives tolerances
    - forces cumbersome correction procedures
Summary – single bunch low emittance

- Relative growth not explained by aberrations in extraction line
- Ring simulation (Kubo) indicates unreasonably small vertical emittance
- Ring tuning relies on poorly optimized BPM system
- Simulation input somewhat unrealistic

- Plans:
  - Complete ring beam based alignment
  - BPM system improvements
    - Extraction line (RF dipole mode BPM’s)
    - Ring
Development of a transition radiation profile monitor - OTR

- some controversy over minimum resolvable beam image
  - achieved 7\(\mu\)m (12/00) well beyond purported limit
- theoretical limit: \(\sim \lambda\)

- Parameters for ATF OTR (built at SLAC)
  - resolution – 2\(\mu\)m
  - field of view – 300 x 200 \(\mu\)m (or \(\sim 2x\))
  - depth of field – 8 \(\mu\)m vertical displacement
  - OK light for normal camera – 5e9 ppb
OTR Thin copper screen

- New – installed 4/5
- 0.5 mm thick
- Lines scribed by CMM
  70 µm spacing

70 µm

360 µm

April 26 2001  Marc Ross – SLAC/ATF 15
• 10 μm $\sigma_y$

April 26 2001
successive images illustrating damage process