Thermal and magnetic stress in the horn: static case

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January 6, 2011

- Model: electrical/resistive heating, Magnetic field/magnetic pressure, Temperature field/ thermal stress
- Material properties: electrical and thermal conductivity function of temperature
- Magnetic stress
- Thermal stress
- Total stress
- Fatigue limit
- Total stress with increased cooling or thickness.
- Conclusion

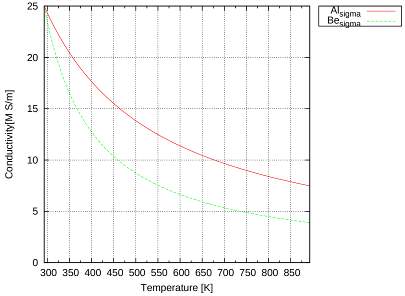
COUPLED PHYSICS MODELS

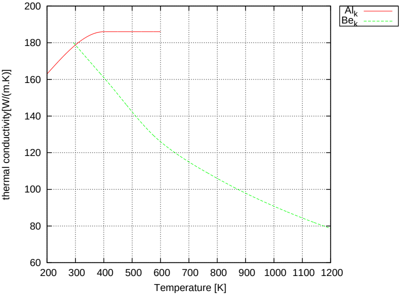
Model	Equation	Input	BC	Output
AC/DC	$j\omega\mu\mathbf{H} + \frac{1}{\sigma + j\omega\epsilon}\nabla \times [\nabla \times \mathbf{H}] = 0$ $\sigma = \sigma(T)$	$H_{0\phi} = \frac{I_{rms}}{2\pi r}$	$\mathbf{n} \times \mathbf{E} = 0 \Leftrightarrow H_n = 0$	$\mathbf{J}, \mathbf{B}$ Qav_{emqh}
Thermal	$\nabla \cdot [k\,\nabla T] + q = 0$ $k = k(T)$	$q = Q_{beam} + Qav_{emqh}$	$q'' = \bar{h}\,[T - T_\infty]$	T
Mechanical linear elast	$\frac{\partial \sigma r}{\partial r} + \frac{\partial \tau rz}{\partial z} + \frac{\sigma r - \sigma_\theta}{r} + F_r = 0$ $\frac{\partial \tau rz}{\partial r} + \frac{\partial \sigma z}{\partial z} + \frac{\tau rz}{r} + F_z = 0$ $\vec{\sigma} = \mathbf{E}\vec{\epsilon}$	$dF_r = -Re(B_\phi) \times Re(J_z)$ $dF_z = Re(J_r) \times Re(B_\phi)$ $\Leftrightarrow p(r) = \frac{\mu {I_0}^2}{8\pi^2 r^2}$	$u_r(r = 0) = 0$ $u_{plates}(z = 0) = 0$	$\mathbf{u}$ $\mathbf{s}$
Mechanical & thermal	idem $\vec{\epsilon} = \vec{\epsilon_{el}} + \vec{\epsilon_{th}}$ $\vec{\epsilon_{th}} = \mathbf{I}\alpha(T - T_{ref})$	idem α, T	idem $T_{ini} = T_{ref}$	$\mathbf{u}_{tot}$ $\mathbf{s}_{tot}$

- $I_0 = 350kA$, $I_{rms} = 8750A$. To model total stress, assume a magnetic pressure corresponding to peak current I_0.
- $Q_{beam} = 55kA$ deposited in the Beryllium target of length $L = 0.78$m and radius $R = 15$ mm.(obtain with Fluka).
- Cooling: $\{h_{target}, h_{horn}\} = \{10 - 20, 1 - 2\}\ kW/(m^2K)$
- non linear because both electrical and thermal conductivity are temperature dependant.
- axisymmetric model: all variables are function of r and z.

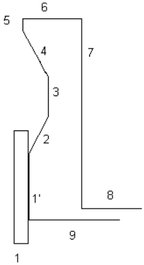
Material properties

- Model 1: constant electrical and thermal conductivity for Al and Be
- Model 2: Temperature dependant electrical and thermal conductivity for Al and Be





RESISTIVE LOSSES



Q[kW]	tot	1+1”	2	3	4	5 + 6	7	8	9
$\sigma = \sigma_0$	27	14	2.5	1.0	2.6	4.1	1.3	0.23	1.4
$\sigma = \sigma(T)$	37	20.8	2.7	1.0	2.9	6.5	1.3	0.23	1.5

- Total electrical loss are 37% higher than the one calculated with constant electrical conductivity
- Most electrical losses came from the inner conductor, conical sections and top end of the horn.
- $q_{elec} = \frac{\rho}{2} J^2$, the resistivity increased with temperature, $\Rightarrow$ essential to maintain the inner conductor at low temperature.

MAGNETIC FLUX DISTRIBUTION

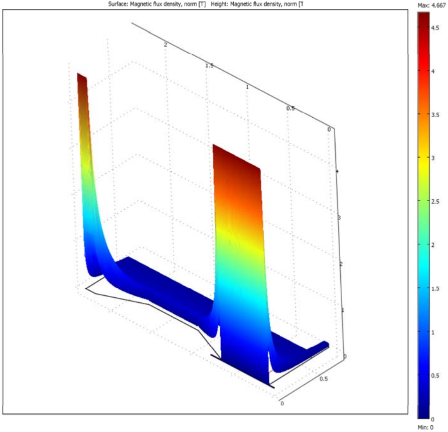


FIGURE: Magnetic flux distribution

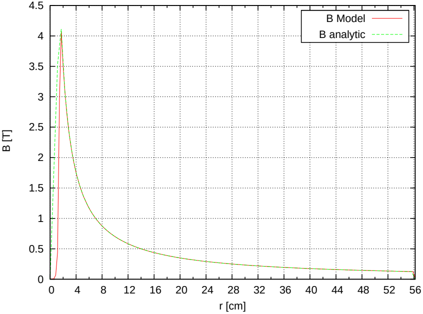


FIGURE: Radial magnetic flux distribution, analytic and model

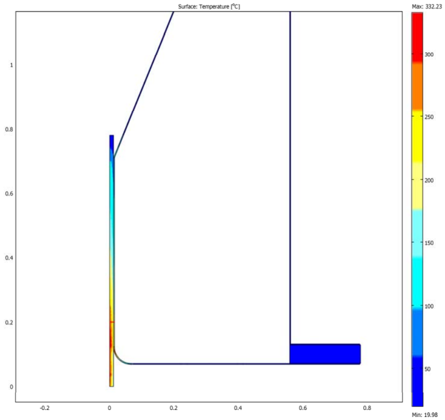


FIGURE: Target and horn, T_{max} is 332 °C, $h_{target} = 10kW/m^2K$, $h_{horn} = 1kW/m^2K$

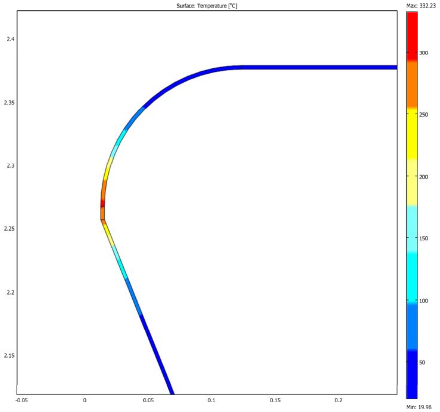


FIGURE: Top end of the horn, T_{max} is 332 °C, $h_{target} = 10kW/m^2K$, $h_{horn} = 1kW/m^2K$

TEMPERATURE FIELD, $\sigma(T), k(T)$

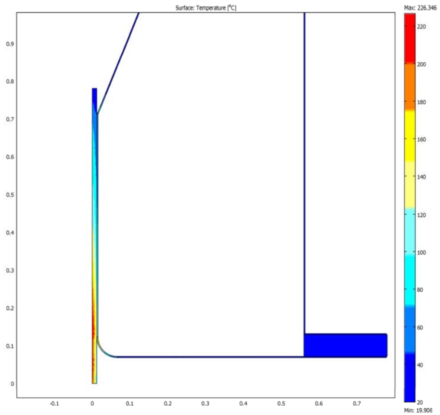


FIGURE: Target and horn, T_{max} is 226 °C, $h_{target} = 20kW/m^2K$, $h_{horn} = 2kW/m^2K$

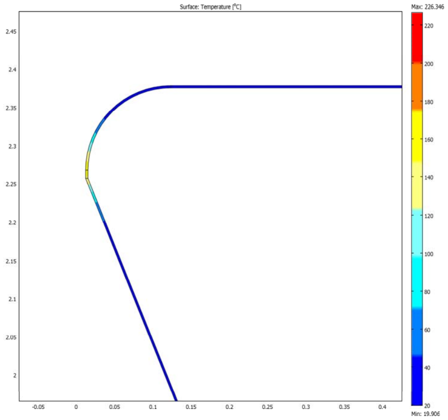


FIGURE: Top end of the horn, T_{max} is 226 °C, $h_{target} = 20kW/m^2K$, $h_{horn} = 2kW/m^2K$

DISPLACEMENT FIELD, $\sigma(T), k(T)$

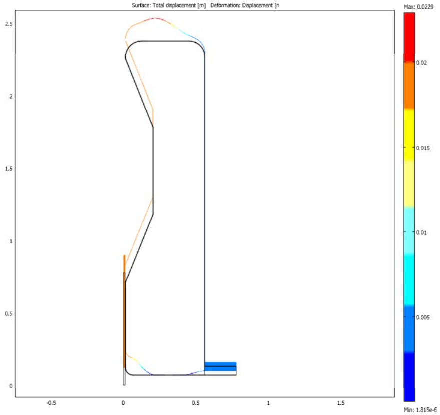


FIGURE: Displacement due to magnetic pressure, $t = 3$ mm $U_{max} = 22$ mm

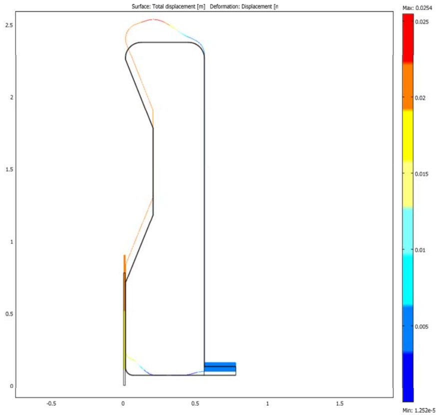


FIGURE: Displacement due to magnetic pressure and thermal dilatation, $t = 3$ mm $U_{max} = 25$ mm

DISPLACEMENT FIELD, $\sigma(T), k(T)$

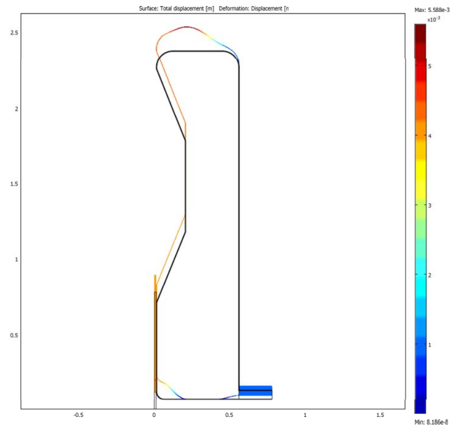


FIGURE: Total displacement due to magnetic pressure, $t = 5$ mm $U_{max} = 5.6$ mm

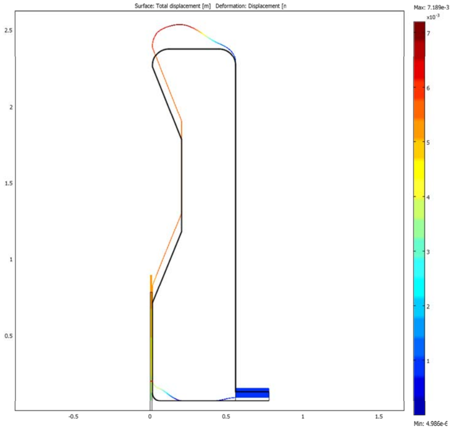


FIGURE: Displacement due to magnetic pressure and thermal dilatation, $t = 5$ $U_{max} = 7.2$ mm

STRESS TARGET, $t = 3$ MM

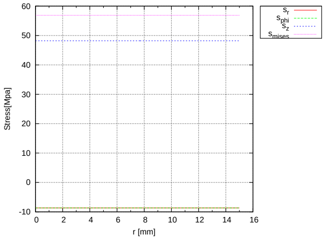


FIGURE: Stress, magnetic; $t = 3$ mm

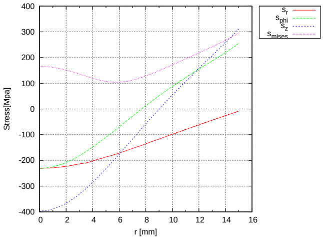


FIGURE: Stress, magnetic + thermal; $t = 3$ mm

Stress target, $t = 5$ mm

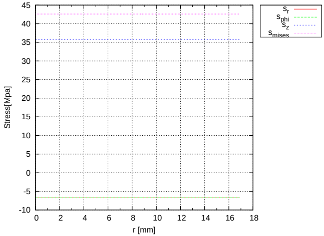


FIGURE: Stress, magnetic; $t = 5$ mm

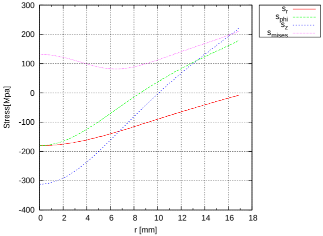


FIGURE: Stress, magnetic + thermal; $t = 5$ mm

STRESS HORN

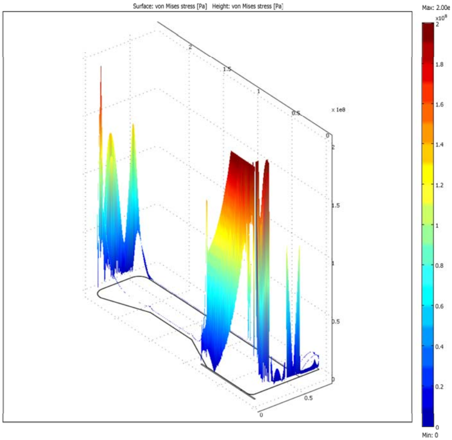


FIGURE: Mises stress, magnetic + thermal; $t = 3$ mm

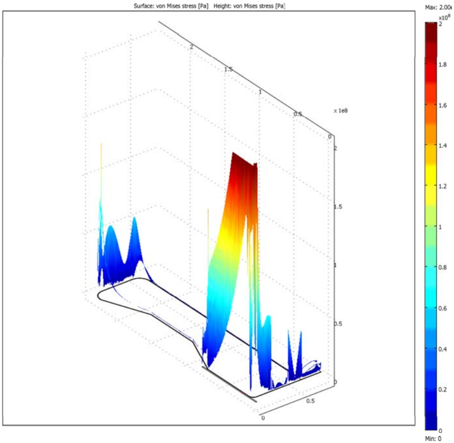
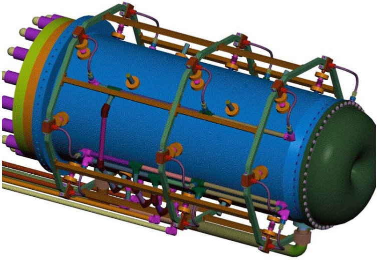


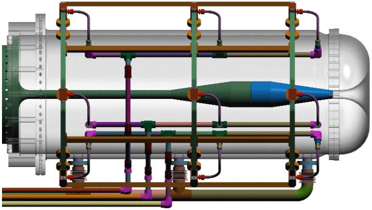
FIGURE: Mises stress, magnetic + thermal; $t = 5$ mm

FATIGUE

- $N = 8E8$: total number of pulses
- 4 horns: $\frac{N}{4}$ pulses per horn at frequency 12.5 Hz.
- $\tau = \frac{N}{f} = 16 \times 10^6$s , $\sim$ 6 months continuously
- Al: no fatigue limit, properties degrading as N increased.
- technical design for MiniBooNe: recommend stress below 68 Mpa for Al 6061-T6
- Need study on irradiation effect on materials and lifetime.
- Effect of water on lifetime ?

COOLING





CONCLUSION

- high stress level in the target
- need very efficient cooling, Miniboone $h \sim 3kW/m^2K$, need $h \sim 20kW/m^2K$ if integrated.
- frame with cooling system.