IR collimators: Thermal analysis of tank cooling and consideration on jaw brazing

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With inputs from: M. Gilarte, L. Gentini

ColUSM#126 08/05/2020
Outline

• Tank cooling system evaluation:
  • Tank with only 1 cooling circuit
  • Tank without cooling
• Brazing consideration
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• Tank cooling system evaluation:
  • Tank with only 1 cooling circuit
  • Tank without cooling
• Brazing consideration
Inputs and assumption

- **Aim:** verify the possibility to keep cooled only the top plate of the vacuum tank

- **Input:**
  - Power deposition on the 6 surfaces (FLUKA). Normalization factor 1.020 (Ultimate operation)
  - Total power ~25W
  - Geometry of the TCLPX (heat load coming from the collision debris, but similar heat load applies for other TCT)

- **Assumption and simplification:**
  - Simplified geometry
  - Power deposited on the surface (conservative) and homogeneous
  - Symmetry of the loads (conservative)
  - Convection on the top surface $h_c = 1050 \, \text{W/m}^2\text{K}$ (scaled to consider the ratio $A_{\text{pipes}}/A_{\text{convection}}$)
  - No convection or radiation cooling

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Results

\[ T_{\text{in}} \approx 22^\circ C \]
\[ \Delta T_{\text{max}} \approx 16^\circ C, T_{\text{max}} \approx 38^\circ C \]

- Updated results with respect to the one presented at HiColDEM#34 (\( \Delta T_{\text{max}} \approx 6^\circ C \), different cooling location)
Outline

• Tank cooling system evaluation:
  • Tank with only 1 cooling circuit
  • Tank without cooling
• Brazing consideration
Assumptions

- No cooling circuit
- Heat deposition on the six tank faces from FLUKA simulation
- Bake-out jacket around vacuum tank (no convection)

We consider 3 heat paths:
1. Conduction through the plate connection bars (2x4 points) to the mechanical table
2. Conduction through the supports to the cradle (2x2 points)
3. Free convection on the upstream and downstream face ($h_c=4 \text{ W/m}^2\text{K}$)
Model

- We removed everything but the tank and we consider series resistances to simulate the heat path.

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- We apply equivalent convection coefficient in the 12 points to represent the thermal resistances.

\[ \Delta T_i = h \cdot A \cdot P_i = R_{eq} \cdot P_i \]
Mechanical table connection bar - Resistance scheme

Thermal resistance scheme: $R_{\text{distributed}}$ and $R_{\text{contact}}$

```
$R_{\text{total}} = 0 + 9 + 0.075 + 3.9 + 0 + 1.1\sim 14 \frac{K}{W}$
```
Cradle-Resistance scheme

Thermal resistance scheme: \( R_{\text{distributed}} \) and \( R_{\text{contact}} \)

\[ R_{\text{total}} = 0 + 9 + 0.25 + 32 + 0.26 + 0.58 + 0.27 + 0.14 + 0.07 + 0.9 \sim 44 \frac{K}{W} \]
Results

• ΔTmax ~31 °C, Tmax ~53 °C
• A relevant part of the tank surface >45 °C
Conclusion

• If we keep only the top plate water-cooled, we reach a maximum temperature of 38°C on the tank.

• If we consider 2 conduction path + natural convection on the upstream and downstream face, we reach a maximum temperature of 53°C, with a relevant part of the tank surface > 45°C → **is it an issue?**

• If we suppress the convection on the upstream and downstream surface, we reach a maximum temperature of 68 °C on the tank.
Outline

- TCLPX cooling system evaluation:
  - Tank with only 1 cooling circuit
  - Tank without cooling
- TCTP brazing consideration
Can we avoid brazing?

- Two interfaces are of interest for the collimator cooling: the **interface 1 absorber/housing**, and the **interface 2 housing/cooling pipes**
- While **interface 2 is brazed** in all collimators installed in the tunnel, **interface 1 is always a pressed contact. Collimators installed since 2005, no issue found.**
- **Already in 2011, before the production of the TCTP series**, the possibility of having both interfaces bolted, removing the brazing, was studied
- **All details are reported in EDMS n. 1265924**
Can we avoid brazing?

- Removal of the brazing is justified by a much smaller load on the TCTP jaw (400 W in steady-state conditions – twice as much as in the TCLPX, but **50 times less** than primary and secondary collimators!)
- With sufficient pressure, a clamped interface, according to numerical and experimental (see later) studies, may reach a thermal conductance of 10 kW/(m²K) or higher, **only a factor of 2÷4 smaller than well brazed interfaces**.
- In the TCTP bolted solution that we studied, we designed a contact with a pressure of **25 bar** given by screws and we checked temperatures and deformations → **OK!**
Creep, stress relaxation, unscrewing...

- The EDMS document also contains considerations and calculations concerning stress relaxation for the proposed materials and design.

- If we remove the brazing, Glidcop is not strictly needed. For the TCTPs, we still considered it as the baseline even for a bolted configuration, for two reasons:
  1. We wanted to be compatible with the brazed solution, allowing a late decision
  2. Glidcop is also the best in terms of creep resistance

- However, CuCrZr is the second best in this sense and is cheaper, much more available, and should be considered if we agree to remove the brazing

- Anti-unscrewing washers are added to the bolts to avoid losing the contact pressure – this could be better investigated based also on recent CERN experience
Experimental validation

- The EN-MME TCTP prototype was just bolted and not brazed, and measured in the thermal conductance test bench conceived by I. Leitao and EN-STI
- Comparison was also done with TCSG and TCSP brazed jaws
- Finally, for the series, given that CINEL showed very good brazing expertise, brazing was maintained
Deflection of bolted TCLPX

- We assumed a thermal conductance of 5 kW/(m²K) at the bolted interface (14 bar contact pressure), wrt 25 kW/(m²K) that we had in the brazed one
- Temperatures and beam-induced deflection are very low! Thermo-mechanically, the solution is perfectly viable

\[ T_{\text{max}} = 34^\circ \text{C} \]

\[ \delta_{\text{max}} = 15 \text{ micron} \]

R. Key
Conclusions

• Given the low loads on the three collimators, we do not expect problems of excessive temperature or deformation replacing brazing with a bolted solution

• The thermal conductance of a bolted interface was also confirmed to be rather good by past tests on the TCTP prototype (which was built already with this philosophy)

• If we go for this solution, we could profit also of past studies done on creep and anti-unscrewing systems

• CuCrZr can then become a valid, cheaper and more available alternative to Glidcop
Inputs and assumption

- **Aim:** verify the possibility to keep only 1 cooled plate on the vacuum tank
- **Input:** power deposition on the 6 surfaces (FLUKA). Normalization factor 1.020 (Ultimate operation)
- Heat loads on TCLPX coming from the collision debris, but similar consideration applies for other TCT

- **Assumption and simplification:**
  - Power deposition homogeneous on the surface
  - Simplified geometry
  - Symmetry of the loads (conservative)

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- \( h_c = 10000 \text{ W/m}^2\text{K} \) (scaled to 300 W/m\(^2\)K on the whole surface)
- No convection or radiation cooling
Results

- $\Delta T_{\text{max}} \sim 6^\circ\text{C}$, $T_{\text{max}} \sim 28^\circ\text{C}$

Results presented at HiColDEM#34
Mechanical table connection bar - Resistance calculation

1. \( R_{\text{insert-vessel}} = 0 \frac{K}{W} \)

2. \( R_{\text{insert}} = \frac{x}{A \cdot k} \sim 9 \frac{K}{W} \)

3. \( R_{\text{insert-connection.bar}} = \frac{1}{h_{\text{contact}} \cdot A_{\text{contact}}} \sim 0.075 \frac{K}{W} \)  
   (F=15kN)

Reference for contact resistance: Snaith, Probert, O'Callaghan, Thermal contact conductance. pag 65
Mechanical table connection bar - Resistance calculation

- We consider the connection bar and the mechanical table in air \( \rightarrow \) convection

Hp: When considering parallel resistance, the resultant is dominated by the lower one \( \rightarrow \)

\[
R_{\text{parallel}} = \frac{R_{\text{convection}} R_{\text{conduction}}}{R_{\text{convection}} + R_{\text{conduction}}} \approx R_{\text{convection}}
\]

\[
R_{\text{connection.bar}} = R_{\text{connection.bar,convection}}
\]

\[
R_{\text{mechanical.table}} = R_{\text{mechanical.table,convection}}
\]

4. \( R_{\text{connection.bar}} = \frac{1}{h_{c,\text{free-air}} \cdot A_{\text{connection.bar}}} \approx 3.9 \frac{K}{W} \)

5. \( R_{\text{connection.bar} - \text{mechanical.table}} \approx 0 \)

6. \( R_{\text{mechanical.table}} = \frac{1}{h_{c,\text{free-air}} \cdot A_{\text{mechanical.table}}} \approx 1.1 \frac{K}{W} \)

\[
R_{\text{total}} = R_{\text{vessel-insert}} + R_{\text{insert}} + R_{\text{insert-connection.bar}} + R_{\text{connection.bar}} + R_{\text{connection.bar}-\text{mechanical.table}} + R_{\text{mechanical.table}} \approx 14 \frac{K}{W}
\]
Mechanical table connection bar - Resistance calculation

\[ R_{total} = R_{vessel-insert} + R_{insert} + R_{insert-connection.bar} + R_{connection.bar} + R_{connection.bar-mechanical.table} + R_{mechanical.table} \approx 14 \ \frac{K}{W} \]

\[ h_c = \frac{1}{R_{total} \cdot A_{contact}} = 62 \ \frac{W}{K \cdot m^2} \]

Tmax \approx 75°C
Cradle-Resistance calculation

Thermal resistance scheme

1. $R_{vessel-insert} = 0 \frac{K}{W}$

2. $R_{insert} = \frac{x}{A \cdot k} \sim 9 \frac{K}{W}$

10. $R_{cradle} = \frac{1}{h_{c,free-air} \cdot A_{cradle}} \sim 0.9 \frac{K}{W}$
Results

Connection bar (A):

\[ R_{total} \approx 14 \frac{K}{W} \]

\[ h_c = \frac{1}{R_{total} \cdot A_{contact}} = 62 \frac{W}{K \cdot m^2} \]

Cradle (B):

\[ R_{total} \approx 44 \frac{K}{W} \]

\[ h_c = \frac{1}{R_{total} \cdot A_{contact}} = 20 \frac{W}{K \cdot m^2} \]

\[ \Delta T_{max} \approx 45^\circ C \]

\[ T_{max} \approx 68^\circ C \]
Cradle-Resistance calculation

Thermal resistance scheme

3. \( R_{\text{insert-screw}} \sim 0.25 \frac{K}{W} \)
4. \( R_{\text{screw}} = \frac{x}{A \cdot k} \sim 32 \frac{K}{W} \)
5. \( R_{\text{screw-washer}} \sim 0.26 \frac{K}{W} \)
6. \( R_{\text{washer}} = \frac{x}{A \cdot k} \sim 0.58 \frac{K}{W} \)
7. \( R_{\text{washer-Belleville}} \sim 0.267 \frac{K}{W} \)
8. \( R_{\text{Belleville}} = \frac{x}{A \cdot k} \sim 0.14 \frac{K}{W} \)
9. \( R_{\text{Belleville-cradle}} \sim 0.07 \frac{K}{W} \)

\[ R_{\text{total}} = R_{\text{vessel-insert}} + R_{\text{insert}} + R_{\text{insert-screw}} + R_{\text{screw}} + R_{\text{screw-washer}} + R_{\text{washer}} + R_{\text{washer-Belleville}} + R_{\text{Belleville}} + R_{\text{Belleville-cradle}} + R_{\text{cradle}} \sim 44 \frac{K}{W} \]
Results-3

• Free convection on the upstream and downstream fins face:
  • $\Delta T_{\text{max}} \approx 35^\circ \text{C} \ (h_c=4 \ \text{W/m}^2\text{K})$
  • $\Delta T_{\text{max}} \approx 36^\circ \text{C} \ (h_c=3 \ \text{W/m}^2\text{K})$
Geometries for R calculation
Thank you