Effects of Externally Applied Lorentz Force on Liquid Metal Surface Stability

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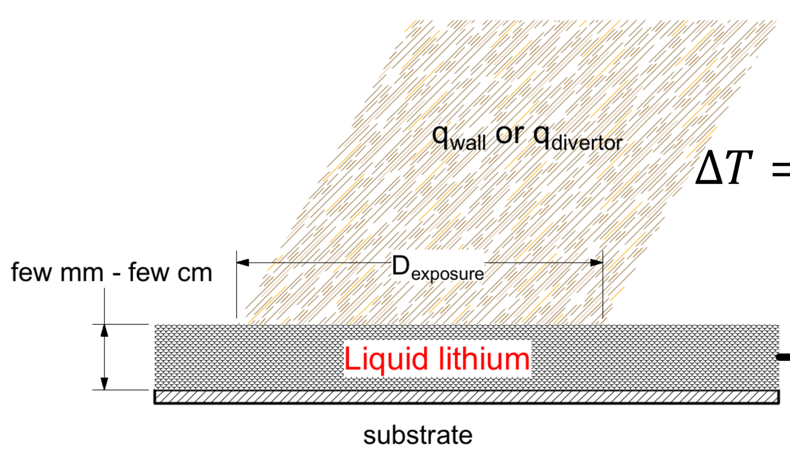
Motivation

There are many reasons why nuclear fusion has not hit commercial viability yet; one of these reasons is the inability to effectively remove heat from the reactor. Current plasma facing components (PFCs) can't withstand the intense heat and radiation created by a high-power reactor, especially in the divertor region. Fast flowing liquid lithium PFCs have the ability to actively remove heat as shown in Figure 1. As also shown in past work, liquid lithium PFCs improve confinement and enhance plasma performance by reducing particle-recycling.

The results presented here were obtained using a eutectic alloy galinstan (GaInSn) rather than lithium. This is done both for lab safety reasons, and that galinstan is far easier to work with as it is liquid at room temperature.



$$\Delta T = 2q_{wall}\left[\frac{W}{cm^2}\right]\sqrt{\frac{t}{\pi\kappa\rho_m C_p}} = 0.92q_w\sqrt{\frac{D_{ex}}{v_{flow}}}$$

κ = thermal conductivity, lithium = 85 W /m°C

ρ_m =mass density=0.5 g/cm^3,

C_p= specific heat capacity=3.56 J/g°C

Figure 1. Reactor heat flux on flowing liquid metal surface.

Liquid Metal eXperiment (LMX)

LMX is an open channel flow of galinstan immersed in a magnetic field directed in the horizontal-transverse direction. Using electrodes located at the inlet and outlet of the channel, electric currents may be injected into the system and generate a force due to the interaction of the currents with the magnet field.

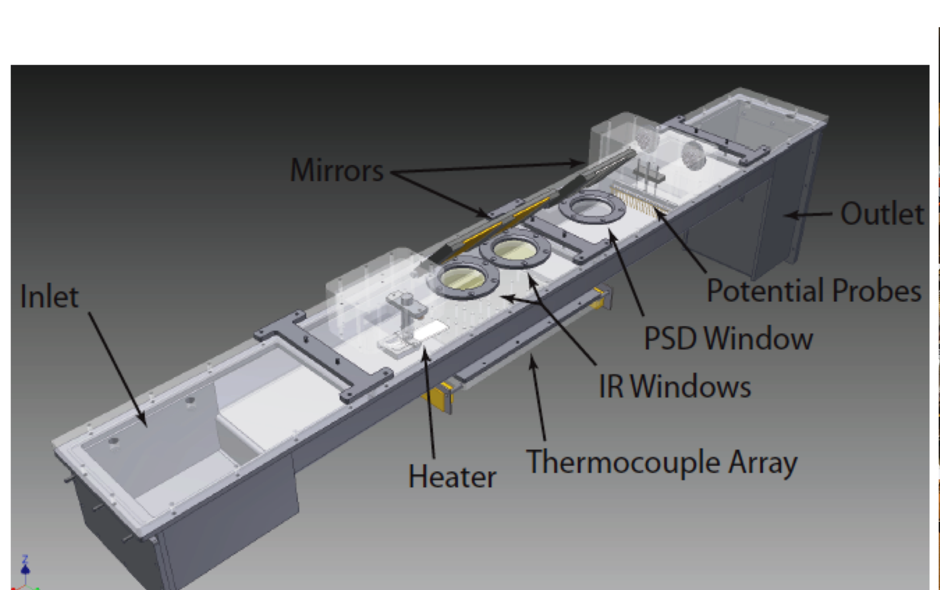


Figure 2. Graphical depiction of the LMX-U channel.

Figure 3. Actual image of LMX Upgrade.

MHD Damping of Surface Waves

The motion of a conductor through a magnetic field induces an electrical current within the medium. A Lorentz force drag is generated through the interaction of the electrical current and magnetic field, and the electrical current dissipates to heat.

$$\boldsymbol{F} = \sigma(\boldsymbol{u}\times\boldsymbol{B})\times\boldsymbol{B} = \boldsymbol{j}\times\boldsymbol{B}$$

$$P_{Loss} \propto \sigma u^2 B^2$$

A magnetic field parallel to wave propagation strongly damps waves:

$$a = a_0 e^{\left(\frac{\sigma B^2}{\rho}\right)t}$$

Damping from a horizontal, transverse magnetic field is not predicted from linear theory but was experimentally observed. As the damping is significantly weaker for these waves high precision measurement techniques were needed. The presented technique has been used on LMX in the past, and can resolve wave structures on the order of tens of microns.

Experimental Setup for Waves

Puffs of argon gas were used to generate small amplitude waves in the LMX-U channel. These waves were measured at different locations between gas puffs. Each wave history can be fit using an exponential law. Looking at the first peak depth across multiple gas puffs allow for fitting a spatial decay to the wave. Two sample waves and the experimental setup are shown in Figures 5 and 4 respectively.

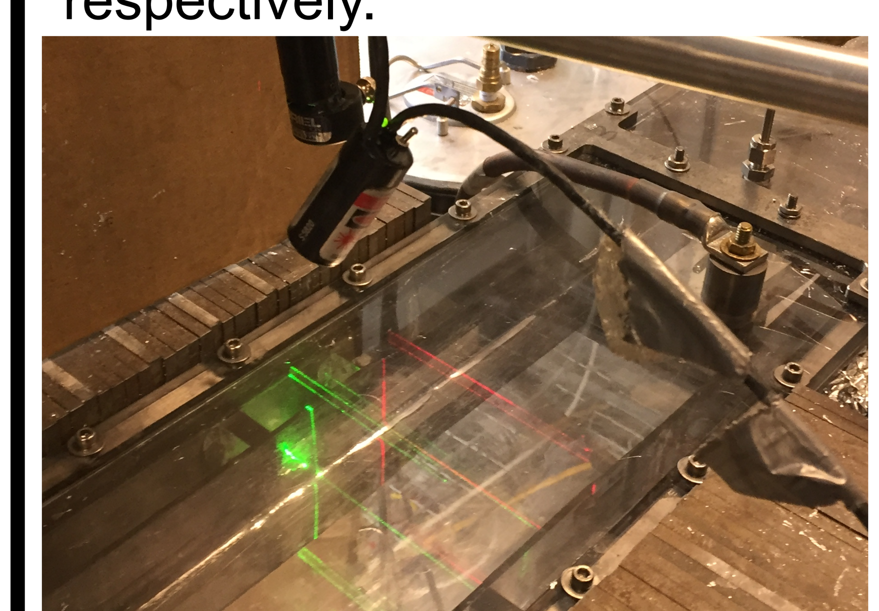


Figure 4. Schematic of the laser sheet diagnostic used to measure the liquid metal height.

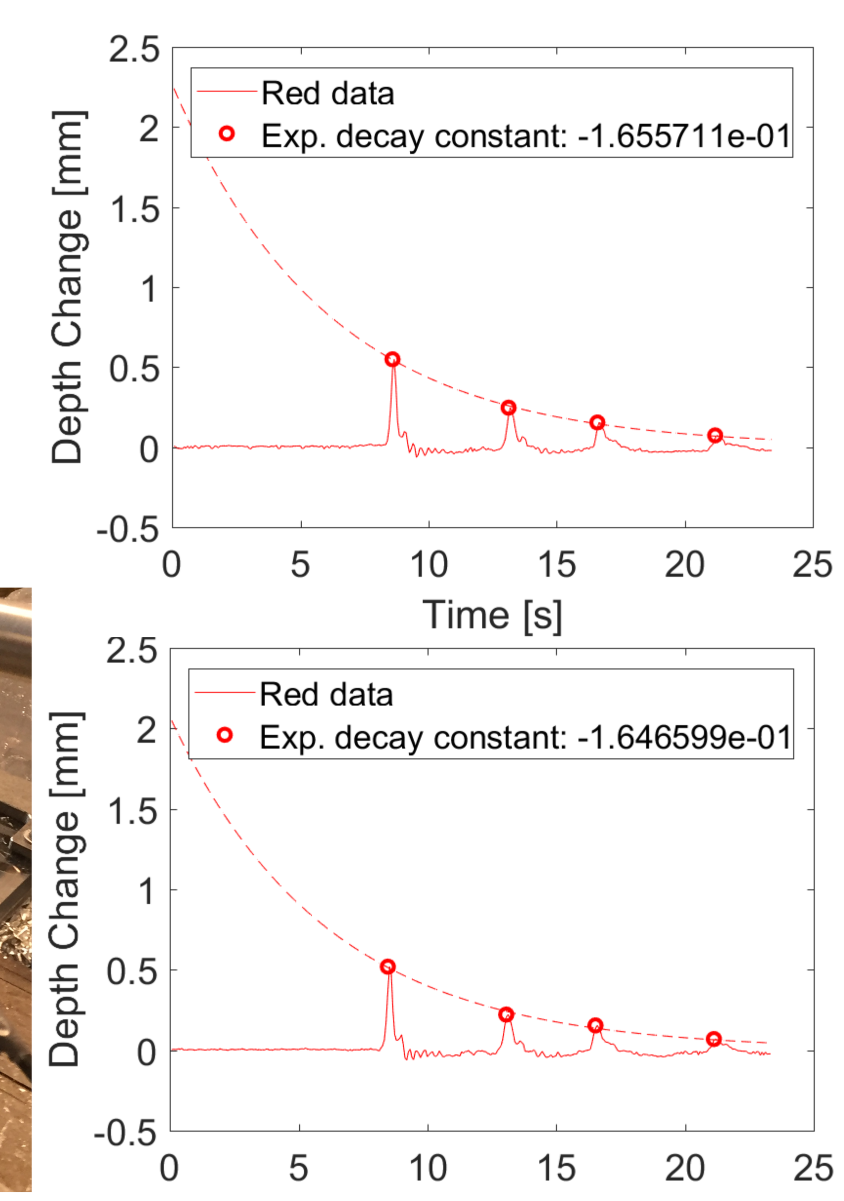


Figure 5. Two gas puffs at the same conditions

Experimental Results and Simulations

Surface waves have been shown to damp in the presence of magnetic fields. We've shown this damping in LMX, and are additionally investigating effects due to jxB. Amplitude was found to decay as: $a = a_0 e^{-x/L_c} = a_0 e^{-t/t_c}$ when fitting either across multiple or single gas puff respectively. Temporal decay includes reflections and fringing magnetic field.

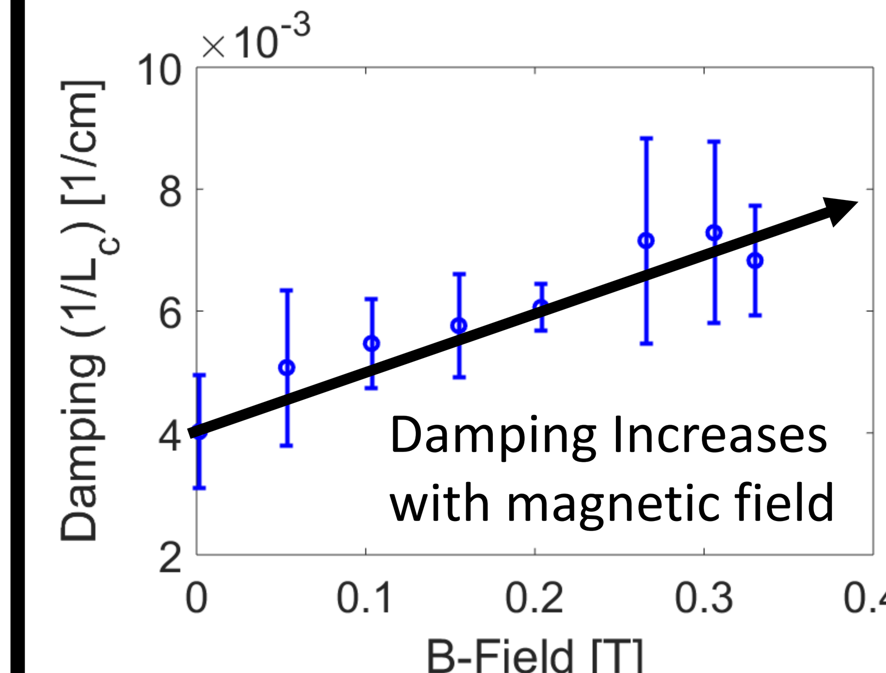


Figure 6. Plot of $1/L_c$ vs. magnetic field: $a = a_0 e^{-x/L_c}$

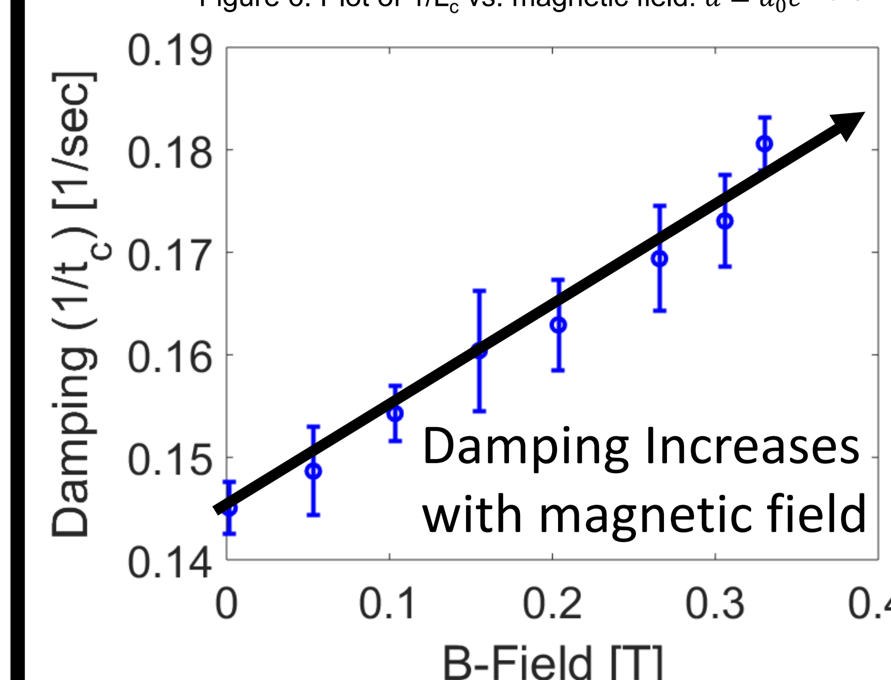


Figure 7. Plot of $1/t_c$ vs. magnetic field: $a = a_0 e^{-x/t_c}$

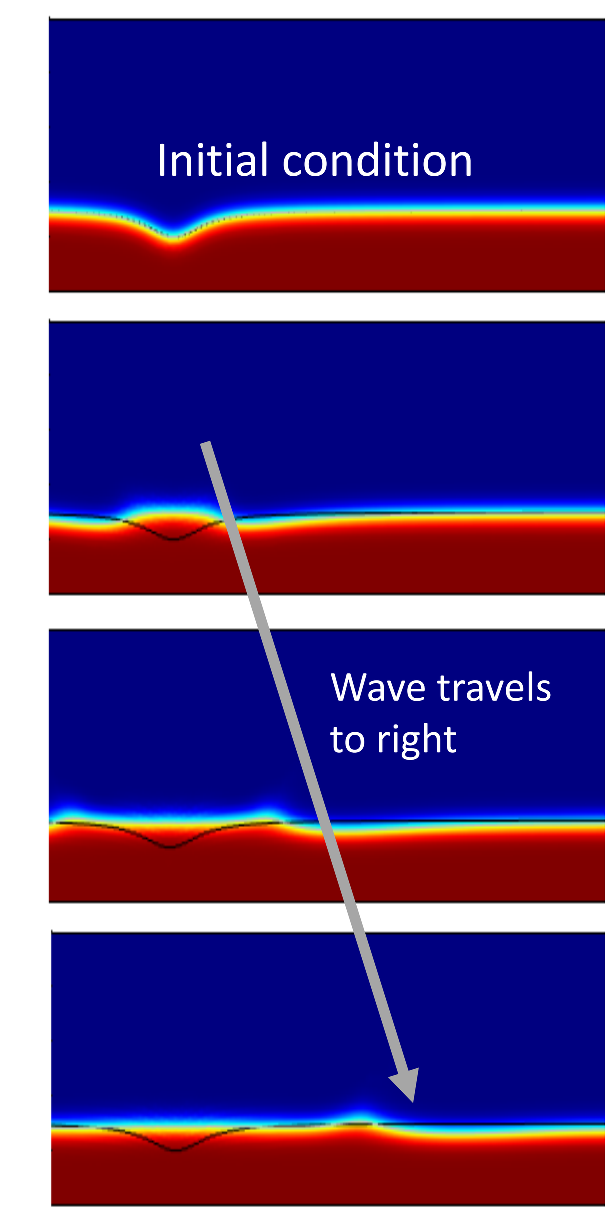


Figure 8. First 0.3 seconds of free-surface galinstan waves simulations in COMSOL

Future Work

Additional wave studies are planned, increasing the number of experimental configurations and improving data resolution. Simulations are in progress and will allow study of various conditions not possible through experiments.

References

H. Ji, et al., 2004

R. Majeski, et al., 2016