Contents

1. Scope

1) This document defines the technical design calculation of thermal links and interceptions in applications like
   - cryo-magnetic modules,
   - auxiliary cryostat systems

   within FAIR accelerators.
2) This document is NOT related to the thermal interception of any electrical cabling.
3) This document is NOT related to any other purpose as afore mentioned.

2. Definitions

1) A *thermal link* in terms of this document means a purposeful connection of two thermal potentials generating a well defined thermal coupling.
2) A *thermalisation strap* in terms of this document means a thermal link, realised by a flexible mechanical component with two terminals, showing a defined heat conductivity and low thermal contact resistance.
3) A *thermalisation port* in terms of this document means the interface at a component a thermalisation strap is connected to.
4) *A thermal interception* in terms of this document means the connection of a component; coupling two different thermal potentials; in between those two potentials, to a third intermediate thermal potential, for the purpose of defining the heat load onto the lower thermal potential.

3. Codes and Standards

1) The cupper material Cu-ETP is defined by DIN EN 13599 [1].
2) The aluminium material EN AW 1050A, (respectively EN AW Al 99.5 or W.-Nr. 3.0255) is defined by DIN EN 573-1 [2] and DIN EN 573-3 [3].

4. Design calculation Issues

1) Within the design calculations upper and lower boundary values of T_{upper} and T_{lower} must be considered for the calculation of best and worst case configurations.

4.1. Design Calculation for Thermal Links

1) An analogue circuit scheme of the design principle of a thermal link is shown in Figure 1.

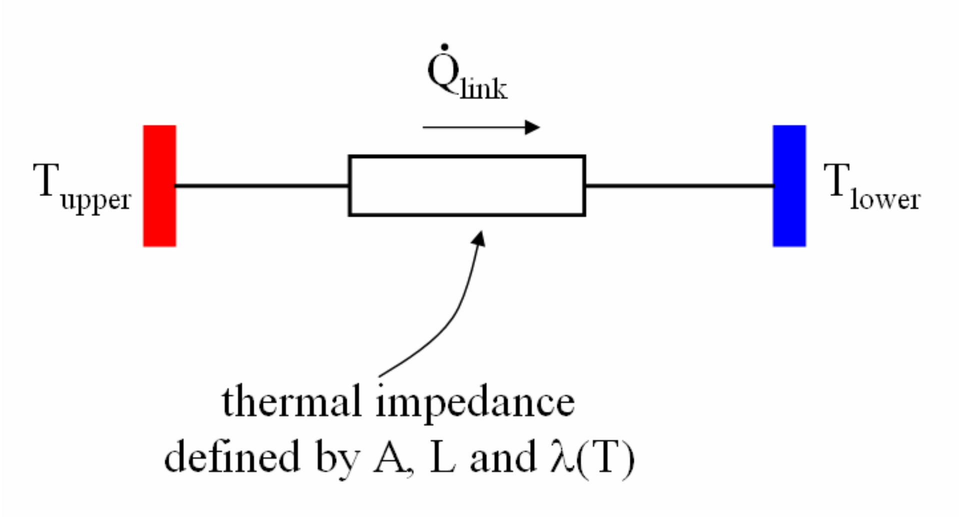

Figure 1: Analogue circuit scheme for the design of a thermal link

2) For the design of a thermal link, the following relation must be considered

Eq. 1 $$\dot{Q} = \frac{A}{L} * \int_{T_1}^{T_2} \lambda(T) * dT$$

T_{upper} :	Temperature of the warm side, upper temperature [K]
T_{lower} :	Temperature of the cold side, lower temperature [K]
$\dot{Q}$:	Heat flux in the thermal link [W]
A:	Cross section of a thermal conductor [m²]
L:	Path length of the thermal conductor [m]
λ(T):	Temperature dependent heat conductivity [W*(m*K)$^{-1}$]

3) The thermal contact resistances between terminal ports and adjacent components shall be assumed and considered within the design calculations.

4.2. Design Calculation for Thermal Interceptions

1) An analogue circuit scheme of the design principle of a thermal interception is shown in Figure 2.

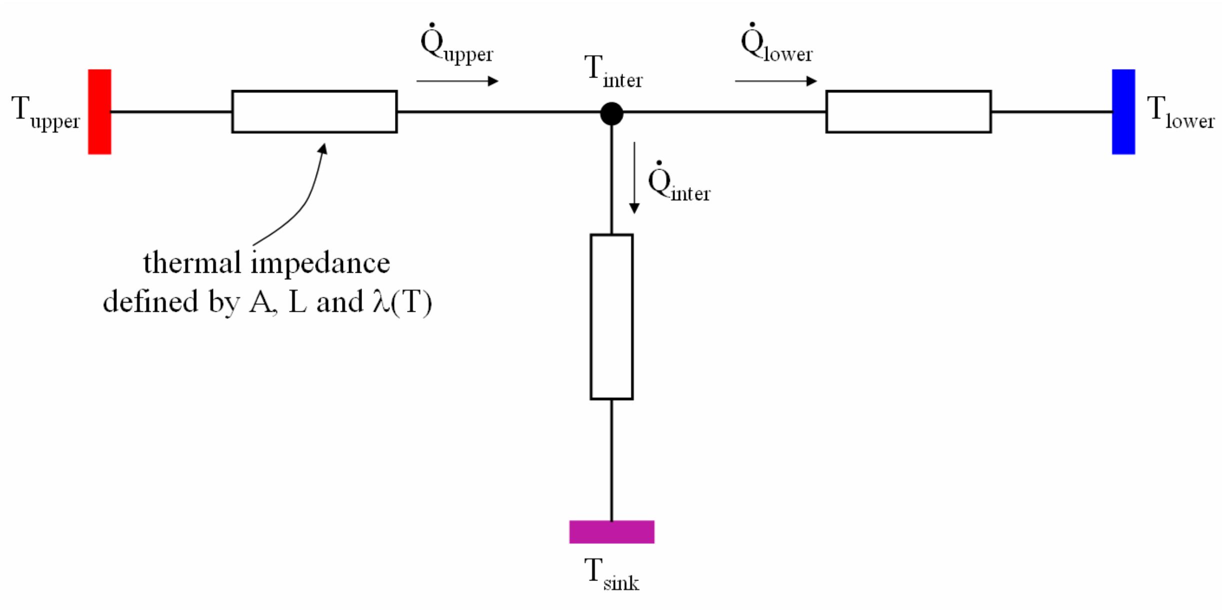

Figure 2: Analogue circuit scheme for the design of a thermal interception

2) For the design of a thermal interception, also the following relation must be considered

Eq. 2 $$\sum_i \dot{Q}_i = 0$$

T_{upper} : Temperature of the warm side, upper temperature [K]

T_{inter} : Temperature of the interception position, interception temperature [K]

T_{lower} : Temperature of the cold side, lower temperature [K]

T_{sink} : Temperature of the intercepting heat sink [K]

$\dot{Q}_{upper}$: Heat flux in the warm path [W]

$\dot{Q}_{inter}$ r: Heat flux in the interception path [W]

$\dot{Q}_{lower}$: Heat flux in the cold path [W]

3) The resulting heat load onto the sink must be considered with respect to the available sink cooling power. The sink must not warm up considerably due to a thermal overload.

5. Technical Design Issues

5.1. Approved Materials

1) Thermalisation straps must be produced preferably from Cu-ETP or if necessary from EN AW 1050A; dependent of the application requirements. No other materials are approved for production.

5.2. Mechanical Design of Thermalisation Straps

1) A thermalisation strap must be optimised for a defined heat flux by fitting in the conductor length and conductor cross section into the available construction space.
2) The thermalisation strap must show an optimum flexibility with respect to the thermal contraction of the adjacent components.
3) A thermalisation strap must show terminal ports providing a connection surface area at least three times the flux cross section of its conductor.
4) Each connection terminal must provide the possibility for applying a maximum contact pressure mostly equal over the full connection surface area. For this purpose massive and rigid terminal blocks must be applied. Standard cable eyelets represent an insufficient solution and must absolutely not be applied.
5) The connection surface must show an optimised surface shape for the connection to the adjacent components to be connected to. Rough and uneven surfaces must be avoided. The surface quality must be better then R_a 1 following DIN ISO 1302 [4].
6) Wherever technological possible the solution of laminated sheet metal packages as thermal conductor must be applied. The application of earthing braids represents a poor solution and must be avoided wherever possible.
7) A laminated sheet metal conductor must be bonded for high conductivity in the terminal regions by processes of
   - pressure welding, electron beam welding, fusion welding, gas shielded arc welding or soldering for cupper material
   - fusion welding or electron beam welding for aluminium material.
8) A terminal block must be bonded for high conductivity to the laminated conductor by processes as listed in 5.2.7).

5.3. Mechanical Design of Thermalisation Ports

1) The thermalisation port must be designed for optimum heat transfer, which means it must provide the optimum contact surface shape for the adjacent terminal of the corresponding thermalisation strap.
2) The connection surface must show an optimised surface shape for the connection to the adjacent terminal. Rough and uneven surfaces must be avoided. The surface quality must be better then R_a 1 following DIN ISO 1302 [4].
3) Whenever possible thread holes must be avoided. The contact pressure between a terminal block and the adjacent component must be applied by bolt and nut connections.

4) For a maximum contact pressure between thermalisation ports and the adjacent components, the thermal contraction of the involved materials of an interconnection must be carefully considered. In an optimum case a connection shall increase the contact pressure when cooled down (e.g. by the use of Aluminium bolts). For the compensation of material contraction also the application of disk springs can be considered.
5) In case thread holes are required in cupper or aluminium materials, a steel made thread insert must be applied in the thread hole.

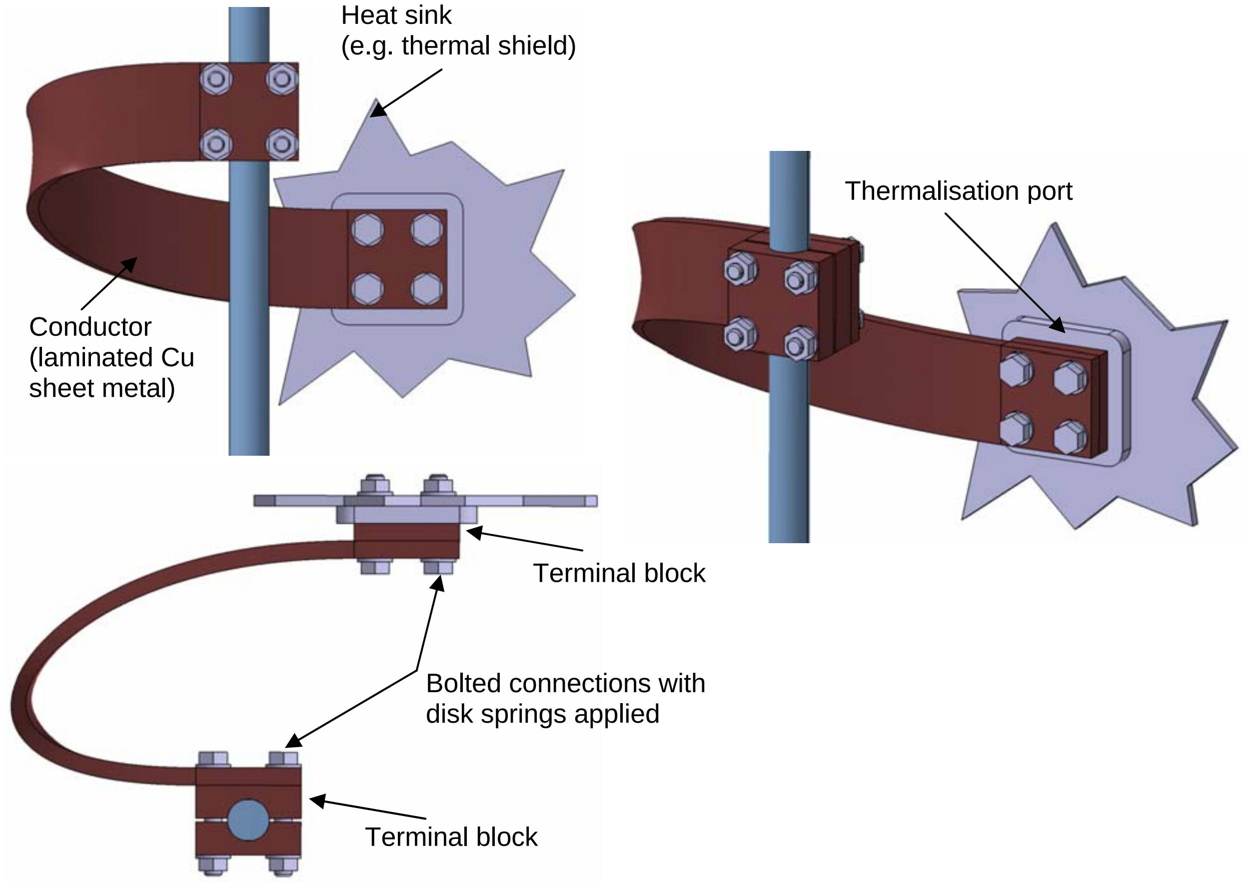

Figure 3: Front-, top- and 3D view of an exemplary solution for thermal interception of a rod

6) Figure 3 shows an exemplary technical design solution for the thermal interception of a rod.
7) If necessary, the application of thin films of Apiezon N® in between the contact surfaces of terminal ports and the adjacent components can be considered.

6. Engineering documentation

1) All thermal design calculations describing at least the values of
   - $\dot{Q}_{link}$ for thermal links
   - $\dot{Q}_{upper}$, $\dot{Q}_{inter}$, $\dot{Q}_{lower}$ and T_{inter} for thermal interceptions
   - A, L of the thermal conductor

   must be performed and delivered within the documentation for a best and worst case configuration.
2) The assumed values for the thermal contact resistance of the contact areas between thermalisation straps and adjacent components shall be documented.
3) The temperature dependent thermal conductivity data of the materials in use for the thermalisation straps must be delivered.
4) For any transfer of mechanical engineering data see [5].
5) Technical drawings of the thermalisation strap must be delivered.
6) An electronic copy of the full CAD-Model of the thermalisation strap must be delivered.

6.1. Structure of Documentation

1) All documentation and certificates (except mechanical engineering data as described in 6.5) - 6)) shall be transferred into EDMS – documents following the relevant EDMS – guidelines.
2) In case of text, tables, diagrams and pictures the electronic version shall be delivered in the PDF-format without any access restrictions.
3) Any certificates shall be delivered as original versions compiled in files and shall be electronically scanned for electronic compilation.

6.2. Material Certificates

1) Adequate certificates
   - stating the material composition
   - dated and accredited

   shall be delivered with each lot of material in use for production.

7. References

[1] DIN EN 13599, Copper and copper alloys - Copper plate, sheet and strip for electrical purposes, Beuth Verlag GmbH, Berlin, Germany, 2002-07

[2] DIN EN 573-1, Aluminium and aluminium alloys - Chemical composition and form of wrought products - Part 1: Numerical designation system, Beuth Verlag GmbH, Berlin, Germany, 2005-02

[3] DIN EN 573-3, Aluminium and aluminium alloys - Chemical composition and form of wrought products - Part 3: Chemical composition and form of products, Beuth Verlag GmbH, Berlin, Germany, 2009-08

[4] DIN ISO 1302, Geometrical Product Specifications (GPS) - Indication of surface texture in technical product documentation, Beuth Verlag GmbH, Berlin, Germany, 2002-06

[5] Terms and Conditions for the Exchange of Mechanical Engineering Data, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany, 2009