Feedback Stabilization of Flowing, Electromagnetically Restrained Liquid Metal Walls

S.M.H. Mirhoseini, F.A. Volpe

Dept Applied Physics and Applied Mathematics
Columbia University, New York, USA
Liquid metal walls offer numerous advantages

- Heat removal \(\rightarrow\) higher volumetric densities of fusion power
- Increased survivability to disruption?
- Neutron attenuation \(\rightarrow\) less radiation damage in structural materials \(\rightarrow\) reduced need for maintenance and replacement
- Stabilizing effect of rotating walls \(\rightarrow\) higher plasma $\beta$
- Reduced impurities and recycling

Liquid walls will need to flow

Different forces were proposed

To sustain the flow:
- Gravity
- Electromagnetic forces
- Magnetic propulsion
- Thermoelectric drive

For adhesion to substrate:
- Capillary forces
- Electromagnetic forces
- Centrifugal
- ...

[Abdou 2001, Zakharov 2003, Ruzic 2011 and others]
Research need: stabilization of liquid metal flows

Free-surface liquid metal flows tend to “bulge” and interact with plasma or “deplete” and expose substrate to heat and neutrons.

Due to:

• Rayleigh-Taylor instabilities
• Non-uniform B (error fields, modes in the plasma)
• Non-uniform eddy currents
• Drag from field gradients
• Non-uniform velocity
• Turbulence

[Narula 2006]
Proposed solution: feedback control by array of electrodes to ensure uniform thickness

Similar to feedback control of MHD instabilities in plasmas by means of arrays of coils:

Electrodes embedded in tiles.
Sensors of local thickness: ultrasound
LIDAR electrodes!
(resistance $\rightarrow$ thickness)

Adjust $V$ in electrodes $\rightarrow$
stronger (weaker) $j$ where
Stronger (weaker) $jxB$ needed
Work begun: liquid metal, movable tile, coil

Liquid metal adopted is Galinstan (alloy of Ga, In, Sn). Non-toxic, low reactivity.

3D printed in corrosion-resistant plastic. Coated with Teflon to reduce wetting, for diagnostic reasons.

Free surface “tile”: 5x10 cm, LM 5mm thick.
Electromagnetic permanent magnet pump will sustain flow at 0.2-2 m/s

Ferromagnets on rotor $\rightarrow$ rotating field, partly frozen in LM $\rightarrow$ LM also rotates, with slip factor

Conventional motored pumps would enter in electrical contact with LM
Summary

• Research need: stabilization of liquid metal flows
  – To prevent undue interaction with plasma
  – To prevent exposing underlying solid wall to heat and neutrons

• Possible solution: feedback control by array of electrodes, to locally adjust \( j \times B \)
  – Similar to f/back control of plasma instabilities by array of coils, to locally adjust \( B_R \).

• Preliminary work started at Columbia
  – LM alloy (Galinstan), coil, hydraulic circuit, tiltable “tile” ✔
  – e.m. permanent magnet pump (in progress)