A3: Magnetically induced instabilities

L. Bühler, T. Boeck, V. Chowdhury, D. Krasnov

A3: Magnetically induced instabilities

Outline

- Motivation (why MHD at KIT?)
- Experimental setup
- MHD code development and validation
- High-resolution DNS of turbulent flows

KIT

TUI
Why MHD at KIT?

Blanket

- Radiation shielding
- Breeding of tritium \( ^6\text{Li} + n \rightarrow \text{He} + \text{T} + \text{energy} \)
- Cooling of the first wall
- Conversion of nuclear power
- Heat removal

Requirements can be accomplished with Li-containing liquids as breeder and coolant

International Thermonuclear Experimental Reactor

⇒ Magnetic confinement of plasma

Liquid metal magnetohydrodynamics (MHD)
Why MHD at KIT?

At KIT in MEKKA we perform →

Component tests for ITER liquid metal blankets using NaK as model fluid
A3: Magnetically induced instabilities

LIMTECH allows complementary basic research which is not covered by fusion program

Goals of A3:

- **Investigation of MHD instabilities in liquid metal duct flows**
  - Study of the influence of magnetic field, flow rate and wall conductance
  - Analysis of unstable flow patterns and their nonlinear interactions
  - Removing the discrepancy between previous experiments and theory

- **Development of reliable computational tools for time-dependent MHD flows**
  - Application of code to duct flow problems like the planned experiment
  - Validation using accurate experiments, extension of existing code capability

- **Study of the transition to turbulence and of turbulent transport properties**
  - Unstable or turbulent MHD flows affect heat and mass transfer in duct flows, influence performance of liquid metal devices (like fusion blankets)

- **Improvement of measuring techniques in liquid metals**
  - Possibilities for experimental collaboration with other teams in LIMTECH
A3: Magnetically induced instabilities

LIMTECH allows complementary basic research which is not covered by fusion program

Present knowledge about unstable MHD duct flows

- Hartmann layers are linearly stable even for very high Reynolds numbers (Lingwood & Alboussiere 1999, Physics of Fluids) - bypass transition at much lower Reynolds number (Krasnov et al 2004, JFM)

- Jet-like side layers tend to become unstable (inflection points)

- In boundary layers with high velocity jets instabilities develop at relatively low $Re$

- Linear stability analysis predicts instability of laminar jets for $Re > 313$ (independently from $Ha$-number) for a square duct with constant electric wall conductivity ($b = 1$, Ting et al. 1991, Int. J. Engng Sci)

- Experiments for MHD flows in electrically conducting ducts show instabilities for
  - $Re > 2650-5300$ ($b = 1$, Reed & Picologlou 1989, Fusion Technology)
  - $Re > 5500-9000$ ($b = 0.5$, Burr et al. 2000, JFM)
  - $Re > 1000$ ($b = 4$, Bühler and Horanyi 2009, Fusion Eng. & Design)

A3: Magnetically induced instabilities

Experiments:
- In side layers high velocity jets are created by $B$ and become unstable
- Test sections with movable probes for velocity measurements and potential electrodes in walls

Theory:
- Further development of a general finite volume code for investigations of fluid-wall interactions in strong $B$ fields (KIT)
- Investigations of transition to turbulence and quantification of transport properties with highly accurate and fast finite difference code (TUI)
Theoretical approaches

- Transition can be studied in the temporal and spatial framework
  - Temporal framework: periodic simulation domain, detection of transition thresholds (simulation is started with laminar state and added noise as initial condition, Hartmann number/Reynolds number are systematically varied)
  - Spatial framework: non-periodic domain as in real experiment, observation of perturbation amplification in space

- Turbulence simulations typically as temporal simulations

- Very high grid resolutions (>10⁹ grid points) required for the parameter ranges of interest, very long computational times required for statistical convergence (only one homogeneous spatial direction for averaging)

- Storage/data handling very demanding for post-processing of simulations (Terabytes of “snapshot” data)
A3: Magnetically induced instabilities

Experiments

- GaInSn as model fluid, loop base material is electrically insulating
- Two MHD pumps supply the fluid symmetrically to the central test section
- Circuit is positioned in a uniform magnetic field of max 2.1T → no 3D perturbations as in other experiments at the entrance and exit of magnets

GaInSn double loop

Loop fits completely in the section of uniform magnetic field
A3: Magnetically induced instabilities

Experiments
- GaInSn as model fluid, loop base material is electrically insulating
- Two MHD pumps supply the fluid symmetrically to the central test section
- Circuit is positioned in a uniform magnetic field of max 2.1T → no 3D perturbations as in other experiments at the entrance and exit of magnets

GaInSn double loop

Loop fits completely in the section of uniform magnetic field

Symmetric entrance flow in test section
A3: Magnetically induced instabilities

Experiments

GaInSn double loop
A3: Magnetically induced instabilities

Experiments

Movable potential probe
A3: Magnetically induced instabilities

First numerical simulation for the GaInSn double loop

$pump$

test section

$Ha = 600$
$Re = 1100$

Contours of pressure