Overview

- The Liquid Metal MHD facility and diagnostics

- Current experimental studies: The manifold experiment
  - Flow distribution
  - Abrupt expansion/contraction problems

- Near future plans: MHD mixed convection
  - 3D to 2D flow transition
  - Quasi 2D turbulence (flow structure and transport properties)
The LM MHD facility

- Liquid metal loop (integrated MHD pump + heat exchanger)
- Magnet (1.8 Tesla uniform at about 5%)
- Diagnostics
  - Low voltage data acquisition system with cold junction compensation (up to 128 channels at up to 10kS/s sampling rate)
  - Differential pressure transducer
  - Ultrasound Doppler Velocimeter
Diagnostics in LM MHD flows

- Velocity: Optical techniques used in fluid mechanic experiments cannot be applied due to the opaqueness of liquid metals
- Pressure: usual techniques apply with some adjustments
- Temperature: usual techniques apply

Two key non-dimensional numbers in MHD

   Hartmann number \((Ha^2=electromagnetic/viscous)\): \(Ha = BL\sqrt{\sigma/\rho v}\)
   Interaction parameter \((N=electromagnetic/inertia)\): \(N = Ha^2/Re\)

For \(Ha \gg 1, \ N \gg 1\) (core + viscous boundary layers)
- No geometrical, electrical or magnetic singularities + non-conducting (or poorly conducting) Hartmann walls: the flow is quasi two dimensional \(i.e.\) flow characteristics do not change in the magnetic field direction except in thin boundary layers
**Consequence:** the 2D velocity field can be derived from wall electric potential gradients measurements (inductive velocimetry)

\[ u_{\perp}^{core} \times B = \nabla \phi^{Ha} \]

- If **one** of the above conditions is not fulfilled: **flow is 3D**

There are not many available non-intrusive techniques to characterize the velocity field...

Ultrasound Doppler velocimetry: *probably the most promising*...

Also

Velocity reconstruction from the induced magnetic field: still in early stages of development

Both inductive and Ultrasound Doppler Velocimetry techniques are used in our Lab.
The manifold experiment

- Three parallel rectangular channels stacked in the direction of the magnetic field
- Flow supplied by a single channel that expands abruptly into a larger channel (symmetrical contraction element used to collect the flow downstream)
- All walls are electrically insulated

<table>
<thead>
<tr>
<th></th>
<th>m</th>
<th>Width (b)</th>
<th>Depth (h)</th>
<th>Length (l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet channel</td>
<td>0.025</td>
<td>0.02</td>
<td>0.25</td>
<td></td>
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<tr>
<td>Large channel</td>
<td>0.1</td>
<td>0.02</td>
<td>0.05</td>
<td></td>
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<tr>
<td>Parallel channels</td>
<td>0.03</td>
<td>0.02</td>
<td>0.32</td>
<td></td>
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<tr>
<td>Outlet channel</td>
<td>0.025</td>
<td>0.02</td>
<td>0.105</td>
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<table>
<thead>
<tr>
<th></th>
<th>ITER TBM</th>
<th>Experiment</th>
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</thead>
<tbody>
<tr>
<td>Magnetic field [Tesla]</td>
<td>4</td>
<td>1.8</td>
</tr>
<tr>
<td>Typical inlet velocity [m/s]</td>
<td>0.3</td>
<td>0.02 – 0.6</td>
</tr>
<tr>
<td>$Ha = B(b_L/2)\sqrt{\sigma/\rho v}$</td>
<td>7500</td>
<td>2430</td>
</tr>
<tr>
<td>$Re = v_o h/\nu$</td>
<td>$2 \cdot 10^5$</td>
<td>$4 \cdot 10^3 – 1.2 \cdot 10^5$</td>
</tr>
<tr>
<td>$N$</td>
<td>280</td>
<td>34 – 1000</td>
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</tbody>
</table>
- Working fluid is circulated using an actively cooled conducting MHD pump
- No three dimensional effects associated with the frigging field regions
- Minimum liquid metal inventory

- Integration of Ohm’s yields:
  \[ \frac{\Delta \phi}{h} = \nu_m B \]

- The influence of the velocity profile on the potential readings is cancelled out by matching the electrode dimensions to the full width of the channel
For $Ha>1000$ and $N>90$ the flow is found to be uniformly distributed (about 5% unbalance)
Let’s have a closer look...

Flow asymmetry

Re, Re_c, Re_l

x 10^4

Ha=421

x 10^4
Let’s plot the cumulated relative flow unbalance vs. $Re$...

Extremum indicates two or more concurrent mechanisms
A possible explanation...
At least three concurrent mechanisms can affect the flow division

**Pressure drop:**
The pressure drop in the parallel channels, where the flow is likely to be quasi-2D, scales differently than the pressure drop associated with the expansion/contraction regions. At small $Ha$ and $Re$ numbers, the pressure drop in the channels becomes comparable to the overall pressure drop, and any small flow differences between the channels may lead to a strong unbalance

**Flow properties in the expansion and contraction elements (Ludford layers):**
Due to the change of the axial velocity at the expansion/contraction regions, axial electric currents appear and are responsible for additional pressure drop and for a strong modification of the flow structure

**Two-dimensionalization of the flow in the expansion region:**
A simple comparison between the time scale associated with the 2-dimensionalization mechanism, $\tau_{2d} = (\rho/\sigma B^2)(b^2/l^2_\perp)$, and the time needed by the liquid to travel from expansion to the parallel channels, indicates that the velocity profile is likely to be quasi-2D at the onset of the dividing channels
- 3D flow characterization is underway
  - Flow distribution
  - Abrupt expansion and contraction

- Some minor modifications of the test article were needed in order to ensure a good acoustic coupling between the ultrasound probes and Hg

- Non-MHD flow characterization in the same geometry is now being addressed as a part of the process towards understanding the physics of this type of flows and also for providing reliable data base
Next Experiment: mixed convection

- Single-wall heated cavity (3 adiabatic walls). All walls are electrically insulated
- Heat evacuated through pump electrodes
- Test article is being designed (heating system, probe locations, hot Hg handling etc.)

Quasi-2D
Turbulent Velocity and Temperature fields will be simultaneously measured using a modified thermocouple ($< u'T' >$ $< u'v'T' >$ etc.)

3D and transition from 3D to 2D
Ultrasound Doppler Velocimetry