X-RAY Absorber Design and Calculations for the EBS Storage Ring

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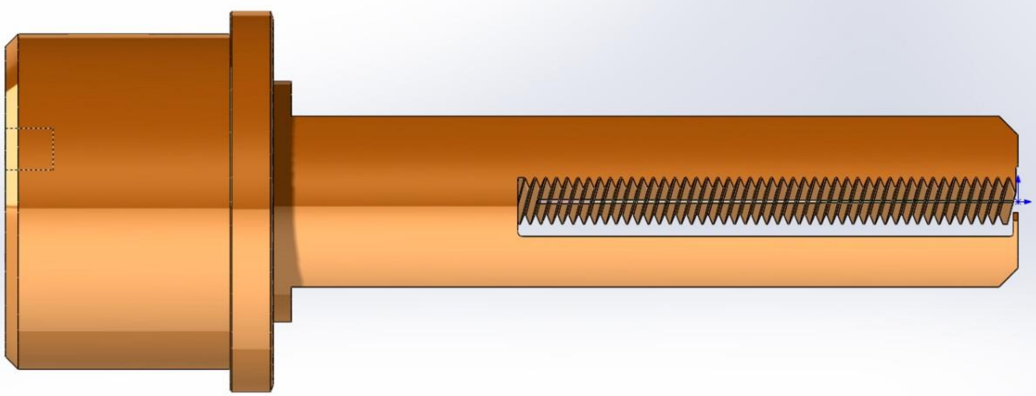


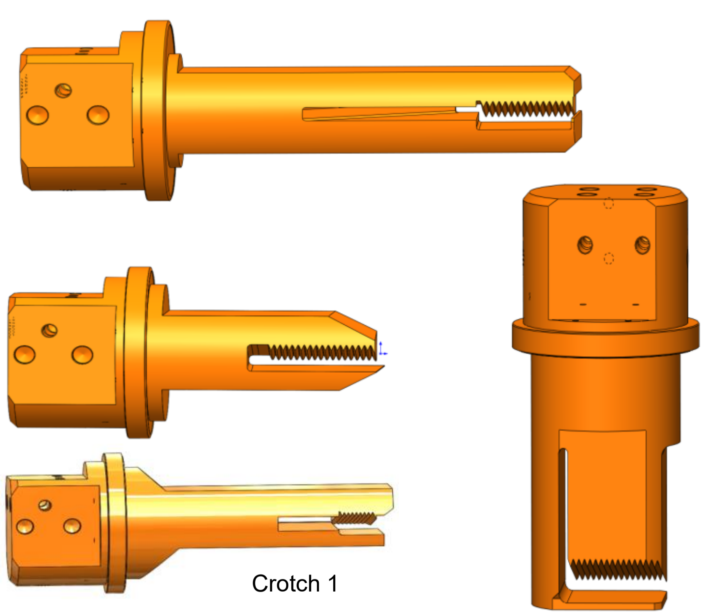
Contents:

- Introduction
- Overview of new Design and Concepts for EBS Absorbers
- CFD Modeling
- Design Criteria and Thermal-Mechanical Modeling
- Conclusion

Introduction

- ~ 400 new Absorbers in the Storage Ring
- Up to 110 W/mm^2 Normal Incident Power Densities
- Using a new Alloy for Storage Ring Absorbers: CuCr1Zr
- 100% Machined. No Braze, no Weld
- New Cooling Channel Design.

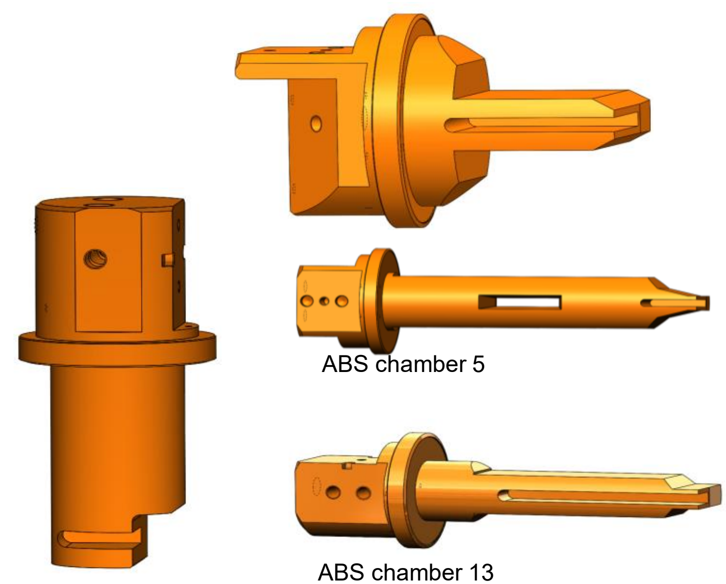
Toothed Family (up to 110 W/mm^2)



Crotch 1

ABS chamber 9

Flat Face Family (up to 50 W/mm^2)



ABS chamber 5

ABS chamber 13

ABS chamber 4

Overview: CuCr1Zr

		Glidcop Al-25	CuCr1 Zr	Cu-OFE
MECHANICAL PROPERTIES	Young's modulus E (GPa)	130	128	115
	Yield Strength (MPa)	330	280	75
	Ultimate limit (MPa)	380	380	200
	Elongation at break (A%)	12	8	45
	Hardness (Brinell)	120	125	100
THERMAL PROPERTIES	Thermal expansion at 20°C (1/K)	16.6	17.5	16.8
	Conductivity at 20°C ($W.m^{-2}.K^{-1}$)	365	320	393
	Typical max. Heat load (W/mm^2)	70	50	20
DESIGN PROPERTIES	CF Knife edge possible	Yes	Yes	No
	Price (€/Kg) for rods > Ø100mm	45	20 (*)	25

(*) Call for tender – 12 t

Use of CuCr1Zr suggested by S. Sharma (**)

Main Advantages:

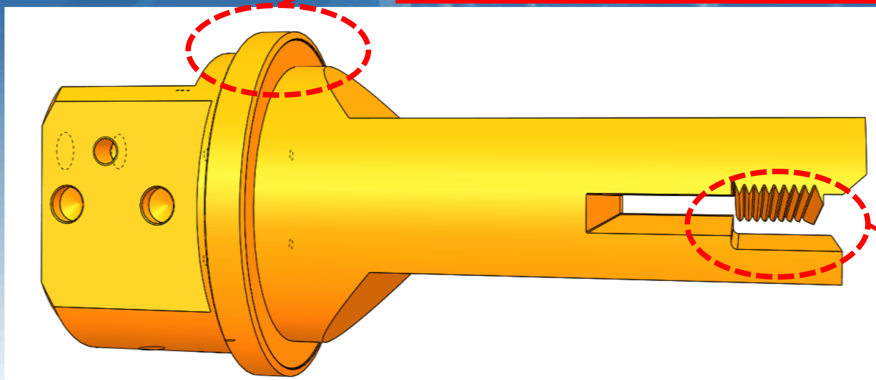
- Close to Glidcop
  - Mechanical properties significantly better than Cu.
  - Hard enough to machine CF flanges: manufacturing simplified, no weld, no braze, no problem.
- Cheap

See E. Gagliardini *et al.* poster
This conference

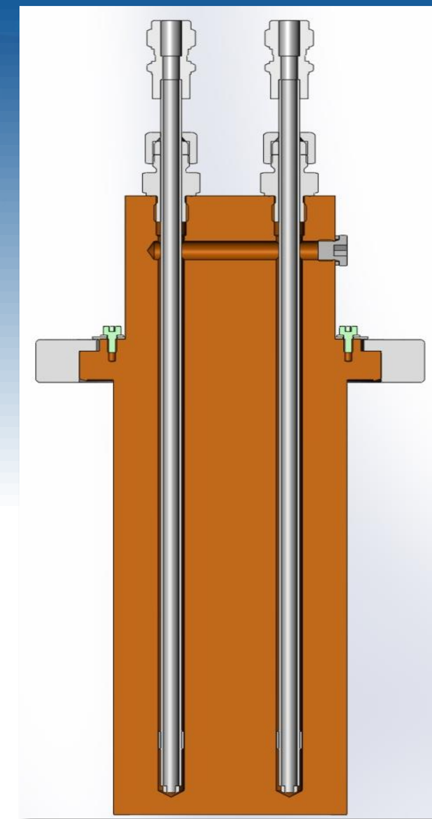
(**) S. Sharma, "A Novel Design of High Power Masks and Slits", Proc. of MEDSI2014, Australia (2014)

Overview: Toothed Absorbers

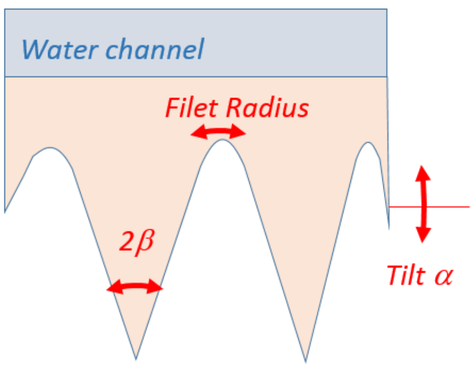
UHV Knife Edge Seal integrated in the Absorber Body



Power Blocking Head:
- *Triangular Tooth (X-Rays)*
- *Super Tooth + Base Face (Compton + Rayleigh + Fluorescence)*



Concentric Cooling Channels Stainless Steel ϕ6x8 mm



Design Choices:

- $2\beta = 45°$
- Filet Radius 0.32 mm
- Tilt ~ 10° (Absorber Dependent)

Power Density Attenuation Factor:

$\sin(\beta)\tan(\alpha) \sim 95\%$

(Theoretical)

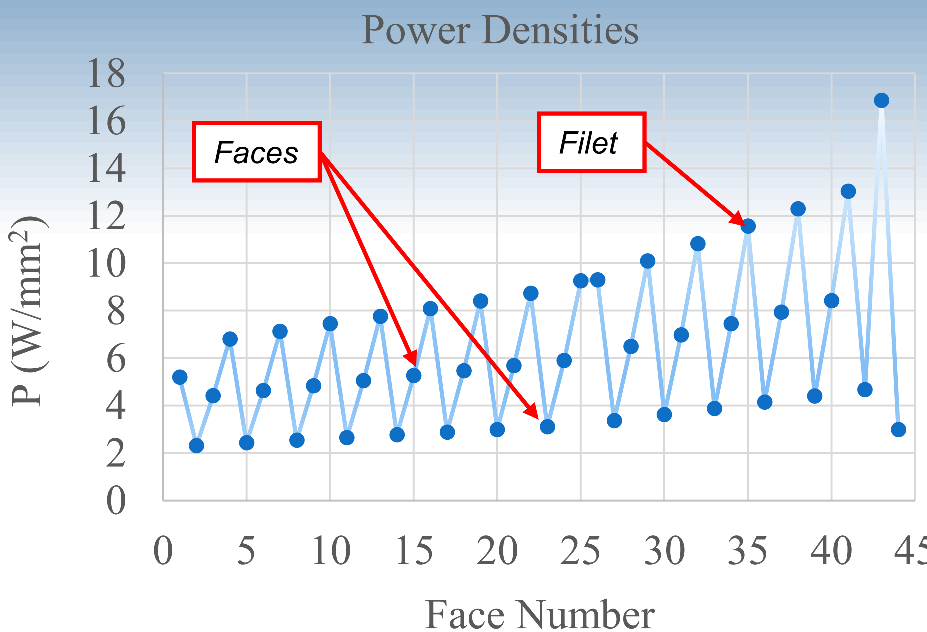
Overview: Precision

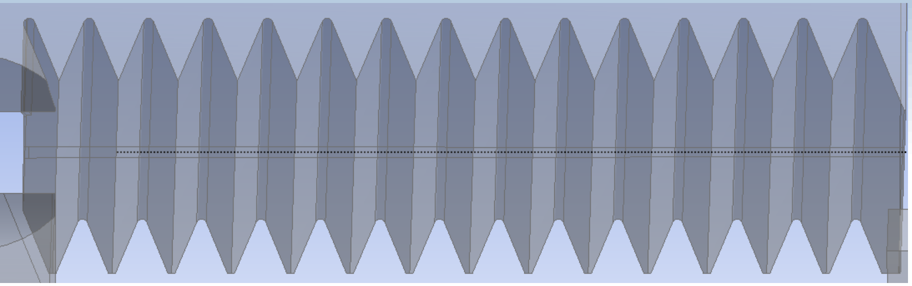
<u>Design Choices</u>:

- ± 2 mm in Height
- λ = ± 1.5° in Angle

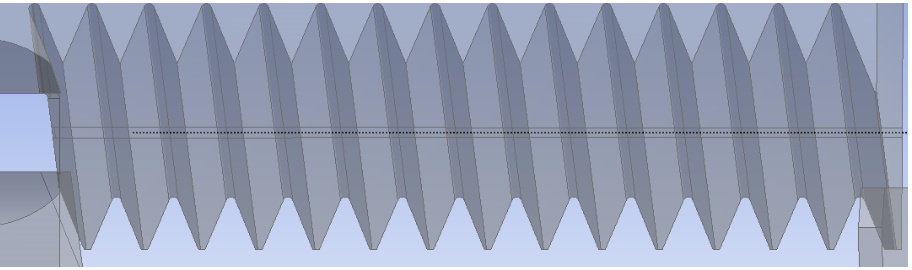
(0.5° Fan Opening)

(1° Alignment)





λ = 0. Symmetric Teeth



λ = +1.5°. Asymmetric Teeth

<u>Optimization</u>:

Worst Face and Filet Power Densities close together

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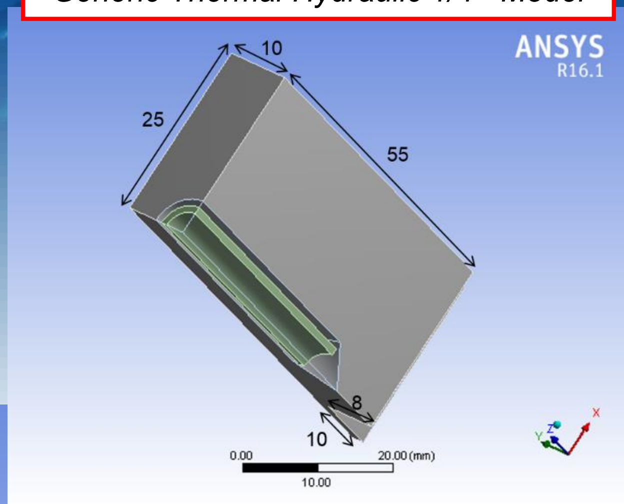
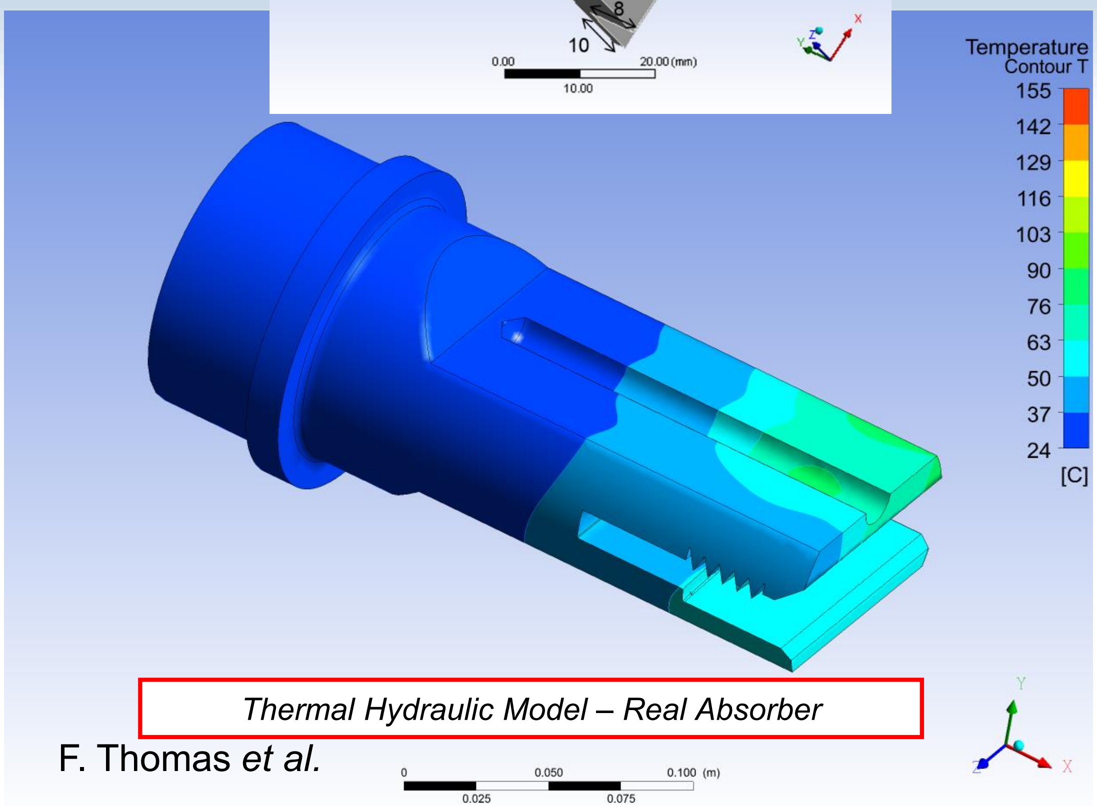
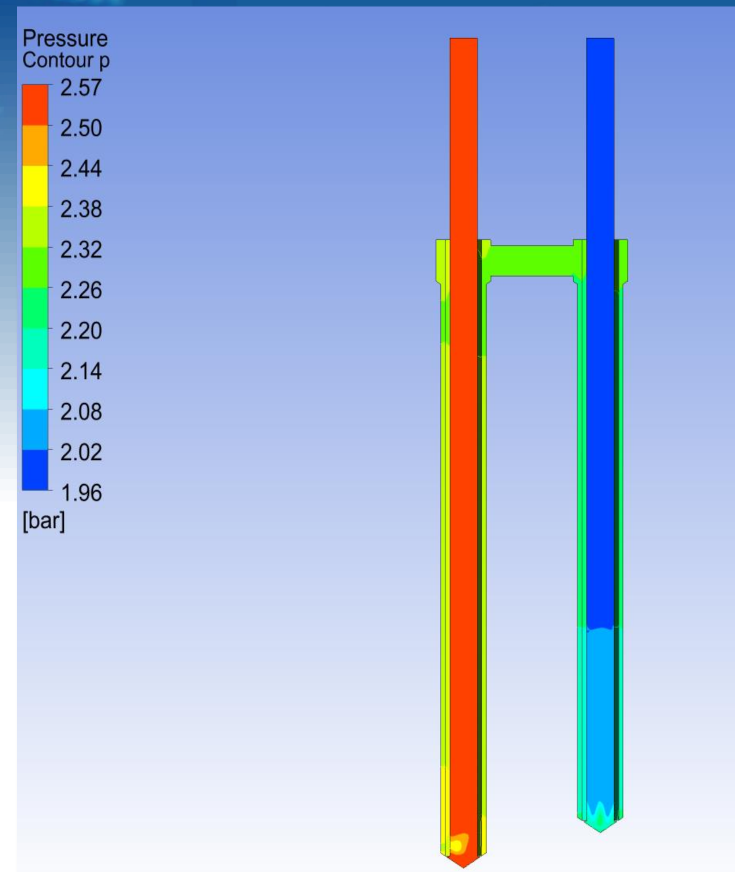
CFD: Hydraulic and Thermal-Hydraulic Models

Generic Thermal Hydraulic 1/4th Model





Thermal Hydraulic Model – Real Absorber



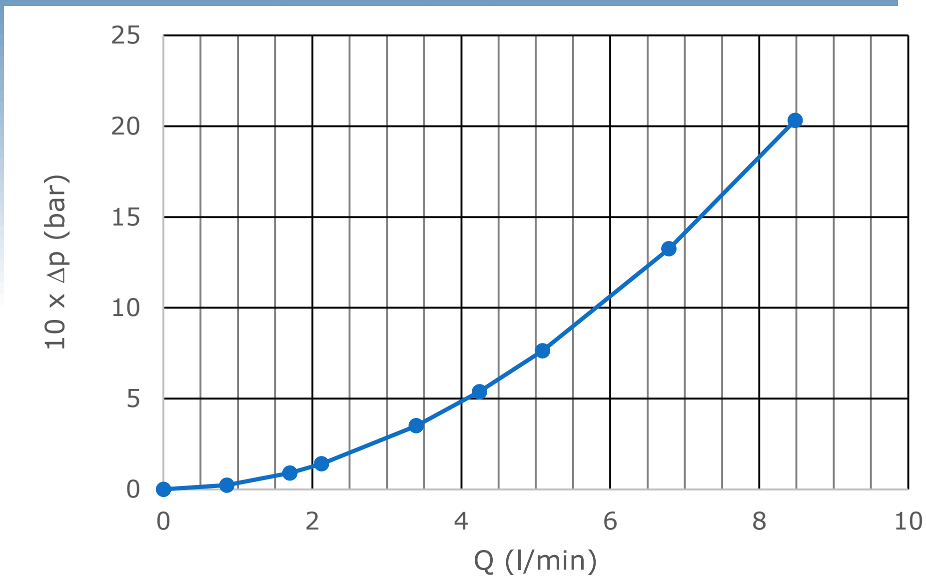
Generic Hydraulic ½ Model

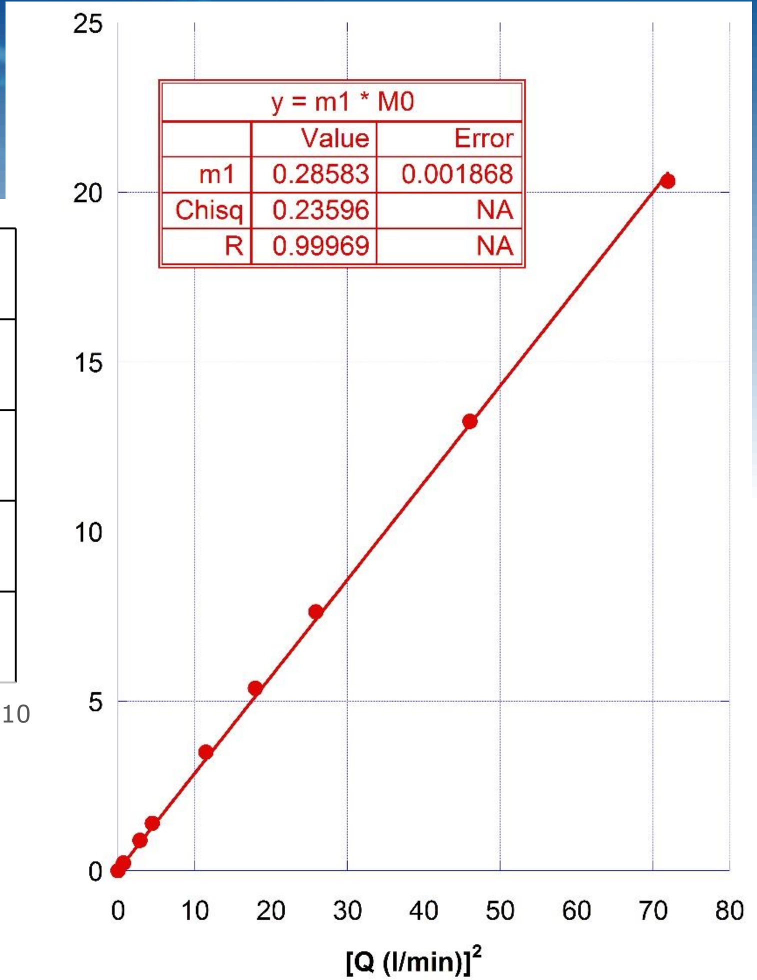
F. Thomas *et al.*

Barcelona, 14 September 2016

CFD: Hydraulic Results

2 Concentric Cooling Channels:
⇒ Turbulent

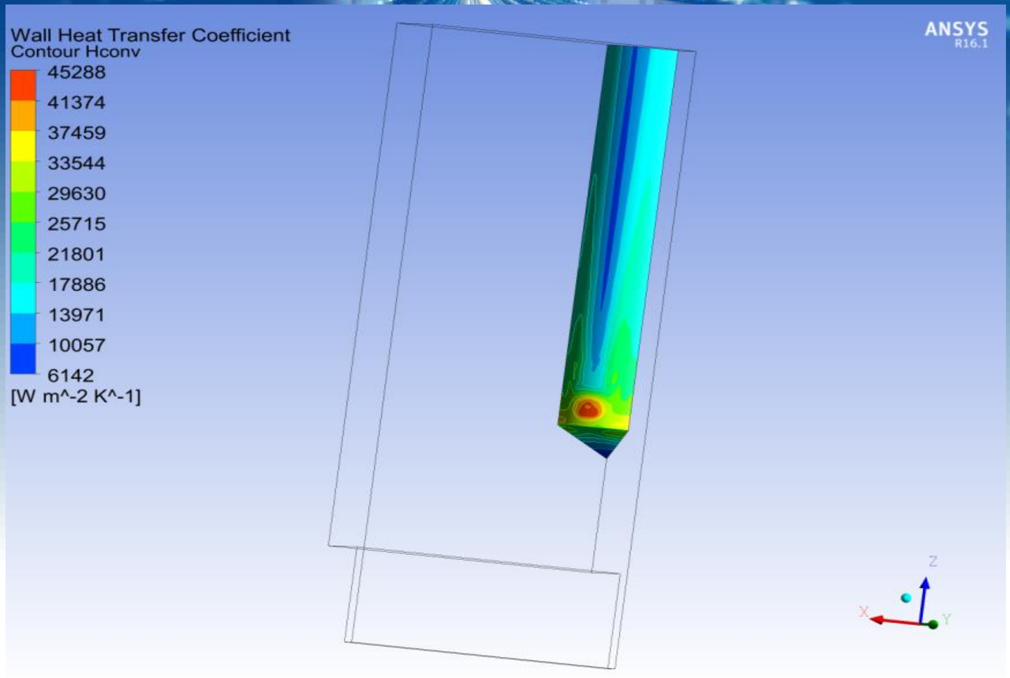


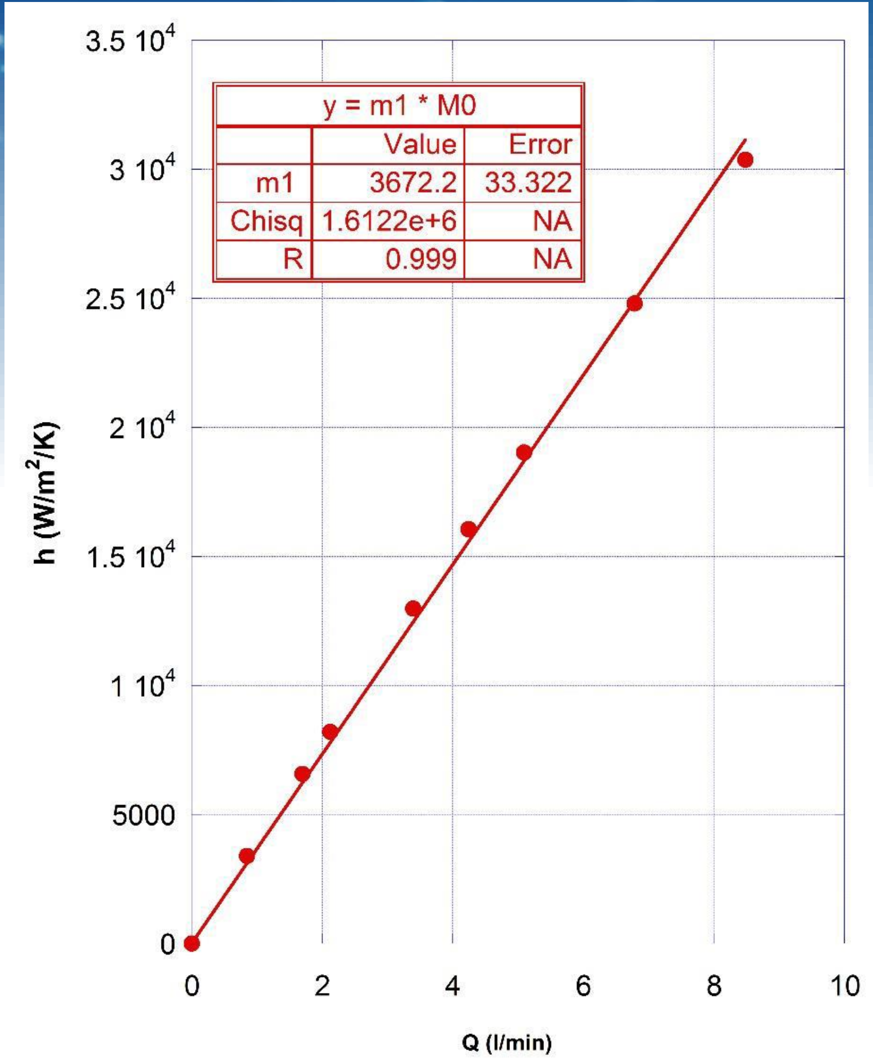


Δp > 8 bar at 25 l/min
Nominal: 4.5 l/min – 0.6 bar

$$\Delta p(bar) = (0.029 \pm 0.002) \times [Q(l/\min)]^2$$

CFD: Thermal-Hydraulic Results





Heat Transfer Coefficient not Constant

Average Heat Transfer Coefficient:

$$h\,(W/m^2/K) = (3672 \pm 33) \times Q(l/\min)$$

$$h = 16.5\ kW/m^2/K\ at\ 4.5\ l/\min$$

Thermal-Mechanical Calculation Criteria

- All Absorbers calculated so far
- Temperature: T_{Max} < 250°C

- *All* Absorbers are in the Elastic Regime. No Fatigue.
  ⇒ S_y is the relevant parameter
- *All* Stresses are Secondary Stresses.
  ⇒ S_y is the relevant limit

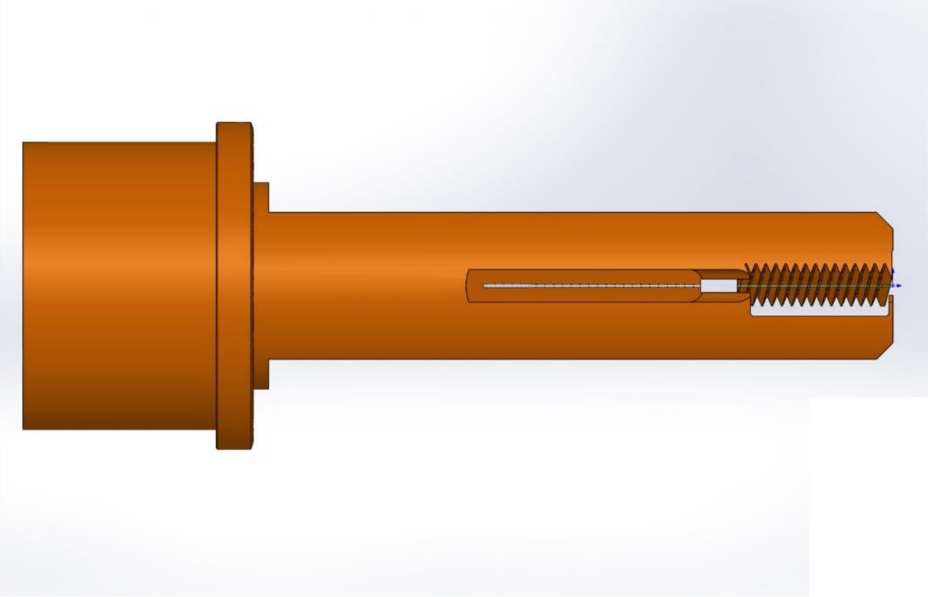
To be "Elastic ASME" like

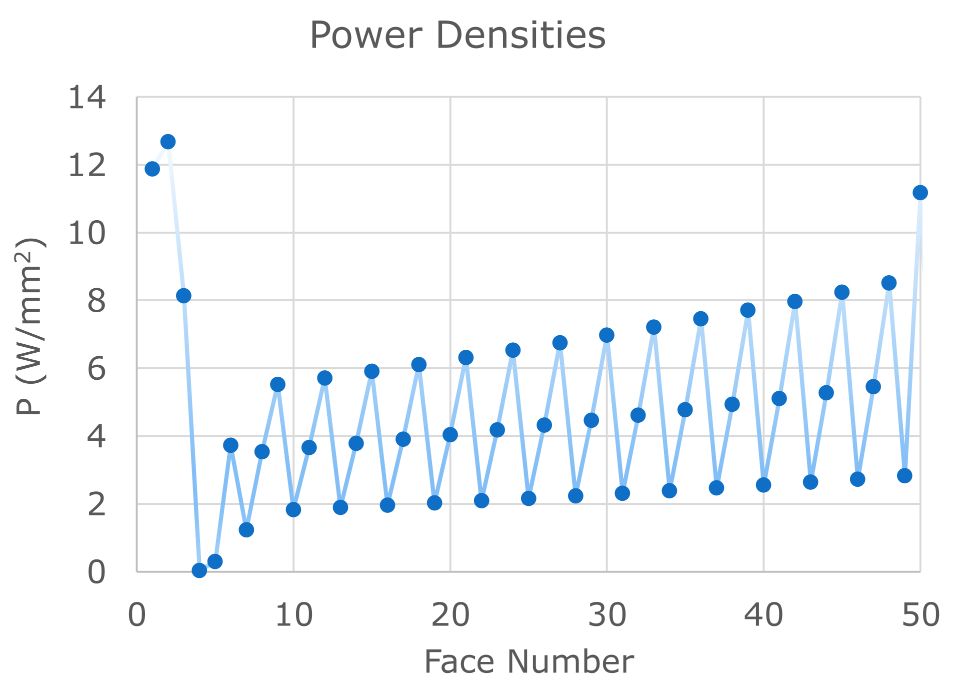
Key point: making optimized tooth geometry allows us to stay within the purely elastic regime

Accelerator	Maximum Temperature	Maximum Stress / Strain
ALBA	400° (Glidcop®)	0.2% strain (10^5 cycles)
ANKA, SLS	(Copper)	0.2% strain (10^4 cycles)
APS	541° (Copper) 405° (Glidcop®)	$2.S_y$, S_F (10^5 cycles) Fatigue Model
DIAMOND	(Copper)	0.5% peak strain 0.1% bulk strain
ESRF	$T_{Melt}/2$ (All Materials)	$\sigma_{VM} < S_y$
ESRF, EBS	250° (CuCr1Zr)	$\sigma_1 < S_y = 280MPa$ $\sigma_3 > -S_y$ $\tau_{Max} < S_y/2$
SOLEIL	(All Materials)	$\sigma_{VM} < 0.75.S_y$
SPRING-8	(All Materials)	Fatigue Model

Updated form: M. Quispe *et al.*, "Development of the Crotch Absorber for ALBA storage ring", Proc. of MEDSI2008, Canada (2008)

Thermal-Mechanical Results

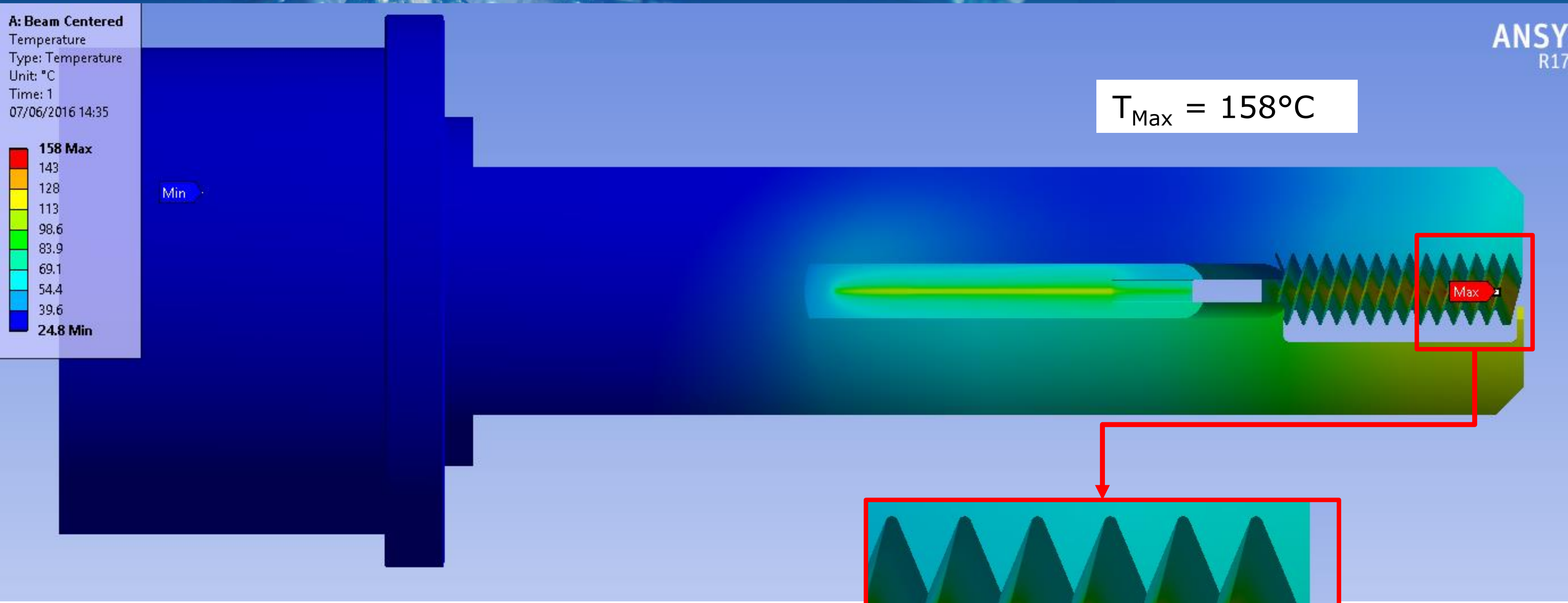




ABS-CH9-1-2:

- Crotch Absorber
- 16 Teeth
- 51 illuminated Faces
- 3 Dipoles – Quadrupoles: 3037 W
- 2 Cooling Channels
- Beam centered, Rotation 1.5°

Thermal-Mechanical Results

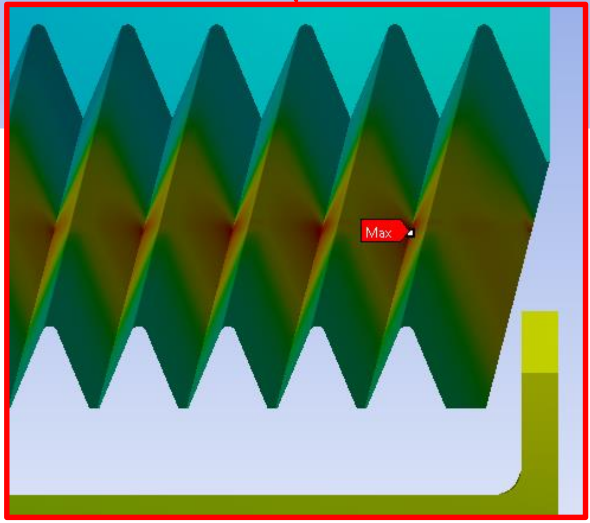


T_{Max} = 158°C

Maximum Temperature:

Tooth 15

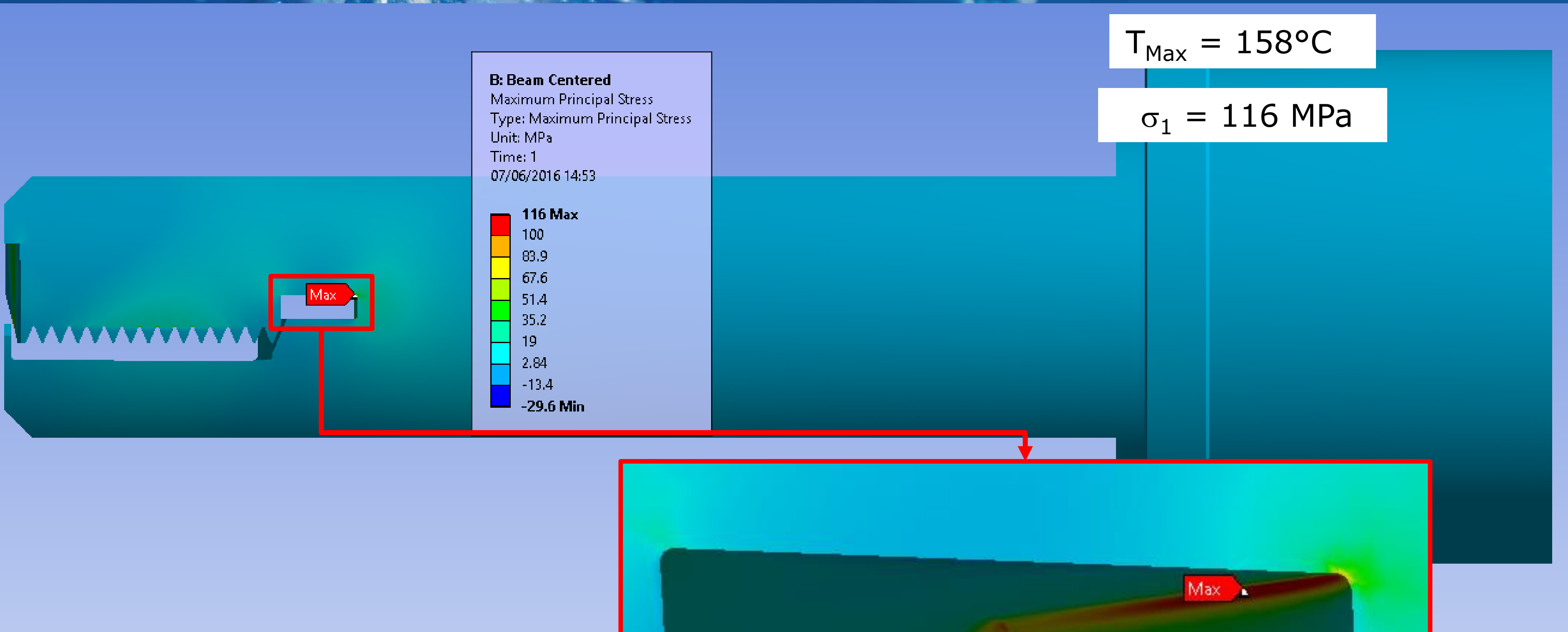
Criterion $T_{Max} < 250°C$

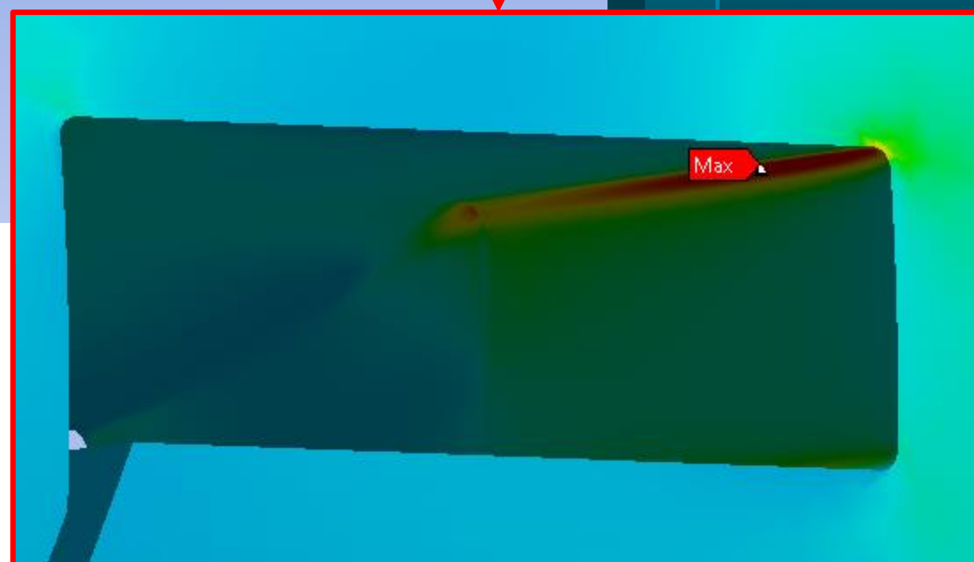


Thermal-Mechanical Results

T_{Max} = 158°C

σ_1 = 116 MPa



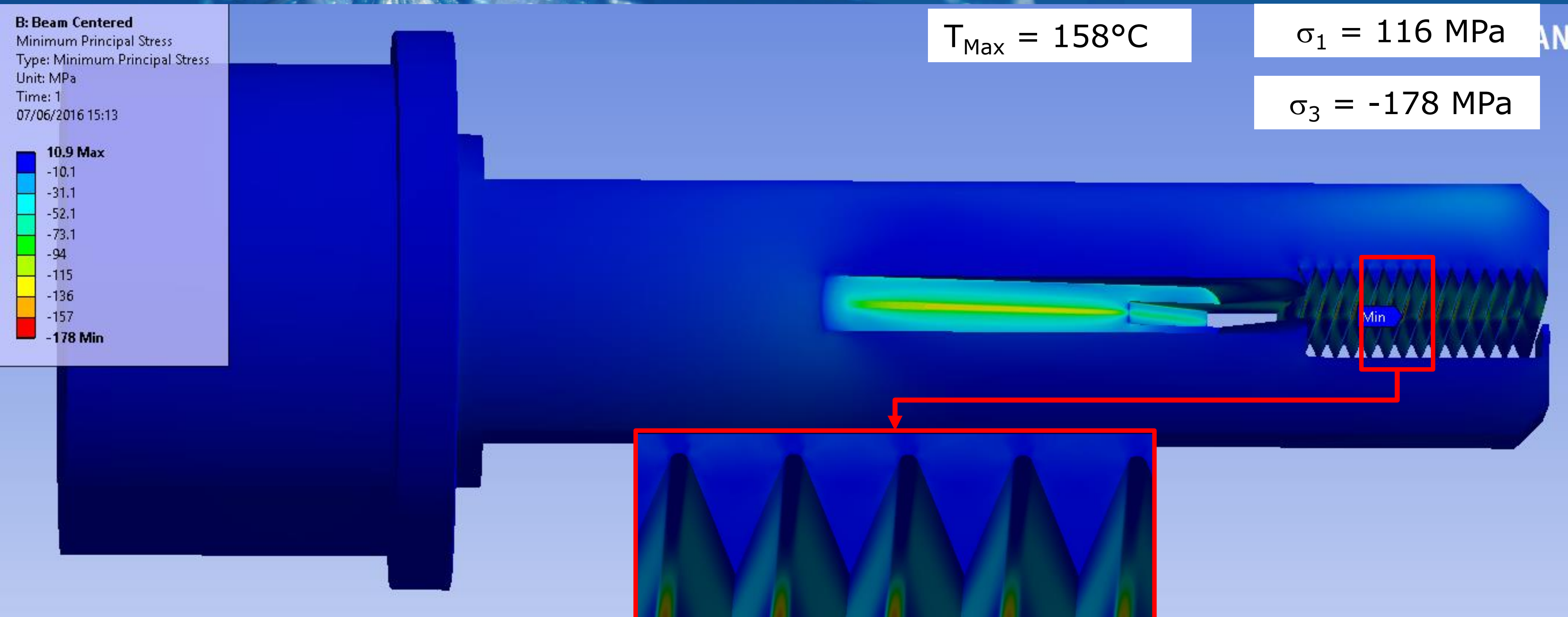


Peak Value Maximum Principal Stress:

Backside Connecting Filet

Criterion σ_1 < 280 MPa

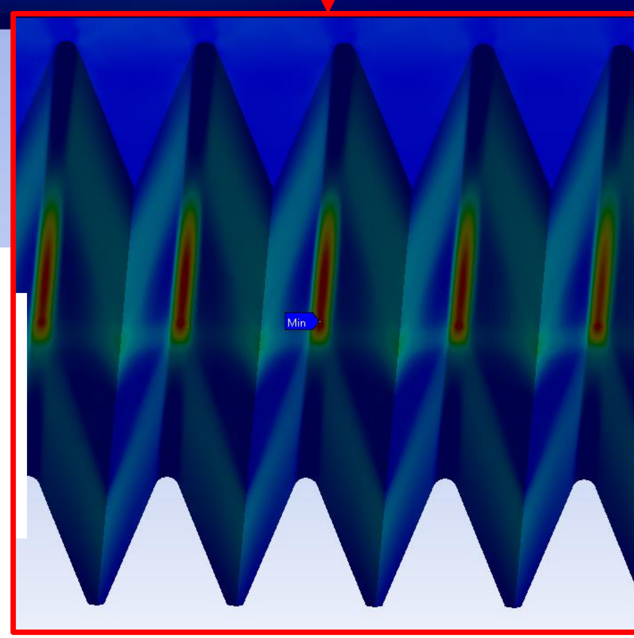
Thermal-Mechanical Results



T_{Max} = 158°C

σ_1 = 116 MPa

σ_3 = -178 MPa

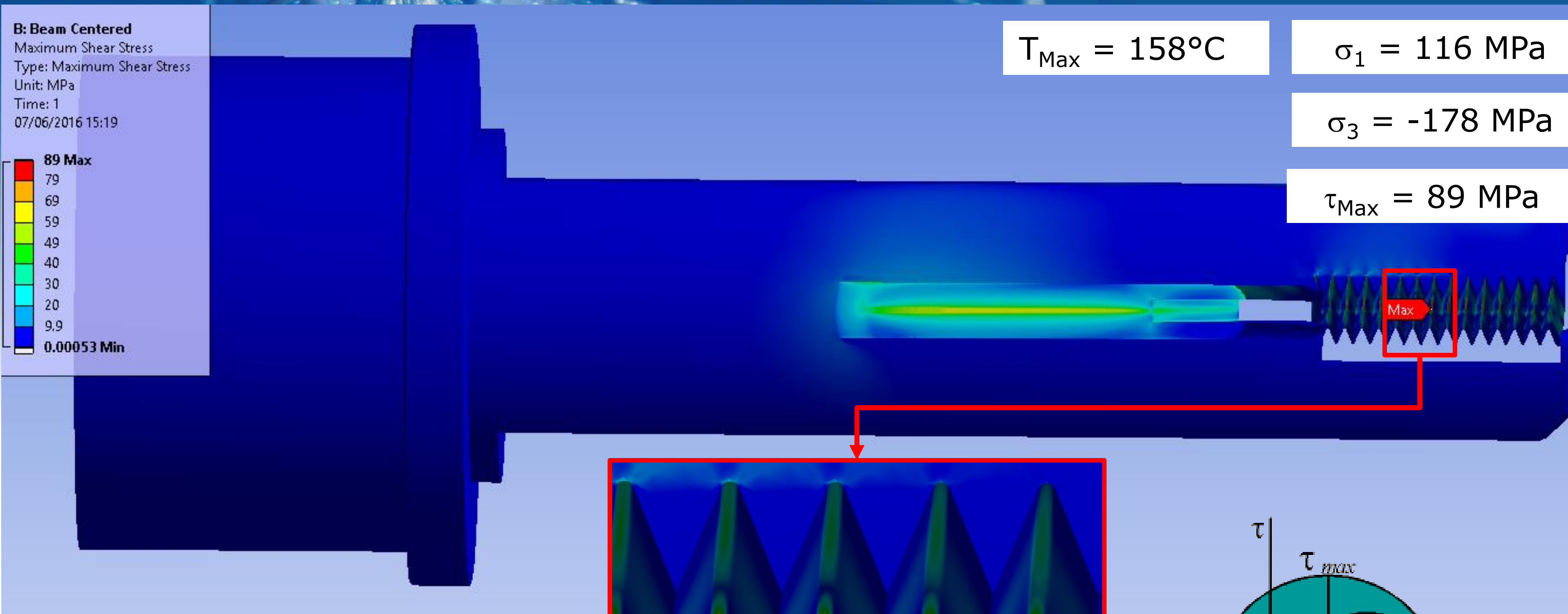


Peak Value Minimum Principal Stress:

Filet between Teeth

Criterion $\sigma_3 > -280$ MPa

Thermal-Mechanical Results

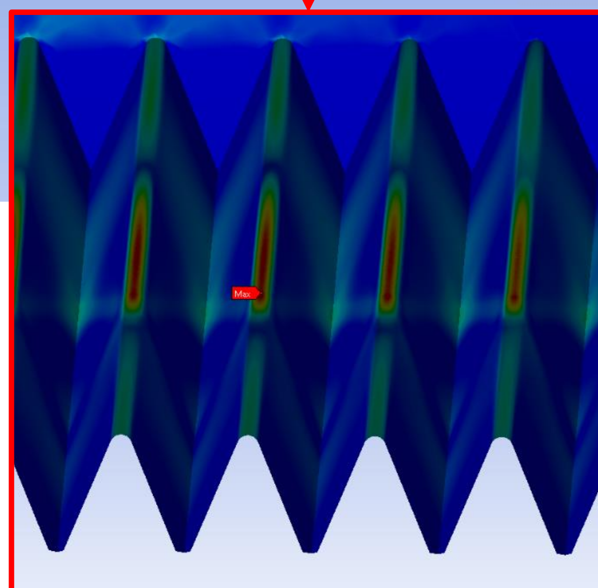


T_{Max} = 158°C

σ_1 = 116 MPa

σ_3 = -178 MPa

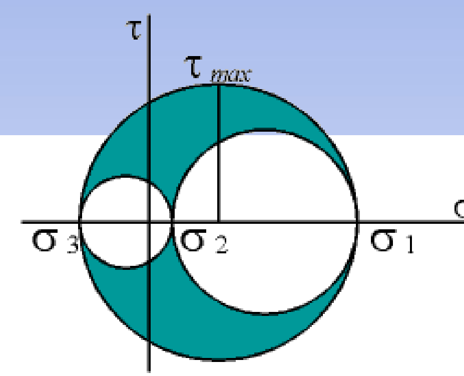
τ_{Max} = 89 MPa



Peak Value Maximum Shear Stress:

Filet between Teeth

Criterion τ_{Max} < 140 MPa



$$\tau_{Max} = \frac{\sigma_1 - \sigma_3}{2}$$

Conclusion:

- ~ 400 new Absorbers in the Storage Ring in CuCr1Zr
- 100% Machined. No Braze, no Weld
- Concentric Cooling Channels for Simplicity and Compactness
- Design Optimization:
  - Working in the purely Elastic Regime
  - No Water Cooling for Vacuum Chambers
- Price Optimization:
  - All Absorbers sharing the same Tooth Profile
  - Loose Mechanical Positioning allowed