Reduction of Energy Demand in Paper Making Using Online Optimisation and Control

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Overview

• Context of work being undertaken: energy used in paper making
• Outline of project & statement of project objectives
• Review of progress to date
• Current and future work
• Conclusion
PM 14 at Aylesford Newsprint, Kent

- Makes ~ 300,000 tonne/yr of 42, 45 & 48 gsm newsprint
- Runs at ~ 1700 m/min, finished sheet width is 9.2m
- Uses 100% recycled fibre feedstock
- Operates 24/7 about 350 days/yr
Typical Paper Machine Characteristics

- Paper machine speed: typically between 600 m/min and 1800 m/min
- Length: typically 150 m with 500 m paper inside: 15 secs to 30 secs in m/c
- Fibre concentration: 0.7% at headbox, ~ 95% at the reel (lots of water to remove!)
- Grades: 18 gm per sq. metre (tissue) to 45 gsm (newsprint) to 350 gsm (board)
- Quality variables: weight, moisture, caliper, porosity, opacity, formation, shade…
- Constraints: pump speeds, fibre concentrations, chemical addition rates, water and stock flowrates, vacuums, pressures, machine drive speeds, steam pressures
Project Context: Energy Used in Paper Making

- Pulp & paper industry processes that persist to the present day were designed when energy was cheap and plentiful:
  - About 70 paper machines are still operated in the UK (>200 50 years ago)
  - Large capital investment (£10s of millions each); not easy to change fast
- Energy consumed in paper making (2006 figures):
  - 4MWhr/tonne x 5,750,000 tonne/yr = 23,000 GWhr/yr
  - A 20% saving, 4,600 GWhr/year, is the equivalent of the power used domestically by a UK town of about 240,000 people
- The rising cost of energy has shut more than 10 UK paper mills in the last three years; similar story elsewhere in Europe
- Most mills are just now establishing energy efficiency improvement groups
1. Project partners:
   • Cambridge University Engineering Dept – Control Group:
     • Jan Maciejowski: nonlinear Model Predictive Control and optimisation
     • Paul Austin: modelling and control in academia & consulting eng’g + pulp & paper industry experience
   • Manchester University School of Electrical & Electronic Engineering – Control Systems Centre:
     • Hong Wang: nonlinear modelling, control & optimisation + academic/industry pulp & paper project experience
     • Puya Afshar: modelling & control expertise
     • Tim Breikin & Martin Browne: identification and modelling, control & optimisation expertise
   • Perceptive Eng’g: a subcontractor providing the real time control work

2. Project is being undertaken on 3 commercial machines:
   • a newsprint machine: PM 14 at Aylesford Newsprint, Kent
   • a two ply board machine: PM 4 at Smurfit Kappa SSK, Birmingham
   • a fine paper machine: PM 8 at Arjo Wiggins Stoneywood, Aberdeen
Project Objectives

Develop a robust, effective approach to reducing thermal energy use in paper making, in two ways:

1. By tackling the issue in existing processes:
   - Research options for using more advanced technology than is currently in use to make operational improvements in thermal efficiency, without reducing product quality.
   - Implement the best options for each of these two different kinds of paper machine, as 24/7 exemplar projects demonstrable to the paper industry.

2. By examining generic possibilities for more energy efficient designs in the future:
   - Develop appropriate generic energy flow models of paper making processes and use them to examine possibilities for redesigning these processes with lower energy use as a design priority.
Proposed Solution Technology:
Model Predictive Control and Optimisation

- Understand process constraints and complex process interactions
- Build multivariable correlation between inputs and outputs
- Predict impact of known disturbances on operation
- Predict best co-ordinated moves to make on multiple actuators
- Exploit all opportunities to optimise, often including pushing quality/throughput close to constraint/consent
Progress to Date

• Approaches worldwide to reducing energy use in paper making by modelling, better control and optimisation have been surveyed and reviewed.

• Discussions between the project team and site personnel have established particular foci to be included within the work on each paper machine:
  • on the board machine, examine the potential to reduce dryer steam use of improving the control of drainage
  • on the newsprint machine, examine the potential to reduce specific energy use by maximising production

• Current energy use by the board machine has been audited and analysed.
The survey drew attention to the known fact that the **drying section of a paper machine:**

- in reducing sheet moisture content, $M$, from $\sim$50% to $\sim$8% [$M = \text{water}/(\text{water} + \text{fibre})$]
- uses more than 80% of mill-wide energy
- while removing less than 1% of water from the sheet
- but it does have a significant effect on finished paper quality
Energy Conservation in Paper Making
Advanced Steam Pressure Control

\[ J_1 = f(\text{Moisture, heat used}) \]
\[ J_2 = g(P_{\text{steam}, \text{setpoint}}) \]
\[ s.t.: \text{Quality is assured} \]

Diagram: Steam header with MPC, Pressure setpoints 1 and 2, Moisture, Paper, Scanner, Tank B, Tank A, Dryer group B, Dryer group A, connections to the condenser.
Energy Conservation in Paper Making

Vacuum-steam pressure trade-off

Multi-Objective Optimisation Problem

Vacuum Power

More Vacuum Power = Less Steam Pressure

More Electrical Energy Consumed

Less Thermal Energy Consumed
Preliminary Energy Audit: Board M/c

- Preliminary analysis of current PM 4 energy consumption has been completed using historical data extracted from PM 4’s PI Historian
- Benchmark period: 1st Apr 2009 to 1st Oct 2009
- Steam usage was assessed:
  - Steam usage by grade
  - This was compared to steam used on a similar Australian machine, useful for benchmarking PM 4
- Variability of sheet moisture and basis weight under the existing control system was analysed:
  - Setpoint error and mean, by grade
  - Standard deviation, by grade
Steam Usage by Grade

Average Steam Usage

Steam Usage (t/t)

Grade Code

2010000 => Grade code 20, target weight 100.00 gsm
Less steam usage when making higher grades..
PM 4 Steam Usage
Comparison with Benchmark Paperboard Machine

- Time weighted steam usage for PM 4, averaged over 6 months = 1.70 t steam/t paper
- For comparison, board machine benchmark steam usage was as shown below; a simple wet end stability MPC system achieved a 9% reduction in steam consumption

<table>
<thead>
<tr>
<th>Basis Weight (gsm)</th>
<th>Steam Usage (t/t)</th>
<th>% Reduction in Steam Use Achieved by Wet End Stabilising MPC System on Benchmark Machine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SSK ≈ 200,000 tonnes/yr</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Paper Machine Benchmark ≈ 125,000 tonnes/yr</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Regulatory control</td>
<td>Under MPC</td>
</tr>
<tr>
<td>105</td>
<td>1.94</td>
<td>1.88</td>
</tr>
<tr>
<td>120</td>
<td>1.83</td>
<td>1.83</td>
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<td>150</td>
<td>1.71</td>
<td>1.87</td>
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<tr>
<td>140</td>
<td>1.78</td>
<td>1.93</td>
</tr>
<tr>
<td>200</td>
<td>1.51</td>
<td>1.85</td>
</tr>
</tbody>
</table>

Average: 8.95%

Above Benchmark  Below Benchmark
Sheet Moisture Variability
Moisture Set Point Error by Grade

Reel Moisture Setpoint Error

On average sheet moisture is 0.32% below setpoint.

The mill was surprised to find they are currently over-drying their sheet
Basis Weight Variability
Basis Weight SPE by Grade

On average basis weight is 1% above setpoint.

Again it was a surprise to find the sheet is being made heavier than target.

PRO-TEM Network Academic Forum, Newcastle University, 26 Jan 10
EPSRC Project Objectives for PM 4

The PM 4 energy audit reveals that to reduce energy use on PM 4 the controller should be designed to meet the following objectives:

• **Improve machine stability**
  - Reduce variability in backwater consistency for both layers of the sheet
  - Optimise the use of additive chemicals, especially drainage aids, against steam usage

• **Maximise drainage to reduce need of dryer steam**
  - Increase the sheet solids content entering the dryer, thus reducing steam usage

• **Minimise steam consumption by better control of weight and moisture**
  - Improve control of sheet moisture across all grades and reduce over-drying
  - Make to target weight
Current & Future Work

• Negotiating with the mills and with a potential instrument supplier to see if online measurement of sheet solids mid-machine can be made available for the project

• Examining data from the newsprint machine with a view to establishing its current energy use patterns

• Initiating a step test programme on the board machine to develop data for modelling it

• Finalising project objectives specific to the newsprint machine

• Beginning to use plant data to develop suitable energy flow models
Conclusion

- Project work has started well. There is good interest and project engagement from all appropriate personnel at each partner mill.

- Data from the first machine to be studied has revealed some specific issues that should be tackled as part of a project aimed at achieving energy reduction.

- We remain optimistic that the project should be able to deliver energy reduction in paper making of at least 20%.