Numerical and experimental investigation on the flow behavior of liquids in narrow gaps

Luca Luberto, Kristin de Payrebrune

Institute of Applied Structural Mechanics, Technische Universität Kaiserslautern
Lapping

- Machining manufacturing process with geometrically undefined cutting edge
- Grains are loose in lapping-fluid
- Lapping produces surface with high precision and small roughness

- Surface formation by lapping are not completely understood
- Knowledge based on employees and company's
Lapping

- **Examples:**
  - piston rings
  - running surfaces
  - sealing surfaces
  - ...

[1]: batch-processing

[2]: parts with lapped surfaces
Lapping-Process

- Interaction of lapping grains are complex and define finished surface:

- Which of these effects have to be considered in model to predict final surface?!
Agenda

- Motivation
  - Why lapping
  - Problem for modeling

- Concept
  - Model of lapping system
  - Fluid behavior while lapping

- Study
  - Parameter study

- Results
  - Experiment vs. model

- Final
  - Conclusion and outlook
Coupled models

- Splitting system in models
- Numerical and experimental investigation of effects

*: planed numeric tools
Flow assumption while lapping

- Assuming COUETTE flow
- Narrow gap due to small grain-size
- Low Reynolds numbers*

*: based on FEPA F grainsize and process speed [5]
Experimental setup

- Install an experiment to generate an ideal COUETTE flow:
  - Construction test facility with conveyer belt as „flow drive“
  - PIV system to measure velocity profile in gap

- CHRONOS 1.4 highspeed camera
- Open source software PIVlab
CFD Setup

- Building a 2D-CFD model in OpenFOAM:
  - SimpleFOAM-Solver for laminar and stationary problems
  - BC: periodic boundaries, wall, moving wall
  - Meshing:
    - SnappyHexMesh-Mesher
    - $\Delta x_0 = h/40 = 0.00025 \text{m}$
    - Mesh with refinement
Test parameters

- Investigate flow with different test parameters:
  1. Different belt speed
  2. Small bricks as simplified lapping particle

<table>
<thead>
<tr>
<th>obstacle [mm x mm]</th>
<th>u [m/s]</th>
<th>h [m]</th>
<th>v [m²/s]</th>
<th>Re [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x0, 3x3, 4x4, 6x6</td>
<td>0.0068</td>
<td>0.01</td>
<td>1e-6</td>
<td>68</td>
</tr>
<tr>
<td>0x0, 3x3, 4x4, 6x6</td>
<td>0.0136</td>
<td>0.01</td>
<td>1e-6</td>
<td>136</td>
</tr>
</tbody>
</table>

GAMM2019
Test parameters

- Test fluid: water
- Seeding: 100 µm polyamide particles
- PIV: Investigation based on 100 image
COUETTE flow (no obst.) $u=0.0068 \text{ m/s}$, $Re=68$
COUETTE flow (no obst.) $u=0.0136$ m/s, $Re=136$
COUETTE flow (obst.) $u=0.0068$ m/s, $Re=68$

Comparison of CFD and EXP results for COUETTE flow with an obstacle. The velocity profiles are shown for different heights $H$.

- **CFD**
- **EXP**

The graphs illustrate the velocity $u$ against height $H$ for different cases:
- $U-C$ and $u-$
- $U0C$ and $u0$
- $U+C$ and $u+$

**Parameters:**
- $u=0.0068$ m/s
- $Re=68$

**Graphs:**
- Two main sections showing velocity profiles for different heights.
- Detailed comparison of CFD and EXP results.
COUETTE flow (obst.) $u=0.0136$ m/s, $Re=136$
Conclusion and outlook

- Experiment vs. simulation:
  - Good agreement

- PIV:
  - Camera and laser suitable for PIV
  - Scale of experiment small
  - Non-uniform illumination

- In future:
  - Experiment with oil
  - More realistic lapping particle
  - Enhance illumination
  - Reynolds number evaluation by further experiments
References:

[1]: https://www.maschinenmarkt.vogel.de/index.cfm?pid=11048&pk=190130&fk=167318&type=article (12.02.19)


[3]: Martin K, (1972) Erkenntnisse über den Werkstoffabtragvorgang beim Läppen, Fachberichte für die Oberflächentechnik 10
References:


[5]: Andreas Risse - Fertigungsverfahren der Mechatronik, Feinwerk- und Präzisionsgerätetechnik (2012)

[6]: M Couliou, Romain Monchaux - Large scale flows in transitional plane Couette flow: a key ingredient of the spot growth mechanism Large scale flows in transitional plane Couette flow: a key ingredient of the spot growth mechanism (2015)