Stress simulation in the ILC positron target with ANSYS

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Introduction

- High energy particles interact with target material
- Pair production $\rightarrow e^+ \text{ and } e^-$
- $e^-$ are dumped
- $e^+$ are accelerated
- Interaction with the target $\rightarrow$ heat load

![Diagram of beam interaction with target material and capture optics.](image)

- Primary Beam
- Target
- Capture Optics

Photons 10-20 MeV
thin target: $0.4 X_0$

Electrons 0.1-10 GeV
thick target: 4-6 $X_0$

Courtesy: K. Floettmann
Photon production:
- Helical undulator, $\lambda_{und} = 11.5\text{mm}$, $K = 0.92$, ($L_{und} \leq 147\text{m}$)
- Drive beam energy $\geq 150\text{ GeV}$

Positron production target: spinning wheel
- Ti- Alloy (Ti6Al4V)
- Thickness $t = 0.4 \times X_0$ (1.4cm)
- Diameter $d=1\text{m}$
- $100\text{m/s}$ at rim $\Rightarrow 2000\text{rpm}$
e\(^+\) Source load parameters

- Drive beam energy 250 GeV, 30% e\(^+\) polarization $\rightarrow$ 95.1 kW photon beam
- Deposition in target 4.6 kW
  - Temperature rise per bunch train (2000rpm) $\Delta T = 119K$

- Resulting stress $\approx 173$ MPa
- Should work but prototype must demonstrate the feasibility to build target wheel spinning in vacuum and operate it at least one year
e\(^+\) Source load problems

> Wheel rotates in vacuum, at 2000rpm, while being exposed to radiation and located close to a magnetic field → „a quite demanding challenge“

> Prototype has been build and tested at LLNL

> Vacuum seal not yet fully developed → first tests show vibrations in the seal and sometimes spikes in the vacuum

> Further R&D work including prototyping is needed
Alternative source

- Suggested by T. Omori et al., see also NIMA672 (2012) 52
- Uses $e^-$ beam ("conventional" source) of 6GeV
- Target: $4X_0$ Tungsten
- 300Hz scheme
  - Stretch ILC bunch train ($\sim 1\mu s$) to 63ms → lower peak heat load
  - Stacking of $e^+$ in the damping ring
- ILC time structure achieved by $e^+$ extraction scheme from damping ring
- Benchmark from SLC target: Peak Energy Deposition Density (PEDD) should not exceed 29J/g
- Electron beam parameters are selected accordingly
Goal of the studies

> Beam parameters are given (⇌ ~29J/g peak energy deposition @SLC)
> How is the dynamic stress evolving in the target with 300Hz scheme in the tungsten target
> Long-term change of material parameters and target lifetime depend on static and dynamic stress
  • Energy deposition within fraction of a nanosecond → instantaneous temperature rise
  • Reaction of material within milliseconds
    → Stress dynamics
> Benchmark: SLC target
  • But SLC number of positrons per second was about 50 times lower than at ILC
Model

> Model 1 – Modified SLC target
  - Fe – ring & Ag – coat & W – core
  - Beam spot radius = 0.8cm
  - Radius for beam = 1.1cm

> Model 2 – cylinder with diameter corresponding to beam spot size
  - W – Layer & Ag – Layer
  - Beam spot radius = 0.8cm = 2\sigma

> Parameters
  - Particle shower has been calculated with FLUKA
  - \( \Delta T(\text{per Bunch}) \approx 1.6K \)
  - Average energy deposition in the target:
    - 35kW without silver layer
    - 49kW with silver layer
Implementation into ANSYS

> Mesh

- Mesh size is related to time steps
- \( \Delta t = \frac{l}{c_s} \) \( \rightarrow \) \( \Delta t \) is given \( \rightarrow \) \( l \approx 1.5\mu m \)
  \( c_s = \) velocity of sound = 5180 m/s
- Model 1: 8152 elements
- Model 2: 9419 elements
- Elements: Hexagonal elements

> Calculation & Results

- Model 1: at the contact regions between different materials and at regions with high temperature gradients mesh had low quality \( \rightarrow \) no useful results yet
- Model 2: works well, needs less computing time \( \rightarrow \) results presented for model 2
Temperature calculation

> Sharp edges in the mesh can produce numerical errors in the analysis procedure

> With good mesh, the temperature change resulting from energy deposition by each bunch shows regular behavior with negligible numerical errors
Results: Stress evolution

- Highest stress after 1.0205 µs
- Deformation is scaled by 730
- Picture taken when the highest stress occurs
- ANSYS results at contact regions have to be checked (solver problems → model must be improved)
Result: Short time

Stress in the center at different Z positions
Result: conclusion

- Max. temperature rise by one triplet is $T=230^\circ C$ within $\sim 1\mu s$
- Heat dispersion into the target body within microseconds is negligible → temperature of the target body is $22^\circ C$
- Max. stress after one triplet 377MPa
- Every mini train adds a different stress load
  - First mini train +225MPa
  - Second mini train +110MPa
  - Third mini train +37MPa
- Max. stress by one triplet is below fatigue stress limit $377\text{MPa}<520\text{MPa}$
Results: Long time

> First attempt → 2 µs pause

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stress [MPa] vs. time [µs]

- Stress max (von Mises)
- Stress z=1.4 cm
- Stress z=1.375 cm
- Stress z=1.35 cm
- Stress z=1.325 cm
- Stress z=1.3 cm
- Stress z=1.25 cm
- Stress z=1.2 cm
- Stress z=1.15 cm
- Stress z=1.1 cm
- Stress z=1.05 cm
- Stress z=0.9 cm

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Summary

> So far, reliable simulation results only for Model 2

> Maximum dynamic stress per triplet is 377MPa (fatigue stress limit is 520MPa)

> longer time → Stress could rise up to 425MPa (to be checked)

> Load cycles per year: $20 \times 3600 \times 2000 \times 5 \approx 75 \times 10^7$ cycles

> With target rotation the number of load cycles at the same beam spot volume can be kept below $10^7$
Next steps

- Optimize the mesh of model 1 in ANSYS to perform simulation studies for the whole target

- Simulations of a longer period:
  - Few triplets
  - Include target rotation
  - Check whether interferences of stress waves are possible

- Degradation of material is expected due to irradiation
  
  → evaluation of dynamic load has to be repeated with modified parameters