Microstructure Simulation of Early Paper Forming Using Immersed Boundary Methods

Fraunhofer CHALMERS
Research Centre
Industrial Mathematics

Erik Svenning
Innovative Simulation of Paper –
Micro-Structure Models for Papermaking
and Paperboard Package Quality

- Virtual fiber web model generation
- Development of software tools for simulation of
  papermaking and paperboard properties
- Measurements for calibration and validation
- Simulations of the effect of fiber properties,
  additives, forming fabrics and process conditions
  on paper forming and paper quality
Paper forming

Goal: Simulation of buildup of a paper web on a virtual forming fabric

- The fibers are modeled as slender objects with elliptical cross section
- The fluid flow around the fibers is resolved with the hybrid immersed boundary method
- The fibers are modeled as Euler-Bernoulli beams
- The contacts are handled with a penalty method

- Fully dynamic refinement and coarsening of Cartesian octree grid
- Novel immersed boundary methods
- Arbitrary, moving and interacting bodies without re-meshing
- Particle and spray models
- Volume of fluids
- Heat transfer
The Hybrid Immersed Boundary Method

- Models the presence of the bodies in the fluid by interior boundary conditions
  - Momentum equation: Implicit Immersed Boundary Condition
  - Continuity equation: Physical condition, zero mass flux over IB
- No boundary fitted volume grid required
- Handles moving, interacting and deforming bodies efficiently

Fiber model

- Euler-Bernoulli beams in co-rotational formulation
  - A coordinate system follows every element
  - Geometric nonlinearity through CR-formulation
- Contacts are modeled with a penalty method
  - Elastic/inelastic collisions are accounted for by introducing the coefficient of restitution in the expression for the normal force
  - Friction is included with a regularization of Coulomb’s law
  - Fiber-fiber contact as well as fiber-fabric contact can be handled

E. Svenning: *Development of a nonlinear Finite Element beam model for dynamic contact problems applied to paper forming*. MSc thesis, Chalmers University of Technology, Göteborg (2011)
Validation

- The fiber model and the contact model have been validated against cases described in the literature
  - Large amplitude oscillation of beams
  - Fiber-fiber and fiber-wall contact
- Fluid-structure interaction: comparison with drag correlation and Fourier series expansion of the Euler-Bernoulli beam equation
Dynamic elbow test case

Simo, J.C. and Vu-Quoc,L: *Comp. methods in app. mech. and eng.* 66 (1988) 125-161

- L-shaped beam
- Clamped at bottom
- Linear load on elbow the first 2 seconds

<table>
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<th>Property</th>
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<th>(EI_1)</th>
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Software tools

- Different forming fabrics and fiber properties
- Software tool with graphical user interface
- Modules tailored for different applications
- Pre- and postprocessing
Initial simulation of paper forming
Conclusions

- Laydown simulations can be performed
- Submodels have been validated against results from the literature
- Comparison with test cases