EPM2021 Summer Course

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Group work plan

	Supervisors	Topic
1	Didzis Berenis, Ivars Krastins	Numerical modeling of some MHD problems (OpenFoam).
2	Martins Klevs, Peteris Zvejnieks, Mihails Birjukovs	Gas bubble dynamics in liquid metals in magnetic field.
3	Reinis Baranovskis, Antra Gaile	Ultrasound liquid metal measurements. Applications and limitations.
4	Valters Dzelme	Simulation of direct metal strip casting with EM flow control.

1. Numerical modeling of some MHD problems (OpenFoam)

(Modelling of liquid metal stirring in a rectangular furnace)

The motivation comes from the metal casting industry where they seek efficient ways of heating and stirring liquid metal inside industrial-scale furnaces to reduce power consumption and improve material integrity. Traditionally metal furnaces are mixed either mechanically or electromagnetically with induction coils. Second is more attractive because mixing is contactless and stirrer is not exposed to the harsh environment inside the furnace. Electromagnetic stirring relies on a moving magnetic field to induce the force that generates the liquid metal motion. However, induction coils are not an efficient way of generating moving magnetic fields because power is consumed in the generation of the magnetic fields. Much simpler way is simply by using permanent magnets attached to the rotor of an electric motor. However, it is not immediately clear which is the most efficient position and orientation for the rotating permanent magnet to generate flow in the furnace.

This is an optimization problem where we seek to find the most efficient way of mixing liquid metal inside a rectangular furnace in a contactless manner using a cylindrical permanent magnet (PM) stirrer. The magnet is placed on the side of the furnace. The optimization parameters include the position and the angle of the PM stirrer and its rotational frequency. The aim is to find the optimal stirring and mixing configuration and answer questions like, is it better to place the magnet at the short side or the long side of the furnace and whether to place it horizontally, vertically, or diagonally.

To model this MHD flow problem, the users will be using the OpenFOAM software (https://openfoam.org/) coupled together with the Elmer solver (http://www.elmerfem.org/) employing the EOF-Library (https://github.com/jvencels/EOF-Library). The problem is multiphysical. On one part, the rotating PM induces volume force in the furnace and generates flow. The flow velocity distribution is then taken into account in force calculation. Additionally, temperature advection is calculated. This can help to answer questions like, which orientation of the rotating PM more efficiently mixes the metal and how long does it take to mix in colder metal with the heated one.

The problem comprises three physics: hydrodynamics, electromagnetism and heat transfer. Navier-Stokes equations govern the liquid metal motion, magnetic induction equation derived from Maxwell's equations together with Ohm's Law for conducting media describe the evolution of magnetic field and electric currents inside the furnace, and the heat transfer equation follows the temperature distribution within the liquid metal. The electromagnetic force is added to the Navier-Stokes equation as a source term. Similarly, the buoyancy force is added as a source term using the Boussinesq approximation. In a system that is actively being stirred the buoyancy term contribution to the overall force is more and more negligible with increased stirring frequency.

Provisional group work outline

- The required programs are introduced and set up.
- Furnace and magnet geometry is drawn.
- Case files are prepared for modelling.
- Calculation is performed.
- The results are presented.

2. Gas bubble dynamics in liquid metals in magnetic field

This numerical lab assignment is dedicated to an in silico study of bubble chains in liquid metal subjected to static magnetic field. In this PhD school track, the participants will learn about or brush up on bubble flow physics and how applied magnetic field affects bubble trajectories and shapes. While the cases considered herein are 2-dimensional and, obviously, deviate from actual physics quite strongly, they nonetheless constitute an adequate physical picture and exhibit behaviour somewhat similar to their 3-dimensional counter- parts. By completing this assignment, one will cover the basics of bubble physics, make use of the OpenFOAM volume of fluid solver, compile two custom solvers for OpenFOAM to enforce a constant magnetic field without using

Elmer, and couple Elmer solutions for magnetic field to OpenFOAM hydrodynamics via the EOF-Library for more realistic simulations. During this assignment, the partici- pants will be assisted by the track group supervisors in processing of bubble flow image sequences rendered in ParaView, necessary to ob- tain physically interpretable results. This will allow one to quantify the effects of applied field for different bubble gas flow rates.

3. Ultrasound liquid metal measurements. Applications and limitations

In magnetohydrodynamics, liquid metal flow is both of interest for theoretical and numerical calculations as well as experimental measurements. In this experimental lab, you will familiarize yourself with a common method for determining velocity profiles inside liquids including liquid metals - the ultrasound Doppler velocimetry technique. In pulsed Doppler ultrasound, instead of emitting continuous ultrasonic waves, an emitter periodically sends a short ultrasonic burst and a receiver continuously collects echoes issued from targets that may be present in the path of the ultrasonic beam. By sampling the incoming echoes at the same time relative to the emission of the bursts, the velocity of the particles can be computed. The method also can be used to track the interface between phases as an example in bubble tracking. In the default setup, the method is suitable for room temperature for alloys up to ~ 100 C but with special waveguides can be used in temperature up to 620 C.

In the practical work, you will be given raw data from a model experiment where a rotating permanent magnet creates a confined flow of GaInSn alloy. At first, you will be taught how to choose the necessary ultrasound parameters for a given experiment to successfully obtain mean velocity profiles. Later we will learn various visualization techniques for velocity presentation and show how to visualize results of transient processes. Additionally, you will observe magnet-driven liquid stirring, which is an underlying principle for liquid metal transport and stirring. Practical examples are liquid metal cooling loops for nuclear reactors and stirring molten metal metallurgy. In this model, you will be able to explore electromagnetically driven flow in terms of velocity distribution, magnitude, and frequency dependence of the applied magnetic field. Some examples will use advanced Mathematica or Python for calculations and result presentation, yet most of the tasks can be carried out with Excel.

4. Simulation of direct metal strip casting with EM flow control

Direct metal strip casting is a relatively novel casting method where liquid metal is poured onto an intensively cooled moving belt. The liquid metal solidifies on the belt and the solid strip or sheet is pulled away for further processing. Traveling magnetic field (TMF) can be used to control the speed of the liquid metal and stabilise its free surface. [1] In this work students will simulate the casting process in 2D using Elmer [2] and OpenFOAM [3] software, which involves solving equations for three-phase flow, temperature and magnetic field. Case templates as well as a custom OpenFOAM solver with solidification will be provided. Scheme of the model is shown in Fig.1. The main goal of this project is to investigate a possibility of reducing the distance at which the metal is fully solidified by using different TMF configurations (magnetic field strength, traveling speed, number of poles etc.) at the beginning of the belt. As can be seen in the results without the magnetic field in Fig.2, there is a zone before solidification where liquid metal flow is faster than the moving belt and the magnetic field will be used to slow it down.

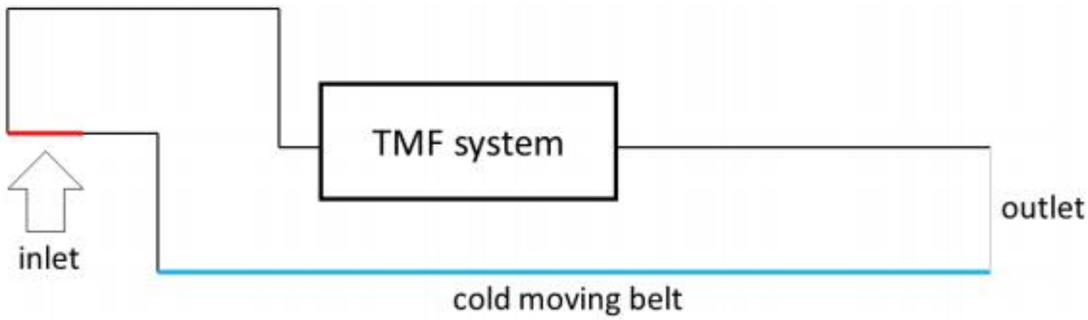

Figure 1: Simple belt casting setup

Figure 2: Example results: red - liquid, black - solid, grey - air

References

[1] Spitzer K H, Ruppel F, Viscorova R, Scholz R, Kroos J and Flaxa V 2003 Steel research international 74 724–731

[2] Elmer FEM, https://www.csc.fi/web/elmer

[3] OpenFOAM, https://openfoam.org