PRINCETON PLASMA PHYSICS LABORATORY

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Magnetohydrodynamic Effects of a Gradient Magnetic Field on Liquid Metal Flows

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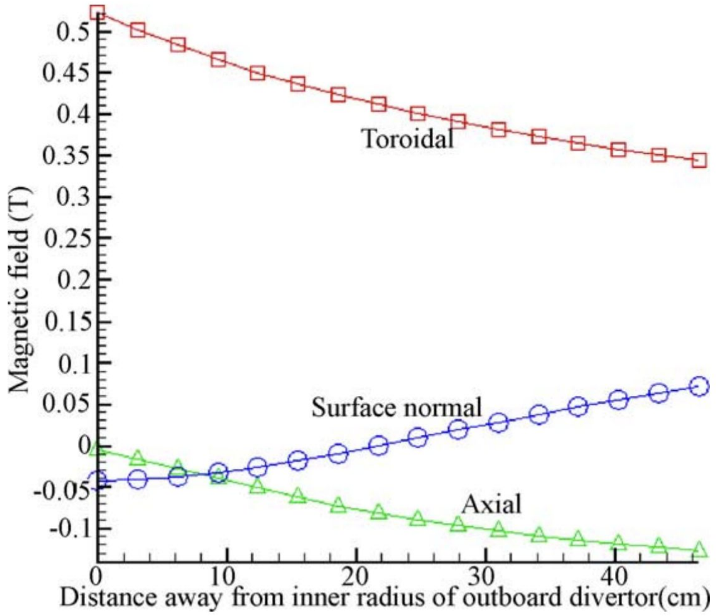
Motivation

Liquid Metal Plasma-Facing Components (LM-PFCs)

- Alternative to solid plasma-facing components in fusion reactors
  - Enables the exposure to large heat-fluxes (on the order of 10 MW/m^2) [1]
  - Provides self-healing surface to avoid radiation damage and thermal stresses [2]
- Investigating free-surface, liquid-metal flows and Magnetohydrodynamic (MHD) effects
- <u>Analysis has mainly focused on uniform magnetic field, now need to look at gradient magnetic field (B) regions</u>
  - Gradient B exists in tokamak divertor regions
  - Could produce undesirable conditions [3]

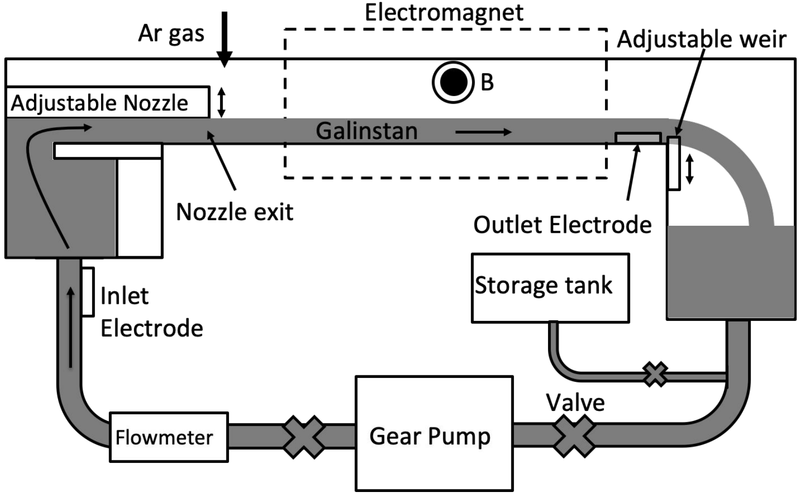


Divertor region magnetic field strengths in NSTX [3]

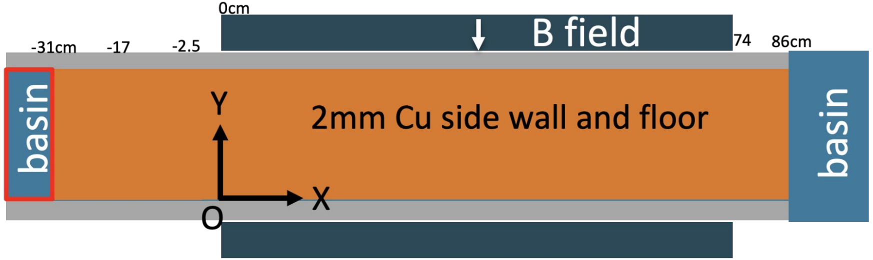
LMX-U Experiment Setup

- Rotary gear pump to circulate the liquid metal (galinstan): 0-25 L/min
- Magnetic field from electromagnet: magnetic flux density of 0-0.33 T
- Conductive liner (2 mm thick copper)
- Laser-sheet measurements with CCD camera for surface height calculations

Side view

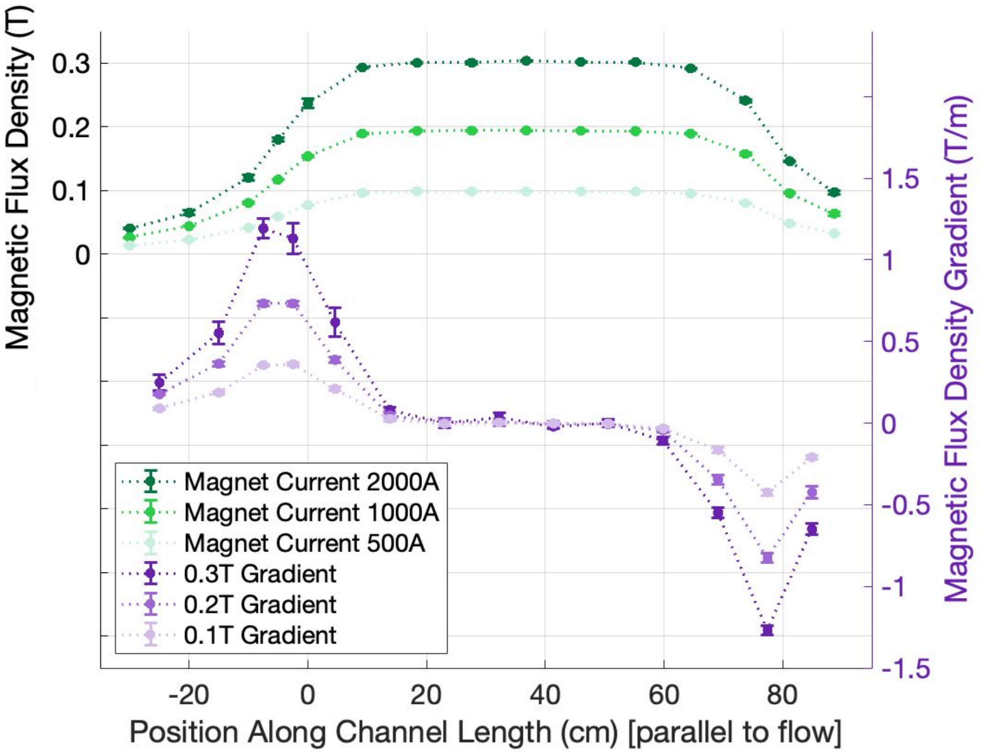


Top view



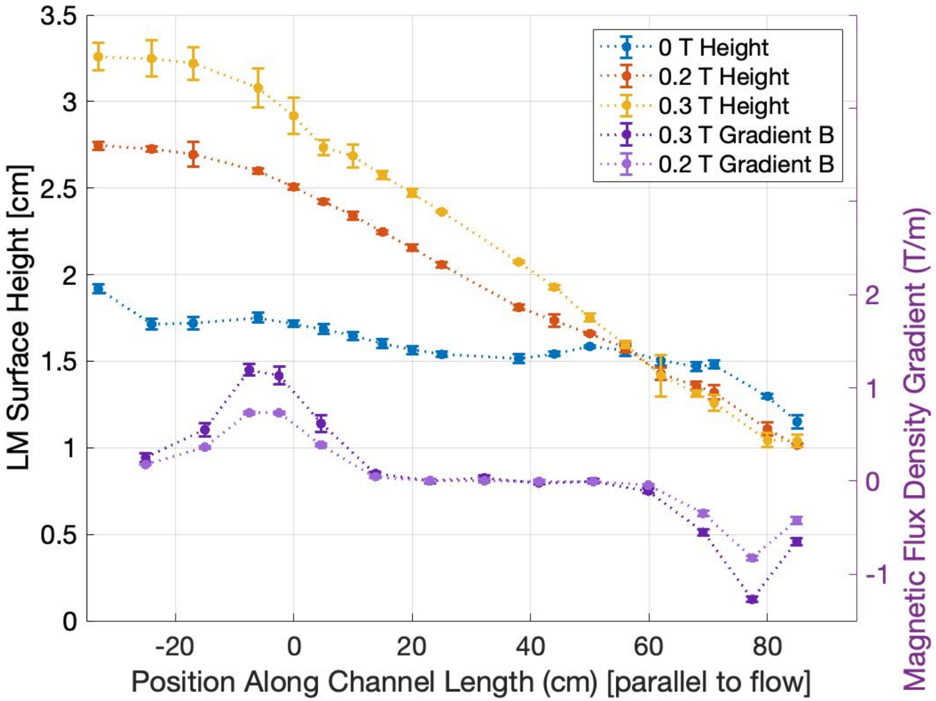
Gradient Magnetic Field in LMX

- Magnetic Flux Density measurements taken at midpoint across channel length
- <u>Gradient under consideration is the B gradient over the X Position</u>
  - (along the flow)
- Gradient B over Y and Z Positions only varies ~5%
  - (width and height)



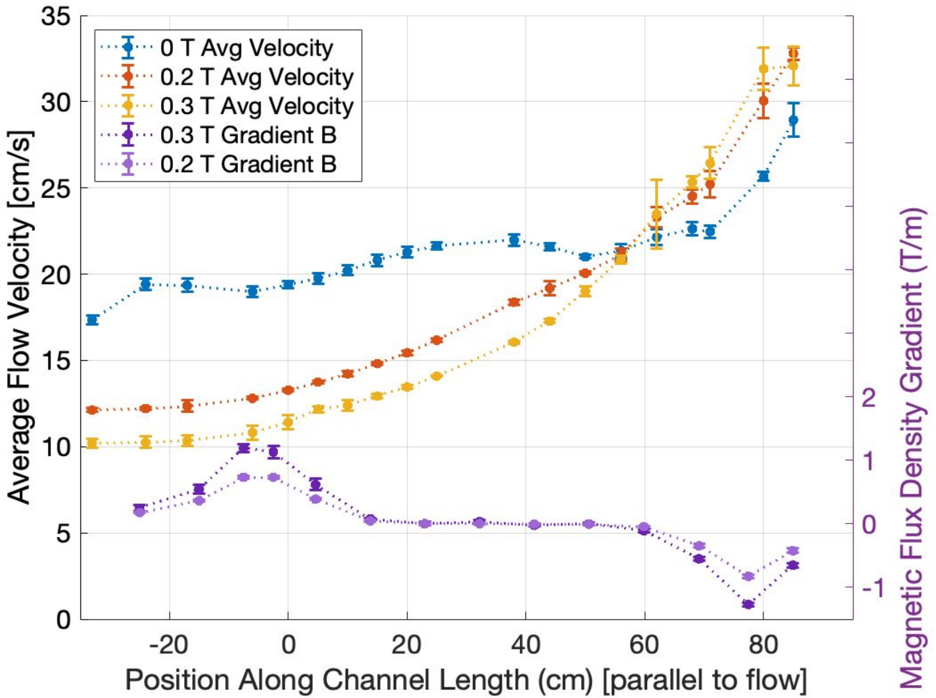
Surface Height Possibly Affected by B Gradient

- Heights of the LM surface, with the magnet at 0, 0.2, 0.3T
- Positive B gradient by inlet
  - Large height increase from 0 T
- Negative B gradient by outlet
  - Small height decrease from 0 T
- MHD Lorentz force leads to MHD drag
- Impact on pileup could be from both gradient and uniform B
- Surface stable despite gradient



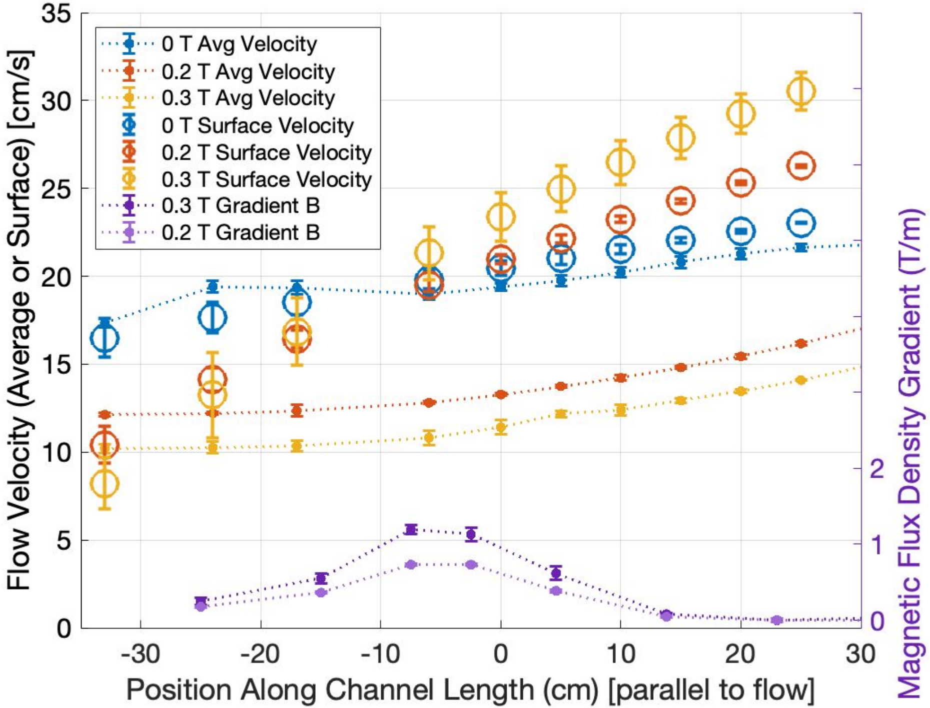
Gradient B Effect on Average Velocity (3 regions)

- 3 regions of B gradient: positive, zero, and negative
- Calculated using laser heights and volumetric flow rate
- Inverse relationship between average velocity and surface height, therefore:
  - Large average velocity decrease from 0 T in positive B gradient region
  - Small average velocity increase from 0 T in negative B gradient region



Gradient B Effect on Surface Velocity (+ gradient region)

- Calculated using particle/bead tracking along surface at inlet region (positive B gradient)
  - With no magnetic field, surface velocity ≈ average velocity
  - With magnetic field, surface velocity > average velocity, and surface velocity increased with increasing magnetic field
- Surface accelerated while core region is slowed



Conclusions

- Successfully ran experiments in B field gradient on LMX
- Measured B field and B field gradient are close to that of NSTX
- Surface accelerates, core region slows with applied magnetic field
  - Could be beneficial for heat flux transport or surface refresh for recycling control
- With available data, cannot yet separate the effects of the magnetic field gradient from the effects of overall MHD drag
  - Will complete additional experiments to test these effects individually

Future Work

- Simulations of open surface flow with gradient B
  - Using COMSOL, ANSYS Fluent, or OpenFoam
- Designs for additional for B gradients with X Position
  - B changing as 1/R with 1/R change in channel width
  - Linearly changing B along whole channel
- More measurements techniques
  - New laser
  - Ultrasound probe
  - Pressure measurements
- Investigating effect of changing B with time (*dB/dt*)

References / Acknowledgements

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