THERMAL STUDY OF AN INTEGRATED AND NON INTEGRATED TARGET, ELECTROMAGNETIC HORN

Benjamin Lepers
IPHC Strasbourg

October 13, 2010

THERMAL MODEL: INTEGRATED AND NON INTEGRATED TARGET

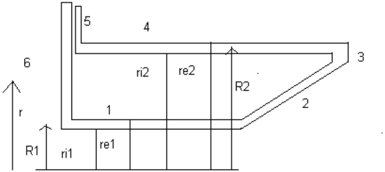


FIGURE: Magnetic horn geometry

integrated target: $r_{i1} = 1.5$ cm, $r_{e1} = 2.1$ cm.
non integrated target: $r_{i1} = 1.9$ cm, $r_{e1} = 2.5$ cm

- $P_{beam} = 1.3$ MW, $T = 80$ms; $I_{rms} = I_0 \times \sqrt{\frac{\tau_0}{2T}} = 7.5$ kA.
- joules losses : inner conductor(1), conical segment (2), top end face (3), outer conductor (4), bottom plate (5) bottom end plate (6) see figure 1
- $\{55, 30\}$ kW deposited in Al and Be target of length 30 cm.

COOLING

- Good approximation for the heat transfer coefficient $\bar{h}$ can be obtained from theoretical/empirical correlations
- h is function of the flow regime, fluid properties, mass flow rate and geometry.
- Water cooling: higher heat transfer rate but a high pressure circuit is necessary, or 2 phases flow (turbulent Water and air, or boiling regime). Used in MINOS, NuMI?, report from 2005, turbulent water flow, $h \sim 15kW/(m^2K)$
- Helium well suited. but high flow rate. used in T2K ($h \sim 1kW/(m^2K)$), difficult to have $h \geq 5kW/(m^2K)$
- In all cases: the maximum cooling heat transfer must occur in the first 10/20 cm of the target
- options: Cross flow, annular or jets.

ESTIMATION OF H COEFFICIENT

For $P_{beam} = 1.3$ MW, $\sigma = 6$ mm, power deposited inside the target are: $\{55, 30.2\}$ kW for Al and Be. Assume a uniform energy deposition, heat flux are: $\{0.19, 0.106\}$ kW/cm^2. For the cross flow case, the energy balance is:

$$q^{''} = \frac{Q}{2\pi R^{tg} L} = \bar{h}(T_s - T_\infty) \tag{1}$$

Hence if a maximal surface temperature of $T_{smax} = 200\,^\circ\mathrm{C}$ is specified, the condition on the h convection coefficient is:

$$\begin{aligned} \bar{h} &\geq \frac{q^{''}}{\Delta T} && (2) \\ &\geq \{10.5, 5.9\} kW/(m^2 K) && (3) \end{aligned}$$

Using the maximum heat flux $\{0.22, 0.12\}$kW/cm^2 calculated with Comsol , the minimum h convection coefficient required to maintain a surface temperature below $200\,^\circ\mathrm{C}$ are $\{12.2, 6.6\}$ kW/(m$^2 K$) for Aluminium and Beryllium respectively.

JOULE LOSS

Conductors	Target Al/Be [W]	1 [kW]	2 [kW]	3 [kW]	4 [kW]	5 [kW]	6 [kW]	total [kW]
$I_{rms} = 15$ kA	7.2/3.9 W	15.8	13.7	0.49	5.4	1.7	2.8	39.9
$I_{rms} = 7.5$ kA	1.8/0.98 W	3.9	3.4	0.12	1.3	0.4	0.7	9.8

TABLE: Joules losses in the conductors of the horn. Target is Al and Be

Joule loss mainly in the inner conductor and conical part. $P_{loss} \propto \frac{I^2}{r}$. for a given current frequency (constant skin depth).

APPLIED BOUNDARY CONDITIONS

The corresponding heat flux between the integrated target conductor and the fluid is :

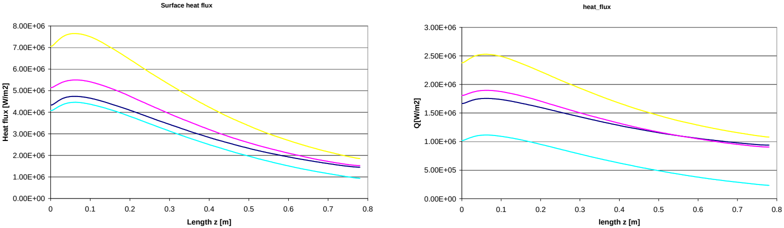
$$k \left. \frac{\partial T}{\partial r} \right|_{r=R^{\mathrm{tg}}} = \bar{h}\,[T(r = R^{\mathrm{tg}}, z) - T_{\infty}]. \qquad (4)$$

with T_{∞} the temperature of the cooling fluid.
The cooling coefficient is assumed to follow a linear variation with the target length as described in equation 5.

$$h(z) = -\frac{h_{max} - h_{min}}{l} z + h_{max} \qquad (5)$$

with the following couples : (h_{min}, h_{max})= $\{1, 2\}$,$\{2, 2\}$, $\{2, 3\}$, $\{5, 10\}$ kW/(m^{2}K)
$h = 1kW/(m^2K)$ on the external wall of the horn.

HEAT FLUX



a) Heat flux, 4MW

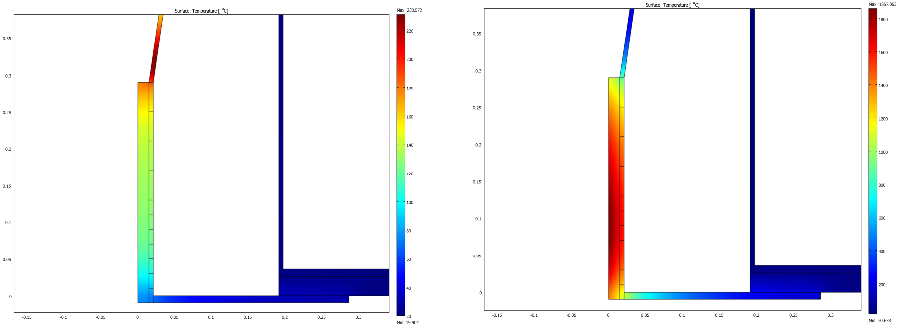
b) Heat flux, 1MW

FIGURE: Heat flux at the target surface $r = 15$ mm for Al, Be, C, AlBeMet (yellow, blue, magenta, pink) and $P^{beam} = \{1, 4\}$ MW

Maximum heat flux for Al and Be are $\{0.25, 0.17\}$kW/cm^2

Heat source are energy deposited from the Beam in the target and joule loss.

Need to include energy deposited from secondary particles in the horn wall (Christoph data).



a)

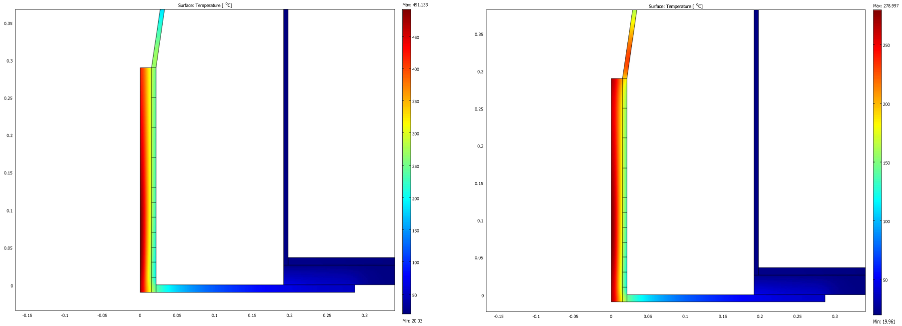
b)

FIGURE: Temperature field, with and without beam power for Al. Power density from Joule effect is important for the inner conductor and beginning of the conical section $i_{rms} = 15$ kA. $h = 1kWm^{-2}K^{-1}$

material	(h_{min}, h_{max}) [kWm$^{-2}K^{-1}$]	Max Temperature, integrated °C	Max Temperature, non integrated °C
Al	(1,2)	1280	1554
	(2,2)	1115	1326
	(2,3)	904	1033
	(5,10)	491	485
Be	(1,2)	822	922
	(2,2)	706	787
	(2,3)	559	601
	(5,10)	279	265

TABLE: Maximal temperature for Al and Be for integrated and non integrated target

INTEGRATED TARGET

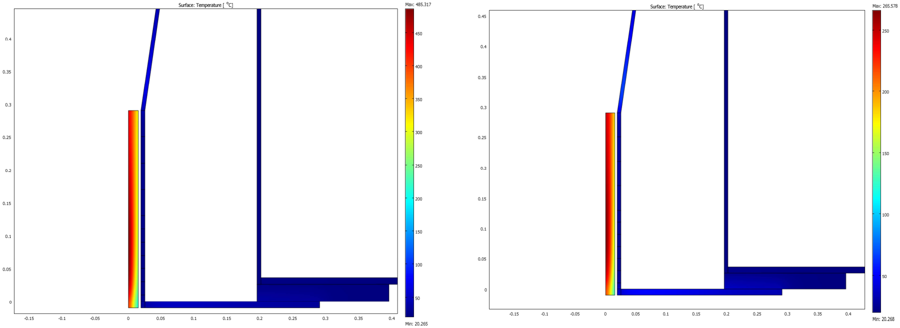


a) Al

b) Be

FIGURE: Temperature of the Al and Be integrated target/horn for $(h_{min}, h_{max}) = (5, 10)$

NON INTEGRATED TARGET



a) Al

b) Be

FIGURE: Temperature of the Al and Be non integrated target/horn for (h_{min}, h_{max}) $=(5, 10)$

CONCLUSION-NEXT STEPS

- Al not feasible for a target material with these cooling regime
- For the same cooling condition; maximal temperature are slightly lower for the integrated target, (thermal conduction target/conductors)
- Heat transfer coefficient will have to be approximately $\bar{h} \sim 10kW/(m^2K)$ or higher to maintain a safe working temperature.
- need to include the heat source deposited in the horn wall from secondary particle to be more realistic.
- choose/freeze the magnetic horn parameters. (Christoph and Andrea optimization)
- choose integrated or non integrated
- design a cooling circuit