TP 149

Estimation of cavitation-induced damage in a long-pulse liquid-metal target

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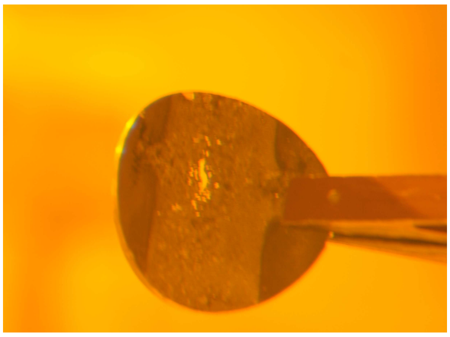
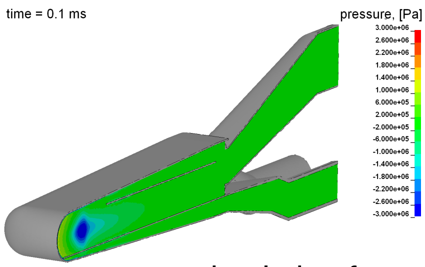
Motivation: The injection of high-energy proton beams into liquid-metal targets generates high pressures in the liquid metal because of its thermal expansion. The subsequent cavitation may lead to erosion of the target vessel, as has been observed in a short-pulse target at the spallation neutron source (SNS) at ORNL. Cavitation erosion may be the factor which determines the lifetime of a high-power spallation target, at least for a short-pulse target. It should be safer to operate a long-pulse target, but is cavitation really no problem here?



cavitation erosion in the first liquid-mercury target at SNS



pressure simulation for the ESS long-pulse target

power deposition

↓

overpressure

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underpressure

↙ ↘

wall motion | liquid rarefaction

↘ ↙

cavitation

↓

erosion

principle of cavitation erosion

wave equation for pressure *P*

$$\frac{1}{c^2}\cdot\frac{\partial^2 P(\vec{r},t)}{\partial t^2} - \Delta P(\vec{r},t) = \frac{3\cdot\alpha}{C_p}\frac{\partial}{\partial t}\eta(\vec{r},t)$$

long-pulse target

$$P(0,\frac{\sigma}{c}) = -\frac{3}{\sqrt{e}}\cdot\frac{\alpha\cdot c\cdot\sigma}{C_p\cdot\Delta t}\cdot\frac{W_{therm}}{(\sqrt{2\cdot\pi}\cdot\sigma)^3}$$

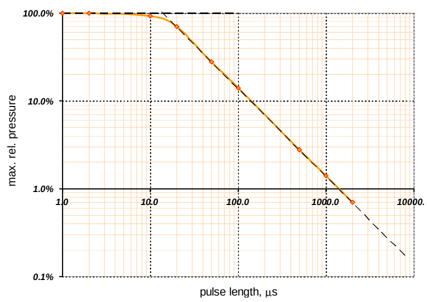
short-pulse target

$$P(0,\sqrt{3}\cdot\frac{\sigma}{c}) = -\exp(-\frac{3}{2})\cdot\frac{3\cdot\alpha\cdot c^2}{C_p}\cdot\frac{W_{therm}}{(\sqrt{2\cdot\pi}\cdot\sigma)^3}$$

dimensionless transfer coefficients
energy density → underpressure

	long pulse	short pulse
Hg	0.021	0.539
PbBi	0.018	0.580

analytical description of pressure development

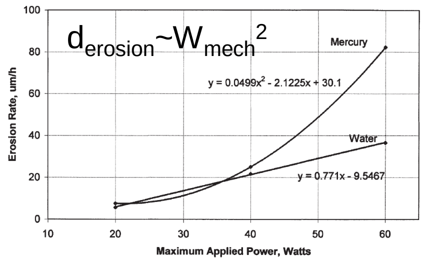


maximum relative pressure as a function of the pulse length

Exercise: Compare the minimum pressures in a 1 MW short-pulse target and a 5 MW long-pulse target.

Answer: The pressure is reduced by a factor of about 30 from short pulse to long pulse. The pressure scales linearly with input energy. Pressure ratio 1/30 x 5 = 1/6.

How does underpressure translate into cavitation damage?



experiments with 316 LN immersed in Hg. Insonified by ultrasound horn.

M.D.Kass *et al*., Tribol Lett. Vol. 5 (1998), p 231-234

Summary

$$d_{erosion} \sim W_{mech}^2 \sim W_{therm}^4 \sim P_{min}^4$$

Conclusion: Underpressures are about 30 times smaller than for short-pulse targets, but still below the cavitation threshold (experimental value: -1.5 bar). Cavitation erosion should be lower for a long-pulse target. Prediction: reduction to a level of $(1/6)^4 < 1/1000$.
Lifetime of the SNS short-pulse target @ 1 MW > 3 months =>
Lifetime of the ESS long-pulse target @ 5 MW > 250 years