Simulations for the Photon Target Cooled by Radiation

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LINEAR COLLIDER COLLABORATION

DESY

Outline

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   - Positron Yield vs Target Thickness
   - Energy Deposition Profile and PEDD
   - Thermal Stress Induced by Pulse
   - Stress in Target
   - Average Deposited Power in Ti6Al4V Target
   - Radiative Cooling
     - Basics of Radiative Cooling
     - 5 kW, 0.4 X_0 Ti Rim
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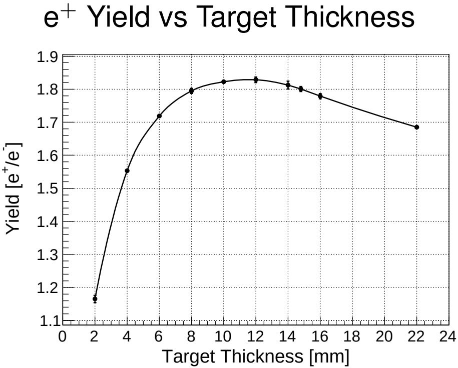
     - 5 kW. 0.4 X_0 Ti Rim + Cu Disk
     - Different Thicknesses of Ti-Alloy Target
2. W-alloy Target
   - Positron Yield vs Target Thickness
   - PEDD and Total Deposited Power
   - Peak Stress after Pulse
   - Radiative Cooling
     - Different Thicknesses of W-Alloy Target
     - Thickness of Cu Disk

Positron Yield vs Thickness of Ti6Al4V Target

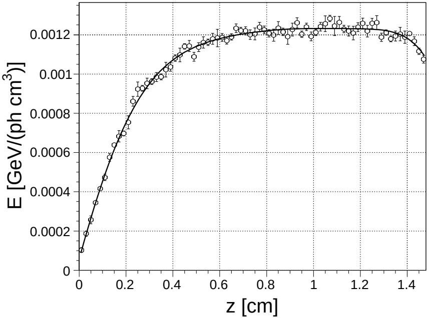


Source Parameters:

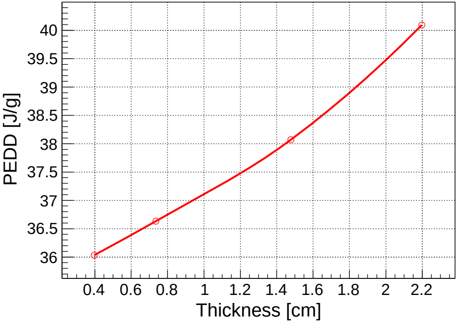
- $L_u =$ **231 m**, $K = 0.92$, $\lambda = 11.5$ mm
- $E_{e^-} =$ **120 GeV**
- Pulsed Flux Concentrator:
  $B_{max} =$ **3.2 T**, $R_{min} =$ **8.5 mm**
- DR Acceptance:
  $\epsilon_{nx} + \epsilon_{ny} \leq 70$ mm rad
  $\delta E/E < 1.5\%$ @ 5 GeV
  $\delta z_{bunch} < 34$ mm

Energy Deposition Profile and PEDD in Ti6Al4V Target

Energy Deposition Profile along Beam Axis; 0.4 X_0



PEDD vs Target Thickness

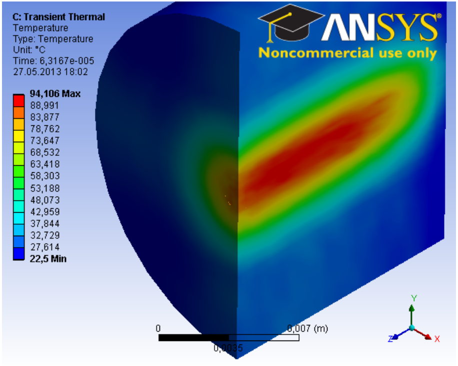


Rotation with 100 m/s; 554 ns bunch spacing

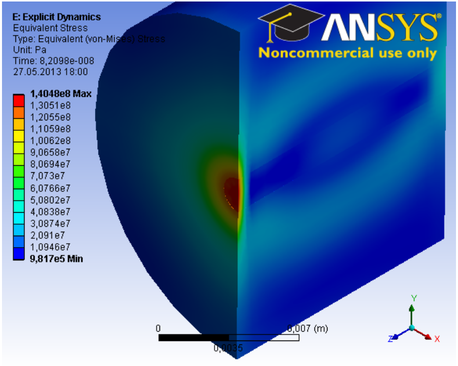
Bunch overlapping factor: 114

$Y_{e^+} = 1.5\ e^+/e^-$

Temperature Distribution



Equivalent Stress



Stress in Target

$$\sigma = \sigma_{mechnical} + \sigma_{eddy\ currents} + \sigma_{thermal}$$

$$\sigma_{thermal} = \sigma_{fast\ \Delta T} + \sigma_{T_{backgroud}}$$

$\sigma_{mechnical}$ is due to fast rotation: $\sim$ 60 MPa for $0,4X_0$ Ti6Al4V, $R = 50$ cm, 2000 rpm

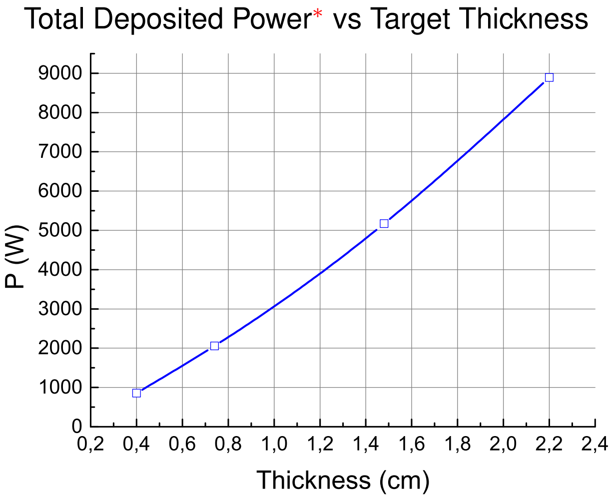
$\sigma_{eddy\ currents}$ is due to rotation in pulse magnetic field: ? MPa

$\sigma_{fast\ \Delta T}$ is due to fast temperature jump induced by a pulse: $\Delta T \sim 70$ °C in $\simeq 60\mu$s $\Rightarrow$ 140 MPa for 120 GeV e^-

$\sigma_{T_{backgroud}}$ is due to increased "background" (equilibrium) temperature distributed not equally over the target: depends on design of cooling system ($P \sim 5$ kW)

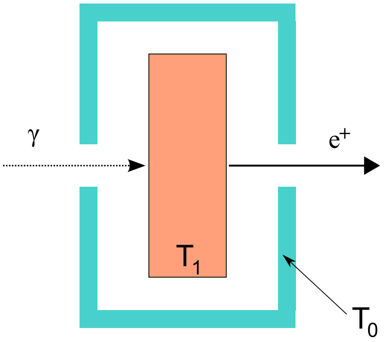
Ti6Al4V:
- Fatigue Strength = 510 MPa
- Tensile Yield Strength = 880 MPa

Average Deposited Power in Ti6Al4V Target



*1312 bunches/pulse; 5 Hz repetition rate; 1.5 e^+/e^-

Basics of Radiative Cooling



Radiation heat transfer:

$$Q_R = \sigma\, \varepsilon\, F\, A\, (T^4_{target} - T^4_{ambient})$$

σ is the Stefan-Bolzman constant

ε is the **emissivity**

F is geometric form factor

A is the **area of radiating surface**

T_{target} is the temperature of "hot" target (T_1)

$T_{ambient}$ is the temperature of "cold" absorber (T_0) or ambient temperature

Simplified model of radiation-to-ambient has been used in ANSYS: $T_0 = 22\ ^\circ$C, $F = 1$, A – surface area of target (or target + additional cooler)

Equilibrium Temperature. 5 kW, 0.4 X_0 Ti Rim

Target Dimensions:

Radius R = 50 cm
(middle of the rim)

Thickness d = **1.48 cm**

Width w = 3.0 cm

Emissivity ϵ = 0.25

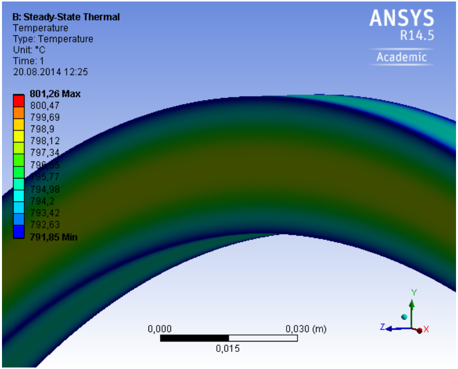
Deposted Power P = **5170 W**

T_{max} = **801 °C**

T_{min} = 792 °C

σ_{max} = **5,5 MPa**
Equivalen (von-Mises) Stress

Temperature Distribution



5 kW. 0.4 X_0 Ti Disk

Target Dimensions:

R = 50 cm

d = **1.48 cm**

w = 3.0 cm

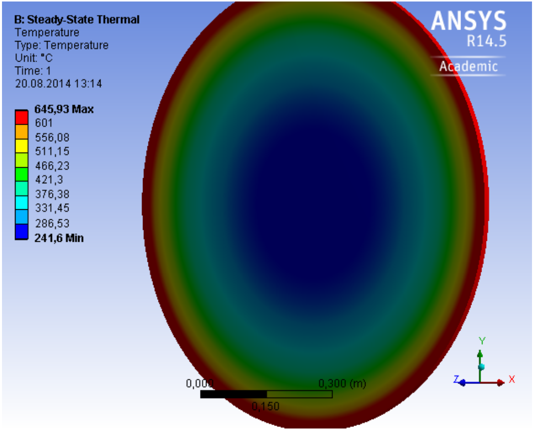
ϵ = 0.25

P = **5170 W**

T_{max} = **646 °C**

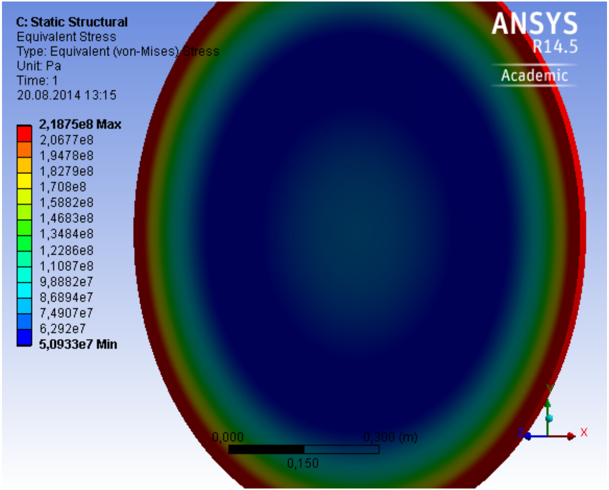
T_{min} = 242 °C

Temperature Distribution



5 kW. 0.4 X_0 Ti Disk

Distribution of Equivalent Stress



σ_{max} = **219 MPa**

5 kW. 0.4 X_0 Ti Rim + Cu Disk

Target Dimensions:

R = 50 cm

d = **1.48 cm**

w = 3.0 cm

ϵ_{Ti} = 0.25

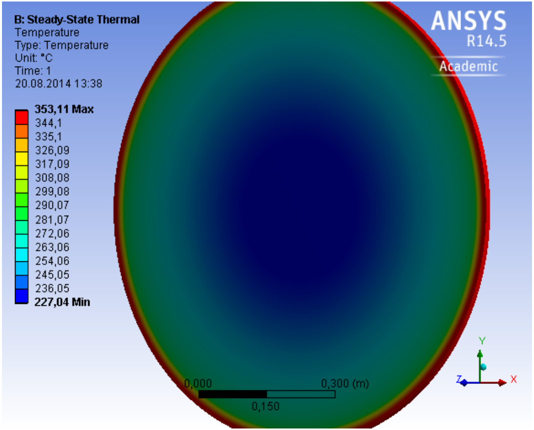
ϵ_{Cu} = 0.9

P = **5170 W**

T_{max} = **353 °C**

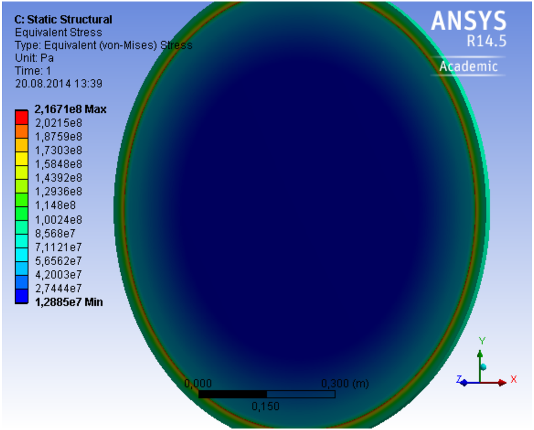
T_{min} = 227 °C

Temperature Distribution



5 kW. 0.4 X_0 Ti Rim + Cu Disk

Distribution of Equivalent Stress



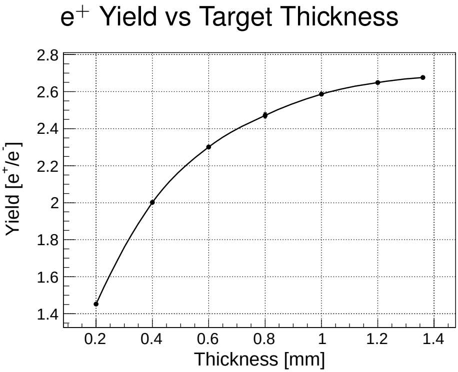
σ_{max} = **108 MPa** (in the middle of Ti)

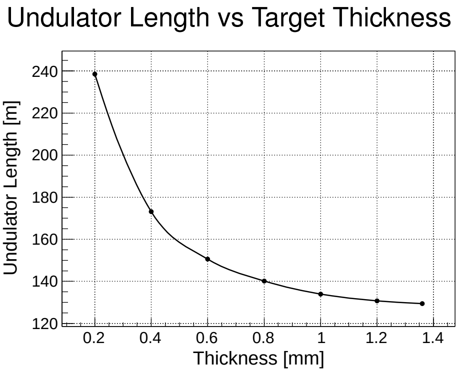
σ_{Ti-Cu} = **217 MPa** (on the boundary between Ti and Cu)

Different Thicknesses of Ti-Alloy Target

Thickness, mm	**14,8**	**7,4**	**4,0**
Power, kW	5,17	2,06	0,945
Ti rim			
T_{max}, °C	801	646	505
Ti disk			
T_{max}, °C	646	451	336
T_{min}, °C	242	113	63
σ_{max}, MPa	219	185	152
Ti rim + Cu disk			
T_{max}, °C	**353**	235	**171**
T_{min}, °C	227	135	86
σ_{max}, MPa	**108**	46	**20**
σ_{Ti-Cu}, MPa	217	136	98

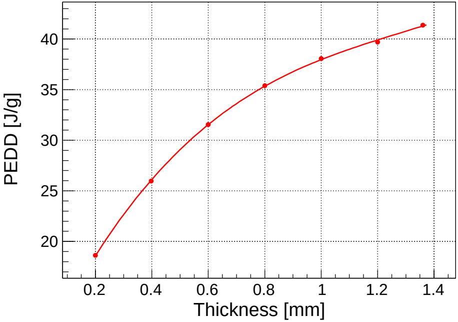
e^+ Yield vs Thickness of W25Re Target. 120 GeV e^-





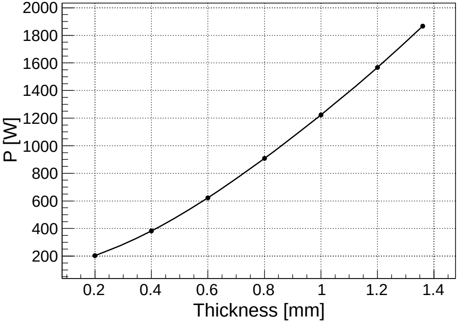
PEDD and Total Deposited Power for W25Re Target

PEDD vs
Target Thickness



Rotation with 100 m/s
554 ns bunch spacing

Total Average Power vs
Target Thickness

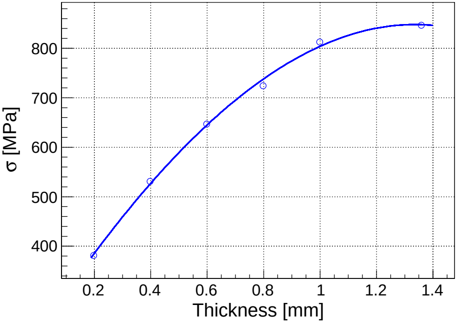


1312 bunches/pulse
5 Hz repetition rate

$$Y_{e^+} = 1.5\ \mathrm{e}^+/\mathrm{e}^-$$

Peak Stress in W25Re Target after Pulse

"Hydrodynamic" Peak Stress per Pulse



Rotation with 100 m/s
554 ns bunch spacing

$Y_{e^+} = 1.5\ e^+/e^-$

$$\sigma = \alpha E \Delta T$$

α – coef. of thermal expansion;
E – Youngs modulus;
ΔT – temperature rise per pulse:
$\Delta T = \text{PEDD}/c_p$,
$c_p = 0.14$ J/(g*K) – spec. heat capacity of W-alloy

$$\sigma \approx \sigma_{static} + \sigma_{pulse} \lesssim 550 \text{ MPa}$$

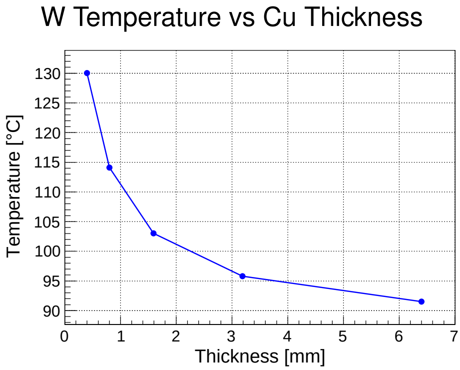
Not much space for σ_{static} left?

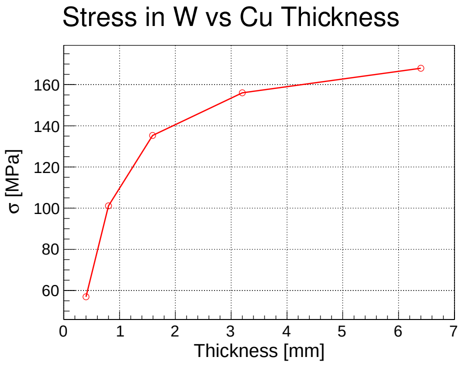
Different Thicknesses of W-Alloy Target

Thickness, mm	**1,4**	**0,8**	**0,4**
Power, kW	1,87	0,91	0,38
W rim + Cu disk			
T_{max}, °C	**261**	195	**130**
T_{min}, °C	80	51	29
σ_{max}, MPa	**390**	217	**57**
σ_{W-Cu}, MPa	459	270	112

Thickness of Cu Disk

0,4 mm thick W (0,12 X_0); 950 W





Summary

Water cooling of rotated target *can be replaced by* **radiative cooling**

- 4 mm Ti rim around Cu disk ($R \approx 50$ cm) could be an option

  Expected equilibrium temperature is 170 °C and quasi-static equivalent stress is 20 MPa (without taking into account contribution of a fast dynamic stress induced by a pulse)

- Design studies for radiative cooling of W target needs more "efforts" (relatively small total deposite power in the target, thickness is very small)