Reducing Energy Consumption in Paper Making using Advanced Process Control and Optimisation

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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, ~ 92% 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....
Synopsis

- Energy use in paper making
- The paper machine as a multivariable process
- Possible performance improvement on paper machines, using MPC:
  - improve machine stability => runnability ↑, production ↑, energy requirement ↓
  - (reduce variations in MD weight and moisture)
  - (improve control of shade (white papers) and colour)
  - reduce grade change times: more production, less broke
  - online control of formation (and opacity & porosity, if measured online)
  - reduce energy use in paper making: optimise drainage and dryer steam use
  - improve dryer control: improve efficiency & lessen energy use, reduce dryer bottleneck effect, provide steadier moisture control
  - control sheet strength online: a new online strength sensor is now available
  - optimise machine production, perhaps using a speed advisor at first
- Case study material from several reference sites:
  - A fine paper machine in France
  - A three ply board machine in England + a two-ply board machine in Australia
  - A newsprint machine in England + an ‘improved newsprint’ machine in Canada

Energy Consumed in UK Paper Making

- Paper-making is a very energy-intensive industrial activity. UK 2008 figures:

<table>
<thead>
<tr>
<th>Paper Type</th>
<th>Energy Consumed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packaging board</td>
<td>2 – 3 MWhr/t paper made</td>
</tr>
<tr>
<td>Newsprint</td>
<td>3 – 4 MWhr/t</td>
</tr>
<tr>
<td>Tissue</td>
<td>5 – 7 MWhr/t</td>
</tr>
<tr>
<td>Fine Papers</td>
<td>4 – 8 MWhr/t</td>
</tr>
<tr>
<td>Specialty papers</td>
<td>Up to 20 MWhr/t</td>
</tr>
<tr>
<td><strong>UK Average</strong></td>
<td><strong>4 MWhr/t</strong></td>
</tr>
</tbody>
</table>

- Present day pulp & paper industry processes were designed when energy was cheap and plentiful:
  - About 70 paper machines are still operated in the UK (>200 50 years ago)
  - Each machine costs £10s of millions each; not easy to change technology fast
- The rising cost of energy has shut more than 10 UK paper mills in the last three years; similar story elsewhere in Europe
Understanding the Magnitude of Energy Used in Paper Making

- Energy consumed in paper making in the UK (2008 figures):
  - Annual production = 5,750,000 tonne/yr across all types of paper made
  - Thus annual energy consumption = 4 MWhr/t x 5,750,000 t/yr = 23,000 GWhr/yr
- We aim at a 20% reduction in energy use: this would save 4,600 GWhr/yr
- How much power is this?
  - During 2008, Cambridge households each used on average 20.796 MWhr/yr
  - 20.796 MWhr = the energy used to make ~5 t of paper (8,333 Sat. ‘Times’)!!
  - 48,000 meter points in Cambridge => 998,208 MWhr/yr = 998.2 GWhr/yr
  - A 20% saving in energy use in the UK = the power used by ~ 4.61 Cambridges
    = the power used domestically by a UK town of about 700,000 people
- Tissue: energy content of two sheets of tissue hand towel (3 gms) = 18 W
  - Compare this with the Dyson hand dryer which uses 6.6 W for a 15 sec dry
- Newsprint: last Saturday’s ‘Times’ weighed 610 gm => energy used = 2.14 KWhr .
  At 10p/KWhr, energy cost of the paper = 21.4p, 14.2% of the £1.50 purchase price.
Energy Use: Paper Making Compared with Other Industries

• Paper-making is not the most energy-intensive industry, as measured by energy used per unit of GDP created

• Representative (but not UK) figures are as follows:

<table>
<thead>
<tr>
<th>Industry</th>
<th>GJ/$000 (2003)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum, chemicals, plastics &amp; rubber</td>
<td>60.77</td>
</tr>
<tr>
<td>Fishing</td>
<td>26.87</td>
</tr>
<tr>
<td>Transport &amp; storage</td>
<td>21.12</td>
</tr>
<tr>
<td>Basic metal industries</td>
<td>18.64</td>
</tr>
<tr>
<td>Paper, printing &amp; publishing</td>
<td>11.29</td>
</tr>
</tbody>
</table>
Paper Machines are Multivariable Processes

Properties of feed stock
- Stock preparat’n
- Stock blending
- Refining
- Broke usage rate
- Rec fibre usage
- Stock consist’y
- Stock flowrate
- Retention aids
- Headbox control
- Wire speed
- Wet end vacuum
- Dryer steam usage
- Cond’sate rec, DPs

Paper Machine
- Weight
- Moisture
- Caliper
- Production
- Brightness
- Colour
- Opacity
- Porosity
- Formation
- Retention
- Ash Content
- Strength
- Energy use

A successful approach to reducing energy consumption in paper making needs to make coordinated, coherent use of such variables as:

- Refining of stock
- Headbox properties
- Drainage, including:
  - Rate of use of drainage aids (often presently just dosed on a wt/wt basis)
  - Vacuums (remain unused for any closed loop control purposes at present)
  - Press parameters (also largely unused in real time)
- Optimisation of the dryer, including pressures, differential pressures and condensate recovery rates (most of these are presently unused for control)
- Given the seriously multivariable character of paper machine behaviour, need multivariable rather than single variable PID control
- Many variables have fixed ranges within which they must be operated
- There are opportunities to optimise machine operation in real time

**Advanced Process Control** has tools that do these things in real time.
Advanced Process Control in Paper Making

- APC developed in oil & petrochem – it is quite new in the paper industry
- Control problems in the paper industry require multivariable solutions:
  - A paper machine has many unused control variables because it has never been clear how to use them in a PID control law eg
    - Formation and drainage are jointly affected by the same input variables
    - Key quality variables are often controlled using a PID loop that adjusts just one of several variables affecting the quality variable eg
    - Recycled pulp brightness: controlled by bleach rate alone (expensive)
- APC offers optimal control subject to specified constraints:
  - profit can often be made by operating close to or at constraints
  - why control a tank level to a setpoint (as with PID) when what is required is simply to keep the tank from over-flowing or under-flowing
- Can run APC with optimisers to determine optimum setpoints. Operating priorities can change hour by hour => need real-time optimisation
- Process industry has ‘slow’ processes (we typically use $\Delta \sim 20$ sec), but computing power not the issue it was, even with real-time optimisation
Advanced Process Control: Some Important Characteristics

• Need first to build a multivariable process model: the model describes how each input affects all the outputs

• There can be a model for each grade range

• Can specify constraints on each input and on each output

• APC includes optimisation which determines optimal setpoint targets within the specified constraints
### Cause-Effect Matrix: Step Response Models

<table>
<thead>
<tr>
<th>Inputs (Cause)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manipulated Variables (MVs)</td>
</tr>
<tr>
<td>Feedforward Variables (FVs)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outputs (Effect)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controlled Variables (CVs)</td>
</tr>
</tbody>
</table>

- Need to determine which variables to include in the controller
- The MVs are usually setpoints to existing PID loops
- Must choose model order, type and length of delays
- Which elements are zero?

To optimise and better control energy use in paper making, a necessary first step is often to improve wet end stability.

White water consistency, retention, ash content, formation and drainage are all affected by a number of stock approach and machine variables, many having an impact on energy use in paper making:

- refiner specific energy targets
- the flowrates & consistencies of fresh stock, broke and recovered fibre
- the dosage rates of wet end chemicals, including retention aids & fillers
- headbox parameters such as slice gap and jet to wire ratio
- wire vacuums

Objective: maintain stability of white water consistency, retention, ash content and other quality parameters to provide a platform from which to be able to optimise drainage and minimise energy use.

Multivariable model-based control tools are very well suited to this multi-dimensional control and optimisation problem.
Wet End Stability Improvement using APC: Newsprint Case Study

- An APC system was implemented on a large newsprint m/c:
  - Production: ~ 300,000 tonnes per annum of 100% recycled newsprint
  - It is a modern high speed machine running at ~1700 m/min, 9.2 m trim width
  - The machine already had PID closed loop wet-end regulatory control systems - APC now delivers setpoints to these loops

- Objectives of the APC system:
  - Stabilise the operation of the wet end:
    - Steadier control of white water and hence headbox consistency
    - Control charge and turbidity within a given range
    - Minimise usage of flocculent consistent with achieving required first pass retention
    - Ensure good sheet properties are maintained: formation, opacity, porosity,…
  - Provide effective control of the broke system
  - Manage the consistency setpoints for fresh recycled feed, recovered fibre and broke, in order to provide better headbox consistency control
Newsprint Case Study: Controller Performance Evaluation 1

4 Breaks over 60 minutes
Broke flow increased to 5100 l/min in steps
Large change in broke flow as tower reaches 20% level
Disturbance to white water consistency for 9 hours after breaks
Regulatory Control (11.5 hours)

3 Breaks over 60 mins
Broke flow increased to 8000 l/min peak
Broke flow reduced as tower reaches 20%
No significant disturbance to white water consistency
APC (7 hours)
Newsprint Case Study: Controller Performance Evaluation 2

- Striking improvement in wet end stability

<table>
<thead>
<tr>
<th></th>
<th>Regulatory standard deviation (10 days run time)</th>
<th>APC standard deviation (20 days run time)</th>
<th>% reduction in standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Water Consistency (g/l)</td>
<td>0.0754</td>
<td>0.0249</td>
<td>67</td>
</tr>
<tr>
<td>Headbox Consistency (g/l)</td>
<td>0.0702</td>
<td>0.0418</td>
<td>60</td>
</tr>
<tr>
<td>(Wire) Retention (%)</td>
<td>0.487</td>
<td>0.378</td>
<td>22</td>
</tr>
<tr>
<td>Ash Retention (%)</td>
<td>0.918</td>
<td>0.797</td>
<td>13</td>
</tr>
</tbody>
</table>

- Also reduced variation, at the reel, in
  - weight
  - moisture
  - caliper
  - opacity
Newsprint Case Study: Controller Performance Evaluation 3

- White water consistency stabilisation
Fine Paper Case Study: Paper Break Response Comparison

Paper break signal
1 = break

White Water Consy
Range 1.4 g/l

Ash
9.5-11%

Polymer Ratio
24-32 t/h

Filler Flow
7.6-14 m3/h

Broke Ratio
10-35%

C8 level 0.9-3.3m

Short break (12 mins)
SD 0.385 g/l

Normal Control
APC Control

Little effect on ash OR WW consy
SD 0.1 g/l

SD 0.129%

SD 0.05 %

Energy Reduction Due to Wet End Stability Improvement: Recent APC Project Work

• What has improved wet end stability done for energy reduction in recent Perceptive Engineering APC projects? Steadier operation => better drainage => reduced moisture load for dryer => reduced dryer steam use.

• On a 2-ply Australian board machine making 100 – 220 gsm grades, APC gave:
  • A big reduction in variation: standard deviations of wet end parameters were reduced by 75% - 90%
  • Energy saving: steam use was reduced by 10% on average
  • For grades whose production rate is limited by dryer steam availability, reduced specific steam use => significantly increased production
  • Improved runnability => a further production increase of 1.2%
  • The mill is commissioning additional work to incorporate control of wet end vacuums into the APC system, to further improve drainage control and reduce dryer steam use

• On a Canadian newsprint machine, making 48 – 58 gsm paper, APC has:
  • Reduced specific steam usage by 7.8%
  • Reduced standard deviation of white water consistency by 55% – 65%
  • Significantly improved control of shade
APC allows a coherent & coordinated approach to energy optimisation, using all the variables affecting energy consumption in paper making:

- Refining of stock
- Headbox properties
- Drainage, including:
  - Rate of use of drainage aids (often presently just dosed on a wt/wt basis)
  - Vacuums (remain unused for any control purposes at present)
  - Press parameters (also largely unused in real time)
- Optimisation of the dryer, including pressures, differential pressures and condensate recovery rates (most also presently unused)
- CUED’s new EPSRC thermal efficiency improvement project aims to provide industry exemplars of successful energy reduction strategies based on the use of APC and optimisation
- We believe that at least a 20% reduction in energy use in paper making is possible
1. Project partners:
   • Cambridge University Engineering Dept, Control Group: Jan Maciejowski & Paul Austin
   • Manchester University School of Electrical & Electronic Engineering, Control Systems Centre:
     Hong Wang, Puya Afshar, Tim Breikin & Martin Browne

2. Project is being undertaken on 2 commercial machines on which our suggested solutions are to be implemented 24/7:
   • a newsprint machine: PM 14 at Aylesford Newsprint, Kent
   • a two ply board machine: PM 4 at Smurfit Kappa SSK, Birmingham

Further data for modelling will be collected from a third machine:
   • a fine paper machine: PM 8 at Arjo Wiggins Stoneywood, Aberdeen
EPSRC 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 optimisation and control technology than is currently in use to make operational improvements in thermal efficiency, without reducing product quality.
   - Implement the best options for each of the 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 paper machine designs in the future:
   - Develop appropriate 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.
Steam Use on the Paper Machine

- Paper machines use between 80% and 90% of all mill energy
- Some of this electrical energy is used in drives, and in running vacuum pumps and stock pumps (for moving fluids)
- But steam used in drying the sheet is the biggest energy consumer
- Water content of the sheet:
  - 99.1% water when sheet just formed: vacuums and aerofoils drain it
  - ~88% water as it enters the press section
  - ~50% water as it enters the dryer: steam entering stainless steel rolls is used to dry the sheet to ~8% water content
- We see three main ways to reduce steam consumption using multivariable Advanced Process Control:
  - Increase sheet solids entering the dryer by better control of drainage
  - Reduce specific energy consumption by maximising production
  - Improve dryer efficiency by better understanding the dryer process: use differential pressures (and maybe condensate recovery rates) as well as steam pressures?
Dryer Steam: the Big Energy User in Paper Making

It is known that the drying section of a paper machine:

• reduces sheet moisture content, $M$, from ~50% to ~ 8%  
  \[ M = \frac{\text{water}}{\text{water} + \text{fibre}} \]

• uses about 80% of mill-wide energy

• but removes less than 1% of water from the sheet

Consider 100 gm of thin stock laid onto the wire at the headbox:

• 0.9 gm total solids
• 99.1 gm water

At the dryer, $M \sim 50\%$:

• there is still 0.9 gm solids
• and just 0.9 gm of water
• 98.2 gm of water have been removed
• less than 1 gm of water remains to be removed through the whole of the dryer.
Effect on Dryer Steam Use of Increasing Sheet Moisture Content

- Take headbox consistency as 0.9% and consider the fate of 100g of stock laid on the wire. Calculate this using the definition of sheet moisture $M$:

  $$M = \frac{\text{weight of water in sheet}}{\text{weight of total solids} + \text{weight of water}}$$

- Wire drains over 92% of water, press drains <6%, dryer removes <1% !!
- If can reduce sheet moisture to dryer by 5%, water to be removed in dryer reduces from 0.822g to 0.658g. A 5% ↓ in sheet moisture => 20% ↓ in dryer load
- “A 1% reduction in sheet moisture to dryer results in a 4% reduction in dryer load”
- Hence improved drainage is a big focus for the EPSRC project

<table>
<thead>
<tr>
<th></th>
<th>At the headbox</th>
<th>At the couch</th>
<th>Into the dryer</th>
<th>Better dryer feed</th>
<th>At the reel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheet moisture</td>
<td>99.1%</td>
<td>88%</td>
<td>50%</td>
<td>45%</td>
<td>8%</td>
</tr>
<tr>
<td>Water in sheet</td>
<td>99.1g</td>
<td>6.6g</td>
<td>0.9g</td>
<td>0.736g</td>
<td>0.078g</td>
</tr>
<tr>
<td>Solids in sheet</td>
<td>0.9g</td>
<td>0.9g</td>
<td>0.9g</td>
<td>0.9g</td>
<td>0.9g</td>
</tr>
<tr>
<td>Water removed</td>
<td>92.5g</td>
<td>5.7g</td>
<td>5.86g</td>
<td>0.822 (0.658)g</td>
<td></td>
</tr>
</tbody>
</table>
Energy Reduction in Paper Making: Vacuum-steam pressure trade-off

- Given that a 1% reduction in sheet moisture entering the dryer results in a 4% reduction in dryer steam demand, there is an optimum to be determined:

  More vacuum power => Better drainage=> Less dryer steam required

  More Electrical Energy Consumed Less Thermal Energy Consumed
EPSRC Project: Preliminary Energy Audit on the Board Machine

- Current PM 4 energy consumption has been assessed using historical data from 1\textsuperscript{st} Apr 2009 to 1\textsuperscript{st} Oct 2009, extracted from PM 4’s PI Historian.

- Analysis of this data confirms clear directions for our energy reduction endeavours!

- Steam usage in the dryer was assessed:
  - Average steam use is 1.7 tonnes steam per tonne of finished paper made (this is lower than average in world terms).
  - Taking sheet moisture entering the dryer as 50\% and target sheet moisture as 8\%, there is 0.8405 tonne water to be evaporated from the sheet in the dryer.
  - \( \text{dryer efficiency} = \frac{0.8405}{1.7} \times 100\% = 49.44\% \)

- Variability of sheet moisture and basis weight under the existing control system was analysed. On average they are:
  - over-drying the sheet by 0.32\% (waste of energy)
  - making a sheet that is 1.0\% heavier than setpoint (waste of fibre and energy)
The board machine energy audit reveals that to reduce energy use, the MPC control system 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
  - (Dryer efficiency improvement is not part of the EPSRC project brief)

We remain confident that a 20% reduction in energy use is a realistic target.
Reduced Energy Consumption in Paper Making: ELCF Seminar, Wed 3 Feb 2010

2. The Role of Better Control of Drainage

• Better control of drainage =>
  • Balancing vacuum power and steam saving, maximise solids content of sheet entering dryer => reduce dryer steam use (1% reduction in moisture at the dryer reduces steam consumption by about 4%)
  • Provide better control of sheet moisture
• Many influences on sheet drainage: amount of refining, rate of use of chemical additives (especially drainage aids), stock consistencies, headbox parameters, vacuums imposed, press pressures
• All of these variables affect other sheet properties than moisture alone => need multivariable control to provide coordinated control of drainage and other quality and production variables
• Thus, more intelligent control of drainage can have both a quality and an energy reduction objective:
  • Reduced steam usage in the dryer, by draining to lower moisture contents
  • Steadier sheet moisture profiles
Newsprint M/c: Modelling Drainage using Vacuums Alone
3. Improved Dryer Efficiency

- The traditional regulatory approach to controlling a paper machine dryer usually uses a three term (PID) loop:
  - driven by the difference between measured and target sheet moisture
  - control action is cascaded to operate on steam pressures in 3 – 7 dryer sections, aiming to meet the moisture target
- A multivariable APC approach to dryer control could be based on building separate models of the effect on sheet moisture of:
  - the **steam pressure** in each dryer section
  - the **differential pressures** across each dryer section
  - the **condensate recovery rate** from each dryer section (if independent)
- A control system with closed loops around steam pressure alone will be ignoring some important variables of influence on dryer operation
- Recognising the multivariable character of the available dryer controls and building model-based controllers should enable APC to deliver a considerable energy saving benefit.
The Paper Machine Dryer

- Dryer section: from 50 to >150 dryer rolls; steam enters interior of rolls
- Rolls divided into min. 5 sections: 2 heatup (fixed steam) at least 3 under control
- **Steam pressures** to 3rd and later dryer sections are under closed loop control
- There is a **differential pressure** across each dryer section; this is usually fixed by the operators and not changed very often i.e. no closed loop control
- On some machines, the **rate of condensate recovery** can also be separately varied: must not flood interior of dryer roll, nor drain it (reduces rate of heat transfer); typically this is used neither by the operators nor for closed loop control.
Towards a Better Understanding of Dryer Operation and Control

• Differential pressures and condensate recovery rates are seldom used in closed loop dryer control schemes.

• Neither operating practice nor the literature provide clear guidelines about how to use these variables to optimise dryer performance.

• A new project has recently been initiated in New Zealand between the School of Engineering & Computer Science at Victoria University and Industrial Research Ltd and two paper mills to better understand the effect on moisture control and dryer efficiency of all dryer variables.

• Once better understood, all available variables could be used in a controller recognising the multivariable nature of dryer controls.

• Several potential benefits:
  • improve dryer efficiency => reduce dryer steam use
  • de-bottleneck the dryer => increase production
  • tighter control of MD moisture profiles => raise the moisture target, further reducing dryer steam demand.

- Aylesford’s PM 14 has a speed limit of 1725 m/min imposed by the electrical drives. The machine seldom operates steadily at this speed: average speed in the last month was 1630 m/min.

- Most motors on a paper machine run at fixed speed no matter what the production rate. Specific energy consumption will therefore be reduced if production is maximised.

  - Model to all the speed-critical CVs on the machine and to appropriate finished sheet properties
  
  - Use APC to maximise machine speed in real time, consistent with prevailing constraint limits imposed by site personnel. MPC could initially be used just in speed advisory capacity.

- This is one of the objectives of the EPSRC project for PM 14. Aylesford is also interested in using vacuums to improve drainage and reduce steam demand
Perceptive Engineering has developed an alliance with a company that is just bringing to market a new generation online strength measurement system they have developed......

- Paper is usually made to exceed strength targets since till now strength could only be measured in the lab after the paper was made.

- Benefits from online control of strength are expected to include:
  - reductions in energy used
  - savings in raw material costs
  - increases in production
Conclusion

- Advanced Process Control (APC) work on commercial paper machines already completed =>
  - Significant energy reduction in paper making is possible using APC
  - Further investigation of energy reduction using APC is warranted
- APC methodology:
  - Model the paper machine as a multivariable process
  - Use this model to design a multivariable model predictive controller
  - Run the controller with powerful real-time optimisation functionality
- Possibilities for reducing energy consumption using APC were reviewed:
  - Improved wet end stability
  - Better control of drainage to reduce dryer steam demand
  - Improved dryer efficiency
  - Production optimisation to reduce specific energy consumption
  - Online control of sheet strength
- Benefits: energy consumption ↓, production↑, quality ↑
- Payback times on commercial projects to date: 3 wks to 5 months
- But the conservatism of the industry has limited the rate of development!
Process Dynamics

- Process output 1
- Process output 2
- Process input

dead time

time
The objective of the MPC control calculation is to determine a sequence of control moves so that the predicted response(s) moves to setpoint(s) in an optimal manner.

The control calculations are based on the current measurements and predictions of the future values of the outputs.

The predictions are made using a dynamic model of the process.

The control algorithm typically uses a Receding Horizon approach - i.e. a sequence of M control moves are calculated at each execution interval, but only the first move is actually implemented.
Better Control Can Allow Optimisation of Targets

- Maximum Allowable Moisture
- New Target
- Mean Level
- Without APC
- With APC
- Time
Wet End Stability Improvement using APC: Fine Paper Case Study

- An APC wet end controller was implemented on a fine paper m/c:
  - Runs at up to 1000 m/min, 3.5m trim, production ~ 100,000 t/yr
  - Four main grades: 60, 80, 120 and 160 gm/sq m, bright copy & writing papers and coloured papers
  - Wet end additives: retention aids, filler, sizing agents, biocide, dye, OBA & cationic starch
- Ash and retention control loops were found to be very interactive
- Complex broke system with limited capacity tanks:
  - Three types of broke: wet end broke, dry end broke + broke from converting plant
  - Using broke disturbs wet end stability. As the broke ratio rises:
    - Ash in stock ↑ and filler addition rate ↓
    - Formation worsens
    - White water consistency ↑, retention ↓; the Recovered Fibre System is disturbed, which affects the polydisk speed control
    - Luminance and brightness ↓, dye and OBA flowrates altered
Fine Paper Case Study: Paper Break Response Comparison

Short break (12 mins)

Paper break signal
1 = break

White Water Consy
Range 1.4 g/l

SD 0.385 g/l

Ash
9.5-11%

SD 0.129%

Polymer Ratio
24-32 t/h

SD 0.1 g/l

Filler Flow
7.6-14 m3/h

SD 0.05 %

Broke Ratio
10-35%

Normal Control                         APC Control

C8 level 0.9-3.3m

Little effect on ash OR WW consy

MPC Performance Improvement on PMs:
2. Reduced Variation in Ash Content

- The standard approach to ash control in paper:
  - a PID loop adjusts filler flow, driven by a measurement of finished sheet ash
  - but ash content is also affected by the varying flowrates of retention aid used for retention control
  - The two separate loops ‘fight each other’ and create oscillation
- Filler flow and retention aid are in fact two of a number of inputs in the stock approach system and at the wet end which determine:
  - the ash content of finished paper; note that variations in ash in the stock create variations in drainage and weight
  - retention which determines sheet weight profiles
  - other quality variables determined at the wet end
- Multivariable MPC can provide a range of benefits here:
  - Big reductions in ash variation
  - This can enable ash targets to be raised: maximum paper ash contents will be reduced but average ash contents increased => fibre savings
  - Better control of ash means broke ratios can be adjusted with greater flexibility
  - Interest in better control of ash is growing – 3 new ash control jobs are in prospect
Fine Paper Case Study: Controller Performance Overview

- Baseline data (before APC) over 1 month, APC data over 2 months
- Shuts and grade changes excluded in both cases
- Big reduction in variation in **ash** and **white water solids** variation

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Unit</th>
<th>Baseline</th>
<th>APC</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>White water consist’y</td>
<td>g/l</td>
<td>0.53</td>
<td>0.09</td>
<td>83%</td>
</tr>
<tr>
<td>Headbox consistency</td>
<td>g/l</td>
<td>0.53</td>
<td>0.08</td>
<td>85%</td>
</tr>
<tr>
<td>Sheet ash</td>
<td>%</td>
<td>0.27</td>
<td>0.08</td>
<td>70%</td>
</tr>
<tr>
<td>Fibre retention</td>
<td>%</td>
<td>2.91</td>
<td>1.08</td>
<td>63%</td>
</tr>
<tr>
<td>Ash retention</td>
<td>%</td>
<td>2.71</td>
<td>1.05</td>
<td>61%</td>
</tr>
<tr>
<td>Mixing tank level</td>
<td>m</td>
<td>0.14</td>
<td>0.01</td>
<td>93%</td>
</tr>
<tr>
<td>White water tank level</td>
<td>m</td>
<td>0.04</td>
<td>0.04</td>
<td>0%</td>
</tr>
<tr>
<td>Polydisk level</td>
<td>m</td>
<td>0.05</td>
<td>0.01</td>
<td>80%</td>
</tr>
</tbody>
</table>
MPC Performance Improvement on PMs: 3. Increased Production

- Wet end stability is well known to be the paper maker’s prime objective
- With improved wet end stability, increased production arises from at least two causes
  - Better runnability
  - Less off-quality production
- APC can be used to specifically target increased production in several ways:
  - Better control draw and centre press roll sheet position => steadier press operation which allows higher machine speeds
  - Improved operation of the dryer can reduce its effect as a production bottleneck
  - The ultimate goal of APC on paper machines: the models can be used to advise what speed the machine is capable of in its present (felt and wire) condition and for current grade
Production Increase using MPC on a Three Ply Board Machine

- The machine makes 90 – 240 gm three ply board from 100% recycled fibre
- Wet end additives include starch (for strength) and retention polymer
- The consistency of thickstock supplied to each layer can drift with time: can see the resulting effect on headbox consistency and Back Water Solids consistency (BWS)
- A simple MPC system was implemented:
  - MVs: polymer flowrates plus fresh stock flowrates for each ply
  - FFs: starch addition rates, refining power, thick stock consistencies for each ply
  - CVs: BWS for each ply
- This wet end stability MPC control system gave steadier operation and considerably increased production
Board Machine Case Study: Controller Performance Overview

Web break signal
1=Break

Controller Mode
4th Active

TL thickstock Consy
4.234-4.43%

TL Backwater Consy
1826-2436 ppm

TL Polymer dosage
699-976 g/tonne

FL thickstock Consy
3.992-4.113%

FL Backwater Consy
2616-3390 ppm

FL Polymer dosage
563.9-649.9 g/tonne

BL thickstock Consy
4.2227-4.391%

BL Backwater Consy
3346-3909 ppm

BL Polymer dosage
750-1110 g/tonne

APC reacting to starch step down during breaks

SP change

Std Dev reduction of 72 %

Std Dev reduction of 57 %

Std Dev reduction of 36 %

Board Machine Case Study: Performance Statistics

- Data was collected over a 3 week period in which:
  - Lightweight (LW), medium weight (MW) and heavy weight (HW) grades were made
  - The standard deviations of the BWS contents were determined before and after APC was implemented: the table shows the reductions, by grade and layer, due to MPC
- In the two months after commissioning, production increased 7%:
  - improved wet end stability => steadier running, reduced sheet breaks
  - steadier operation => improved dryer efficiency, increased m/c speeds

Reductions in standard deviations

<table>
<thead>
<tr>
<th>Grade</th>
<th>GSM</th>
<th>TL</th>
<th>FL</th>
<th>BL</th>
</tr>
</thead>
<tbody>
<tr>
<td>LW</td>
<td>100 - 117</td>
<td>36%</td>
<td>49%</td>
<td>65%</td>
</tr>
<tr>
<td>MW</td>
<td>125 - 150</td>
<td>61%</td>
<td>67%</td>
<td>70%</td>
</tr>
<tr>
<td>HW</td>
<td>170 - 220</td>
<td>53%</td>
<td>84%</td>
<td>67%</td>
</tr>
</tbody>
</table>

- On a two ply Australian board machine, a recent wet end stability controller provided a production capacity increase of 9%.
Fine Paper Case Study: Production Increase

- The enormous reduction in wet end variation (ash and wwc) results in:
  - 35% reduction in production loss associated with sheet breaks
  - Shorter sheet break down-times
  - An 11% reduction in production loss due to off-quality production
  - Increase in saleable production ~ 3% (2.6% + shorter breaks):

<table>
<thead>
<tr>
<th></th>
<th>Before APC (6 months of data)</th>
<th>After APC (2 months of data)</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average length of sheet break</td>
<td>15 mins</td>
<td>12 mins</td>
<td>20%</td>
</tr>
<tr>
<td>% production loss due to sheet breaks</td>
<td>4.9%</td>
<td>3.2%</td>
<td>1.7% (35%)</td>
</tr>
<tr>
<td>% production loss for quality reasons</td>
<td>8.1%</td>
<td>7.2%</td>
<td>0.9% (11%)</td>
</tr>
</tbody>
</table>
MPC Performance Improvement on PMs: 
4. Reduced Grade Change Times

- Once the machine is MPC controlled from the headbox to the reel, better control of grade changes becomes possible.
- The MPC system’s models allow robust, accurate forward prediction. Can thus determine optimal times to make setpoint changes in steam and weight to keep quality parameters within allowed ranges.

- On a 70,000 t/yr French fine paper machine, our grade change controller reduced grade change times by more than 50%. With an average of 5 grade changes/day, production increase was significant.