Possibilities of reducing energy consumption at papermaking process

Peter Fisera CF ProcSim, Andreas Roither-Voigt VOIGT+WIPP Engineers

Drying belongs to the most energy intensive processes in the Pulp and Paper industry. Even a small improvement brings significant benefits into the production efficiency.

Let's name some points where the energy balance can be improved:

a- Heat recovery systems: The majority of all upgrades in the past were concentrated into production increase or into quality protection. The heat recovery systems became the weak point of the drying equipment

b- False air: The control of so called zero zone in the machine hood is in many cases off. It causes false cold air into machine hood unnecessary increasing steam consumption to heat it.

c- Air balance: The air moisture in the machine hood does not reflect current running production. Although the low air moisture lowers dew point and makes drying comfortable, it raises energy costs as well.

d- In case of two energy resources (steam/gas) there is hardly an optimizing system in order to decrease energy costs

e- A predictive based control system can decrease off quality production during grade change and deduce start up time and so decrease specific energy costs.

A few points above are only general examples how to lower energy consumption at papermaking process. All of them can be solved without expensive investment costs using available instrumentation by simulator aided predictive control technology.

Mondi Group installed a new control technology for the drying process.

The project "rigorous model based simulation and multivariable control of a paper machine to optimize performance, quality of product and energy efficiency" is an entirely new development based on physic equations, geometry of the machine, paper properties and parameters of equipment. This new technical approach enables the control of a paper machine at its economic and technological optimum.

Process control from the future

This new control technology is based on a simulated future, which is calculated in milliseconds using online process data, the ***rigorous model*** and paper properties.
This control technology is relatively new in this area of the paper industry. The results of the new set points before activation will be tested and tuned in the simulated future. ***There is no comparison to the "standard control"***, where the process results must be corrected after deviations have already happened.

This control strategy is an extension to the concept of nonlinear model predictive control, by integrating a non-causal, partially inverted physical model to allow the control solver a calculation of optimal manipulated variables anticipating future reactions on disturbances, to reject them and "follow" future target trajectories.

This control technology enables the use of complete available capacity of the production lines in the paper industry without additional investments. Energy consumption and CO2 emission will be reduced and nonstandard (off spec) production minimized.

The rigorous model of the paper machine

The drying process has been described and modelled in countless publications. The mathematical background of these publications is predominantly public knowledge combined with specific parameters of drying equipment. The calculated results are usually in conformity with reality. The disadvantage of most of them is that:

They are isolated and concentrated to the solution of specific drying problems only.

The rigorous model of the paper machine is based on geometrical data of paper machine components, mechanical parameters of all relevant equipment and physical properties of material and therefore is more general and more widely applicable. The fiber properties like sorption, specific heat, sorption heat of bounded water, heat conductivity and porosity complement the model of the evaporation process. The model itself is composed as a system of partial differential equations with boundary conditions derived from the geometrical data of the paper machine.

The software structure is based on separate models of paper machine components saved in the library as components of the virtual machine. The equations which are already used are public knowledge. ***The novelty of this project is the complexity of the task in combination with the numeric solver and the way of online (real time) implementation.***

The virtual paper machine is a substantial representation of all important functions of the real paper machine through which the processes can be simulated in all production conditions. The precision of the simulated results represent the measured values of the real processes with accuracy of the instrumentation.

The complexity of this simulation turns the virtual paper machine into an ideal test machine, not only for reconstructions and extensions, but also as an instrument for process and energy optimization, particularly for steam and condensation systems, heat recovery and conditions of the air hoods.

The modeled functionality of each equipment part reflects the actual performance, identifies bottlenecks, quantifies energy losses and checks countermeasures.

Paper web is split into 3 layers in the z direction (thickness of the web). This allows to model web surface temperature in higher accuracy displaying conditions for web shrinkage and fiber hornification. The capillarity water flow from web middle to the surface is interrupted by the lack of free water in the web surface layer (defined by sorption fiber properties). The vapor diffusion from the middle web layer through the dried layer to the web surface is combined with rewetting according to the relative vapor pressure in the web hydroscopic porous structure.

The heat transfer from condensing steam in the cylinder section to the web is the most important process. The heat which transfers through the cylinder wall is equal to the heat for web heating and evaporation. In principal this heat balance can be solved using five basic equations complemented by boundary conditions.

$$Q_{ToWeb} = Q_{Evap} + Q_{Heating} \tag{1}$$

Q_{ToWeb} is the total heat absorbed in the paper web
Q_{Evap} is the energy used to evaporate free and bounded water
$Q_{Heating}$ is the energy to heat web to latent temperature

$$Q_{ToWeb} = \sum_{k=1}^{n} \left(Ak * Kk * \left(T_{Steam} - T_{Web}(k) \right) \right) \tag{2}$$

Ak is the web contact surface in the partial position *k*
$T_{Web(k)}$ is the web temperature in the partial point *k*
T_{Steam} is the saturated steam temperature for a particular steam group

$$\frac{1}{Kk} = \frac{1}{K_{Cond(speed)}} + \frac{1}{K_{Shell}} + \frac{1}{T_{Web(D(k))}} \tag{3}$$

Kk is heat transfer coefficient through cylinder shell to the web in the partial position k calculated from particular heat transfer coefficients for condensate, cylinder shell and web

$$Q_{Evap} = \sum_{j=1}^{m} \left(mj * h_{Evap}\left(T_{Web}(j), D(j)\right) \right) \tag{4}$$

mj is the evaporated water in partial position *j*
h_{Evap} is the evaporation of heat including sorption heat in position *j*

The evaporation equation will complete this mass and heat balance for a given grade

$$\dot{m} = \beta j * d(D(j)) * \ln\left(\frac{Pa-Pv}{Pa-Pp}\right) / \left(Tweb(k) * Rv\right) \tag{5}$$

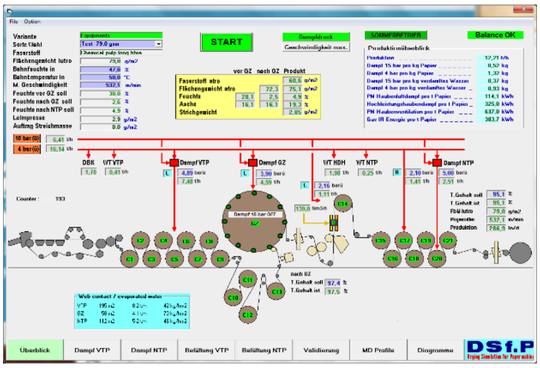
$\dot{m}$ is the evaporation rate in the position *j*
βj is the mass transport coefficient in partial position *j*
D is the vapor diffusion in the partial position *j*
Pa is the atmospheric pressure
Pv is the partial vapor pressure in the air
Pp is the vapor pressure in the pulp web inclosing hydroscopic sorption property
Tweb is the web temperature
Rv is the vapor constant

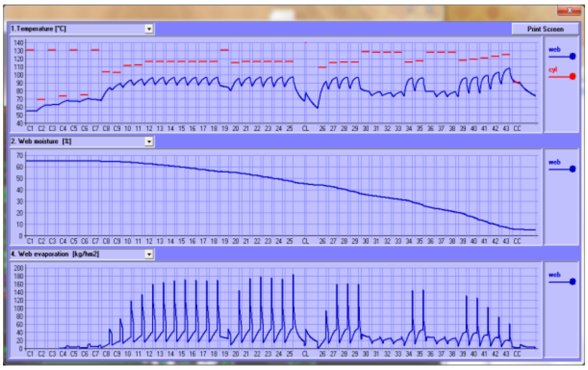
Partial position k is dedicated to conductive heat transfer only - this means web contact surface with cylinder (geometrical data of steam cylinders). Partial positions j define the whole web evaporation surface in PM.

User Interface

The user interface of the simulation is very similar to the real machine, but ***it offers significantly more technical and technological process data, profiles and trends*** compared to a conventional control system. Therefore the simulation can easily quantify planned changes both in the process and in the drying equipment configuration.

The figures below show the user friendly interface for the simulated process and MD profiles of web and cylinder surface temperature, web moisture and web evaporation rate.





Validation

The validation has to answer the following question: ***does the simulation represent and correctly reproduce the behavior of the real world system?***

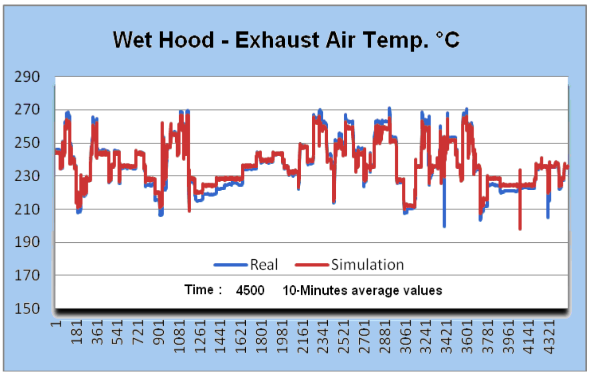
The validation ensures that the simulation meets its intended requirements in terms of the method employed and results obtained. The ultimate target of the simulation validation is to make the simulation useful in the sense that the simulation addresses the right problem and provides accurate information about the system being simulated.

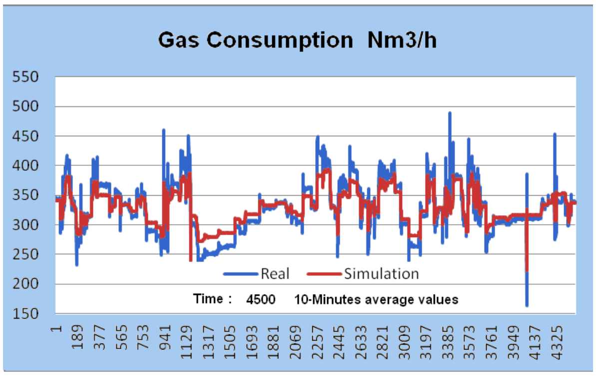
In our case the validation means that the parameters of the simulated equipment, for example the heating cylinder, heat exchangers, ventilators, infrared dryer, air dryer etc. will represent the behavior of the real equipment. The model parameters will be very close to technical data of particular real equipment. Only physical meaningful parameters are adjusted to fit real process data. No data-mining or correlations are used like in grey-box type models.

The heat transfer in the cylinder section is the most important process to be validated. The real cylinder surface temperature must be investigated by at least two different working machine speeds in order to determinate condensation distribution inside of the cylinders to fulfil equation (3). The evaporated water can be derived directly using web dryness after the press section and final dryness values and/or, indirectly using steam flow measurement. The simulated web temperature is determined by the cooling effect of evaporation. The evaporation rate is generally defined by the web temperature and the surrounding air moisture. The removing of evaporated water from web surface is defined by mass transfer coefficient β as tuning parameter in the equation (5).

The validation procedure is based on the historical process data stored in the database as 10 minute mean values (resulting in more than 4,300 data samples for one month). These values are split into two categories: process set points and process results. Process set points are used to control the virtual machine. The simulated results are compared with results from the real process. The precision of the simulated results by validated models is usually within an accurate scope of the installed instrumentation. The simulated drying process represents physical behavior of the real paper machine and copies its results in all production conditions.

The graphical illustration below represents a comparison of measured and simulated values at a Yankee machine showing over 4,300 time samples.





Online simulation

As with the real machine, the model must use real conditions (e.g. outside air properties, set points for production and paper web properties). To minimize simulation errors due to imprecise input data, the model algorithm demands only a few robust well maintained measurements like machine speed, scanner measured values or steam pressure***. This is usually enough to simulate the whole drying process.*** Both input data and simulated results are checked by fixed and dynamic limits.

Because the simulation (virtual paper machine) represents the behavior of a real paper machine, the simulated process variables can be used as soft sensors being directly displayed on the operator screens. This is one of the applications advantages using this innovated approach. Expensive instrumentation, inaccessible positions or hard ambient conditions can be avoided using virtual processes running parallel to real processes. ***Simulated process values from hundreds of different positions can be used as real process measured information***. Even the values from “isolated” measurement equipment can be compared with simulated values from an integrated and balanced system of physical equations to create a list for measurement calibration.

One of the most interesting process values is the web dryness after the press section. There are very few paper machines which have such measurements in this position. The solver continuously recalculates web dryness before the drying section using scanner values after drying***. Long term observation gives information about changes in the felt dewatering properties; short term observation informs the user about changes in fiber dewatering properties.***

The cylinder surface temperature is an important process variable heaving extreme impact on quality of paper gloss. The low cylinder surface temperature limits production, the high one threatens the paper quality. Due to the conventional real temperature measurement at this position not being reliable, there are very few paper machines equipped with such instrumentation. Of course, the virtual machine must have this information to complete the heat transfer into the paper web. This information can even be used as a recipe value for grade to control steam pressure accordingly keeping paper quality and maximizing production.

Process control novelty

Conventional control systems are controlling processes using information from the past. The control systems are correcting deviations, which have already happened. The process is moving itself into the wrong direction and the controller tries to put it back on target.

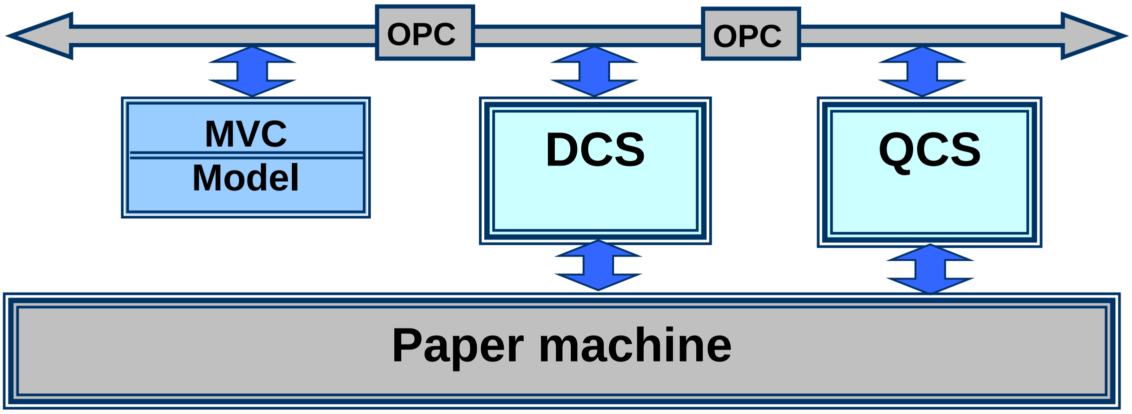
The new approach to control task is ***to control the process from the future***. In order to avoid process deviation in the real future the control system is continuously testing results of the control steps observing simulated results in the virtual future using virtual machine (grade change, speed change, new quality set points and so on). ***This enables it to carry out the process to the new target using the best way there is.***

The control system is analyzing and optimizing control results in the virtual future before activating it, looking for the most economical way according to the given criteria, leading the process and keeping it near to the calculated optimum with precision close to instrumentation accuracy. This is a completely different approach comparing classic controller reaction on deviation, especially for processes with a long delay time.

The automatically working adapting routines cover long period changes due to equipment wear.

Realization

The new control system is connected to the conventional DCS via OPC communication software (more or less standard for all DCS control systems). The new control system consists of multivariable controllers (MVC) and model of real machine (virtual machine). MVC reads grade recipe and current process data from DCS, calculates remote set points for selected controller in DCS (machine speed, steam pressure, basis weight) and sends them back to DCS. The figure below shows the connection principals.



To assess immeasurable ambient conditions of paper production a school mark based rating system, changeable by the operator, has been integrated into the control software. This feature speeds up or slows down the reaction speed of the multivariable controller.

Results

- Significant increase of production by approximately two percent
- Halving of start-up and boot up time to key performance parameters
- Reduction of gas consumption by six percent
- New soft sensors for sensible proses parameters

References

PhD Work	Paper Fibres and Water Mixtures	Joseph Markel Prahl	Harvard University - Boston
PhD Work	Simulation der Trocknung Gestrichener Papire	Miklos Kanzamar	TU - Darmstadt
R&D project	The Effect of Water Penetration on Offset Mottling	Hideki Fujiwara	Research and Development Division - Tokyo
R&D project	Simulation of a Linerboard Paper Machine	Gary L. Jones	Institute of Paper Science and Technology - Atlanta
PhD Work	Heat Transfer and Energy Efficiency in Infrared Paper Dryers	Magnus Pettersson	Lund University - Sweden
R&D project	A Modelica Library for Paper Machine Dryer Section	Johan Akesson	Lund University - Sweden
R&D project	Computational Modelling of Paper Drying Machines	Shaun A. Reardon	TU - Tasmania
R&D project	Hard to Remove Water in Cellulose Fibres Characterised by Thermal Analysis	Sunkyu Park	State University – North Carolina

R&D project	A Critical Review of Drying Models for Coated Paper	Homero L. Noboa	A&M University - Texas
R&D project	IR dryers as a Tool in the Press Section	Peter Fisera	Andritz - Graz
R&D project	Optimisation of Steam and Condensate Systems of Paper Machines	Gerald Bachmann	Allplan – Wien
R&D project	The Wall Jet – to Surface heat transfer in Impingement Drying	Nenad Milosavljevic	Metso - Turku
R&D project	Combustion Measurement from an Impinging Radial Jet Reattachment Flame	J.W.Mohr	A&M University - Texas
R&D project	Effects of Drying Conditions on paper Quality on Wood Containing Light Weight Paper	Philip C. Norrdahl	Valmet - Tennessee
R&D project	Modelling of Web Drying	Mauri Soininen	Akademi - Turku
R&D project	Modelling Heat and Mass Transfer within a Moist Sheet of Paper or Board	Peter F. Lee	Weyerhaeuser – Washington
R&D project	Evaporation Drying Theory	Edward F. DeCrosta	Albany – New York
R&D project	A Simulation Model for Board and Paper Machine Dryer Section	Jouni T. Paltakari	University of Technology - Helsinky
R&D project	An Experimental Study of Contact Coefficients in Paper Drying	B Wilhelmsson	Lund University - Sweden

Authors

Peter Fisera
CF ProcSim GmbH
Responsible for simulation

Andreas Roither-Voigt
VOIGT+WIPP Engineers GmbH
Responsible for MVC