University of Science and Technology of China

Strand-Jacket Contact thermal resistance measurement on dummy conductors

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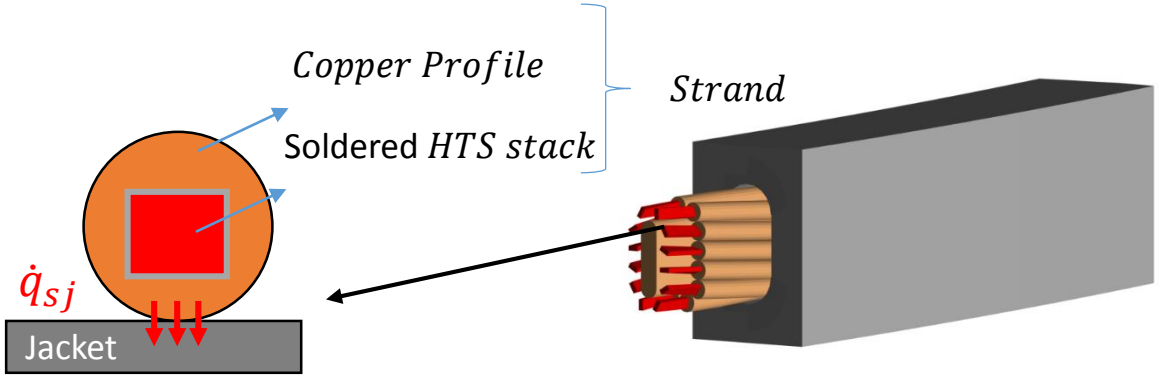
1. Motivation

Thermal contact resistance (H_{sj}) between strand and jacket is

$$\dot{q}_{sj} = \frac{T_s - T_j}{H_{sj}}$$

H_{sj} is in Km/W



For modelling:

- **An important input parameter**
- **Influenced by many factors: material type, roughness, temperature, contact area and pressure…**
- **Difficult to estimate**
- **Few relevant literatures can be found**

For conductor design:

- **CS conductor has large cross section of steel, which dominates the heat capacity at temperature above 20 K**
- **TCR decides how this huge heat capacity participates quench behavior of conductor**

At least to know the magnitude.

2. Method

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The thermal equation can be descript with:

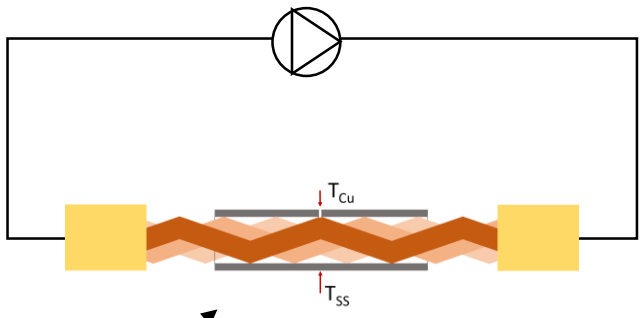
$$A_{Cu}C_{Cu}\rho_{Cu}\frac{\partial T_{Cu}}{\partial t}+\frac{(T_{Cu}-T_{ss})}{H}+\frac{(T_{Cu}-T_{ss})}{H_{air\_in}}=Q_{Cu}\ \dots(1)$$

$$A_{ss}C_{ss}\rho_{ss}\frac{\partial T_{ss}}{\partial t}+\frac{(T_{ss}-T_{Cu})}{H}+\frac{(T_{ss}-T_{cu})}{H_{air\_in}}+\frac{(T_{ss}-T_{air\_out})}{H_{air\_out}}=Q_{ss}\ \dots(2)$$

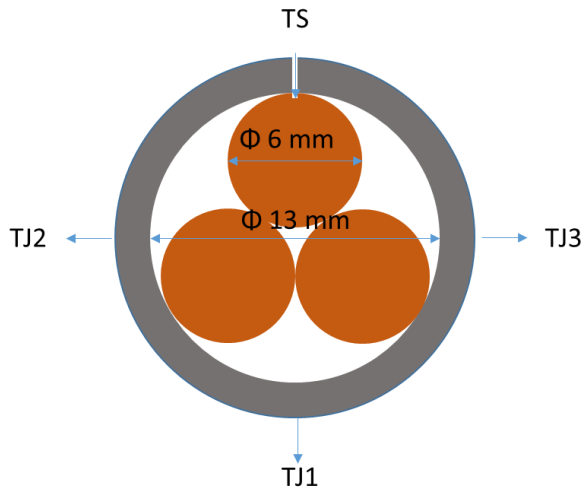
At 300 K, $\rho_{ss}:\rho_{cu}$~40

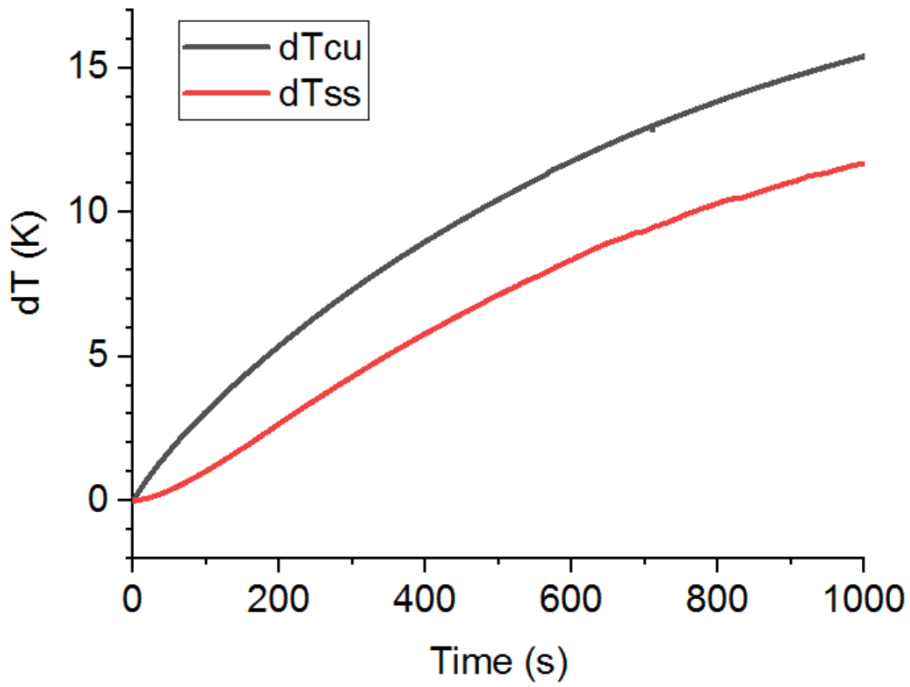
➔heat copper with current.

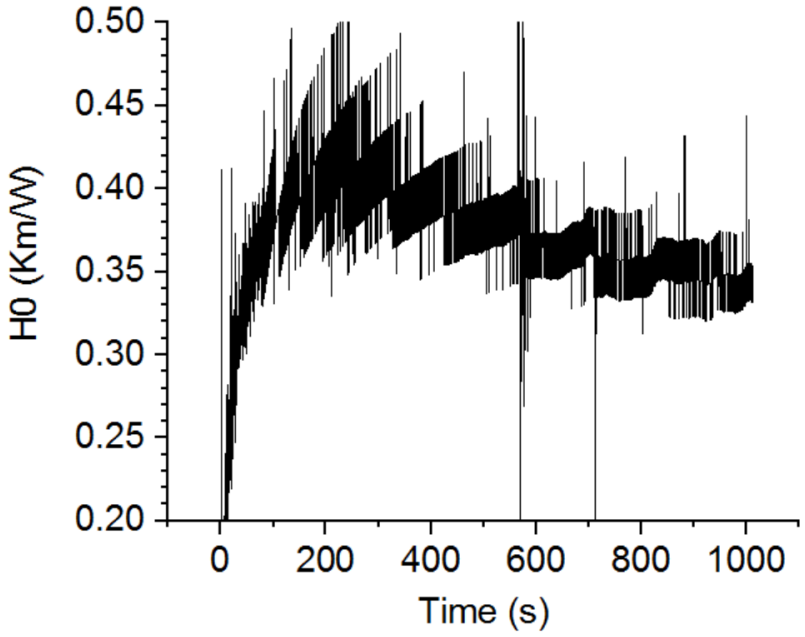
Introduce $\frac{1}{H_0}=\frac{1}{H}+\frac{1}{H_{air\_in}}$ ➔ $H_0=\frac{(T_{Cu}-T_{ss})}{Q_{Cu}-A_{Cu}C_{Cu}\rho_{Cu}\frac{\partial T_{Cu}}{\partial t}}$



3. Triplet dummy







Current = 250 A

Taking 400 s as an example:

$T_{Cu} - T_{ss}$ = 8.98-5.79 K = 3.19 K

$\frac{\partial T_{Cu}}{\partial t}$ = 0.015 K/s

Q_{Cu} = 12.7 W/m

$A_{Cu} C_{Cu} \rho_{Cu}$ = 291 J/mK

➔ H_0 = 0.38 Km/W

H ?

4. Heat exchange with air

During cooling down, T_{Cu} and T_{ss} soon become the same, and:

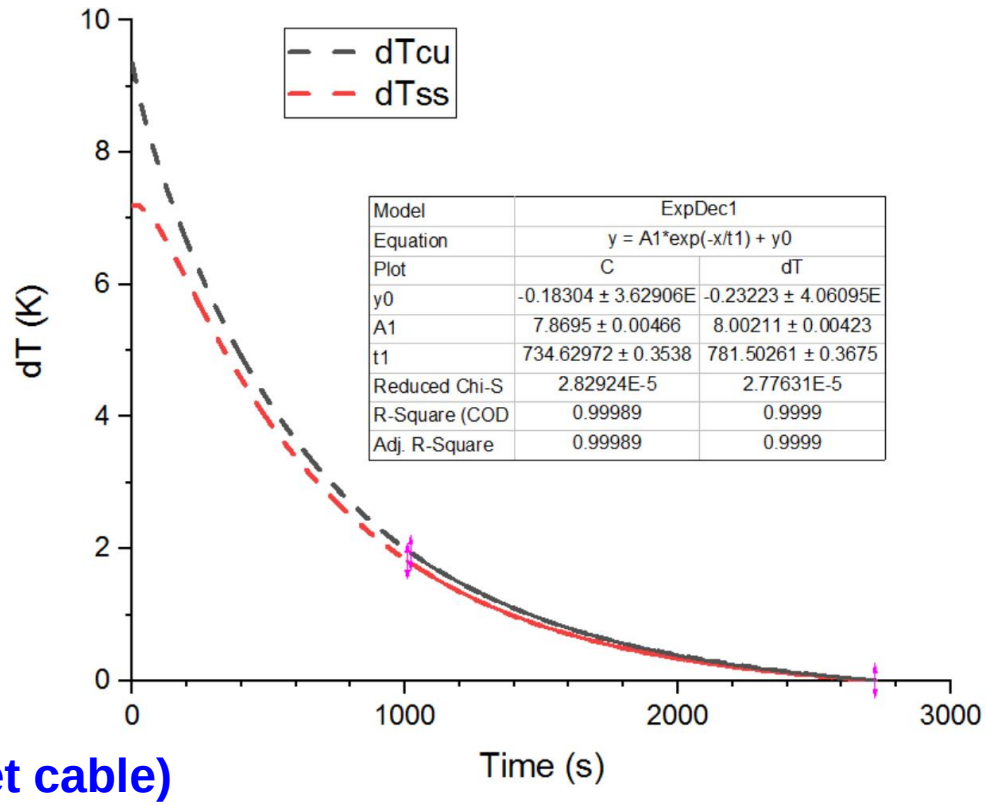
$$(A_{Cu}C_{Cu}\rho_{Cu} + A_{ss}C_{ss}\rho_{ss})\frac{\partial T}{\partial t} + \frac{(T-T_{air})}{H_{air}} = 0$$

$$T = e^{r_0 t} + T_{air}$$

$$r_0 = -\frac{1}{(A_{Cu}C_{Cu}\rho_{Cu} + A_{ss}C_{ss}\rho_{ss})H_{air}}$$

$$r_0 \approx -0.0013 \text{ s}$$

$$A_{ss}C_{ss}\rho_{ss} = 259.3$$



Model	ExpDec1	
Equation	y = A1*exp(-x/t1) + y0	
Plot	C	dT
y0	-0.18304 ± 3.62906E	-0.23223 ± 4.06095E
A1	7.8695 ± 0.00466	8.00211 ± 0.00423
t1	734.62972 ± 0.3538	781.50261 ± 0.3675
Reduced Chi-S	2.82924E-5	2.77631E-5
R-Square (COD	0.99989	0.9999
Adj. R-Square	0.99989	0.9999

➔ H_{air}= 1.4 Km/W ➔ **H = 0.5 Km/W (for triplet cable)**

For each strand, H is about 1.5 Km/W.

5. Some facts

After conductor manufacture:

- What will be the contact length and pressure?

When cooling down:

- Thermal strain could influence the contact length and pressure;
- Thermal conductance of material (metals and alloys) reduces.

When charged:

- Cable is pushed to one side by the Lorenz force, which influence the contact length and pressure.
- Could this dominants the effect of pressure?

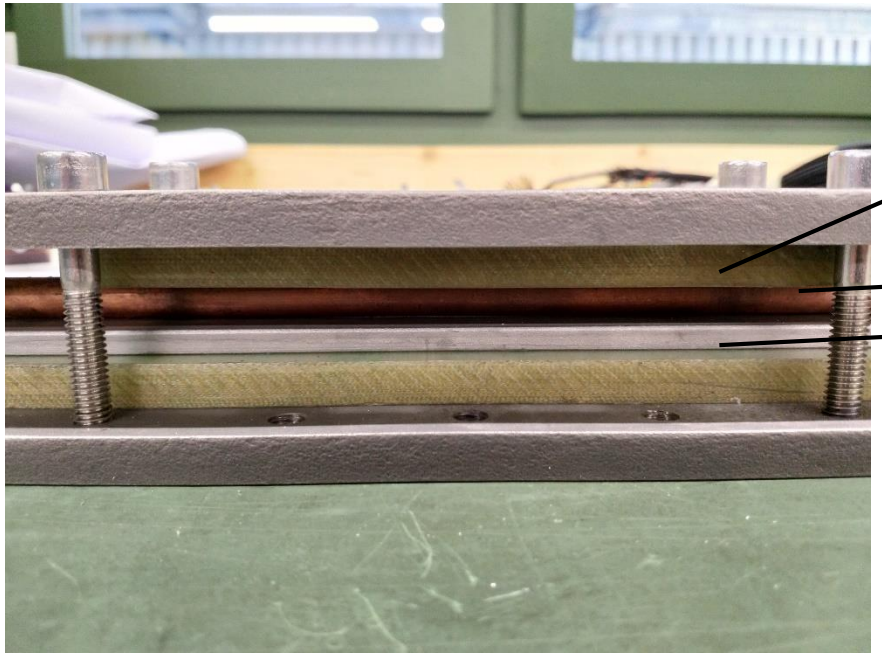
During quench:

- Temperature is increasing (5 K to 250 K);
- Contact pressure is dropping once current starts to dump;

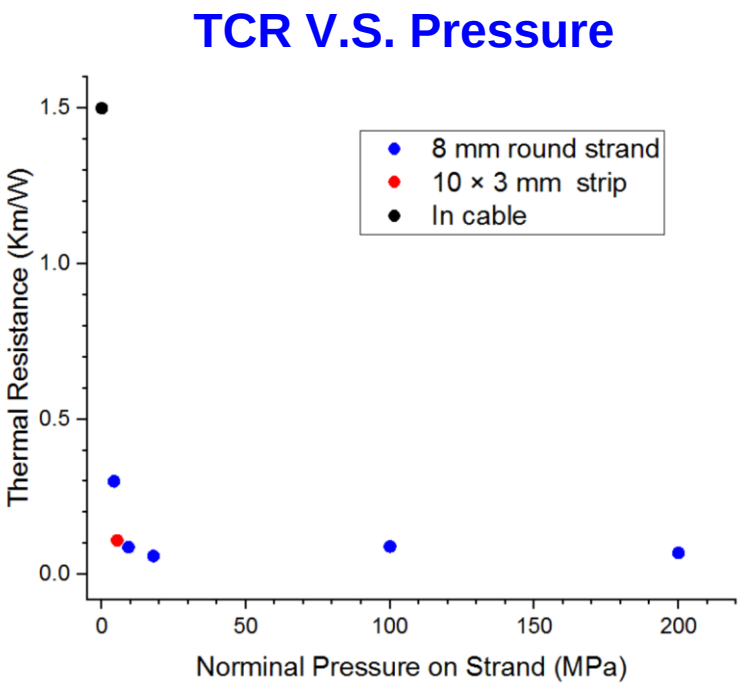
Roughness, can it vary a lot?

- The roughness of the copper and steel used in measurement are respectively 250 µm and 300 µm.

6. Scaling to operating condition



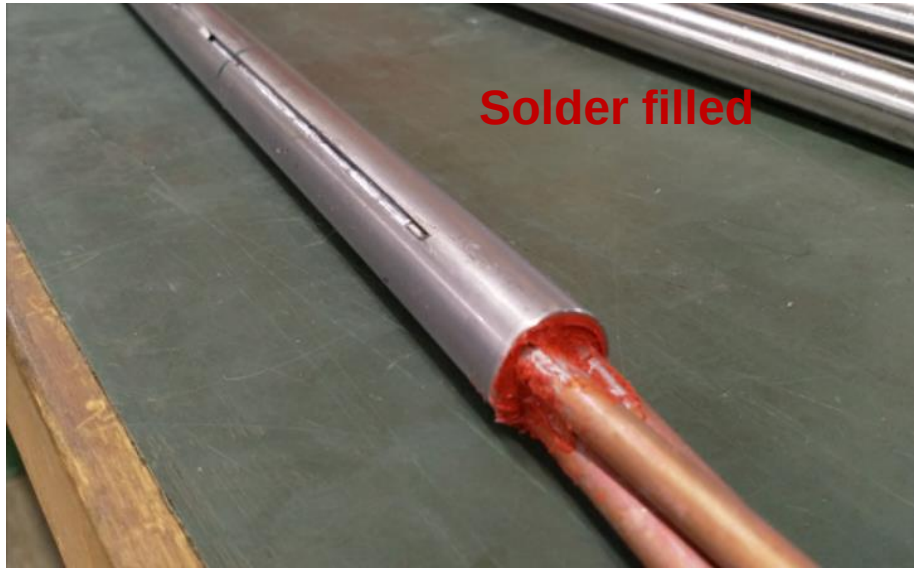
Torque wrench is used to apply a certain pressure through the bolt

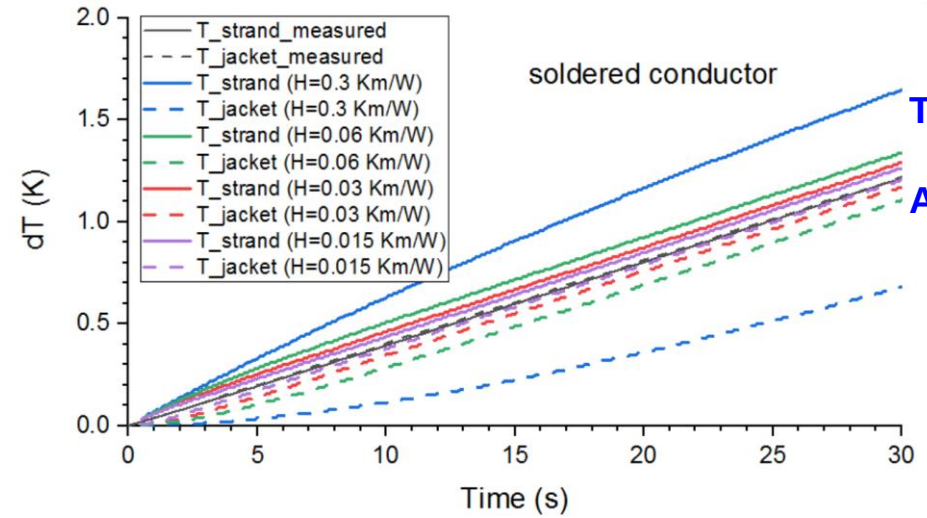


- **TCR decrease rapidly with contact pressure when pressure is below 10 MPa. Above that, it hardly changes and is around 0.1 Km/W.**
- **The transverse pressure for our strand is about 10 Mpa.**
- **From 300 K and 0 T (RT) to 4.75 K and 17.5 T, heat conductance of copper reduce from 386 W/Km to 102 W/Km.**
- **For steel, it is from 15 W/Km to 0.3 W/Km. Which dominants, copper or steel?**
- **An estimation of TCR at operation is then 0.1*386/102~0.4 Km/W or 0.1*15/0.3~5 Km/W (or some value in between).**

Compare with the result with a 10 mm wide strip, the equivalent contact length for 8 mm strand is about 3.6 mm.

7. Other layouts

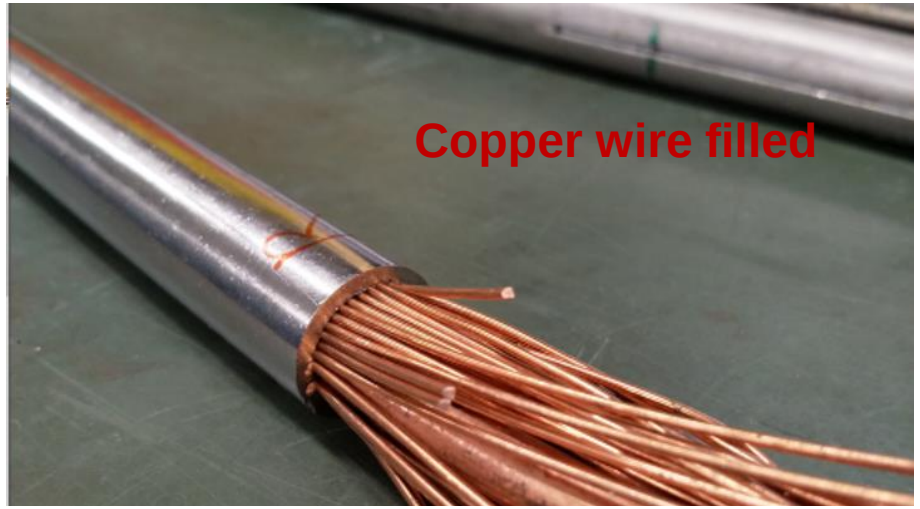


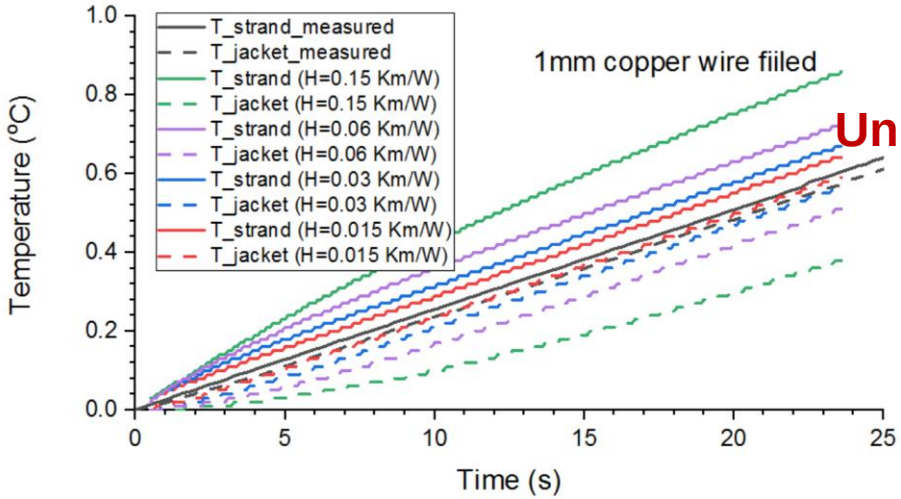


TCR < 0.015 Km/W at RT

At 5 K, TCR < 0.022 Km/W

Current = 400 A





Unknown pressure ☹

8. Summary

- During operation, the strand-jacket thermal contact resistance could be roughly estimated as 0.4-5 Km/W, the contact pressure of which is dominated by Lorenz force.

- Fill the void with soldered or smaller copper wires are benefit for reduce the thermal contact resistance, but they also lead to different conductor layouts, which need further study.

Thank you for your attention!