Update on Target Simulations of the Undulator Based e^+ Source

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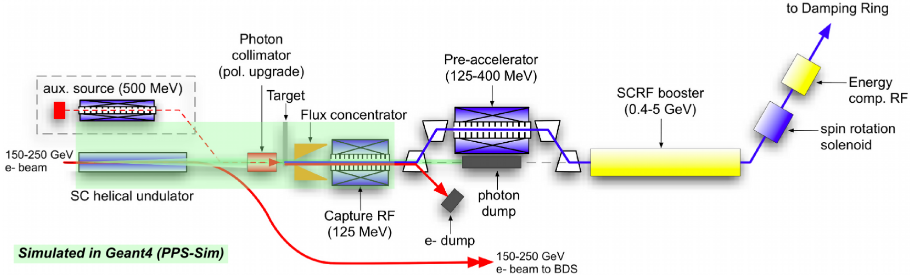
LINEAR COLLIDER COLLABORATION

DESY

Outline

- Source parameters
- Deposited energy in target
- Thermal stress at 250 GeV e^- beam
  - Bunch-by-bunch simulations
  - Temperature and stress after 1st pulse
  - Background temperature and stress of radiative cooled target
  - Peak stress for 250 GeV e^- beam
- Thermal stress for high luminosity case at 250 GeV e^- beam
- Thermal stress at 120 GeV e^- beam
- Summary

Schematic Layout of e^+ Source

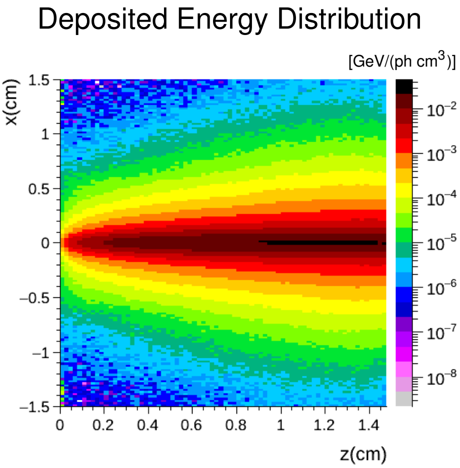


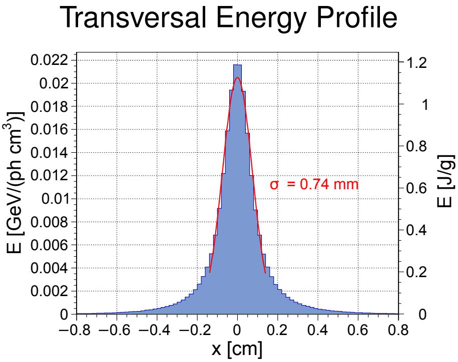
- SC Helical Undulator: 231 m length, 11.5 mm period, $K \leq 0.92$ ($B \leq 0.86$ T)
- (Optional) Photon Collimator: exist principal design (to improve polarization)
- Target: $0.4X_0$ thickness, Ti6Al4V rim rotated with 100 m/s tangential speed
- Flux Concentrator: 12 cm length, $B_{\rm max} = 3.2$ T, $B_{\rm end} = 0.5$ T
- NC Capture RF: 1.3 GHz, $\approx$10 m length, 14.5 MeV/m and 8.5 MeV/m

Nominal Undulator Source Parameters at 500 GeV

e^- Energy [GeV]	250
Number e^- per Bunch	$2 \cdot 10^{10}$
Number of Bunches per Pulse	1312
Bunch Spacing [ns]	554
Pulse Repetition Rate [Hz]	5
Undulator Field [T] (Undulator K value)	0.42 (0.45)
e^+ Polarization [%]	30
Photon Energy (1st harmonic) [MeV]	42.9
Required Undulator Length [m]	147
Average Photon Power [kW]	43
Relative Energy Deposition in Target [%]	5.3
Average Deposited Power in Target [kW]	2.3
Max. Thermal Stress in Target [MPa]	**?**

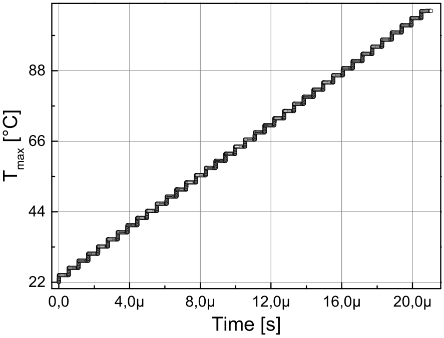
Energy Deposited in Target by Bunch (FLUKA)



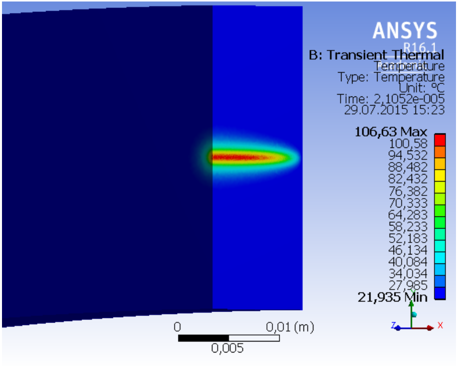


Bunch-by-Bunch Simulations: Temperature

Temperature vs Time



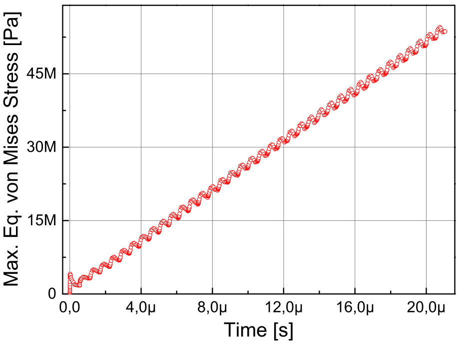
Temperature at “Pulse End”



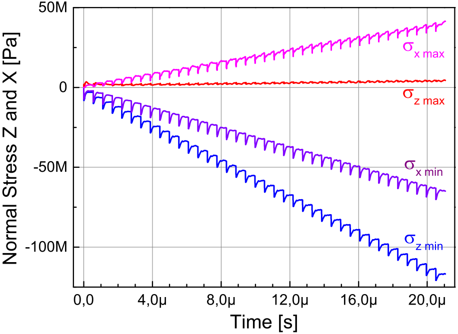
ΔT_{max} per pulse $\approx$ 85 °C

Bunch-by-Bunch Simulations: Thermal Stress

Equivalent Stress vs Time



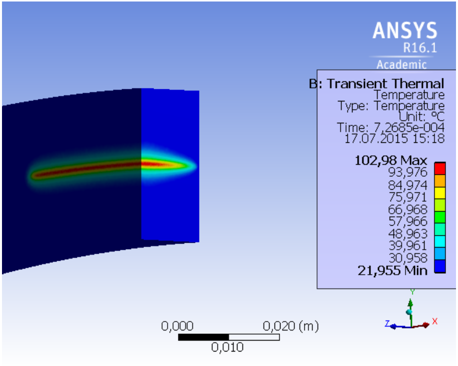
Normal Stress vs Time



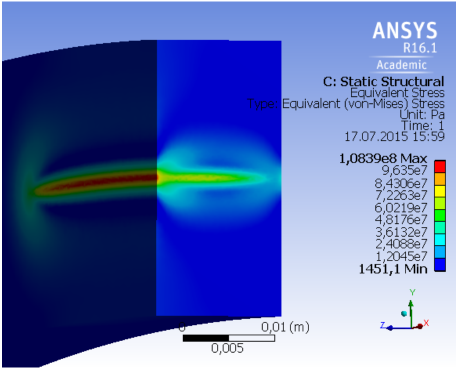
- Dynamic (transient) thermal stress “follows” the temperature
- Dynamic effects induced by individual bunches are small

T and σ in Rotated (100 m/s) Target after 1st Pulse

t_{pulse} = 0.727 ms; Pulse Length = 7.27 cm
Absorbed Energy = 456 J; Average during Pulse Power = 627 kW
Peak Power Density = 276 kW/cm^3



$$PEDD_{pulse}/\Delta PEDD_{bunch} = 37.8$$
$$PEDD_{pulse} = 45.3 \text{ J/g}$$

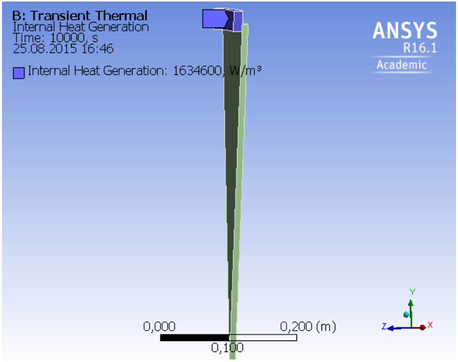


$$\max \sigma_{vM} = 108 \text{ MPa}$$

What stress in target can be expected after long irradiation time?

- Background target temperature could play an important (?) role
- Background temperature depends on choice of cooling system
- Design studies of radiative cooled target are ongoing (Felix talk)
- Simplified model of target cooled by radiation has been used below

Radiative Cooled Target



Case 1:

Equal (homogeneous) heating Ti

2280 W / 1.3949E-3 m^3 = 1.6346E+6 W/m^3

Ti-alloy (ANSYS Data Source):

Radius = 50 cm
Thickness = 1.48 cm
Width = 3 cm
Thermal Conductivity = 21.9 W/(m °C)
Specific Heat = 522 J/(kg °C)
Coef. Thermal Expansion = 9.4E-6 °C^{-1}
Young' Modulus = 96 GPa
Poisson'S Ratio = 0.36
Tensile Yield Strength = 930 MPa
Emissivity = 0.25 (not in ANSYS database)

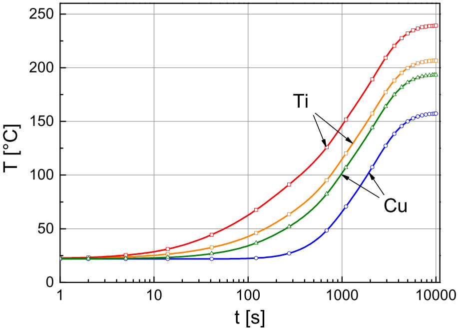
Cu-alloy (ANSYS Data Source):

Radius = 49.5 cm
Thermal Conductivity = 401 W/(m °C)
Specific Heat = 385 J/(kg °C)
Coef. Thermal Expansion = 1.8E-5 °C^{-1}
Young' Modulus = 110 GPa
Poisson'S Ratio = 0.34
Tensile Yield Strength = 280 MPa
Emissivity = 0.7 (not in ANSYS database)

Ti-Cu Contact:
Thermal Conductance = 4000 W/(m^2 °C)
Contact type: frictionless

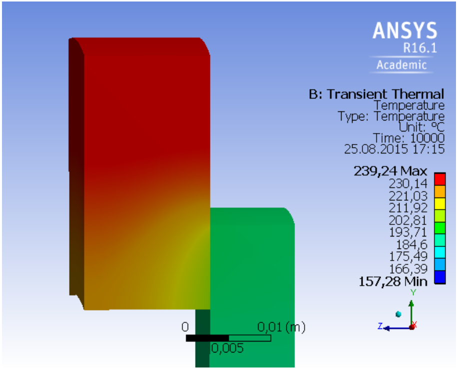
Temperature for Homogeneous Ti Heating

T_{max} and T_{min} vs Time



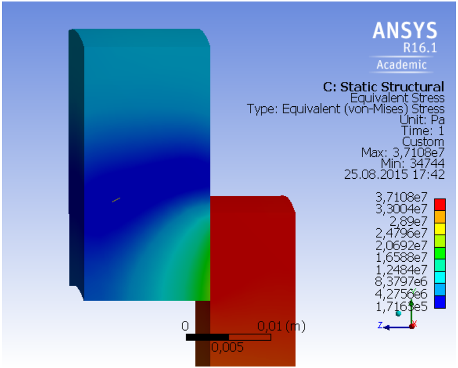
Thermal contact resistance results in difference between minimal T_{Ti} (orange) and maximal T_{Cu} (green).

Equilibrium Temperature

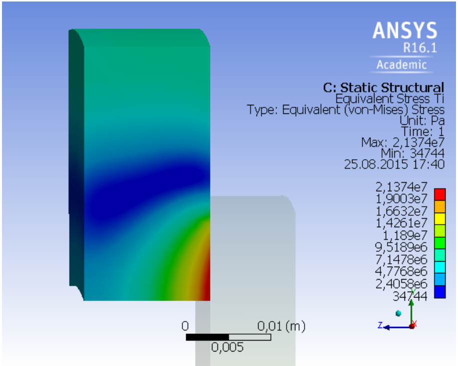


T_{max} = 239 °C

Stress for Homogeneous Ti Heating



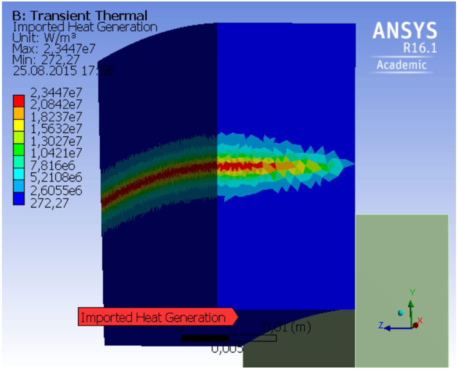
σ_{max} = 37 MPa



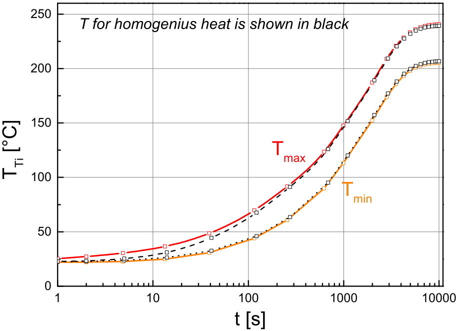
σ_{max} = 21 MPa

Temperature for Inhomogeneous Ti Heating

Heat Distribution



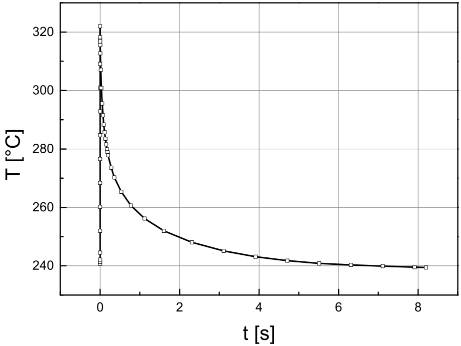
Background Temperature vs Time



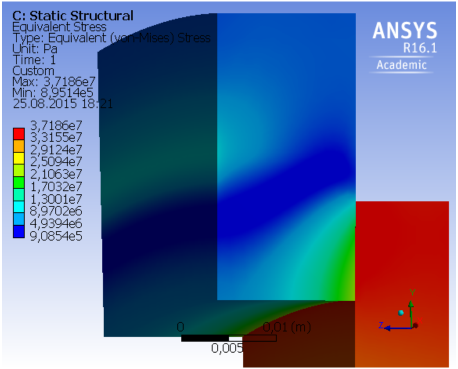
Equal Ti-alloy heating and real profile of energy deposition result in same equilibrium background temperature

Temperature and Stress Induced by Pulse

T_{max} vs Time



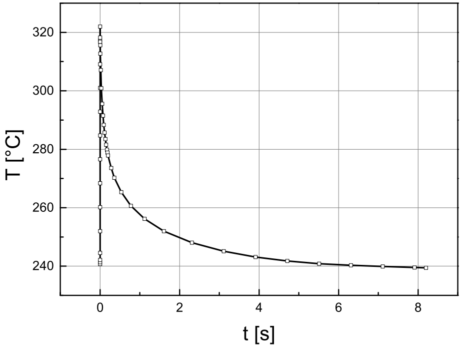
Equivalent Stress at t = 0 s
(background stress)



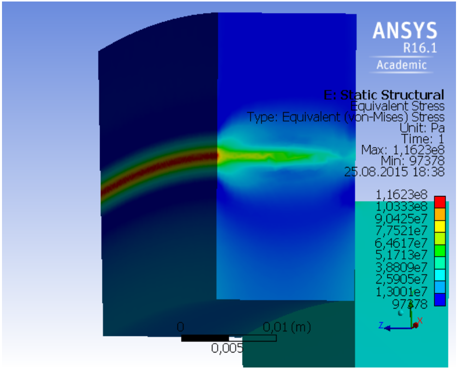
Max. background thermal stress in the beam area is ≈10 MPa

Temperature and Stress Induced by Pulse

T_{max} vs Time



Equivalent Stress at Pulse End
($T_{max} \approx 320$ °C)

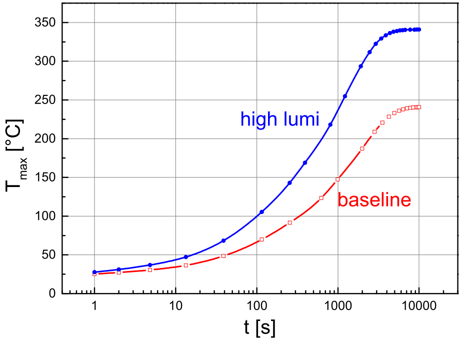


$$\sigma_{max}(T_{max} = 320^{\circ} C) = 116 \text{ MPa}$$

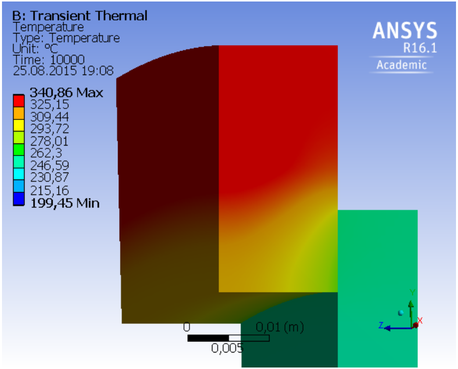
Background Temperature for High Luminosity Case

High luminosity operation mode with 250 GeV e^- beam:
2625 bunches; 366 ns bunch spacing; 961 μs pulse length;
doubled average heat power $\approx$ 4.6 kW

Background Temperature vs Time

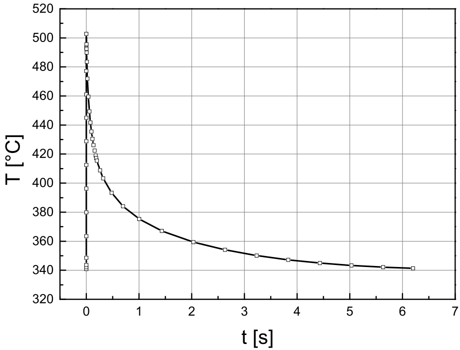


Equilibrium Temperature

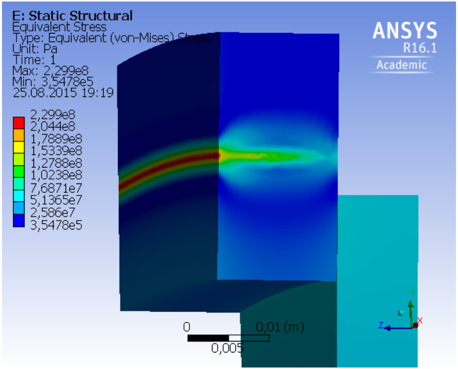


Temperature and Stress Induced by Pulse

T_{max} vs Time

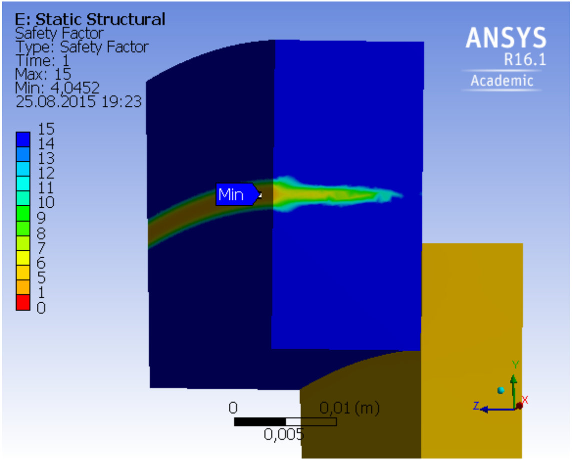


Equivalent Stress at Pulse End
($T_{max} \approx 500$ °C)



$$\sigma_{max}(T_{max} = 500^\circ C) = 230 \text{ MPa}$$

Safety Factor at T_{max} = 500 °C

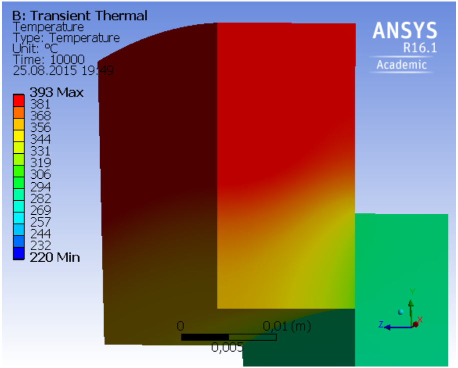


Min. Safety Factor = 4

Temperature for 120 GeV e⁻ Beam

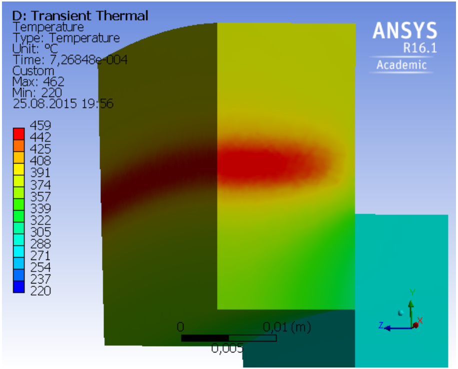
Operation mode with 120 GeV e^- beam:
1312 bunches; 554 ns bunch spacing; average heat power $\approx$ 5 kW

Background Temperature



$T_{max} = 393\ °C$

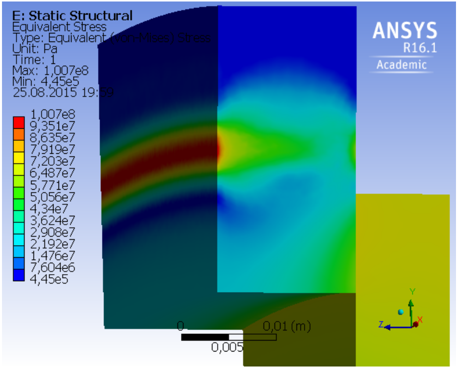
Temperature at Pulse End



$T_{max} = 459\ °C$

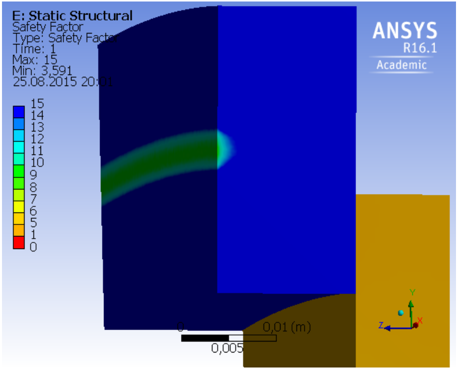
Equivalent Stress and Safety Factor

Eq. Stress at Peak Temperature



$\sigma_{max} = 101$ MPa

Safety Factor at Peak Temperature



Min. Safety Factor = 3.6

Summary

- Dynamic effects induced by bunches are small.
- Peak equivalent thermal stress in simplified target model with radiative cooling at 250 GeV e^- is $\simeq$116 MPa.
- Maximal stress for high luminosity case at 250 GeV e^- is $\simeq$230 MPa.
- At 120 GeV e^- beam the maximal background temperature is the highest ($\simeq$393 °C).
  The maximal equivalent von Mises stress is $\simeq$100 MPa.
- Optimization of the target model will be continued.