Analysis and Optimization of Paper Machine Clothings by Computer Simulation

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Outline

1. Introduction
   • Fraunhofer Society
   • Institute for Industrial Mathematics (ITWM), Kaiserslautern
   • GeoDict

2. Virtual Structure Generation
   • Nonwoven, Woven, Sintered Materials, Fabrics and Felts

3. Structure Characterization
   • Pore Size Distribution, Bubble Points, Permeability by CFD

4. Summary and more
Fraunhofer-Society

13,000 Employees
1,3 Billion € Budget

Applied Research Institutes
- Mechanical Engineering
- Experimental Physics
- Computer Science
- Life Science
- Applied Mathematics
- ...

Fraunhofer Institute for Industrial Mathematics
Kaiserslautern
Department *Flow and Material Simulation*

Subdivisions

- Hydrodynamics and CFD
- Complex Fluids
- Micro-structure simulation and virtual material design
- Structure optimization in mechanics and acoustics

Research Topics

- Efficient numerics for large complex systems
- Multi-scale simulation
Virtual Material Design Cycle

Property Requirements Fulfilled?

Virtual Design Cycle

Selection of Media Types, Dimensions, etc.

Computation of Microscopic Properties of the Filter Medium

Computation of Macroscopic Properties of the Filter

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Virtual Structure Generation (Geometry)

Structure Characterization (Prediction)
Virtual Structure Generation

Multilayer Virtual Nonwoven

- Stochastic generation of the structure with guaranteed adjustable properties, e.g.
  - Distribution of fiber diameters and cross sections
  - Fiber orientation
  - Porosity
  - Layer thickness
  - ...
- Stacking of layers with different parameters
- Use of highly flexible voxel meshes
Virtual Structure Generation

Virtual Nonwoven with Binder Material

- Randomly generated nonwoven
- Morphological operations create the binder material
- Amount of binder is an input parameter
- Binder appears as new material with individually assignable properties -> important, e.g. for elasticity computations
Virtual Structure Generation

Virtual Woven

(a) (b) (c) (d) (e)

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Virtual Sinter Structure

- Stochastic generation based on
  - Packings of spheres
  - Morphological operations (to generate sinter necks)

- Packings of spheres selected to match the initial grain size distribution of the sinter process

- Approach was applied in an industrial project when no tomographies were available due to
  - Difficult preprocessing of samples
  - Too coarse resolution
Virtual Structure Generation

Virtual Fabric

Virtual Felt
Virtual Structure Generation

Quality Measures for Virtual Structures

• “The Eye”
• Porosity, specific surface area
• Chord length distribution
• Pore size analysis
• Flow properties, e.g. effective permeability or flow resistivity
• Bubble point, capillary pressure curves
• Filtration properties
• Acoustic properties

Comparison of Effective Flow Properties

Simulation
Experiment
Simulation of Pore Size Distributions

![Image of pore structure]

![Graph showing pore size distribution]

- Geometric
- MIP

Vol. Fraction [%]

Pore Diameter [µm]
Structure Characterization

Maximum Through Pore  ➔  Young-Laplace Equation  ➔  Bubble Point

\[ p_c = \frac{2\sigma}{r} \cos \beta \]

non-wetting fluid
wetting fluid
Structure Characterization

Flow Solver is based on Navier-Stokes-Brinkmann equations

\[-\mu \Delta \vec{u} + \nabla \vec{u} \cdot \vec{u} + \kappa^{-1} \vec{u} + \nabla p = \vec{f}, \quad \text{momentum balance}\]
\[\nabla \cdot \vec{u} = 0, \quad \text{(continuity)}\]

+ boundary conditions,

\( \vec{u} \) : velocity
\( p \) : pressure
\( \vec{f} \) : force (density)
\( \mu \) : fluid viscosity
\( \kappa \) : permeability of porous voxel
Structure Characterization

Air / Water Permeability

Darcy's law:

\[ Q = \frac{K}{\mu} \cdot \frac{\Delta p}{\Delta l} \]
Comparison: GeoDict and Measurement

- mesh 1 - measurement
- mesh 1 - simulation
- mesh 2 - measurement
- mesh 2 - simulation
- mesh 3 - measurement
- mesh 3 - simulation

Velocity (m/s) vs. Pressure drop (Pa)
R. Rundqvist: Microstructure simulations of early paperforming (PRS 2009)
Press Nip Simulation

Paper Machine

Press Section

Tomography

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Press Nip Simulation

Modeling and Simulation of the Pressing Section of a Paper Machine

**GeoDict** provides input parameters for macro simulations:

- Image processing (filters, cut-outs)
- Analysis of porosity distribution
- Computation of layer wise permeability
- Porosity and permeability variations under virtual compression
- Pressure-saturation curves by pore morphology method
Press Nip Simulation

Dry solids content of paper [%]

Pressure [Pa]

Saturation [%]
4. Summary and more

- **FiberGeo, SinterGeo, WeaveGeo, GridGeo, PackGeo** (Structure generation)
- **ProcessGeo** (3d image processing)
- **LayerGeo** (building media stacks)
- **ImportGeo** (Tomography, STL, etc.)
- **ExportGeo** (Fluent, Abaqus)
- **FlowDict** (Flow properties)
- **ElastoDict** (Effective elasticity)
- **ThermoDict** (Heat conductivity)
- **DiffuDict** (Effective diffusion)
- **FilterDict** (Filtration)
- **SatuDict** (Capillary pressure curves)
- **PoroDict** (Pore size analysis)
- **AcoustoDict** (acoustic absorption properties)
GeoDict Development Teams

The GeoDict Team
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Software for Generation, Simulation, Visualization:

www.geodict.com

Thank You Very Much for Your Attention!