Design and FEA of an Innovative Rotating SiC Filter for High-Energy X-ray Beam

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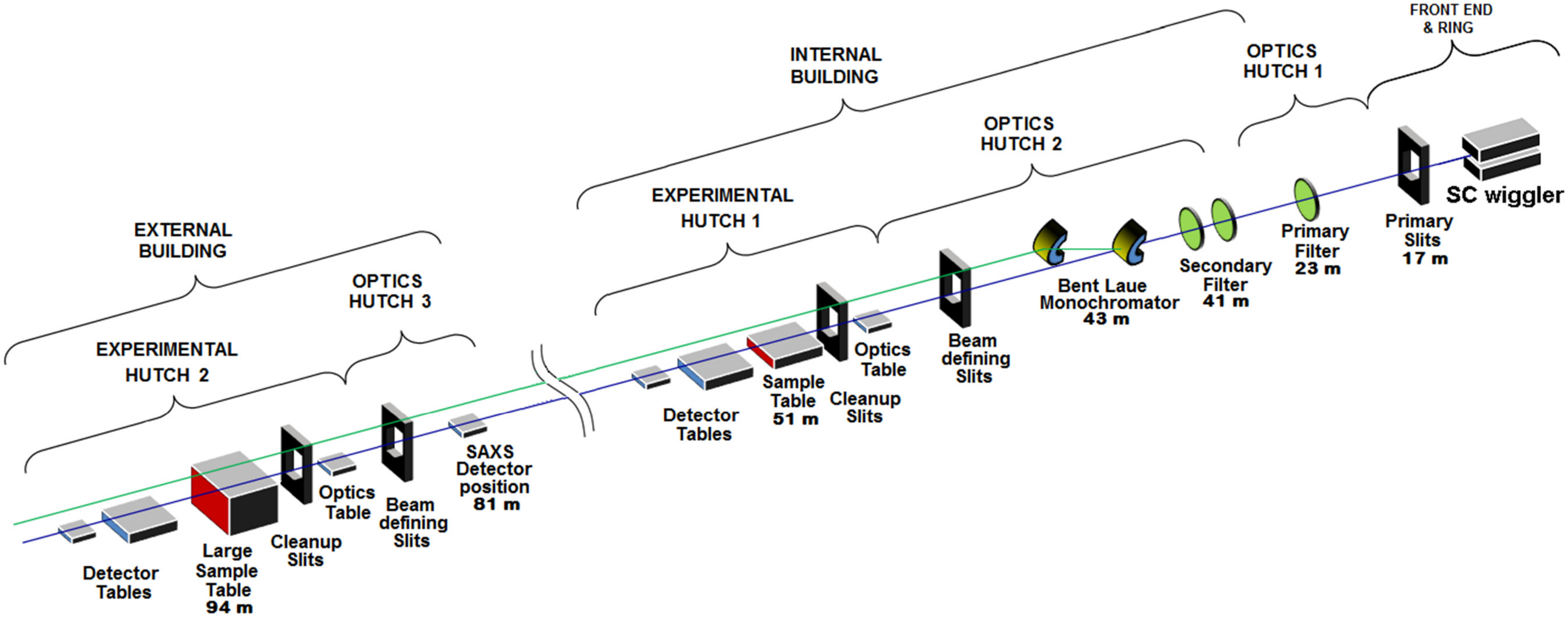
I12 JEEP*

A high energy imaging, diffraction and scattering beamline



*Joint Engineering, Environmental and Processing

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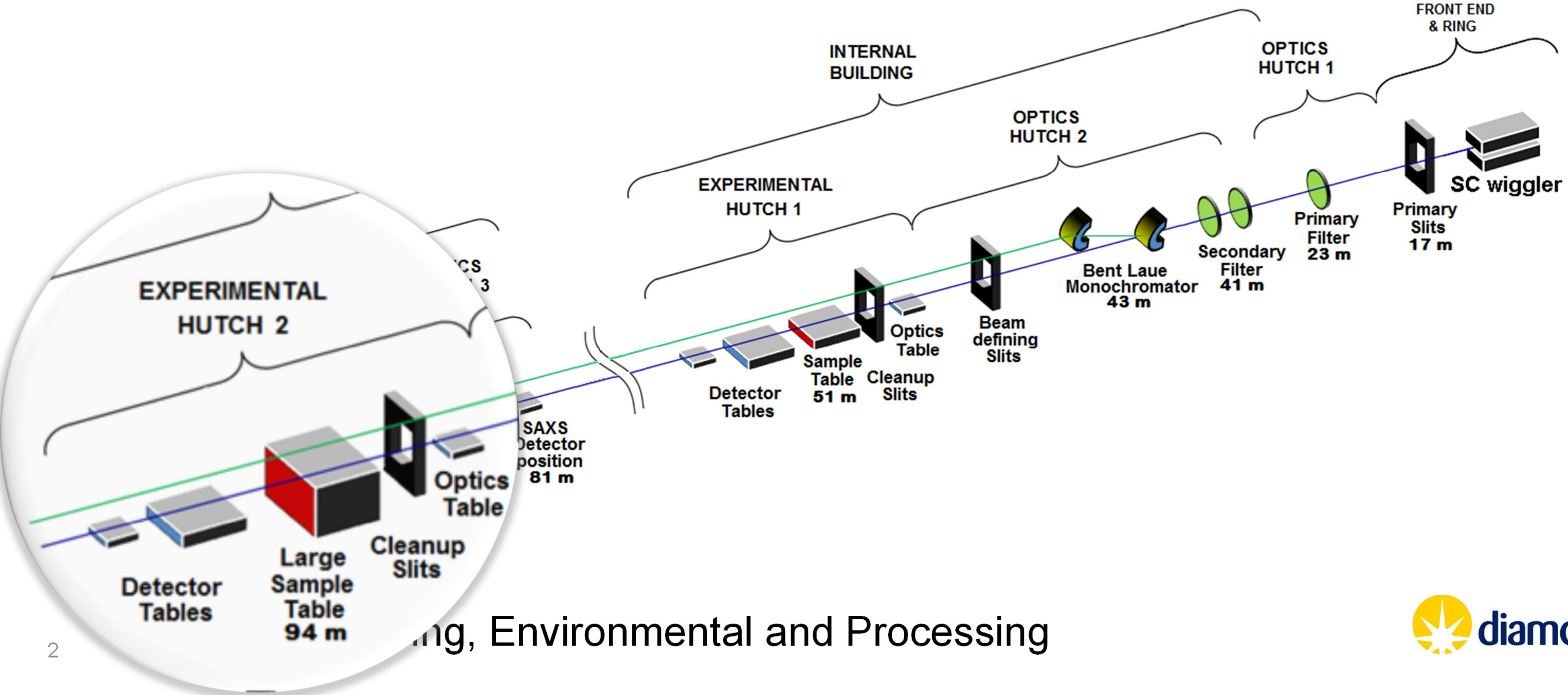

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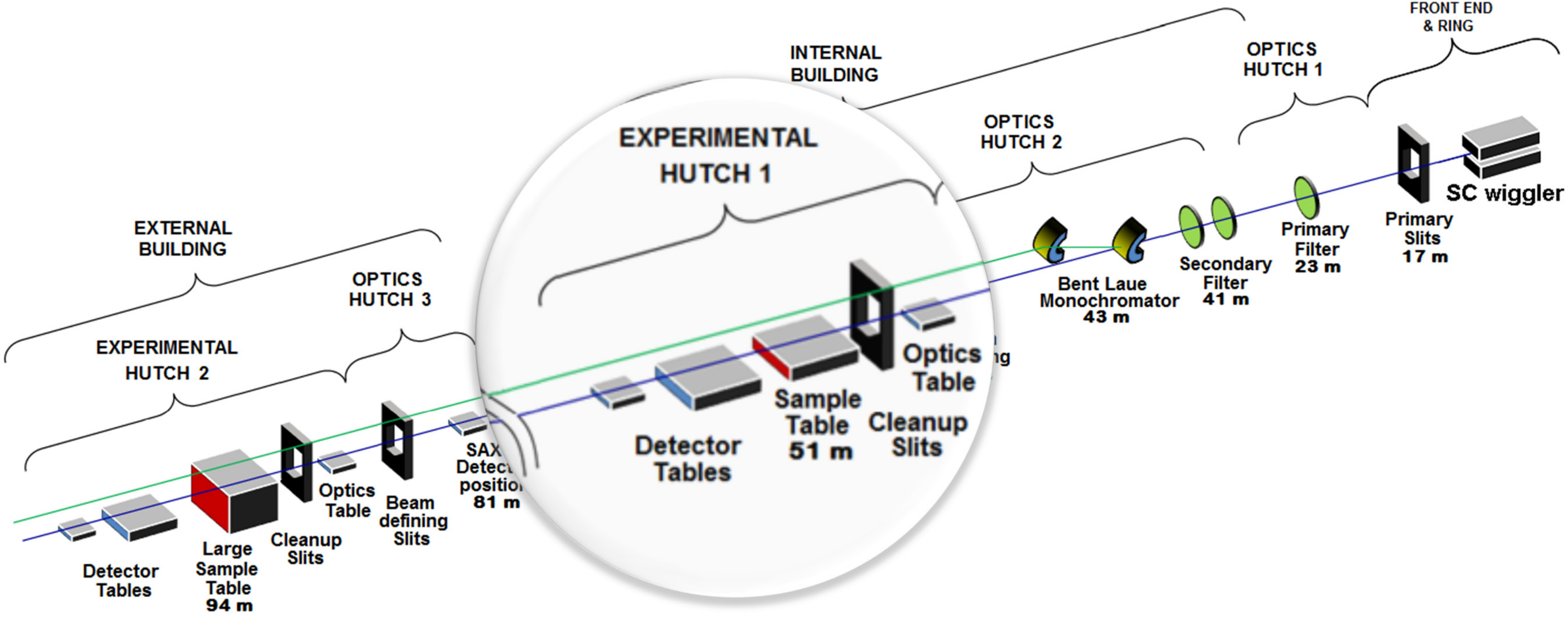

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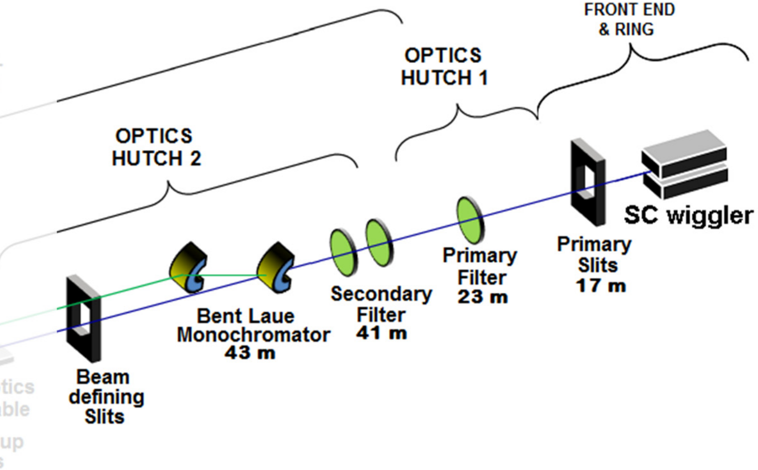
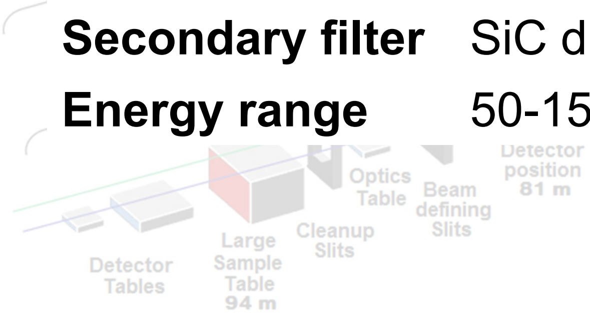
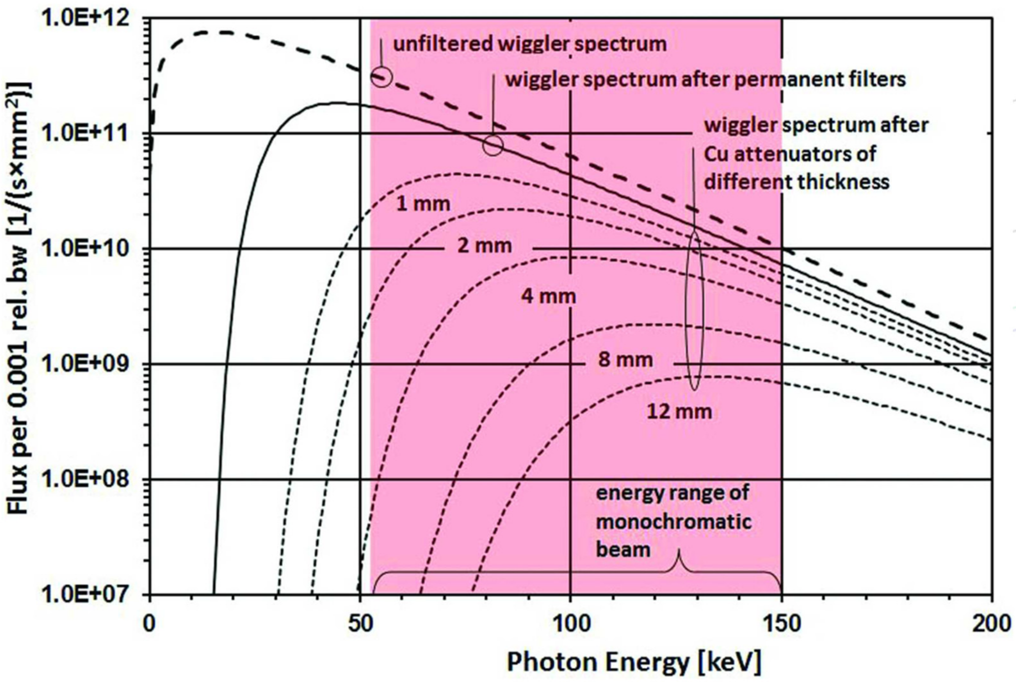
ID, Front End and Optics

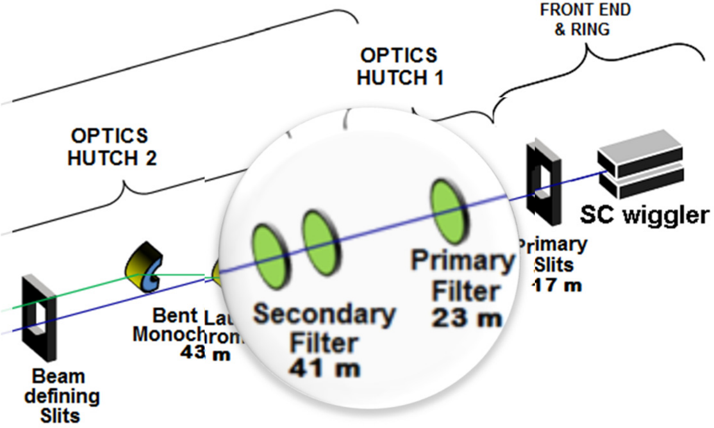
Source	Super-conducting wiggler 4.2 T, 48mm periodicity, 22 periods
Monochromator	Cryo-cooled double crystal bent Laue
Primary filter	CVD diamond
Secondary filter	SiC disk
Energy range	50-150 keV





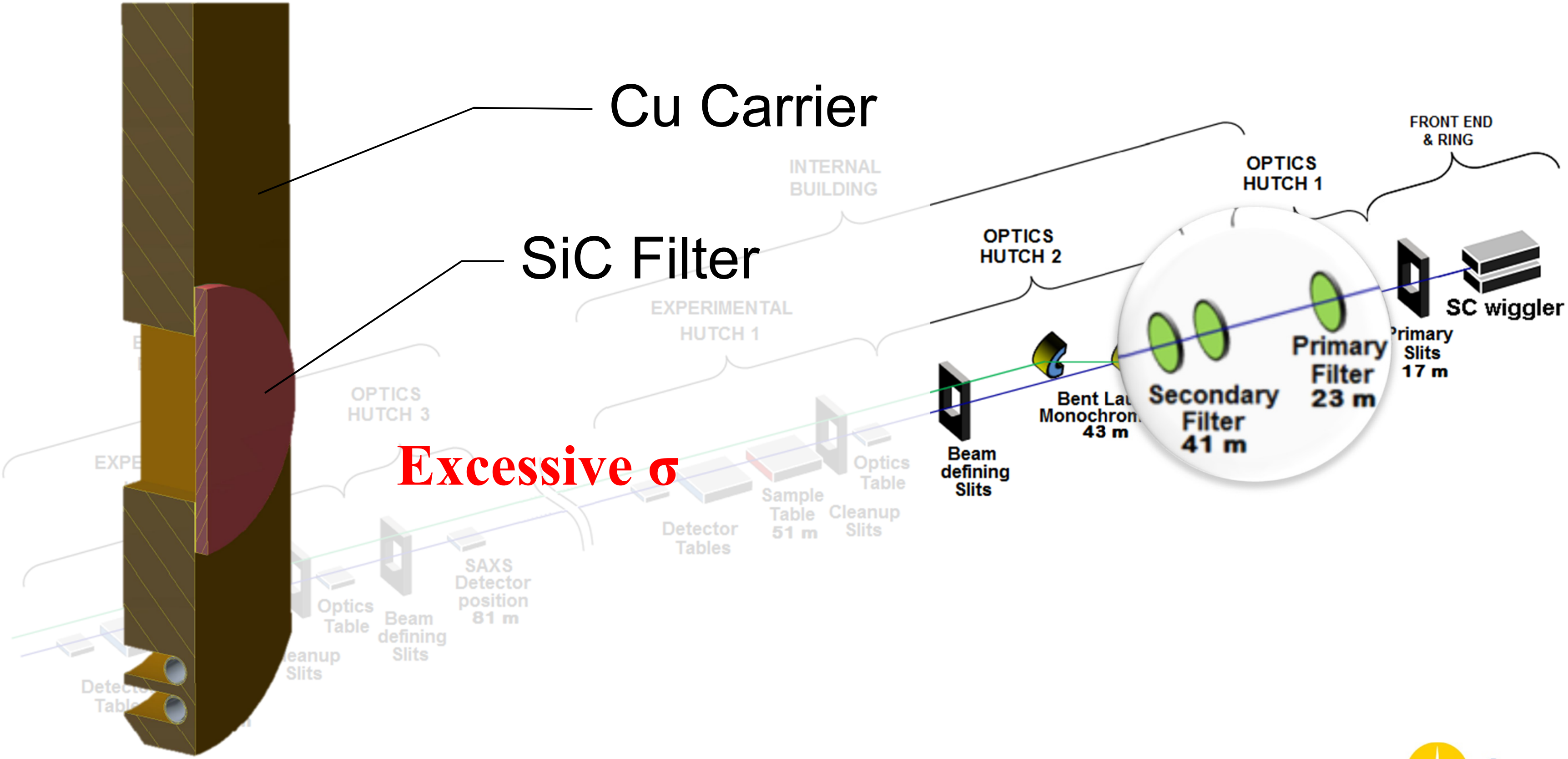
Heat Load Management



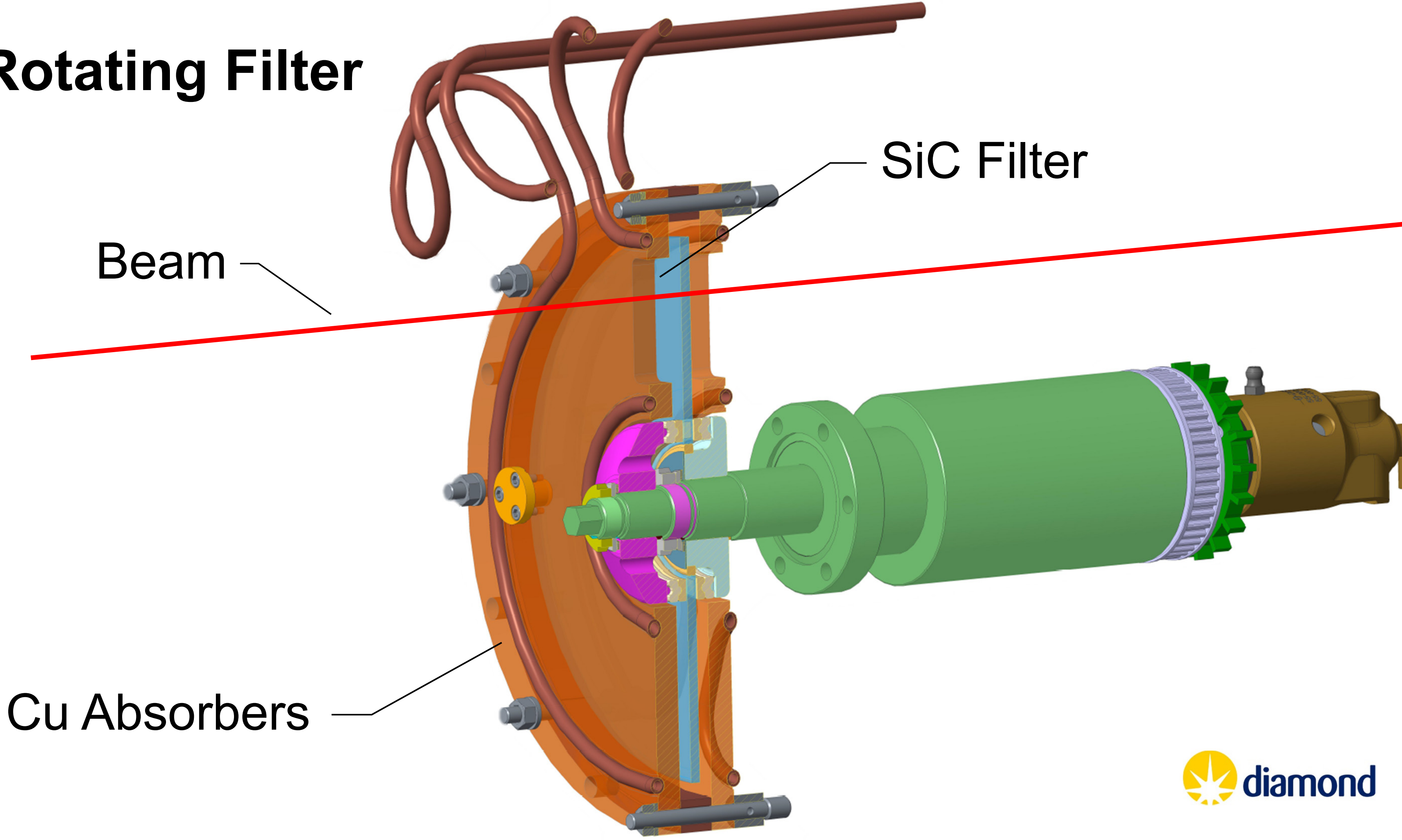


9 kW @ 500 mA after front-end
6.2 kW after primary filter
2.6 kW after secondary filter

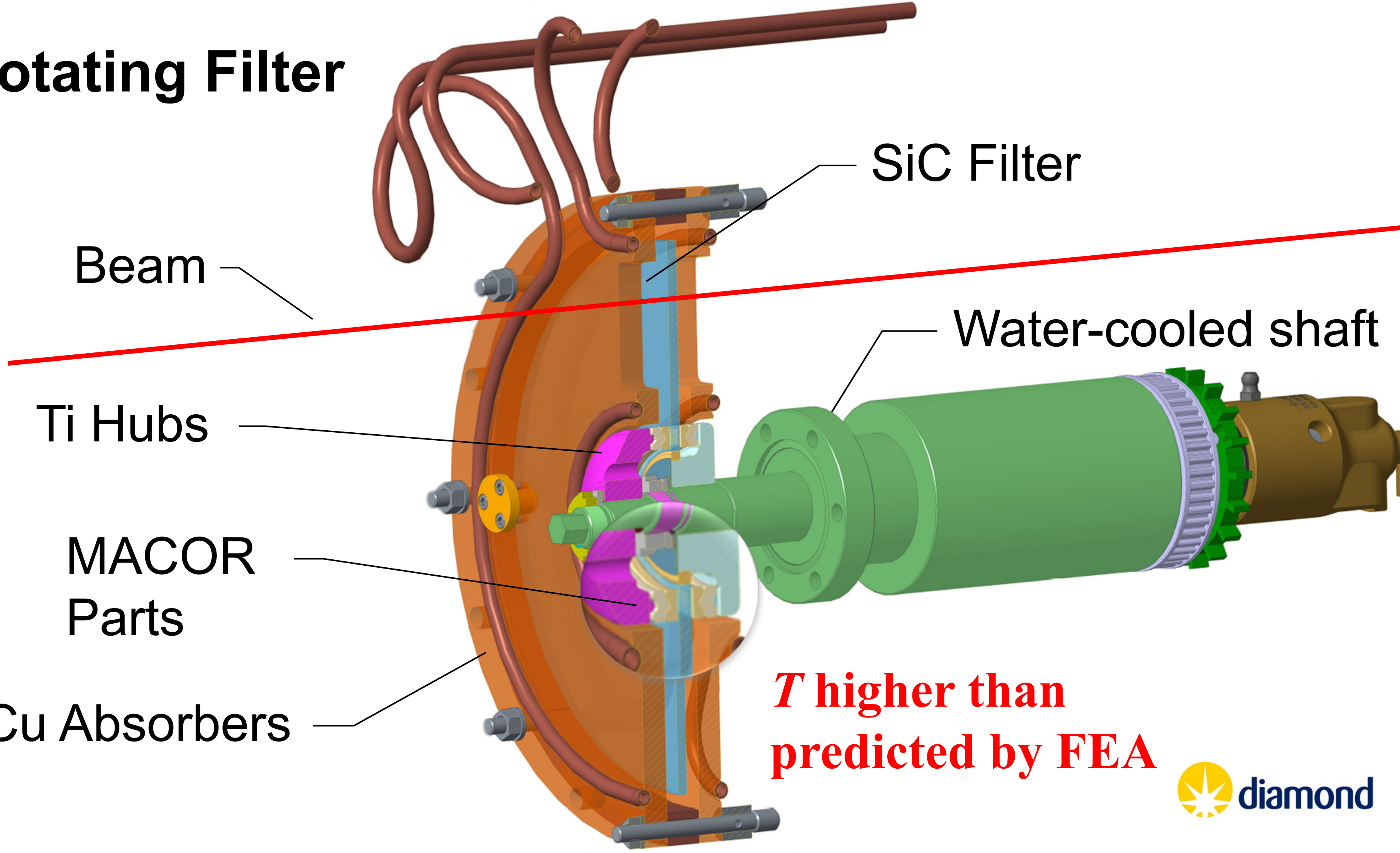
Secondary Static Filter



Rotating Filter



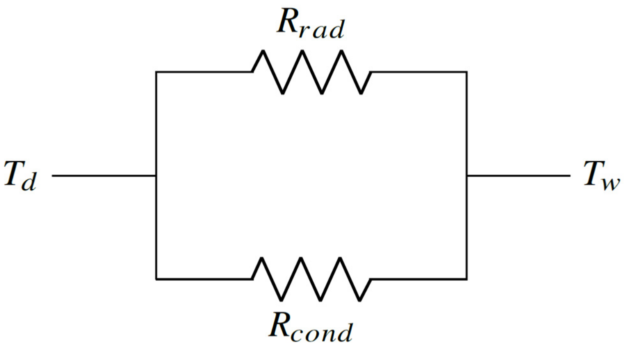
Rotating Filter

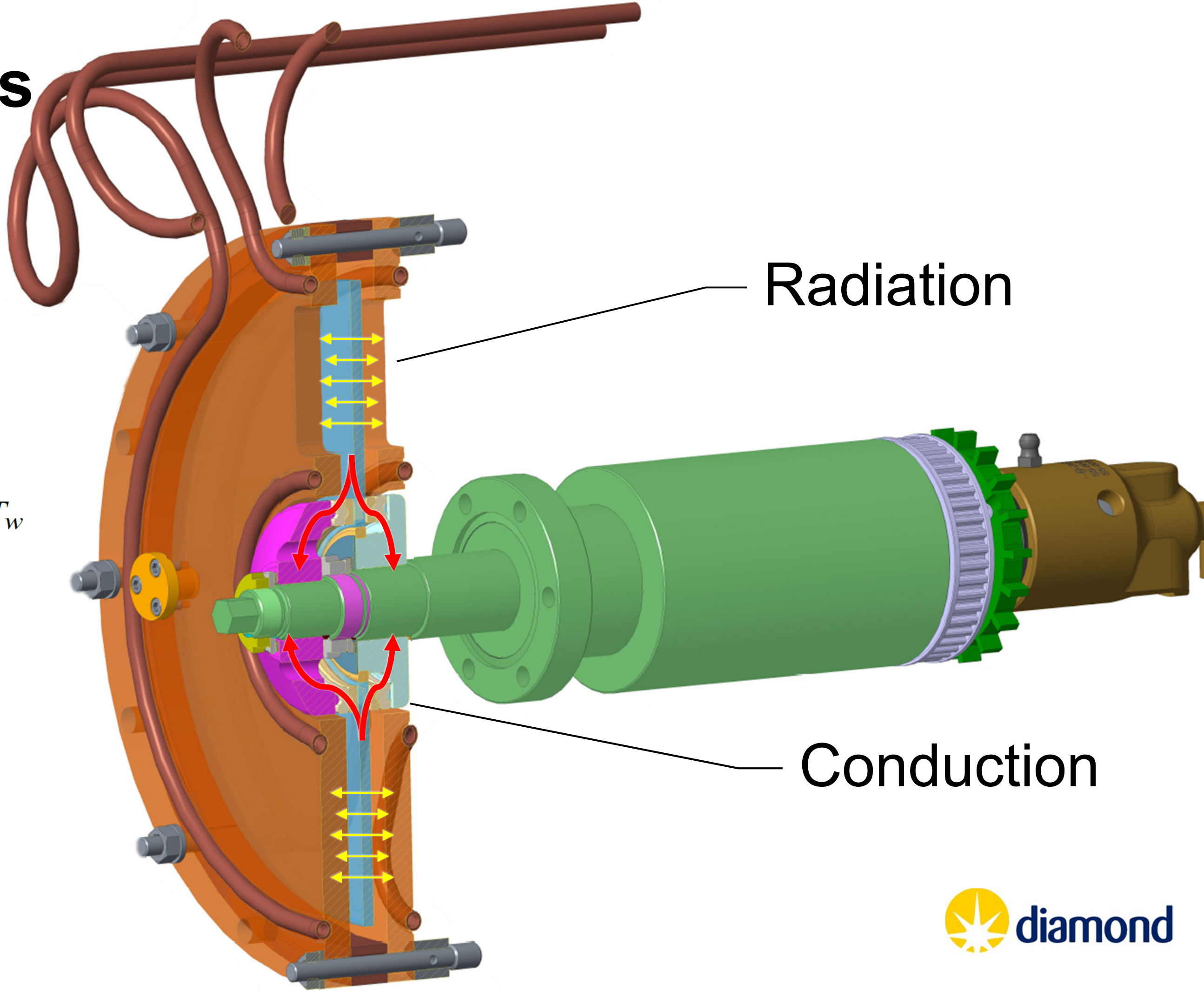


T **higher than predicted by FEA**

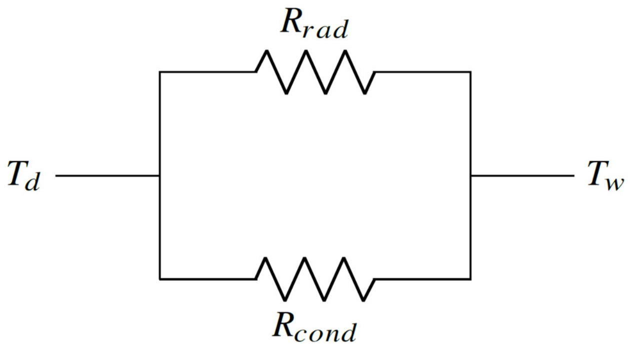
diamond

Failure Analysis



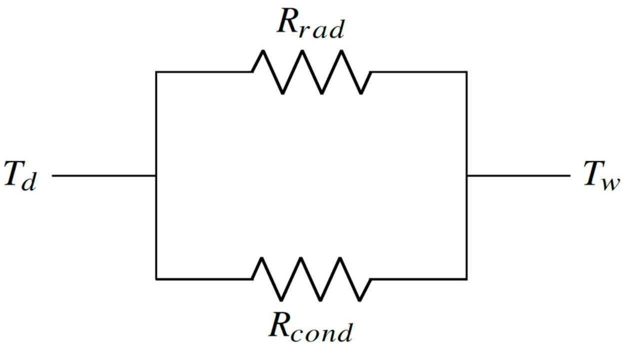


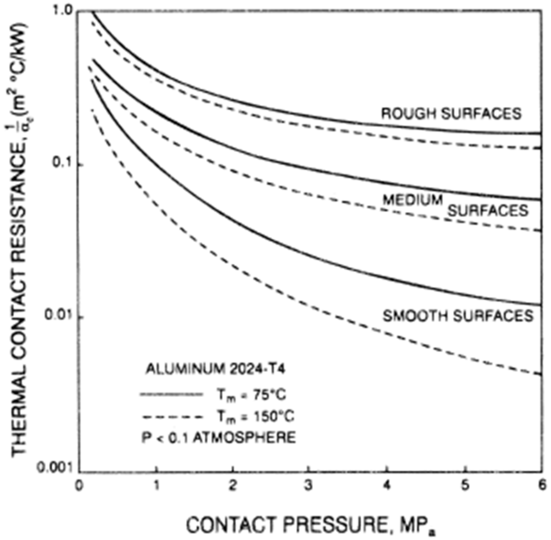
Circuit Analogy

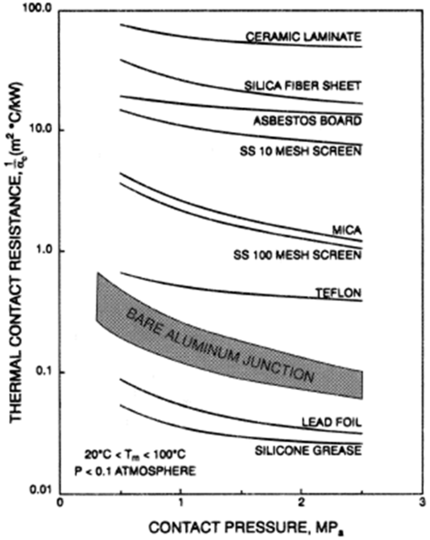


Boundary conditions	Heat load, convection (*h* coefficient, T_w…)
Radiation	Emissivity ε, geometry and view factor
Conduction	Materials (conductivity) and geometry; contacts

Circuit Analogy



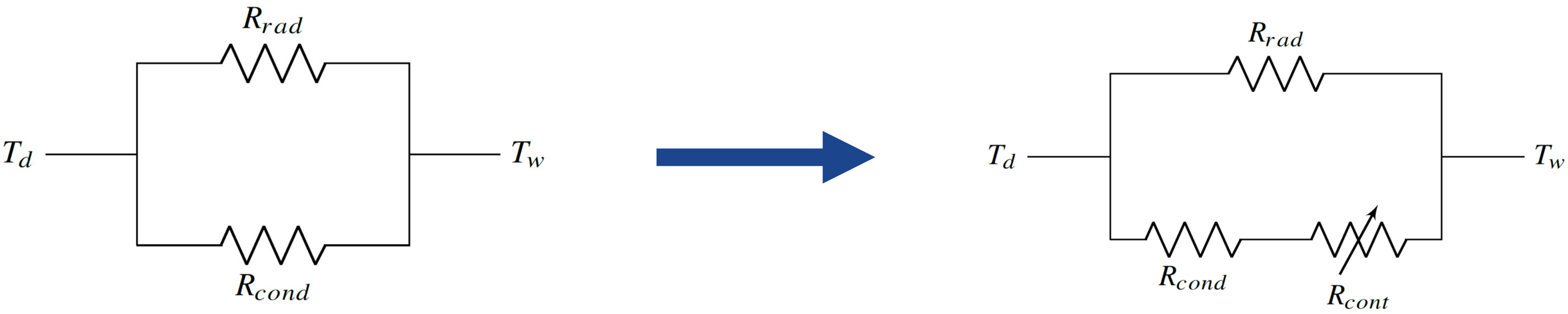




Conduction

Materials (conductivity) and geometry; contacts

Estimating the Thermal Contact Resistance

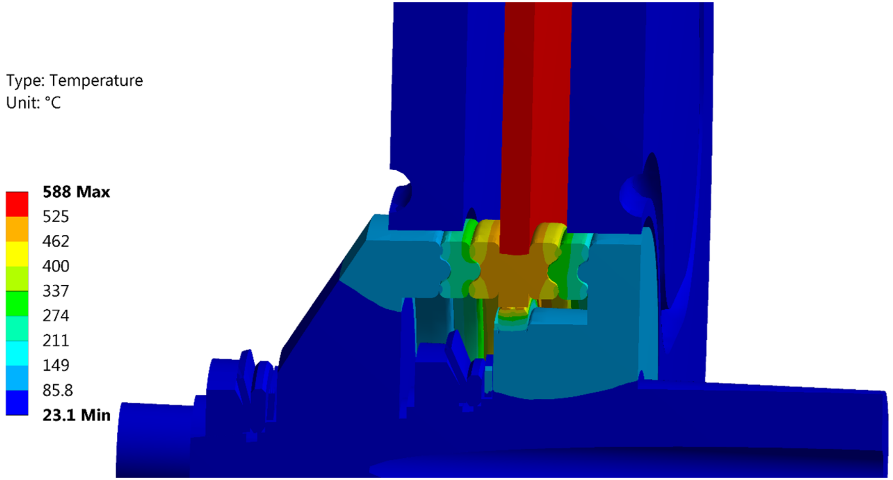


$T_d \approx 780℃$, measured with a LAND SoloNet SN21 Infra-red pyrometer looking at the SiC disc through a viewport

Effect of TCR

$\mathrm{TCR} \approx 0^{*}$

60% of Q to the shaft



$^{*}\mathrm{TCC} = K_{xx} 10^3 / ASM_{diag}$

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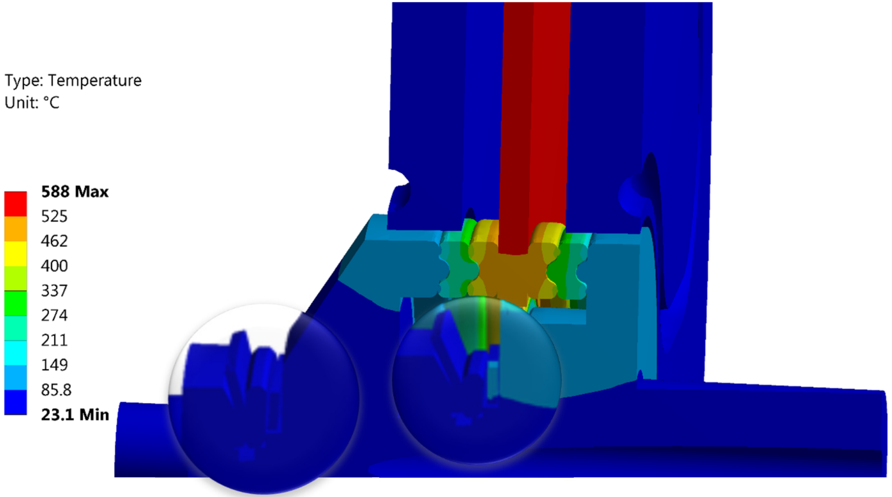

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diamond

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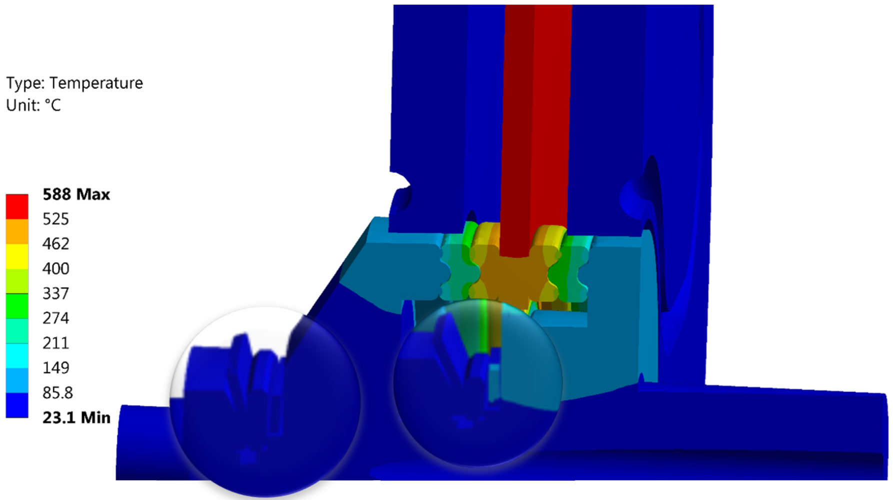
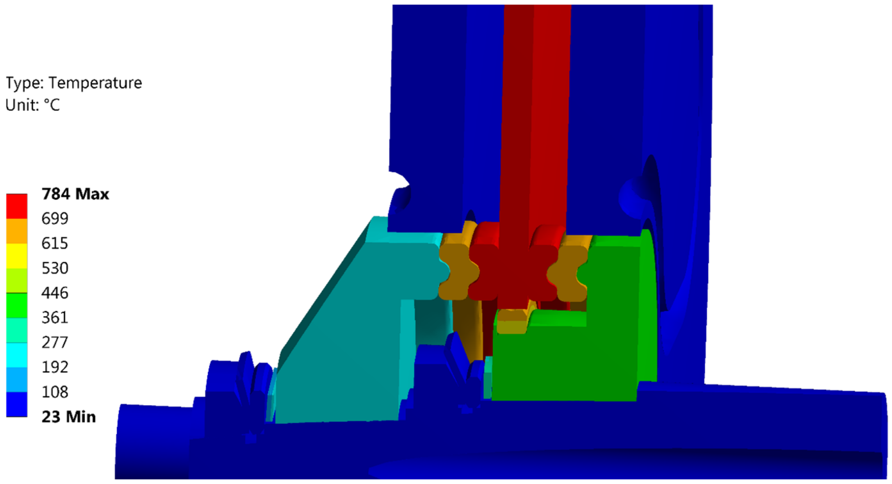
$$\text{TCR} = 5\,\frac{m^2 \cdot {}^\circ\text{C}}{kW}$$

11% of Q to the shaft





*$TCC = K_{xx} 10^3 / ASM_{diag}$

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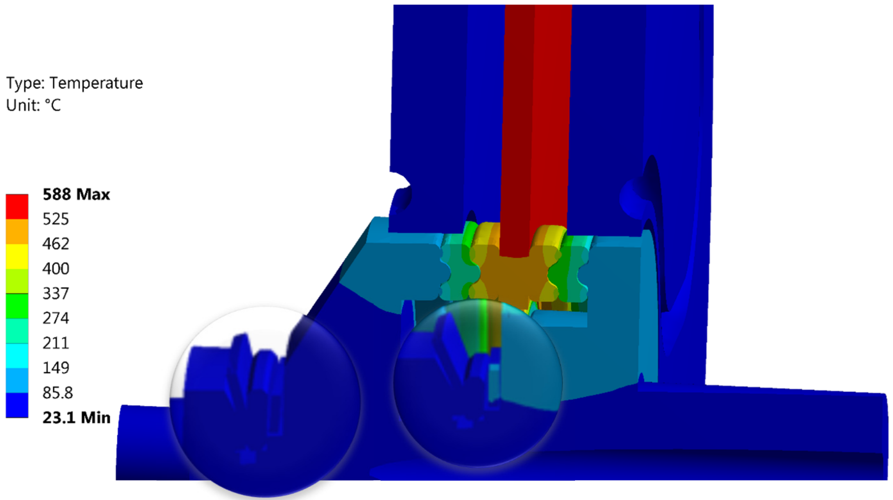
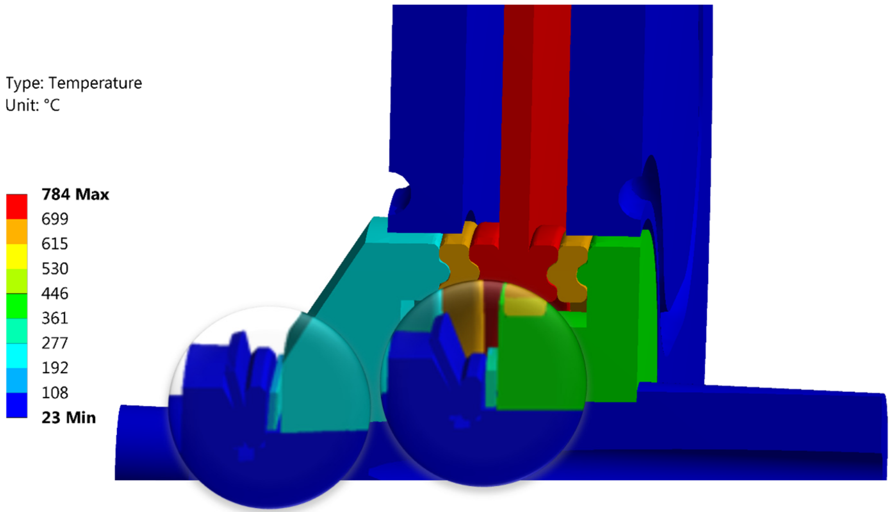
High TCR for metal parts!



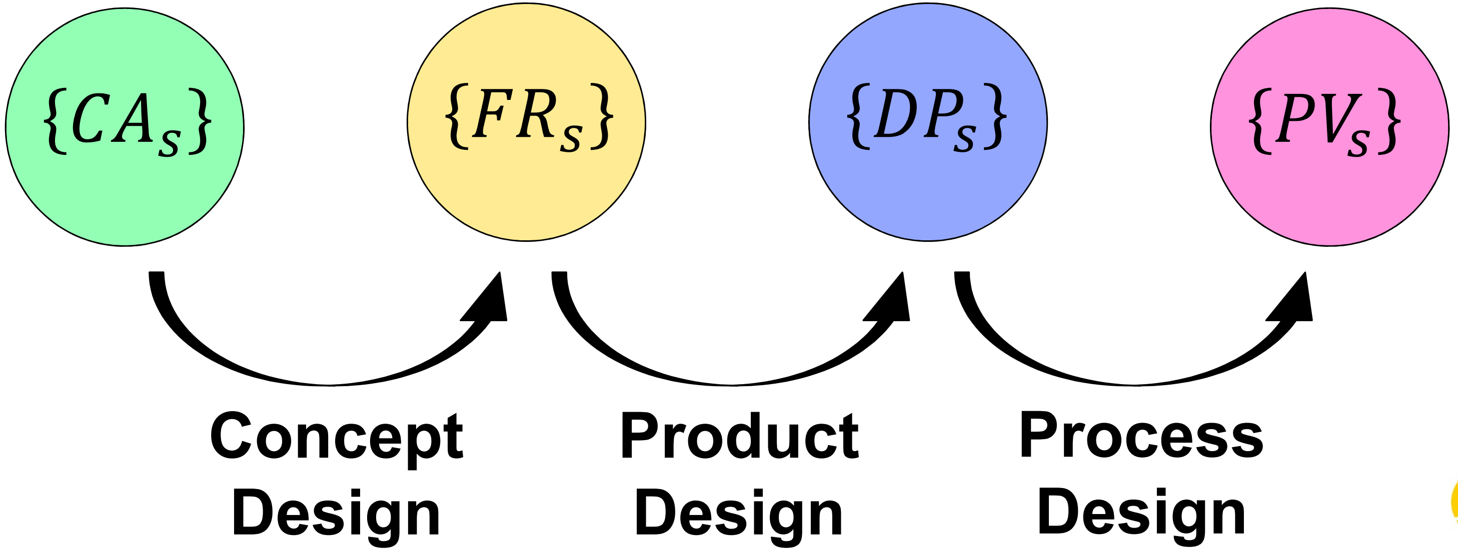


*TCC=$K_{xx}10^3/ASM_{diag}$

Axiomatic Design

Four design domains

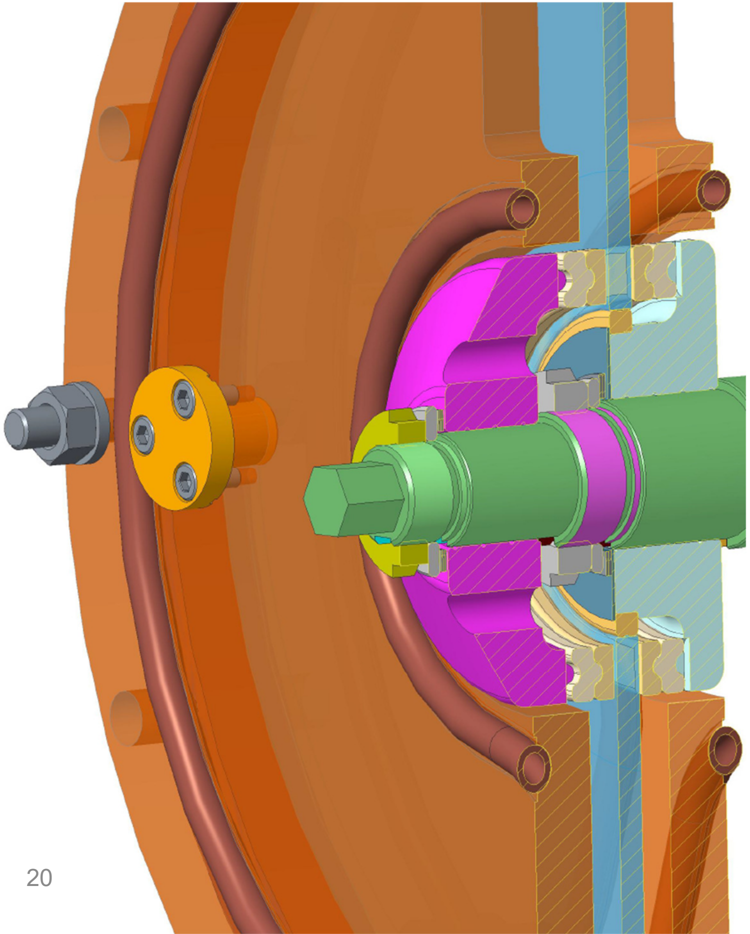
Customer $\{CA_s\}$, Functional $\{FR_s\}$, Physical $\{DP_s\}$, Process $\{PV_s\}$; The relationship between them is modelled with matrices.



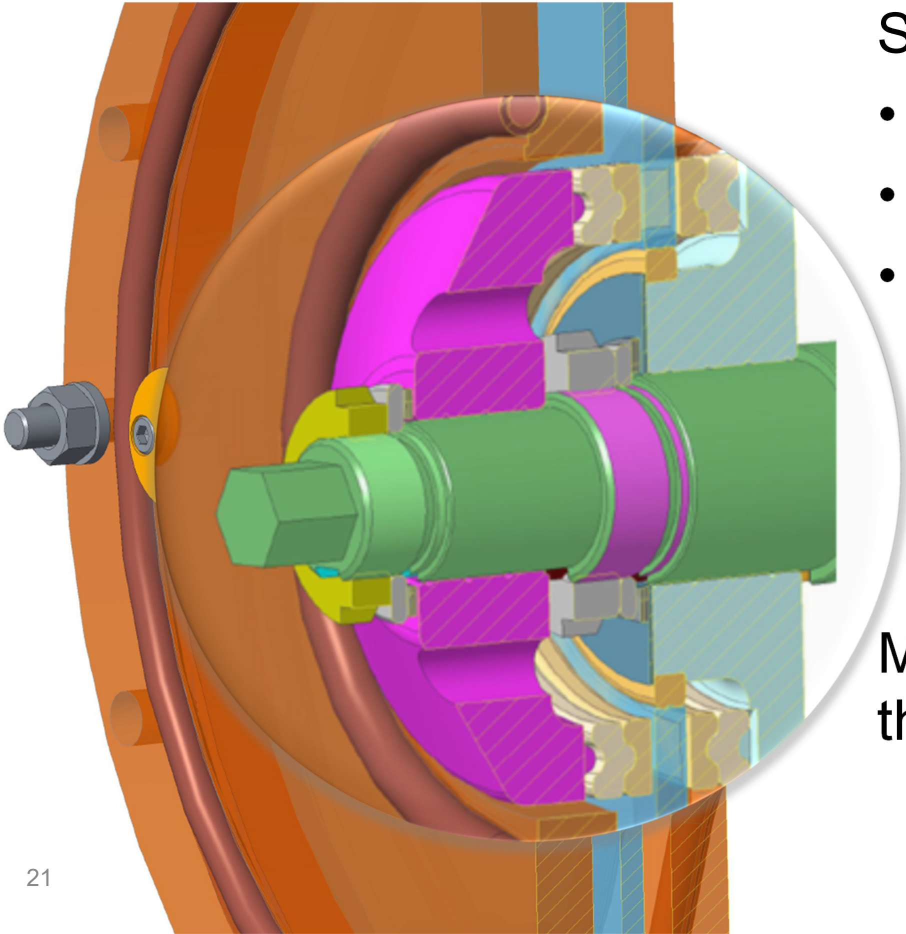
Axiomatic Design

Four design domains	Customer $\{CA_s\}$, Functional $\{FR_s\}$, Physical $\{DP_s\}$, Process $\{PV_s\}$; The relationship between them is modelled with matrices.
Independence Axiom	Functional Requirements should be independent: $\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} a_{1,1} & a_{1,2} \\ a_{2,1} & a_{2,2} \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix}$ The matrix $[A]$ should be diagonal.
Information Axiom	Information content should be minimised: $I = \log_2 \frac{1}{P} = -\log_2 P$

Axiomatic Design



Axiomatic Design



Subassembly with hubs and shaft:

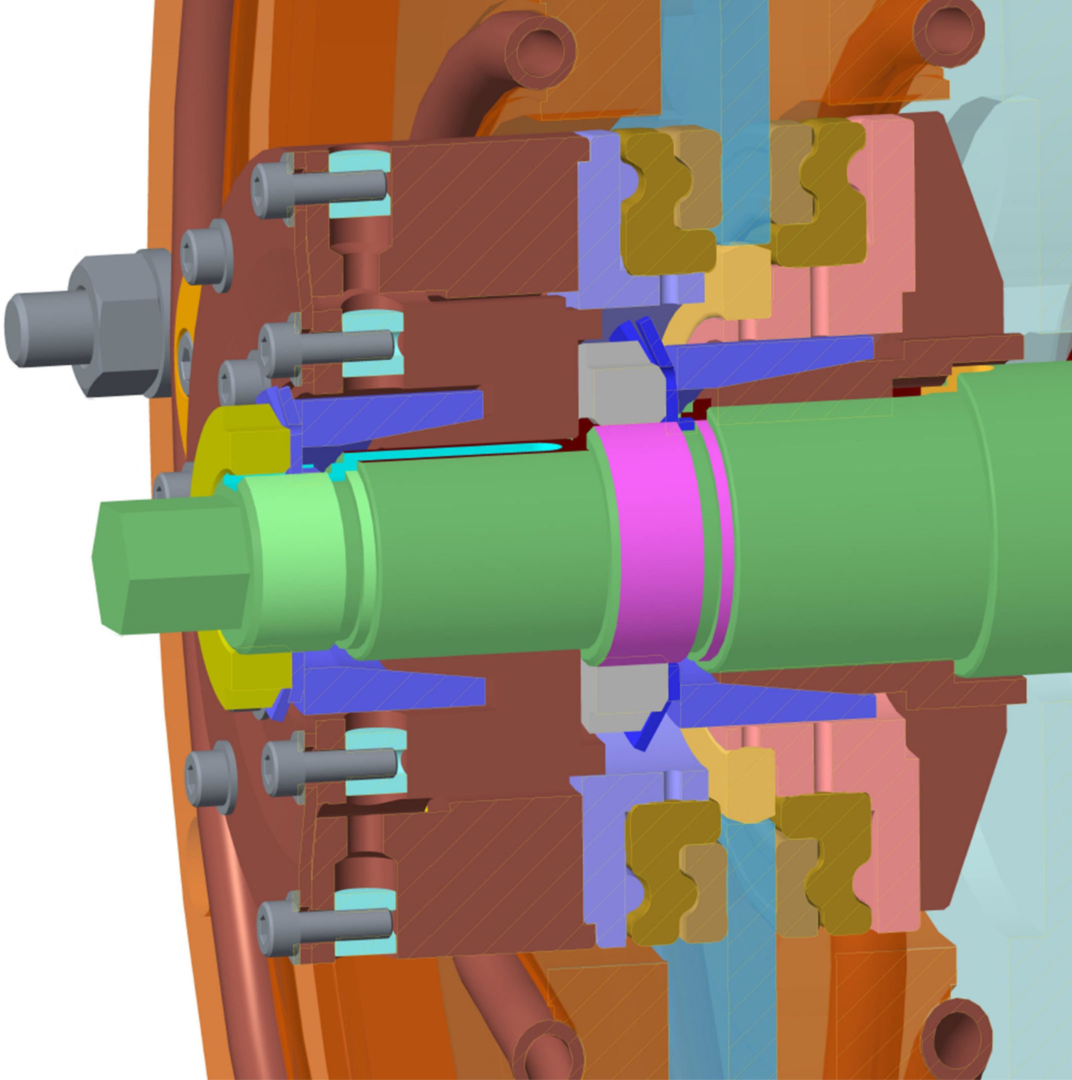
- Can assemble $\{FR_1\}$
- Transfers heat $\{FR_2\}$
- Contact pressure x $\{DP_1\}$

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} a_{1,1} & 0 \\ a_{2,1} & 0 \end{bmatrix} \begin{Bmatrix} x \\ 0 \end{Bmatrix}$$

Coupled design

Moreover, x depends on ΔT;
thermal runaway (positive feedback)

Final Design



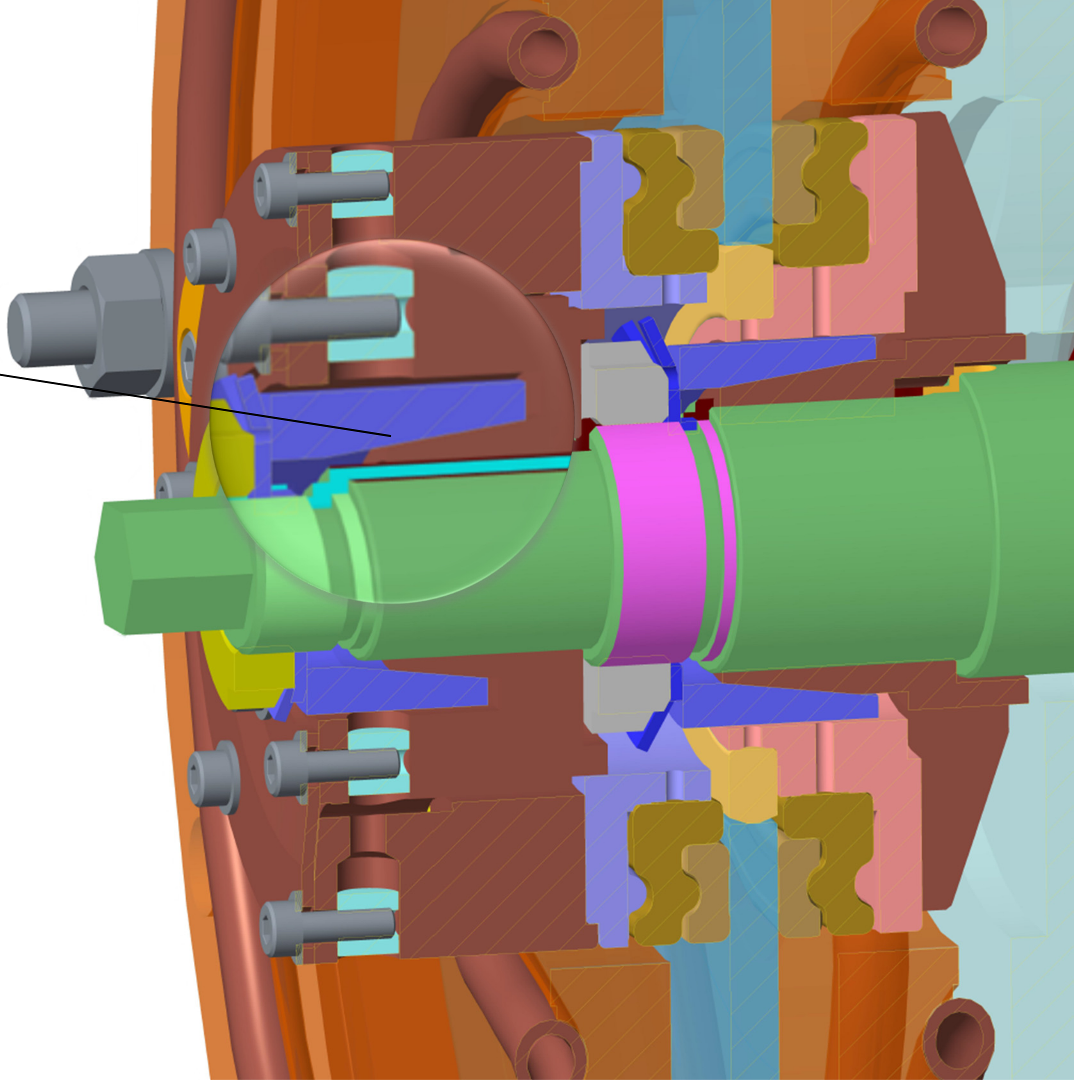
Final Design

Wedges

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} a_{1,1} & 0 \\ 0 & a_{2,2} \end{bmatrix} \begin{Bmatrix} x \\ y \end{Bmatrix}$$

Uncoupled design

Also, y depends on ΔT;
(negative feedback)



Final Design

Wedges

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} a_{1,1} & 0 \\ 0 & a_{2,2} \end{bmatrix} \begin{Bmatrix} x \\ y \end{Bmatrix}$$

Uncoupled design

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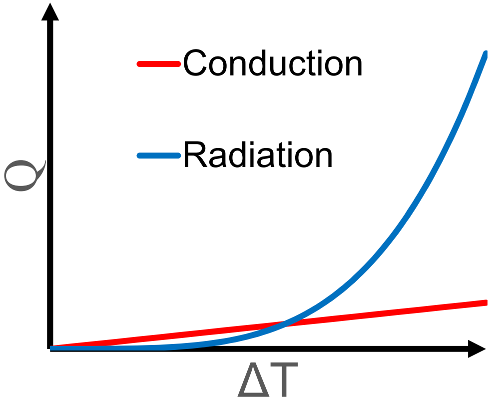

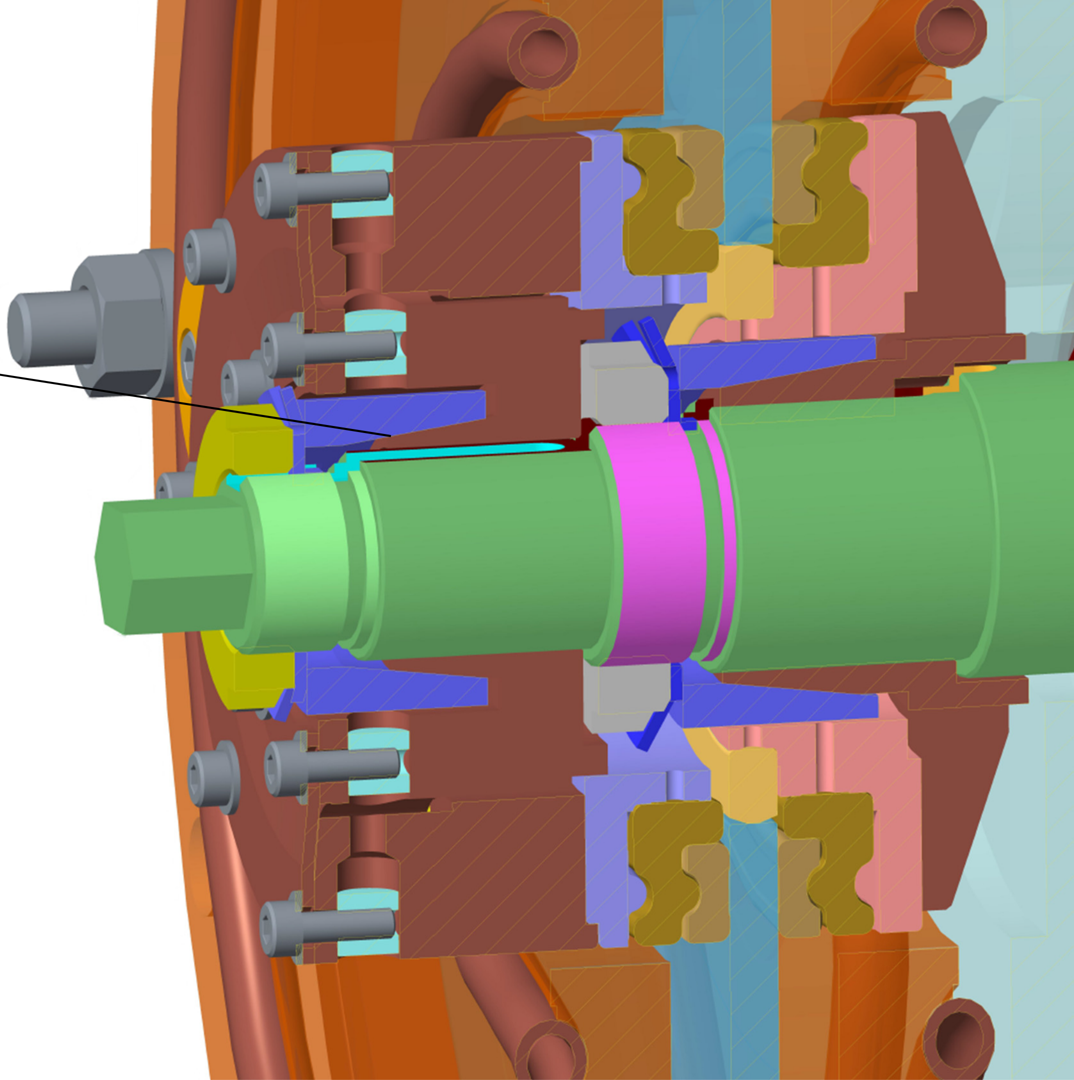

Final Design

Wedges

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} a_{1,1} & 0 \\ 0 & a_{2,2} \end{bmatrix} \begin{Bmatrix} x \\ y \end{Bmatrix}$$

Uncoupled design

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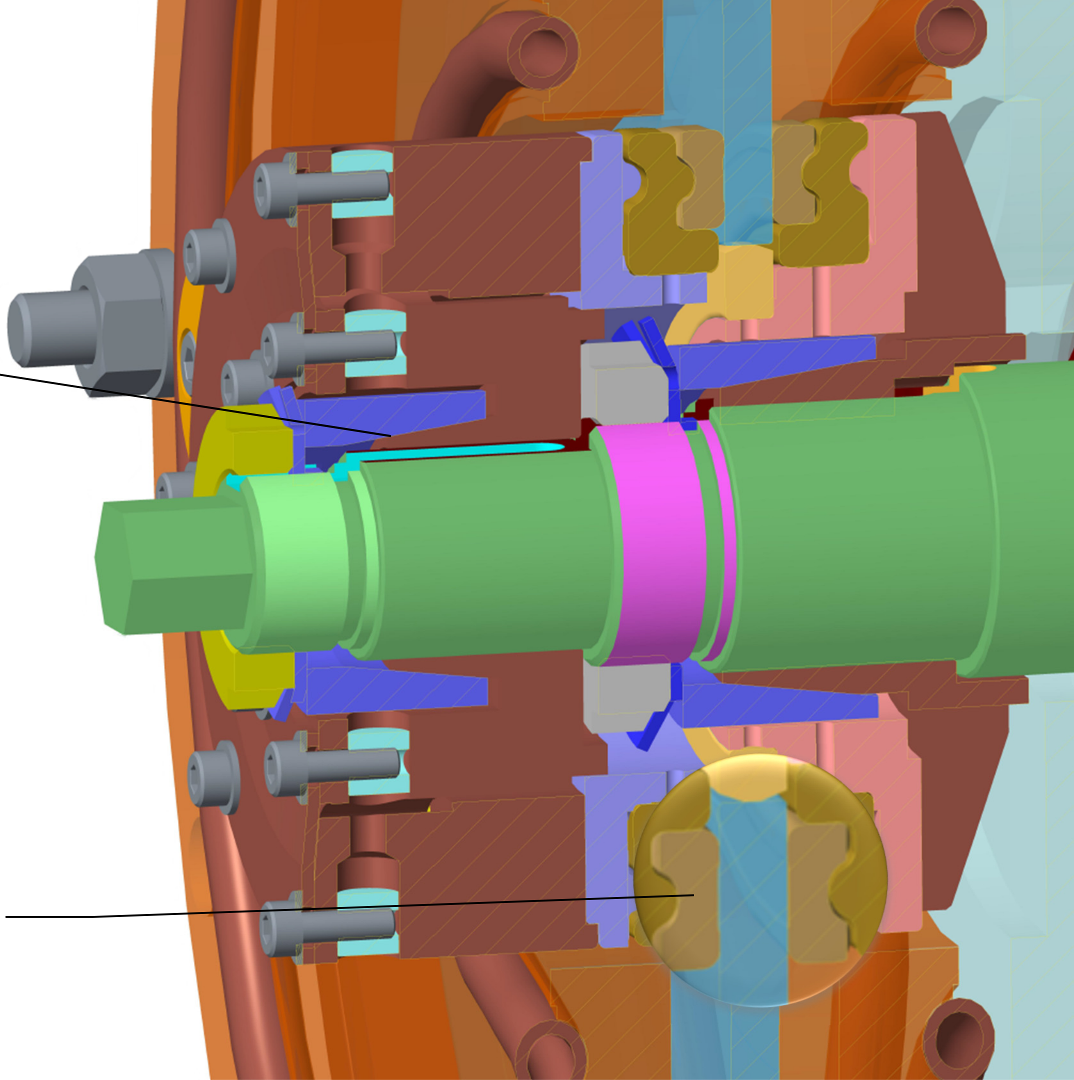


Grooves

to reduce contact area and heat transferred to the shaft

Final Design

Wedges

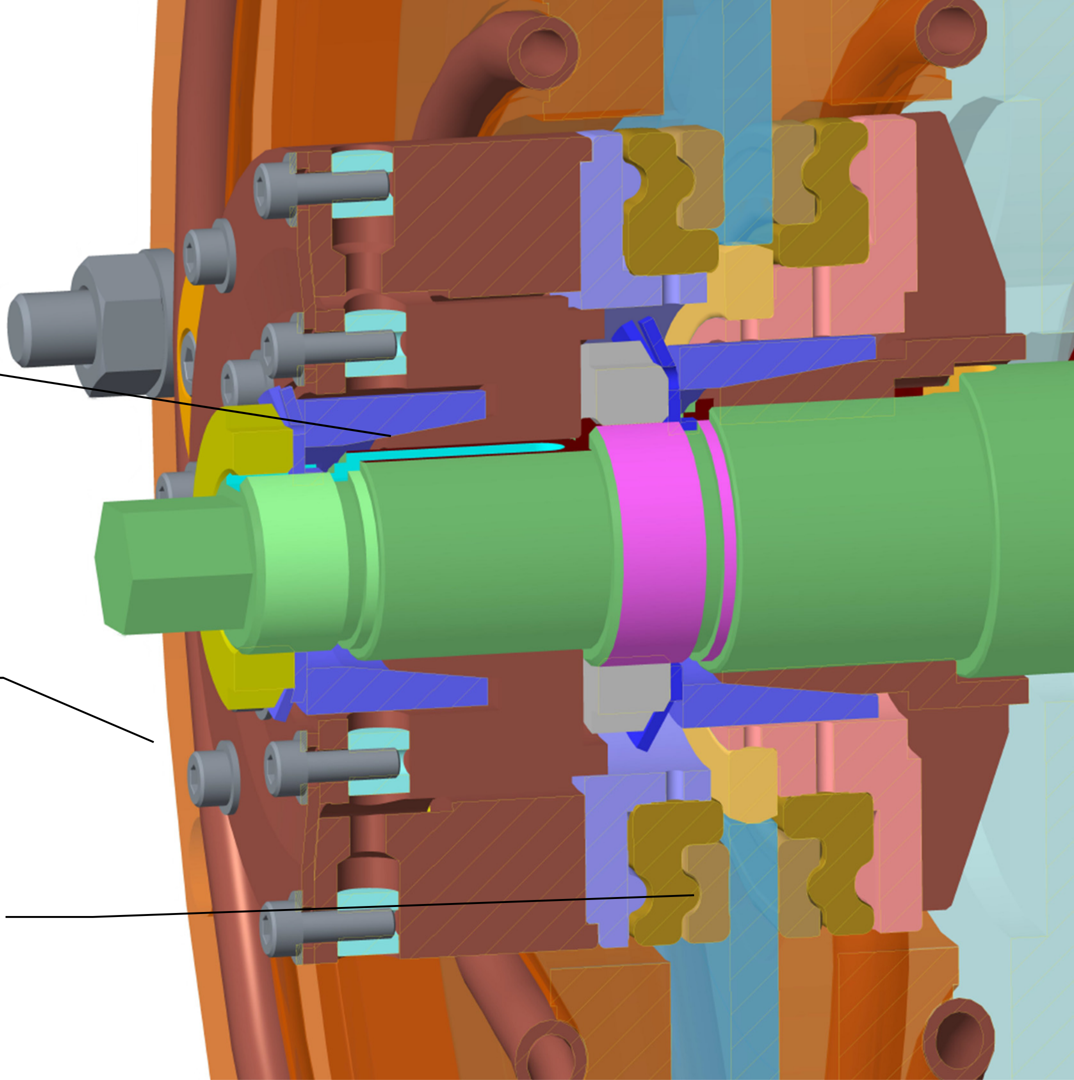
$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} a_{1,1} & 0 \\ 0 & a_{2,2} \end{bmatrix} \begin{Bmatrix} x \\ y \end{Bmatrix}$$

Uncoupled design

Also, y depends on ΔT;
(negative feedback)

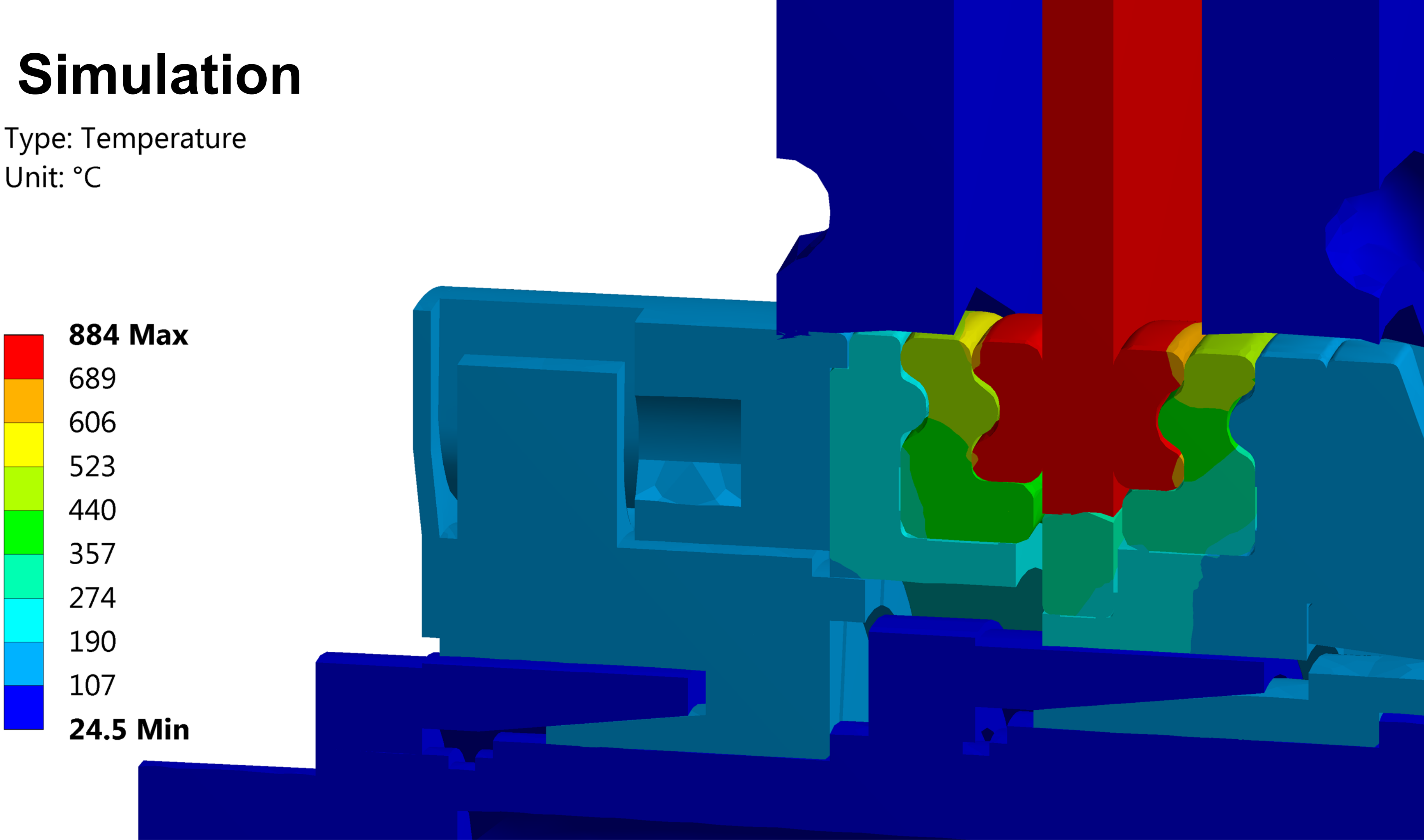
Blackened Cu
increased ε

Grooves
to reduce contact area and heat transferred to the shaft



Simulation

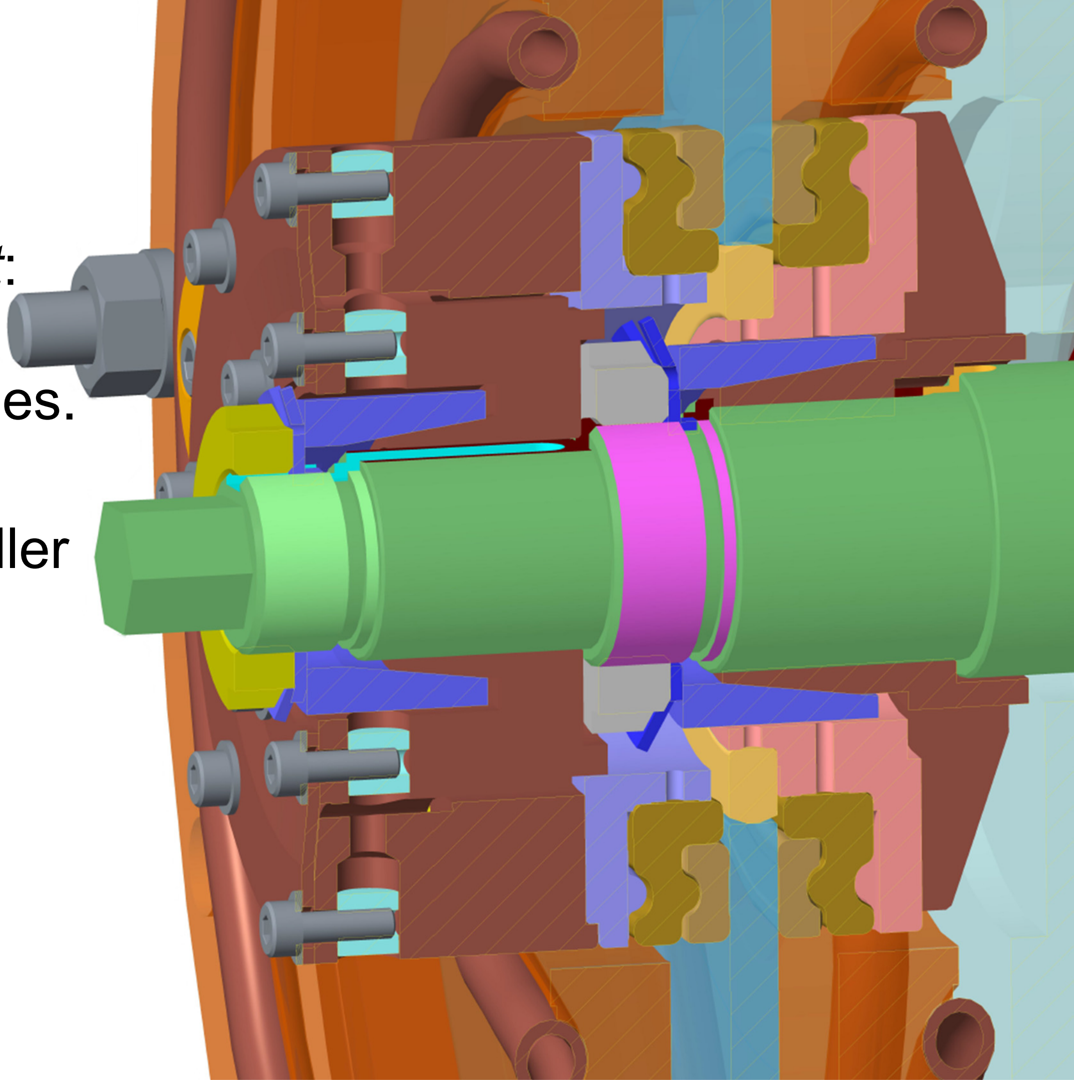
Type: Temperature
Unit: °C



Conclusion

Design *Reliable* and *robust*: operational since Sep’16 with no issues.

FEA *Conservative*, the measured T is smaller than the simulated one. *Accurate*, the error is <10%

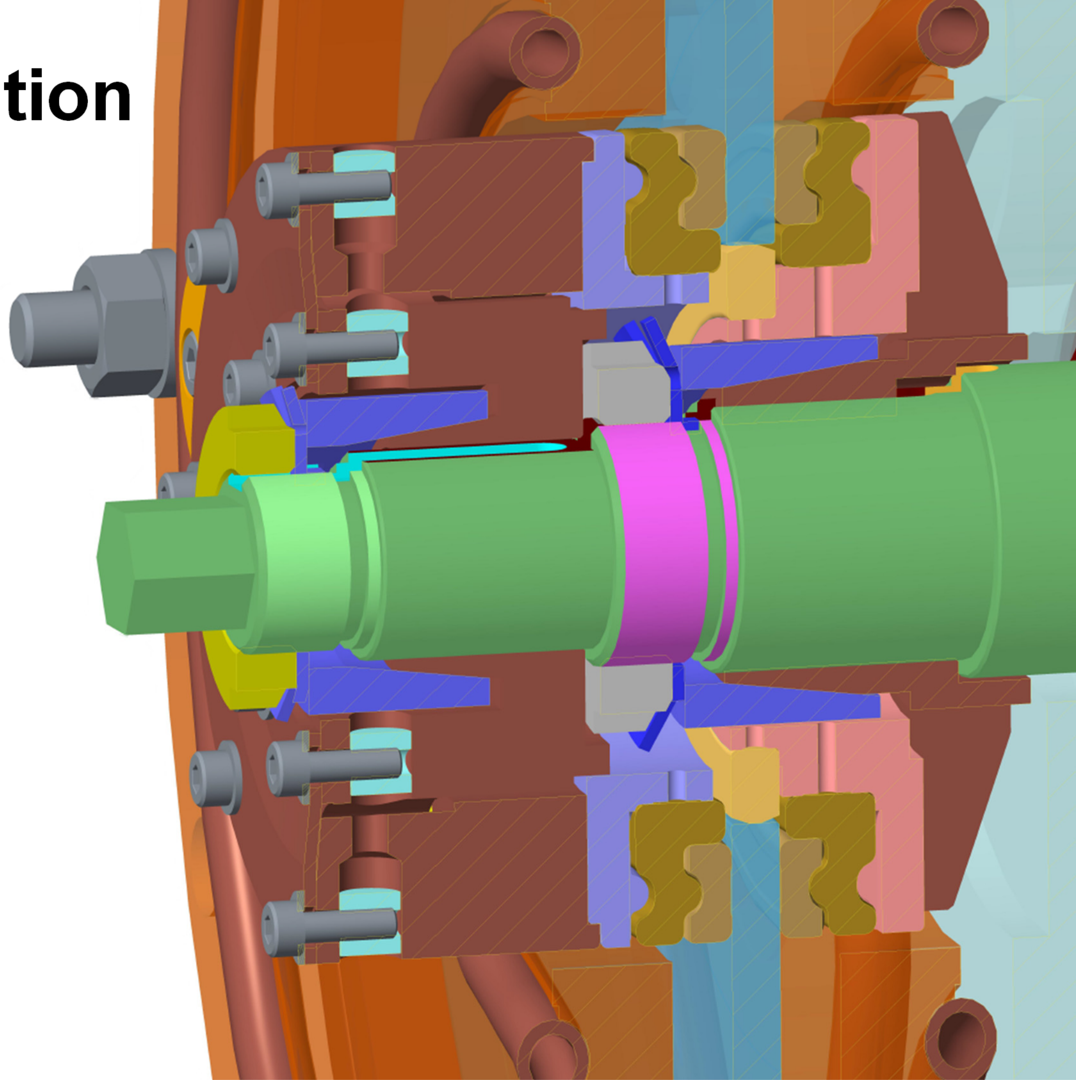


Thanks for your attention

… and thanks to

George, Michael, Steve, and Thomas

Any questions?



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