PIV Measurements of Flow immediately above Woven Fabrics

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Introduction

• Paper making contains three basic processes: forming, pressing and drying.

• In the forming section, a dilute suspension of pulp (0.7%) is forced through a woven forming fabric to create a fibrous pulp mat.

• High quality paper ➔ Uniform fiber distribution ➔ Uniform velocity profile on the upstream side of fabric layer on which the pulp mat is formed.
Introduction

- Forming fabric structure: complex 3d woven matrix, which consists of machine direction (MD) and orthogonal cross machine direction (CMD) filaments in two or more layers.

- A scaled model is used for the experiments to investigate flow property based on the same Re of real papermaking process. (Re is defined by paper side filament diameter, 6.5~65)
Objective

- To measure 3d velocity fields in the approach flow to a multiple layer forming fabric by Particle Image Velocimetry (PIV).
- To investigate the flow non-uniformity and its probable effect on paper.

Assumption:
- The pulp at the beginning of the forming section has a very low concentration of fibers in water (0.7%), and therefore single phased glycerin solution was used in the experiments.
Literature Review

1. Numerical and experimental investigation were done of the flow through two rows of cylinders.

2. Single layer fabric was used to represent the fabric model.

3. A novel method, CT scan, was found to create an accurate 3d cad model of forming fabric by a rapid prototype machine.
Experimental Methods: PIV

- Principle of Particle Image Velocimetry
Experimental Methods: Flow loop

- Velocity: 1.5 to 8 cm/s in the 30cm × 30cm test-section
- Dynamic Viscosity: 10 to 25 cP by using a glycerin solution
- Fabric Model: 80 times-scaled fabric model
- Reynolds Number: 10-65
Experimental Methods

△ 30cm×30cm test section

△ Optical setup of the PIV experiment
Experimental Methods

• The fabric model using in the flow loop is a portion smaller than one fabric repeat;

• Only the portion of the fabric away from the test section wall was studied;

• Measurements were taken at different CMD plane for different Re. (15 to 65);

• CMD=17cm (the plane with multiple open areas);

• CMD =19cm (the plane with multiple filament knuckles).

△ MD-CMD view of the scaled fabric model
PIV Results and Discussions

- Velocity vs. MD, @ CMD=17cm, 0.25d upstream, Re=35.
- 95% confidence interval based on 60 PIV image pairs. Highest uncertainty for Vz is ±2.8%.
- \((V_{MD})_{RMS} \approx 0.1 \times (V_z @0.25d)_{average}\)
PIV Results and Discussions

- \((V_z@0.25d)_{std} = 15.1\% \) decrease to \((V_z@1.5d)_{std} = 3.8\%\). The flow non-uniformity caused by the fabric is only significant within about 1.5 paper side filament diameters (300\(\mu\)m) upstream the fabric.

\[ \Delta V_z \text{ profile for different distances upstream the fabric; CMD=17cm, Re=35} \]
PIV Results and Discussions

- \( (V_z @ 0.25d)_{max} = 2.2 \times (V_z @ 0.25d)_{min} \), the initial accumulation of fines and/or filler content would be 2.2 times higher than in adjacent areas if 100% retention.
- Once fines and fillers start to accumulate on the fabric, the “healing effect” will reduce the magnitude of this variation.

\[ \Delta V_z \text{ profile on different CMD plane, 0.25d upstream, Re=35} \]
PIV Results and Discussions

- Pulp fiber exposed to flow field forcing related to the average velocity along fiber.

- \((V_z)_{std}\) decrease from 15.1% to 4.2% when averaged over a 0.8mm fiber (shorter than most wood fiber) oriented in MD.

- If fibers were uniformly distributed in the approach flow, they would remain so during interaction with this forming fabric.

\[\Delta V_z\] averaged over different fiber length in MD
PIV Results and Discussions

• The standard deviation for a Re of 65 is 16% lower than the deviation for Re 15.
• The reduced standard deviation is consistent with the fact that the distance over which objects affect flow is smaller at higher Re.

\[ \Delta V_z \text{ comparison at different Reynolds number} \]
Preliminary Simulation Result

- Solution Method: 3d laminar in Fluent.
- Boundary Condition: Velocity Inlet, Pressure Outlet, No-Slip Wall
Preliminary Simulation Result: Mesh Independence

\[ \Delta \text{Upstream average velocity against mesh density for a pressure drop of 125 Pa} \]
PIV vs. Simulation

- Simulations were consistent with PIV measurements within 9%.
- Simulations conducted at higher and lower Reynolds numbers were also in fairly good agreement with the experimental measurements.

\[ \Delta 0.25d \text{ upstream, CMD}=17\text{cm, Re}=35 \]
Conclusions

- \((V_{MD})_{RMS} \approx 0.1 \times (V_Z @ 0.25d)_{\text{average}}\)

- \((V_Z @ 0.25d)_{\text{std}} = 15.1\% \text{ decrease to } (V_Z @ 1.5d)_{\text{std}} = 3.8\%\). The flow non-uniformity caused by the fabric weave is constrained to a short distance above the fabric.

- \((V_Z @ 0.25d)_{\text{max}} = 2.2 \times (V_Z @ 0.25d)_{\text{min}}, the initial accumulation of fines and/or filler content would be 2.2 times higher than in adjacent areas if 100\% retention.

- However, this non-uniformity is not particularly felt by fibers, whose length scale results in averaging of the local velocity field.

- The Z direction velocity variation decreases by 15.5\% when the Reynolds number is increased from 15 to 65.

- CFD simulations of the same flow were consistent with the PIV measurements within 9\%.
Future Work

- Conduct multiple measurements at enough CMD plane to create a full Z direction velocity distribution in certain Z plane, e.g. 0.25d upstream fabric, then we can predict the movement of fiber that not oriented in MD.

- Rotate the whole experimental set up with 90 degrees to measure the CMD velocity distribution.

- Test different fabric model for the comparison between different design of forming fabric.
Industry Application

- Different fabrics will have different velocity distributions and therefore different effects on the fines and filler distribution in the finished paper.

- By better understanding the velocity distributions of fabrics we may then design fabrics that produce a superior (more uniform) distribution of fines and fillers in the finished paper.
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Questions