Stress evaluation at the ILC positron source

A. Ushakov[1], G. Moortgat-Pick[1], S. Riemann[2], A. Ignatenko[2], F. Dietrich[2], K. Aulenbacher[3], V. Tyukin[3], P. Heil[3]

[1]University of Hamburg, [2]DESY, [3]University of Mainz

DPG Spring Meeting of the Matter and Cosmos Section

3 March 2016

University of Hamburg

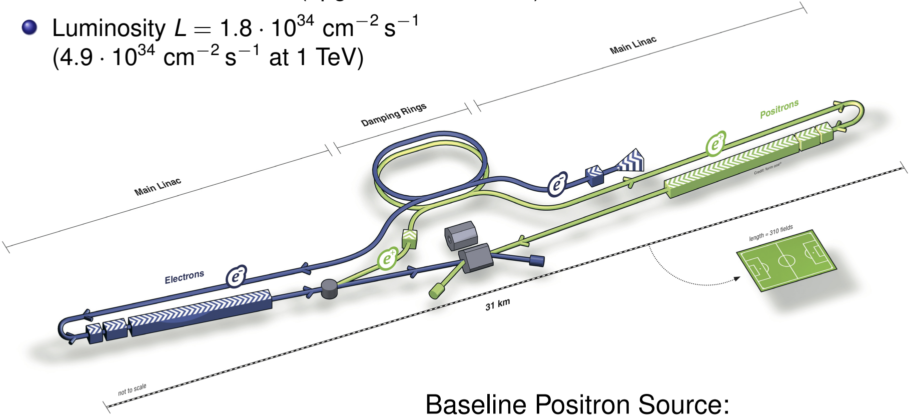
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

International Linear Collider. e^+ Source

International Linear Collider (ILC):

- $E_{CM} = 250 \div 500$ GeV (upgradeable to 1 TeV)
- Luminosity $L = 1.8 \cdot 10^{34}$ cm^{-2} s^{-1} ($4.9 \cdot 10^{34}$ cm^{-2} s^{-1} at 1 TeV)

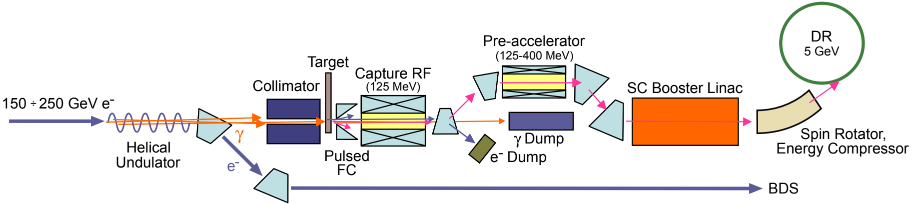


Baseline Positron Source:

- $N_{e^+} = 3 \cdot 10^{10}$ e^+/bunch at DR
- 1312 bunches in 0.727 ms pulse, 5 Hz

Scheme of ILC e^+ source

ILC undulator-based source (30% up to 60% e^+ polarization)



e^- Beam Energy: $150 \div 250$ GeV

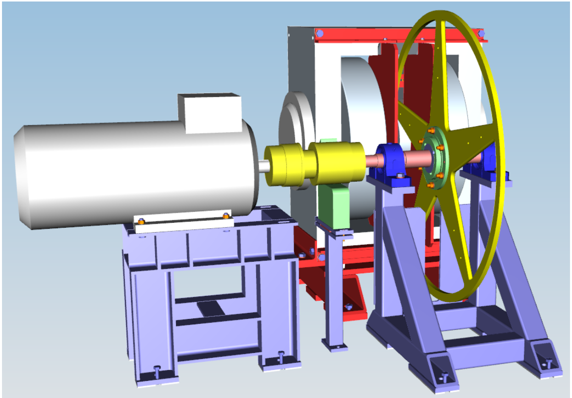
231 m SC Helical Undulator: 11.5 mm period, $B_{max} = 0.86$ T ($K_{max} = 0.92$)

Target: solid Ti6Al4V, 1.4 cm thickness ($0.4\ X_0$)

Source Parameters at $E_{CM} = 500$ 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]	0.42
Average Photon Energy [MeV]	26.8
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
Photon rms spot size on target [mm]	0.8

Prototype of Target (Cockcroft Institute, UK)

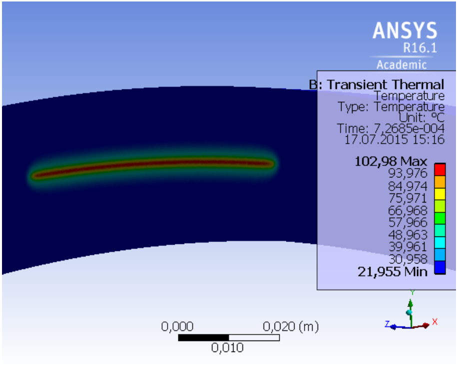


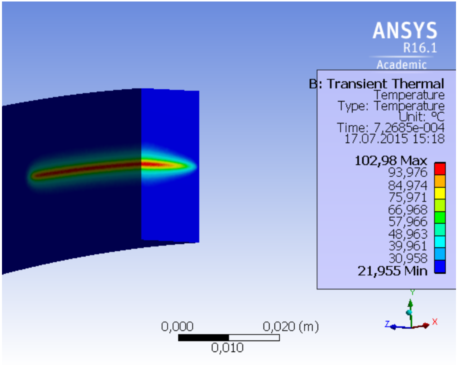
- Target diameter: 1 m
- Tangential speed: 100 m/s at rim (2000 rpm)
- 0.727 ms pulse $\Rightarrow$ 7.27 cm beam path

Temperature Distribution in Rotated (100 m/s) Target

after 1st Pulse and Nominal Source Parameters ($E_{CM} = 500$ GeV, $P_{e^+} = 30\%$)

Average Deposited Power in Target during 727 μs Pulse = 627 kW
Absorbed Energy = 456 J
Peak Power Density = 190 kW/cm^3



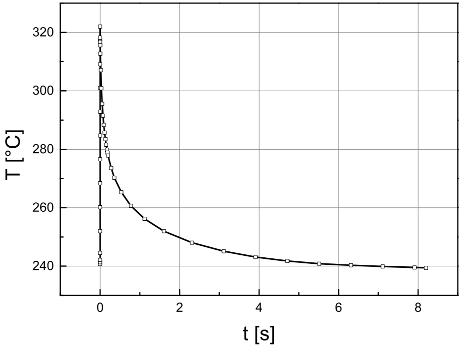


$\Delta T_{max} \approx 81\ ^\circ$C

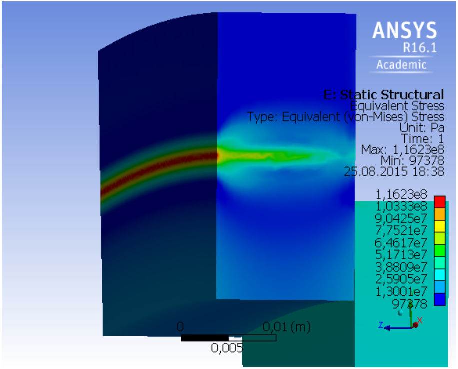
Peak Energy Deposition Density (PEDD) = 42 J/g

Temperature and Stress in Radiative Cooled Target

T_{max} vs Time



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



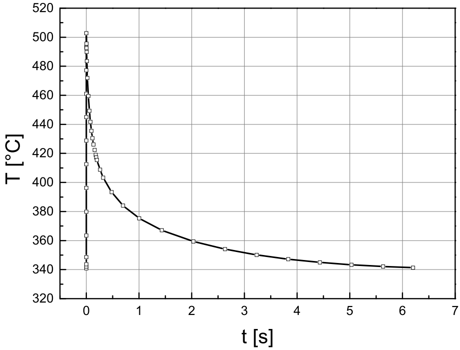
$$\sigma_{max}(T_{max} = 320^\circ C) = 116 \text{ MPa}$$

Temperature and Stress for High Luminosity Case

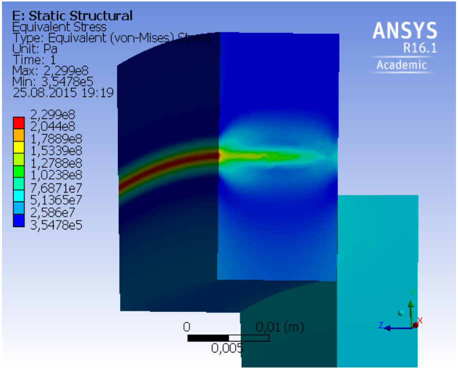
High luminosity operation mode with 250 GeV e^- beam:

Beam time structure: 2625 bunches; 366 ns bunch spacing; 961 μs pulse;
Average heat power $\approx$ 4.6 kW

T_{max} vs Time



Equivalent Stress at Pulse End



$$\Delta T_{max} \approx 165\ ^\circ\mathrm{C}; \qquad \sigma_{max}(T_{max} = 500^\circ C) = 230\ \mathrm{MPa}$$

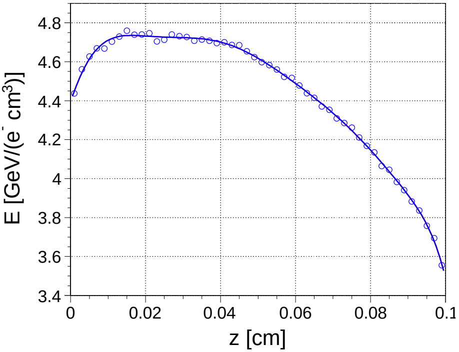
Summary on Heat Load of ILC Positron Source Target and Material Tests with MAMI e^- Beam

- Temperature rise per $\sim$1 ms pulse of ILC e^+ source: $\approx 80 \div 200$ °C. This corresponds to a peak energy deposition densities of about $\approx 40 \div 100$ J/g.
- The average temperature depends on cooling design. For the target cooled by radiation, the expected average target temperature is about $\approx 250 \div 350$ °C.
- Tensile yield strength for Ti6Al4V material is 565 MPa at 370°C. Fatigue strength after 10^7 cycles is about 50% of yield strength. These limits do not include material degradation under irradiation.
- Material tests at typical for ILC target thermal load conditions are needed.
- Material tests using 3.5 MeV and/or 14 MeV MAMI (Mainzer Mikrotron) e^- beam are started.

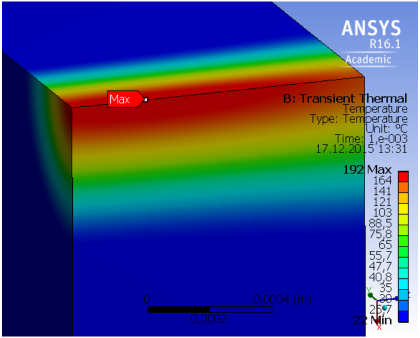
MAMI: Energy Deposition and ΔT per 1 ms Pulse

100 μA @ 14 MeV e$^-$, 0.4 ns bunch spacing, $2.45 \cdot 10^6$ bunches/pulse (1 ms)
Beam spot size on target: 200 μm rms radius

Energy Deposition along Beam Axis



Temperature Distribution



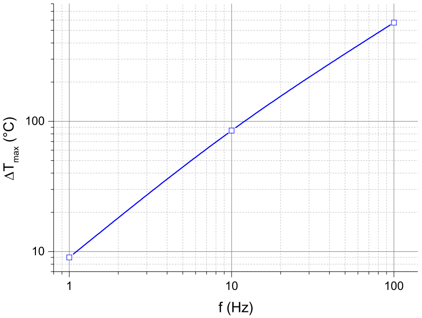
4.7 GeV/(e$^-$ cm^3) $\Rightarrow \Delta T_{pulse} = 200\ ^\circ$C

$\Delta T_{max} = 170\ ^\circ$C*

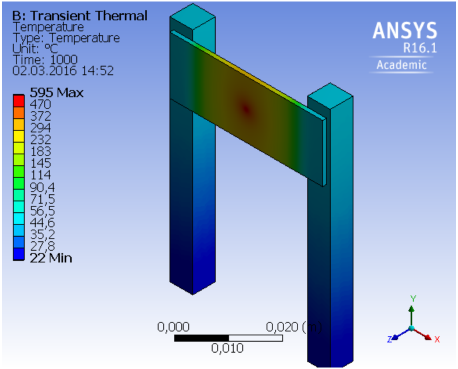
*Thermal conductivity was taken into account

Average (Background) Temperature

Max. Temperature vs Rep. Rate



Temperature Distribution for 100 Hz



$$\Delta T_{\max} \simeq 300\ ^\circ\text{C at 50 Hz rep. rate}$$

Summary

- 100 μA MAMI e^- beam (with 1 ms pulses and $\sim 10 \div 60$ Hz repetition rates) allows to achieve same ***peak*** and ***average*** temperatures as in ILC positron source target.
- Material aging can be investigated too.
- Same area of ILC target is heated again after $\sim$ 7 seconds, that corresponds to $2.5 \cdot 10^6$ thermal cycles per year.

  This number of cycles can be reached after 2–3 days of irradiation with MAMI beam.