THERMAL AND DYNAMIC STRESS IN THE HORN

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OUTLINE

- Horn geometry
- Model
- Results - Thermal
- Results - Mechanics
- Fatigue limit
- Conclusion

GEOMETRY - DRAWINGS, V.ZETER

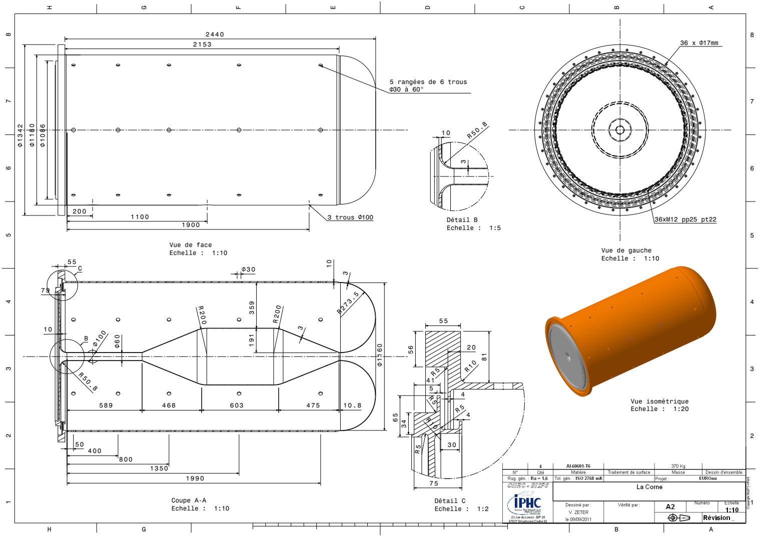


FIGURE: Horn drawings

Model	Equation	Input	BC	Output
AC/DC	$j\omega\mu\mathbf{H} + \frac{1}{\sigma + j\omega\epsilon}\nabla \times [\nabla \times \mathbf{H}] = 0$ $\sigma_{60} = 2.27 \times 10^7 \frac{S}{m}$	$H_{0\phi} = \frac{I_{rms}}{2\pi r}$	$\mathbf{n} \times \mathbf{E} = 0 \Leftrightarrow H_n = 0$	$\mathbf{J}, \mathbf{B}$ 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
Thermo Mechanical linear elast	$\nabla \cdot \sigma + \mathbf{F} = 0$ $\vec{\sigma} = \mathbf{D}\vec{\epsilon}$ $\vec{\epsilon} = \vec{\epsilon_{th}}$ $\vec{\epsilon_{th}} = \mathbf{I}\alpha(T - T_{ref})$	$dF_r = 0$ $dF_z = 0$ α, T	$u_{plates}(z = 0) = 0$	$\mathbf{u}$ $\mathbf{s}$
Transient mechanical	$\epsilon(t), \sigma(t)$ $\vec{\epsilon_{th}} = \mathbf{I}\alpha(T - T_{ref})$	$\mathbf{u_{tot}}(t = 0) = \mathbf{u}$ $p(r, t) = \frac{\mu i(t)^2}{8\pi^2 r^2}$	idem	$\mathbf{u_{tot}}(t)$ $\mathbf{s_{tot}}(t)$

TABLE: Electrical, thermal and mechanical model.

- $I_0 = 350kA$, $I_{rms} = 10.1\,kA$. magnetic pressure corresponding to peak current I_0.
- About $Q_j = 20\,kW$ from joule losses and $Q_s = 40\,kW$ from secondary particles
- Cooling minimum flow rate: 24l/min, will be probably in the range 60-120l/min. (function of the working temperature of the horn)
- axisymmetric model: all variables are function of r and z.

POWER DISTRIBUTION - TEMPERATURE

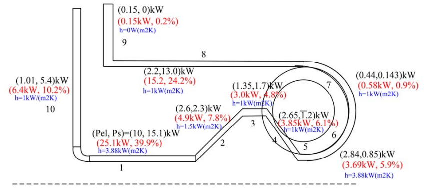


FIGURE: Power, h coefficients to maintain 60 $^\circ C$

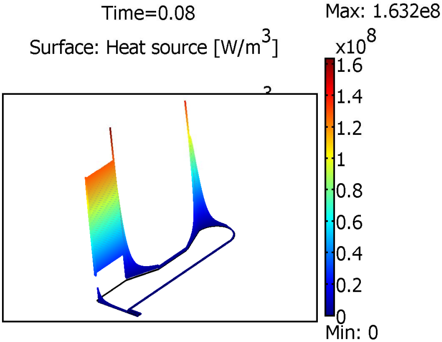


FIGURE: Power distribution

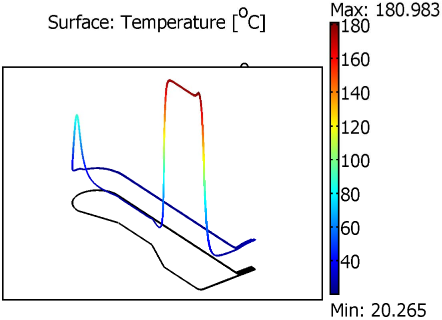


FIGURE: temperature with $\{h_{inner}, h_{horn}\} = \{1, 1\}$ kW/(m^{2}K

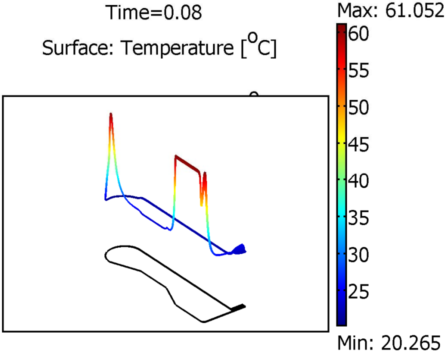
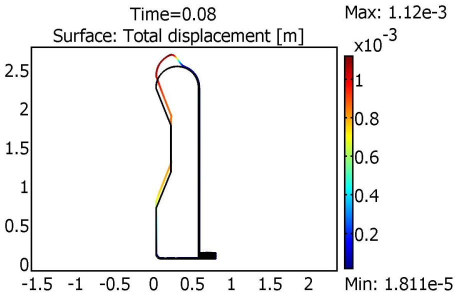


FIGURE: Temperature $\{h_{inner}, h_{horn}, h_{corner}, h_{conv}\} = \{3.8, 1, 6.5, 0.1\}$ kW/(m^{2}K

THERMAL DILATATION - THERMAL STRESS STATIC



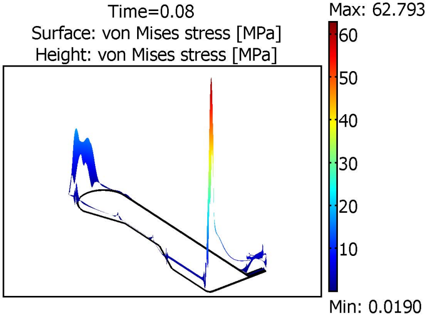


FIGURE: displacement $u_{max} = 1.12$ mm, $T_{max} = {}^\circ C$

FIGURE: Von Mises stress $s_{max} = 62$ MPa, $T_{max} = {}^\circ C$

Thermal dilatation - thermal stress static

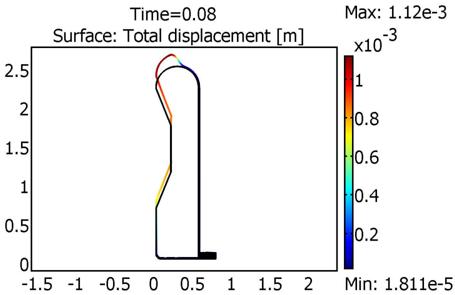


FIGURE: displacement $u_{max} = 1.12$ mm, $T_{max} = {}^{\circ}C$

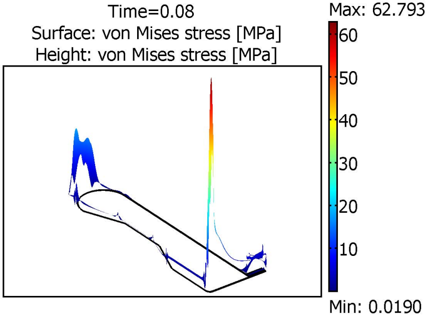
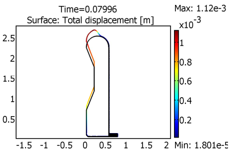
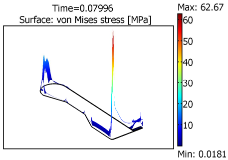


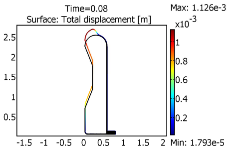
FIGURE: Von Mises stress $s_{max} = 62$ MPa, $T_{max} = {}^{\circ}C$



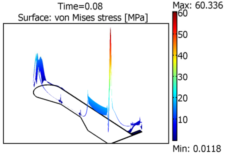
a) $u_{max} = 1.12$ mm, $t = 79.96$ ms



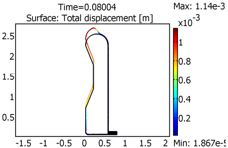
b) Von Mises stress $s_{max} = 62.6$ MPa, $t = 79.96$ ms



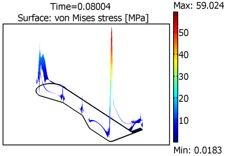
c) $u_{max} = 1.12$ mm, $t = 80$ ms



d) Von Mises stress $s_{max} = 60.3$ MPa, $t = 80$ ms

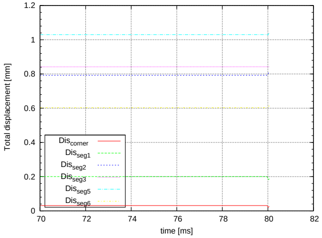


e) $u_{max} = 1.14$ mm, $t = 80.04$ ms

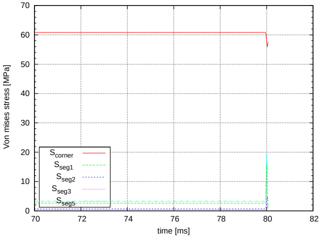


f) Von Mises stress $s_{max} = 59.0$ MPa, $t = 80.04$ ms

FIGURE: Displacement field a) and von mises stress b) due and pulse magnetic pressure.



a) Total displacement



b) Von Mises stress

FIGURE: Displacement and stress due to thermal dilatation and magnetic pulse. Corner, conductor segments 1, 2, 3, 5, 6 at locations $\{r, z\} = \{6.6, 6.5\}, \{3.2, 20\}, \{15, 100\}, \{22.3, 148.6\}, \{3.2, 225.8\}, \{30.5, 254.1\}$ cm. The origin is located at 6.8 cm upstream from the inner back plate.

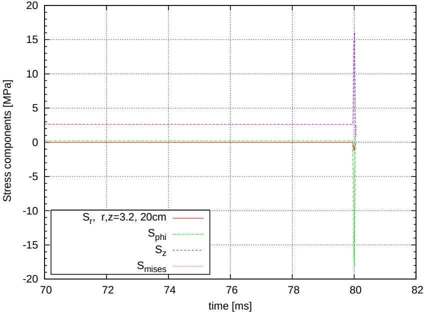
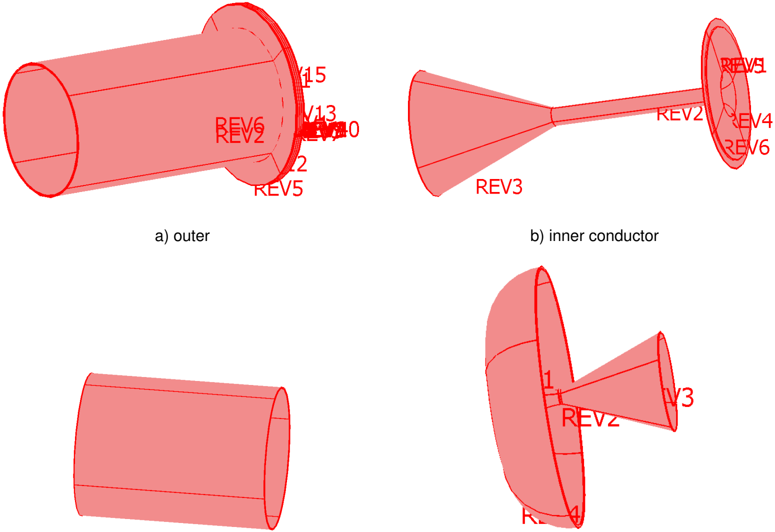


FIGURE: Stress components inside the inner conductor, $\{r, z\} = \{3.2, 20\}$ cm

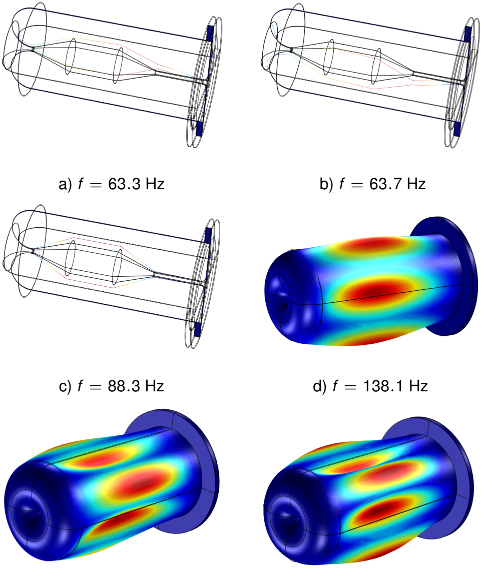
- thermal static stress about 60 Mpa in the inner waist corner of the horn
- magnetic pressure pulse contributes of about 20 Mpa in the conductor region $r = 3$ cm (inner conductor and downstream part)
- Fatigue: CNGS design report: take 68 Mpa as a fatigue limit for 10^8 cycles
- Fatigue design curves of 6061-T6 Al (ASME Boiler and pressure vessel committee): limit of 40 Mpa with no mean initial stress
- 20 Mpa with maximum mean stress effect. (maximum mean stress: intersection with max cyclic stress conditions and Goodman or Gerber fatigue strength relation).
- 10 Mpa for weld junction. (weld reduction factor 2)
- Conclusion: may need to improve the design in the inner waist region of the horn
- Construction: no weld junction in the inner conductors $r = 3$ cm.



a) outer   b) inner conductor

c) middle conductor   d) end cap

FIGURE: Part assembly of the horn



a) $f = 63.3$ Hz b) $f = 63.7$ Hz

c) $f = 88.3$ Hz d) $f = 138.1$ Hz

e) $f = 138.2$ Hz f) $f = 144.2$ Hz

FIGURE: First six eigenfrequency of the 3D model horn. End back plate is fixed.

CONCLUSION

- stress level low, except in the inner waist corner of the horn: thermal stress is dominant
- magnetic pressure pulse: about 20 MPa in the inner conductor, not negligible
- Fatigue: no fatigue limit for Aluminium, below $40, 50$ Mpa would be good
- Eigenmode, eigenfrequency: the inner conductor vibrates at low frequency
- forced periodic excitation
- may need to design some spacers to increase the horn stiffness