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Feedback Stabilization of Flowing, Electromagnetically Restrained Liquid Metal Walls

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Liquid metal walls offer numerous advantages

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

Liquid walls will need to flow

[Moir 1997,
Kotschenreuther 1999,
Abdou 2001,
Majeski 2003
and several others]

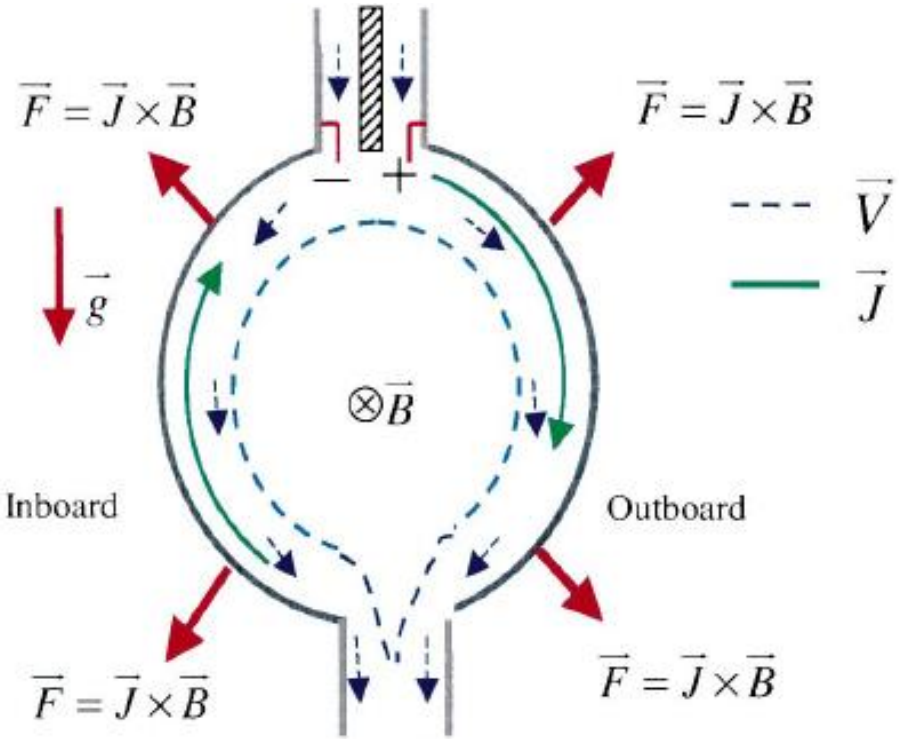
Different forces were proposed

To sustain the flow:

- Gravity
- Electromagnetic forces
- Magnetic propulsion
- Thermoelectric drive

For adhesion to substrate:

- Capillary forces
- Electromagnetic forces
- Centrifugal
- …



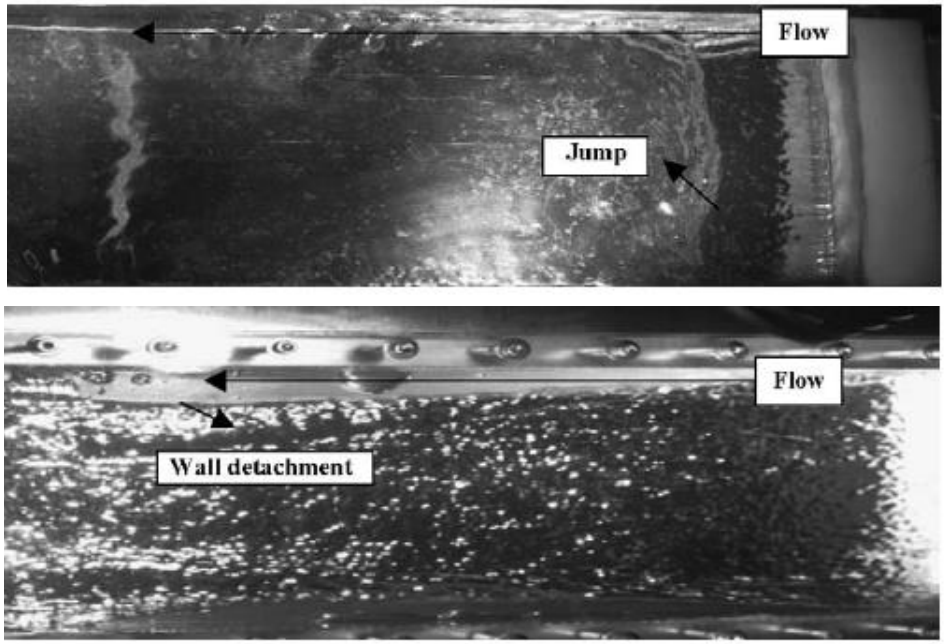
[Abdou 2001, Zakharov 2003, Ruzic 2011 and others]

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:

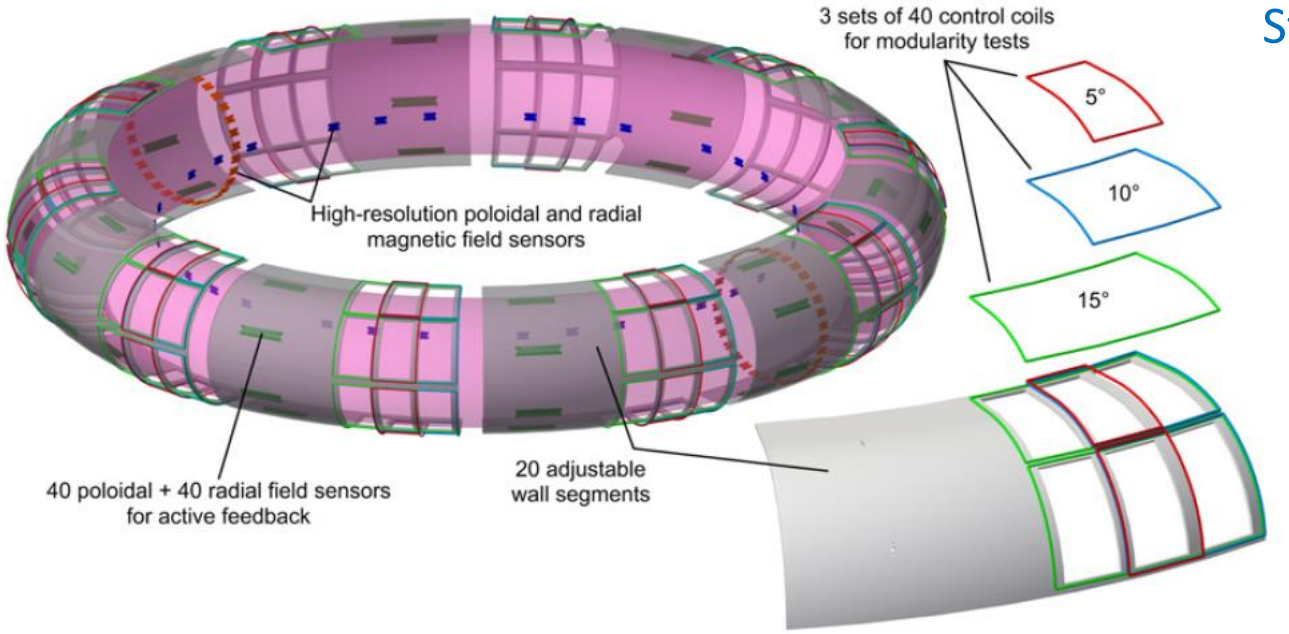
- Rayleigh-Taylor instabilities
- Non-uniform B (error fields, modes in the plasma)
- Non-uniform eddy currents
- Drag from field gradients
- Non-uniform velocity
- Turbulence



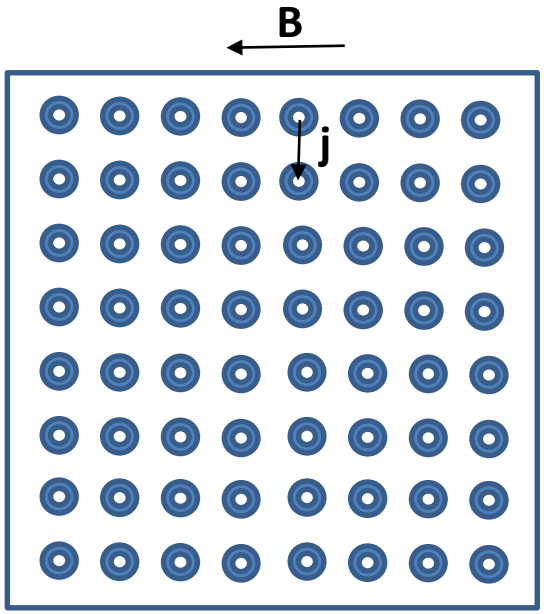
[Narula 2006]

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:



Adjust *V* in electrodes → stronger (weaker) *j* where Stronger (weaker) **jxB** needed

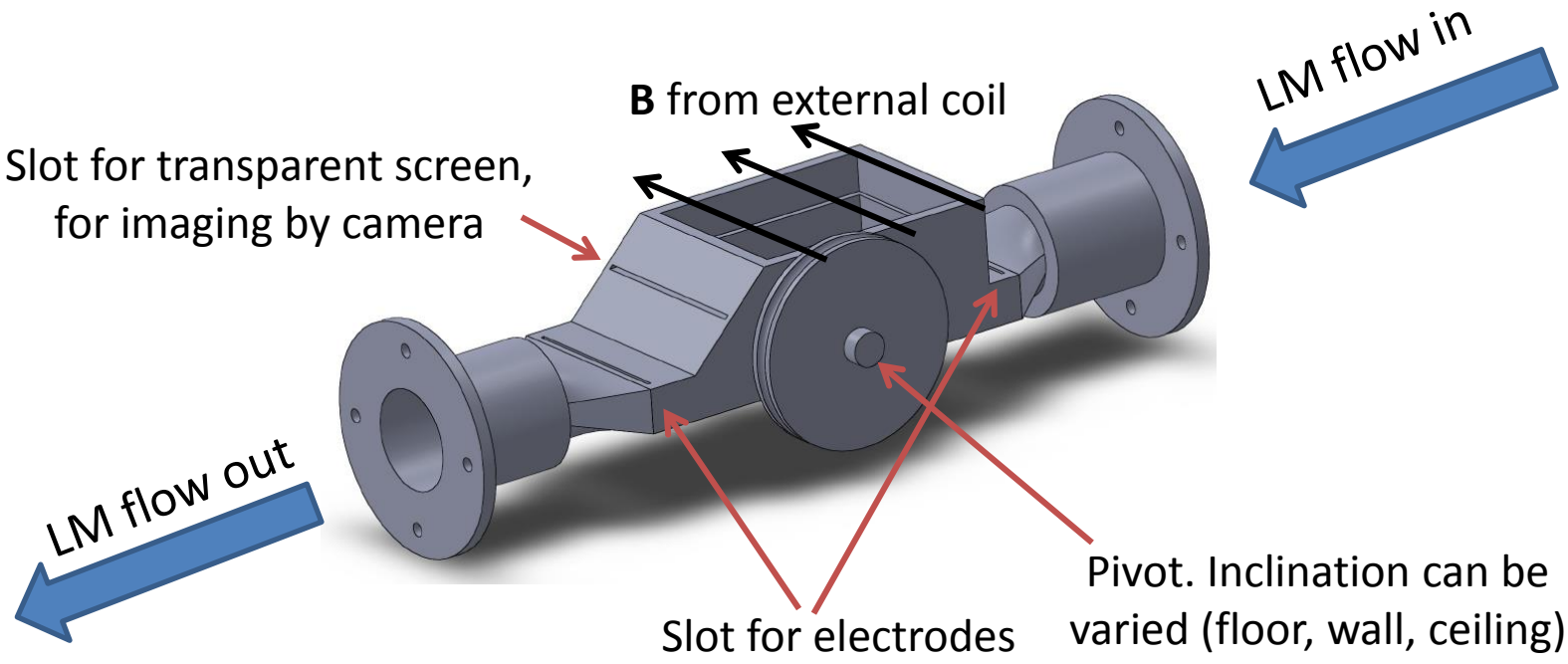


Electrodes embedded in tiles.
Sensors of local thickness: ultrasound
LIDAR
electrodes!
(resistance → thickness)

Work begun: liquid metal, movable tile, coil

Liquid metal adopted is Galinstan (alloy of Ga, In, Sn).

Non-toxic, low reactivity.



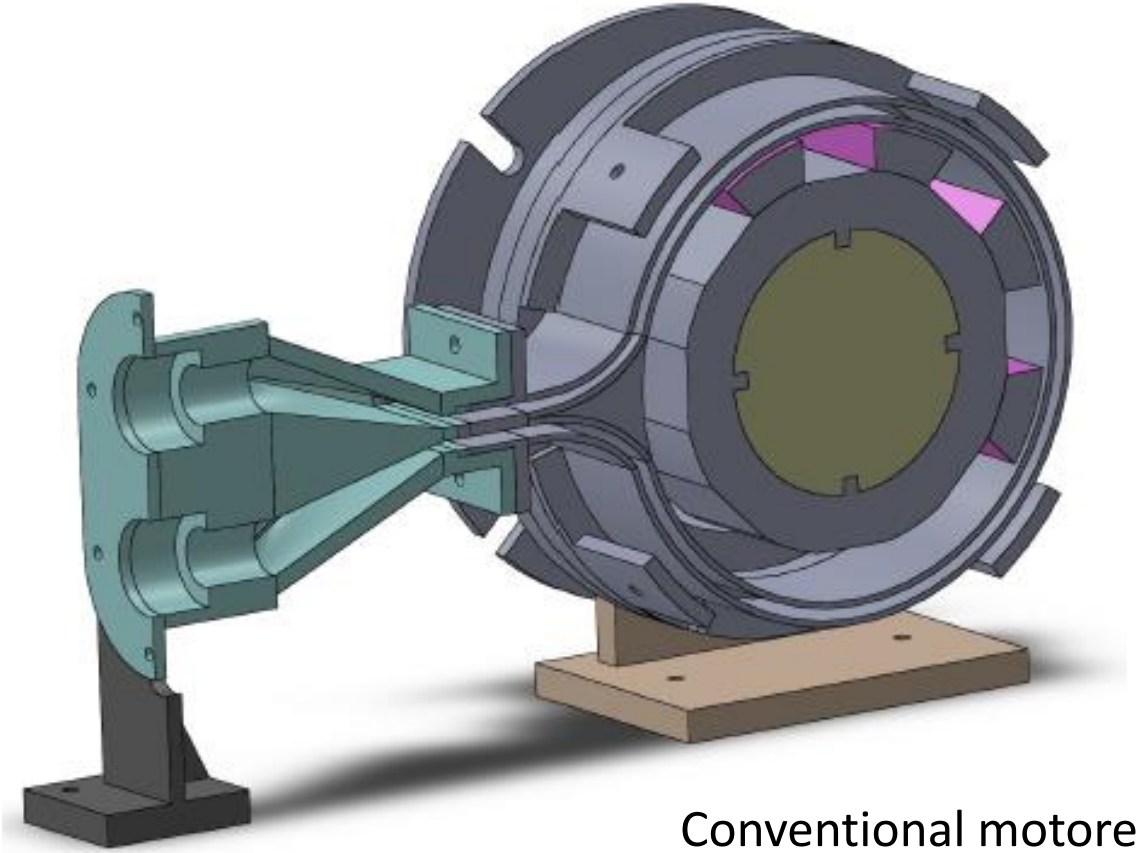
3D printed in corrosion-resistant plastic.

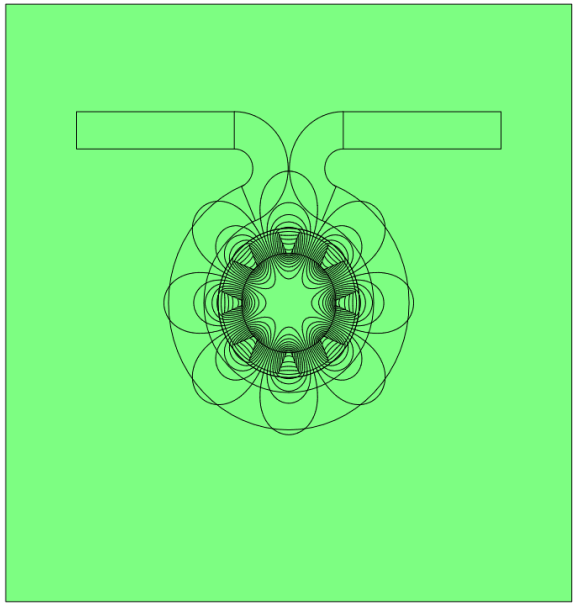
Coated with Teflon to reduce wetting, for diagnostic reasons.

Free surface "tile": 5x10 cm, LM 5mm thick.

Electromagnetic permanent magnet pump will sustain flow at 0.2-2 m/s

Ferromagnets on rotor → rotating field, partly frozen in LM → 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 jxB
  - 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)