DOE/GO/10416-P

**Quarterly Progress Report**

**For:** Improving Paper Machine Efficiency/Productivity Through On-Line Control of Stock Delivery, Headbox, and Forming Section

**Covering Period:** January to March 2000
**Date of Report:** April 30, 2000

**Recipient:** Institute of Paper Science and Technology
**Award Number:** DE-FC36-99GO10416

**Subcontractors/Other Partners:** none

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**Project Team:** AF&PA - Sensors and Control

**Project Objective:** The main objective of the proposed project is to replace the current headbox with an on-line controlled hydrodynamic system for uniform dispersion and distribution of fibers on the moving wire. These are:

1. generation and control of axial vorticity in the headbox tube bundle;
2. pilot machine implementation and trials (collaboration with industry)
3. commercial implementation on a small hydraulic headbox (collaboration with a supplier)

The initial benefits for the industry include a more isotropic fiber orientation in the sheet resulting in higher CD strength and, consequently, 10 to 15% reduction in fiber and energy usage.

**Background:** The fundamental concepts of a new technology, referred to here as *microforming*, have been developed at IPST. Once implemented in a headbox, microforming can produce isotropic sheet significantly reducing the MD/CD stiffness ratio (increasing CD specific STFI by 10 to 25%) and improving sheet uniformity; potentially to *micrometer* scales. This technique requires generation of a special form of axial vorticity prior to the converging nozzle of the headbox. The currently technology is implemented in a static form, it involves replacing the entire tube block requiring a new headbox in most cases. The technology to modify an existing tube block for implementation of the microforming concept as an on-line device for the hydrodynamic control with modest capital investment, that is the *retrofit technology*, is not currently available. The objective of this project is to develop an on-line retrofit technology for implementation of the microforming concept and extend the technology to on-line control of the forming hydrodynamics and the wet-end, in general. The result will be considerable improvement in the performance and capital effectiveness of the paper machine (PM). This is a pre-competitive project which includes development of new technologies for broad commercial use in almost every PM with significant impact on reduction of fiber consumption and energy, and increase in productivity and quality.

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The new method for on-line control (patented by IPST) is based on fluidics control of a coanda jet in the headbox tube. The interior geometry of the tube would remain identical to the current tubes. Acoustic pressure pulse generating probes will be placed at the guiding point of the coanda jet. A function generator with a multiplexer board control the frequency and pattern of the pulse generation. This allows generation of optimum axial-vorticity in the tube with an external signal processing system for most effective performance. The on-line feature of the device allows rapid optimization for headbox flow for grade changes enhancing productivity and product quality. It is demonstrated with the pilot trials that, with this technology, the potential savings in consumption of fiber, water and energy are significant.

The unique feature of this project is that the basic flow required for production of an isotropic sheet has been found and demonstrated to be effective through extensive pilot trials. The means for on-line control and optimization of the flow needs to be developed through this project.

**Benefits to the Industry Should the Research Yield Positive Results**: The effect of this technology is to improve one of the most fundamental physical properties, that is fiber orientation isotropy, in a sheet of paper. Since the improvement is at a fundamental level, the impact is broad and significant. In many grades, the advantages of producing an isotropic sheet are two fold. First it will increase the CD stiffness resulting in higher CD STFI in board grades. Therefore, reducing fiber, water, and drying energy consumption. This will result in higher machine speeds increasing productivity for dryer limited machines. Furthermore, since this technology produces an isotropic sheet, there is no preferential fiber orientation, eliminating fiber orientation nonuniformities, altogether.

Many problems such as diagonal curl, hygroexpansive lean and other defects in the physical properties related to fiber orientation anisotropy and nonuniformity disappear. The impact on product quality is significant.

Consider the problems arising in paper conversion and end use due to "hygroexpansive lean", a consequence of fiber orientation anisotropy and orientation nonuniformity. Rectangular sheets, originally cut square along the MD-CD axes, becomes rhomboid as moisture content changes. Because of lack of perpendicular sheet edges, printing and reprographic machines designed to operate with perpendicular sheet edges malfunction and fan-folded graph and computer papers can exhibit stack lean. Producing an isotropic sheet with the microforming technology eliminates these problems.

**Status:** The emphasis has now shifted to the design, fabrication and evaluation of the control unit for on-line adjustment of the turbulence and CD shear in the headbox. The objective is to control the fiber orientation profile across the machine during operation by manipulating and dynamically adjusting the flow characteristics in the headbox and the forming jet. The flow characteristic in the converging nozzle of the headbox is controlled by generation and on-line control of the axial vorticity (swirl) inside the tubes in the tube bank.

The project is focusing on two concepts; the first, Concept A, is to control the axial vorticity on-line using 'smart materials' in conjunction with an imposed electric field to adjust the geometry of the vorticity generating elements. The development of this concept has progressed rapidly to the point where it can be fabricated and demonstrated in a laboratory headbox in a relatively short time. This is a robust and practical method for on-line control of turbulence and CD shear, and consequently, fiber orientation in the headbox. The goal is to have a working system ready for demonstration in a laboratory headbox at commercial flow rates by Dec. 2000. The design of this system for the laboratory demonstration started in January of this year.

The second concept, that is Concept B, is the most ideal system where the vorticity field itself is generated and controlled by an external field; we are continuing to work on ultrasonic and electromagnetic field controlled systems. The difficulty with both techniques is the size of the unit; our challenge is to fabricate a small enough unit where it can be placed inside each tube in the tube bank. We estimate that a working unit of the Concept B will be ready for installation in a laboratory headbox by Dec. 2001.

The design of the on-line control systems with Concept A has started with the goal of demonstrating the system in a laboratory headbox at commercial flow rates by the end of this year. The computational fluid dynamics analysis has been completed. The image analysis software for rapid measurement of fiber orientation in the laboratory headbox has been completed. Preliminary experiments for evaluation of the laboratory headbox and the flow loop constructed during the past year have been operational for some time. The diagnostics equipment including the high-speed imaging and the Laser-Doppler Anemometer have been evaluated with the conventional headbox system. An ultrasonic system for measurement of the jet velocity profile has been added to the facility for evaluation of the hydrodynamic characteristics of the forming jet.

Variances to cost or schedule:

It has been proposed and verbally accepted by the OIT Office in Washington to use part of the funding for the second year (~$128.8K) for partial funding of the AF&PA project for commercial application of a microforming retrofit to the Escher Wyss headbox in Florence, SC. The OIT office has agreed to add the $128.8K funding to this project above the previously funded budget for the fourth or fifth year of the project. Therefore, with this additional task, some of the other tasks have been postponed for a quarter, as reflected in the schedule presented in the next section. The remaining part of the project is on schedule.

**Project Schedule:** The added tasks to the project will only influence the schedule of tasks for the on-line control system. The Schedule for the Development of the Static Microforming System remains unchanged.

A. Schedule for the Development of the Static Microforming System:

| TASKS | Year 1 | | | | Year 2 | | | | Year 3 | | | | Year 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quarters--> | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| **Phase I - CFD Analysis & Exp. verification** | | | | | | | | | | | | | | | | |
| Design Retrofit Concept | | | | | | | | | | | | | | | | |
| CFD Evaluation of Concept | | | | | | | | | | | | | | | | |
| LDA measurements and CFD Verification | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| **Phase II - Pilot Trials** | | | | | | | | | | | | | | | | |
| Retrofit Concept for Pilot Trials | | | | | | | | | | | | | | | | |
| Laboratory Evaluation | | | | | | | | | | | | | | | | |
| Pilot Machine Installation/Trials | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| **Phase III - Commercial Trials** | | | | | | | | | | | | | | | | |
| Commercial Retrofit Concept | | | | | | | | | | | | | | | | |
| Laboratory Evaluation | | | | | | | | | | | | | | | | |
| Fabrication | | | | | | | | | | | | | | | | |
| Machine Installation/Trials | | | | | | | | | | | | | | | | |
| Commercial Trial/Escher-Wyss HB, Florence ($128.8K) | | | | | | | | | | | | | | | | |
| **Report at each milestone** | | | | | | | | | | | | | | | | |

B. Schedule for the Development of the On-Line Field Control System:

| TASKS | 2000 | | | | 2001 | | | | 2002 | | | | 2003 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Quarters→** | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| **Phase 1 – Laboratory Experiments:** | | | | | | | | | | | | | | | | |
| Design/Fabricate Headbox & Tubes for the Tube Bu | √ | | | | | | | | | | | | | | | |
| Headbox & Flow loop System Installation/Optimizati | √ | | | | | | | | | | | | | | | |
| CFD Characterization | √ | √ | | | | | | | | | | | | | | |
| Laser-Doppler Turbulence Characterization | | √ | √ | √ | | | | | | | | | | | | |
| System Installation/Optimization in Lab, Concept A | | | √ | √ | | | | | | | | | | | | |
| System Installation/Optimization in Lab, Concept B | | | | | | | √ | √ | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| **Phase II – Pilot Trials:** | | | | | | | | | | | | | | | | |
| Design/Fabrication for Pilot Trials, Concept A | | | | | √ | √ | √ | | | | | | | | | |
| Design/Fabrication for Pilot Trials, Concept B | | | | | | | | | √ | √ | √ | | | | | |
| Pilot Machine Installation/Trials, Concept A | | | | | | | | √ | √ | | | | | | | |
| Pilot Machine Installation/Trials, Concept B | | | | | | | | | | | | √ | √ | | | |
| | | | | | | | | | | | | | | | | |
| **Phase III – Commercial Trials:** | | | | | | | | | | | | | | | | |
| Commercial Retrofit Design, Concept A | | | | | | | | | | √ | √ | | | | | |
| Commercial Retrofit Design, Concept B | | | | | | | | | | | | | | √ | √ | |
| Fabrication, Concept A | | | | | | | | | | | | √ | √ | | | |
| Machine Installation/Trials/Optimization, Concept A | | | | | | | | | | | | | | √ | √ | |
| Fabrication, Concept B | | | | | | | | | | | | | | | √ | √ |
| Machine Installation/Trials/Optimization, Concept B | | | | | | | | | | | | | | | | √ |
| **Report at each milestone** | | | | | | | | √ | | | | √ | | | | √ |

**Milestone Table:** A list of milestones, anticipated completion dates and actual completion dates along with the milestone ID number corresponding to the task are presented below:

| ID Number | Task / Milestone Description | Planned Completion | Actual Completion | Comments |
|---|---|---|---|---|
| A.1 | Implementation of the Microforming system on a Beloit Concept III Headbox | 9/30/99 | 12/30/99 | This section is focused on the static microforming system |
| A.1.1 | Design | 12/30/88 | 2/20/99 | |
| A.1.2 | Fabrication | 3/30/99 | 6/15/99 | |
| A.1.3 | Pilot Trials | 8/30/99 | 8/24/99 | |
| A.1.4 | Paper Testing and Analysis | 12/30/99 | 12/30/99 | |
| B.1 | Trial on an EW Headbox at Smurfit Stone with the Vortigen Microforming System | 9/15/00 | | Added tasks to the project |
| B.1.1 | Design/Fabrication | 7/30/00 | | |
| B.1.2 | Commercial Trials | 8/30/00 | | |
| B.1.3 | Paper Testing and Analysis | 9/15/00 | | |
| I.1 | Demonstration of On-line Concept A in a Laboratory Headbox | 12/30/00 | | |
| I.2 | Demonstration of On-line Concept B in a Laboratory Headbox | 12/30/01 | | |
| II.1 | Pilot Trials with an on-line Concept A | 3/30/02 | | |
| II.1.1 | Design/fabrication | 9/30/01 | | |
| II.2 | Pilot Trials with an On-line Concept B | 3/30/03 | | |
| II.2.1 | Design/Fabrication | 9/30/02 | | |
| III.1 | Commercial Trial, Concept A | 9/30/03 | | |
| III.1.1 | Design | 9/30/02 | | |
| III.1.2 | Fabrication | 3/30/03 | | |
| III.2 | Commercial Trial, Concept B | 12/30/03 | | |
| III.2.1 | Design | 9/30/03 | | |
| III.2.2 | Fabrication | 11/30/03 | | |
| IV | Final Report | 1/31/04 | | |

**Budget Data** (as of 3/31/00):

| Phase / Budget Period | | | Approved Spending Plan | | | Actual Spent to Date | | |
|---|---|---|---|---|---|---|---|---|
| | | | DOE Amount | Cost Share | Total | DOE Amount | Cost Share | Total |
| | From | To | | | | | | |
| Year 1 | 10/1/98 | 9/30/99 | $349,712 | 136,000 | | 323,806 | 109,694 | 433,500 |
| Year 2 | 10/1/99 | 9/30/00 | $440,644 | 160,500 | | 349,569 | 83,634 | |
| Year 3 | 10/1/00 | 9/30/01 | $448,661 | 243,000 | | | | |
| Year 4 | 10/1/01 | 9/30/02 | $503,375 | 243,000 | | | | |
| Year 5 | 10/1/02 | 9/30/03 | $128,800 | 60,000 | | | | |
| | | Totals | 1,871,192 | 842,500 | 2,713,692 | | | |