SHEET THICKNESS CONTROL SYSTEM OPTIMISATION BY MATHEMATICAL MODELLING AND SIMULATION

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ABSTRACT

Sheet thickness control systems usually regulate on felt speed and fresh slurry feeding flow. Determination of suitable controller parameters for both controllers by trial-and-error method can be raw material and time consuming. A time-discrete computer simulation of mathematical models representing the involved process components and software controllers can help to shorten commissioning times and to find better operating parameters.

The equations of the model can further be used to generate a feed-forward pilot control for the felt speed to reduce the sheet thickness tolerance range. This software add-on allows compensation of deviations of the slurry feeding system and faster changes in felt speed and machine capacity.

KEYWORDS:

Thickness control; sheet thickness; simulation; slurry density; felt speed

INTRODUCTION

Sheet thickness control systems are in most cases based on measurements with laser-triangulation-sensors. These can generate a large number of measurements within seconds on a high accuracy level of around 1/100 mm. To keep time delays low, the measurements should be generated in the earliest possible stage of the production process. Most advantageous is thickness measurement on the forming roller. Compared with widely-used sheet thickness measurement on the sheet conveyor system, this method additionally permits determination of the layer thickness. A new value is generated by each turn of the forming roller and even before the sheet is coiled up to the target thickness.

Figure 1: laser-triangulation-sensor

This paper reflects upon the current WEHRHAHN sheet thickness control system, consisting of two aligned software PI-controllers, a real time slurry density simulation and a model-based pilot speed calculation as shown in **Figure 2**. Flowmeters supply volume information of all slurries entering the homogenizer. Densities are either known from upstream processes or, in case of the return slurry from the recuperator tank, measured with a density-meter.

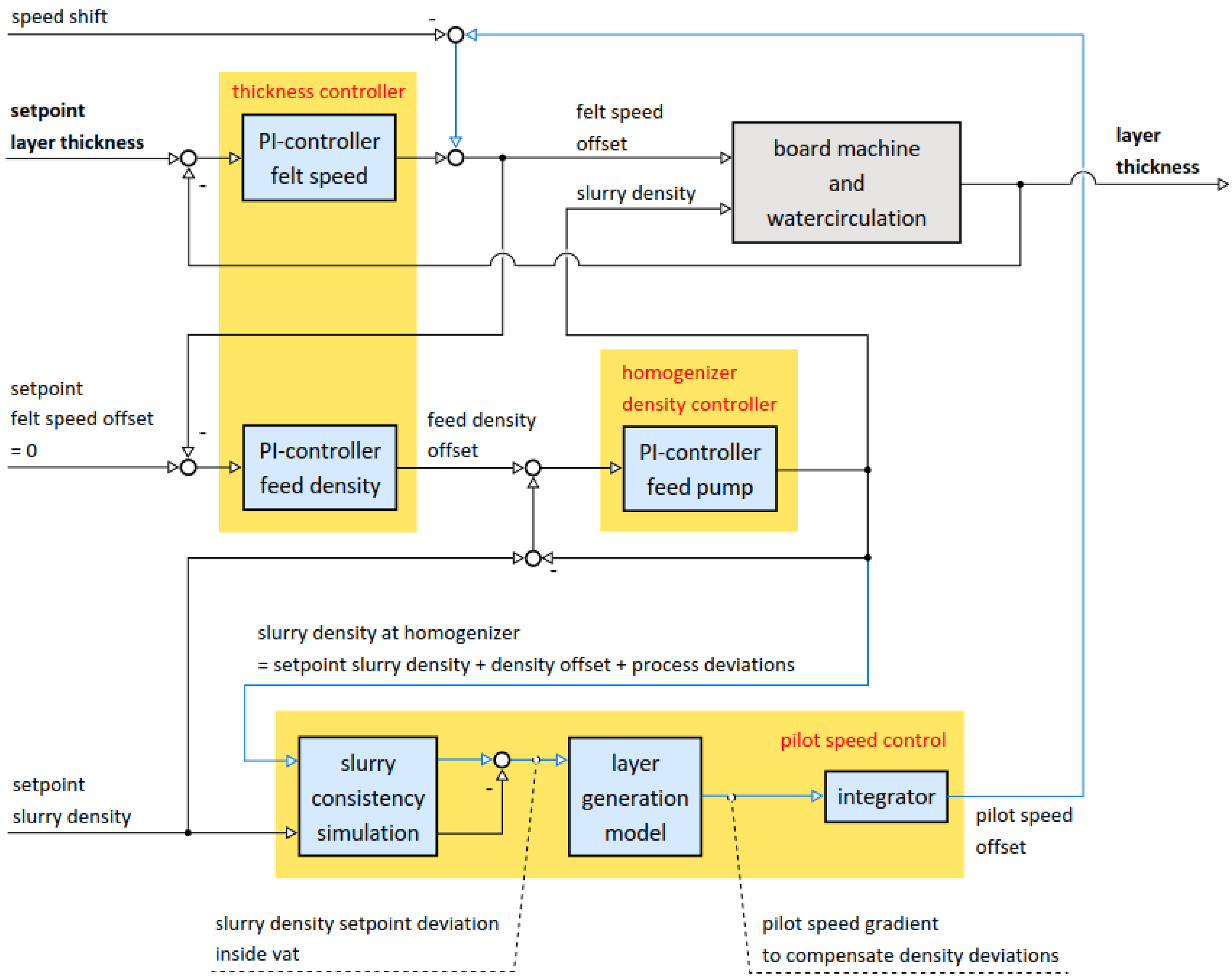

Figure 2: sheet thickness control system setup

MATHEMATICAL MODEL AND SIMULATION

Flow rates and slurry densities can be measured and controlled at the homogenizer. However, the primary layer thicknesses are generated on the sieves inside the vats of the board machine. Their measurement as a compacted secondary layer can earliest be done on the forming roller. The control path therefore contains several delay times and mixing operations that makes determination of suitable controller parameters difficult. Moreover trial-and-error activities for controller tuning can be very time consuming, ending up with lots of product outside the allowed thickness tolerance.

An expedient method for understanding and optimizing thickness control systems is mathematical modelling of the involved components and control devices. Based on mass balances, this method can describe the entire process of slurry feeding, mixing inside the homogenizer, feeding into the vats, mixing inside the vats, layer generation on the sieves and layer transport to the forming roller up to the thickness measurement. PID controller models can link the layer thickness signal with the slurry feeding characteristics and the felt speed. The resulting set of equations image the complete control path and the thickness control system.

Time-discrete simulation of the model-equations allows an approximate calculation and graphical display of e.g.

- slurry consistency inside the vats
- generated primary layer thickness depending of the actual felt speed and slurry density in the vat
- generated secondary layer thickness at the forming roller

- in- and output signals of the involved controllers

The system behaviour on different controller parameter settings for gain and integration time can easily be compared.

The results can be calculated by special simulation-software or, more simple, just by programming the equations in a spreadsheet program. Optimized controller parameters can be determined within short time. Applied to the PLC of the real system, improved performance of the thickness control can save tons of raw materials and improve the product quality.

THICKNESS CONTROL BY DENSITY VARIATION

Controlling the layer thickness only by variation of the homogenizer feeding density leads to a slow system reaction on any kind of disturbance or changes of the setpoint layer thickness. The time delay between changes in slurry density and full reaction on layer thickness is typically in the range of 2 minutes. Big volumes inside homogenizer and vats of older board machine designs and operation on low felt speed even increase this reaction time.

Figure 3 shows the typical behaviour after an increase of the setpoint layer thickness by 0,1 mm (upper diagram). The activity of the PI controller is shown in the centre diagram: Determined by the *gain-parameter* of the proportional part of the controller it immediately increases the feed density into the homogenizer by around 0,3 kg/m3. The further slurry density adjustment follows according to the controller's *integration-time-parameter* and the remaining control deviation between setpoint layer thickness (grey) and actual layer thickness (blue). Approximately 120 seconds after the setpoint change, the actual thickness has reached the new target thickness. The lower diagram shows the felt speed remaining constant as the felt speed controller is switched off.

THICKNESS CONTROL BY FELT SPEED VARIATION

Another option building a thickness control with only one controller is to regulate the felt speed as shown in **Figure 4**. Here the feed density into the homogenizer remains unchanged. As a reaction to the new target thickness, the controller tends to immediately reduce the felt speed. Fast speed changes however require immediate adjustment of the slurry flow into the vats to maintain the vat level. In practice the felt acceleration and deceleration therefore need to be limited, here to around 10 m/min², identifiable as the speed gradient at the first controller reaction. The felt speed is then continuously adjusted according to the setting of the controller's *integration-time-parameter*.

Due to the lag time between sieve pickup and layer transport up to the forming roller, the layer thickness does not change during the first approx. 30 seconds after the felt speed is starting to regulate. It then increases according to the controllers felt speed adjustment and approximates with a small overshoot to the new target.

It is obvious that thickness control by felt speed variation acts faster than variation of slurry density. In less than 60 seconds after the setpoint change the new target thickness is reached. The felt speed however remains permanently reduced by 4 m/min.

THICKNESS CONTROL BY DENSITY AND FELT SPEED VARIATION

Application of both, felt speed and feed density variation allows combination of the advantages of both systems: fast reaction time without permanent deviation from the setpoint felt speed. The number of controller parameters to be adjusted however is minimum two *gain-parameters* and two *integrative-time-constants*. Finding a suitable set of parameters can be time consuming without taking a closer look to the system properties and without setting up a system simulation.

Controller adjustment can have different targets. **Figure 5** shows setting to fastest possible response without oscillations, accepting comparatively slow return of the felt speed to its target. Another focus could be to achieve a universal setting that works on a wide range of felt speeds, compromising on response time and accuracy.

In case a system simulation is not available, parameters are usually set by experience and observation of the real system. A typical result is shown in **Figure 6**. The controller reacts in a similar time as in the optimized case, but with considerable overshooting of layer thickness and slight oscillations of felt speed and density. Faster return of the felt speed to its target but also increased thickness tolerances are the result.

HOMOGENIZER DENSITY CONTROL

The slurry density in the homogenizer has a strong influence on the layer thickness. It is therefore necessary to either keep the density constant, or in case the sheet thickness control system affects this density, it has to follow the sheet thickness controller demand.

Density control on the homogenizer can generally be realized in two different ways: One is to measure the slurry density at the homogenizer outlet and combine this measurement with an additional pump controller to regulate the input flow rate, coming from the slurry stock tank. Practical realisation of this method however is difficult, as it requires a high sensitive density meter that reliably operates under the rough conditions of a fibre cement production with abrasive solids and continuous material build-ups on all type of equipment. Another disadvantage is the reaction speed and the unavoidable high density tolerance, caused by measuring on the homogenizer outlet and controlling on its inlet.

The other way of homogenizer density control is to determine all input slurry densities individually and control the flow rate of the feeding slurry in such a way, that the mix density of all incoming slurries is determined and controlled according to the demand of the thickness control system. In detail: The *slurry density in the stock tank* is known from the preceding process. The *backwater density* usually does not change fast and can be double-checked regularly by manual measurements. The smaller quantity of *recuperator tank return slurry* can be measured e.g. with a continuous-flow metering tank on load cell before it enters the homogenizer. Flow rate information for all incoming slurries can easily be generated with flowmeters. Hence the mix density at the homogenizer is determined at its infeed. Control of the feed flow rate from the slurry stock tank likewise at the homogenizer infeed allows high control dynamic with low system related tolerances.

THICKNESS CONTROL BY DENSITY AND FELT SPEED VARIATION WITH PILOT SPEED CONTROL

The thickness controller demands a certain slurry density in the homogenizer. Deviations will lead to changes in layer thickness and again feedback to the thickness controller which will increase or decrease the demanded homogenizer slurry density anew.

As a mathematical model of the control path, consisting of homogenizer, vats and layer-generation already exists, this model can be used to predict the effect of density deviations on the layer thickness. The mathematical equations can be implemented into the PLC system to calculate the required felt speed to compensate the actual slurry density development in the vats in real-time. The computed felt speed is then used as a feed-forward pilot speed control.

In case the thickness controller includes a slurry density regulator and a felt speed regulator, the pilot speed control can be added to the felt speed regulator output. The pilot speed controller then compensates all slurry density influences and the felt speed regulator output corrects all other thickness disturbing impacts.

Implementing pilot speed control into the thickness control system has two advantages:

1. Deviations in the homogenizer slurry density control do not fully affect the layer thickness.
2. The dynamics behaviour of the sheet thickness control system improves as density changes are compensated before they get measurable as layer thickness deviations.

The setup of the complete system including felt speed controller, feed density controller and pilot speed controller is shown in **Figure 2** with the additional pilot speed control path marked in blue colour. The felt speed controller is working directly on the layer thickness feedback to achieve fast response on setpoint changes or process disturbances. The feed density controller returns the felt speed offset to zero by adjustment of the slurry density inside the homogenizer.

Figure 7 illustrates the above described thickness control supplemented by behaviour with the additional pilot speed feed forward control: Compared with figure 5 the layer thickness reaches its target likewise within 60 seconds after the new target thickness is set, but with even slightly reduced tolerance. The felt speed however recovers significantly faster. 300 seconds after the setpoint change speed deviation is less than 2 m/min.

Moreover pilot speed control allows changes in felt speed and machine capacity on a minimum of sheet thickness deviation during the adjustment phase. The density can continuously be increased while the pilot speed control increases the felt speed accordingly. If the mathematical model behind is close enough to the real process, then the felt speed controller is doing a minimum of thickness compensation during machine capacity adjustment.

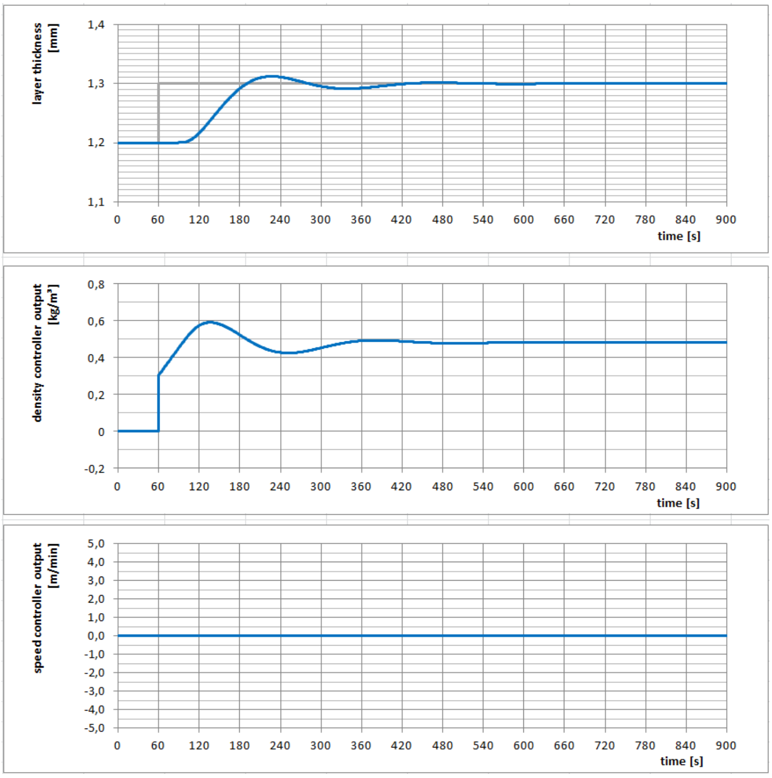

Figure 3: thickness control by density variation

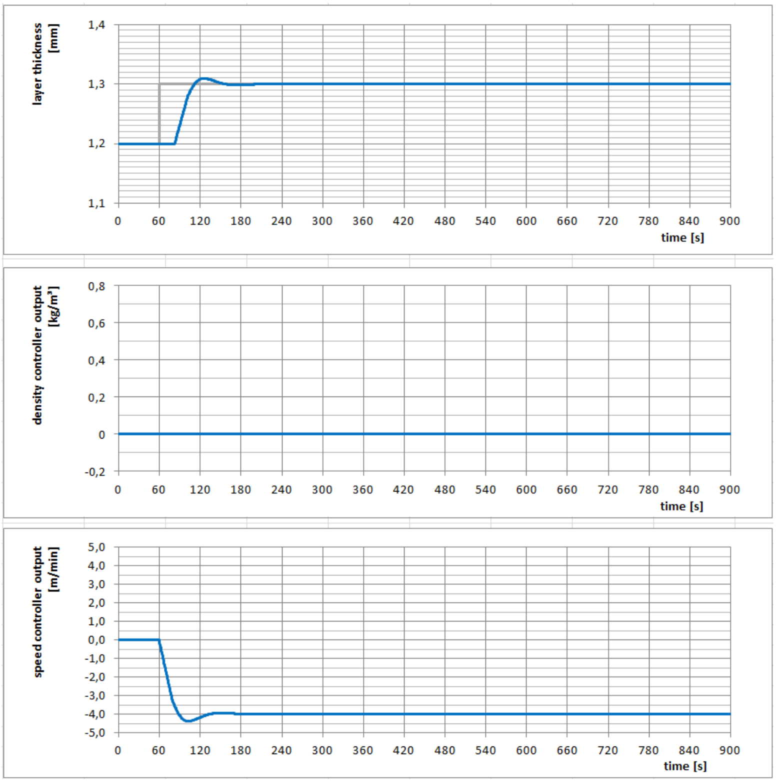

Figure 4: thickness control by felt speed variation

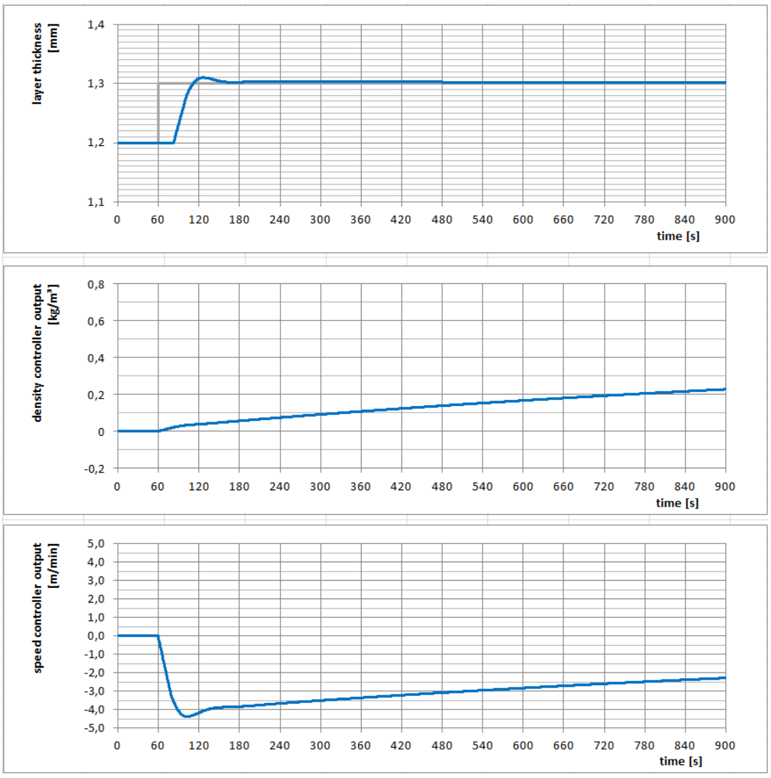

Figure 5: thickness control by density and felt speed variation, optimized parameters

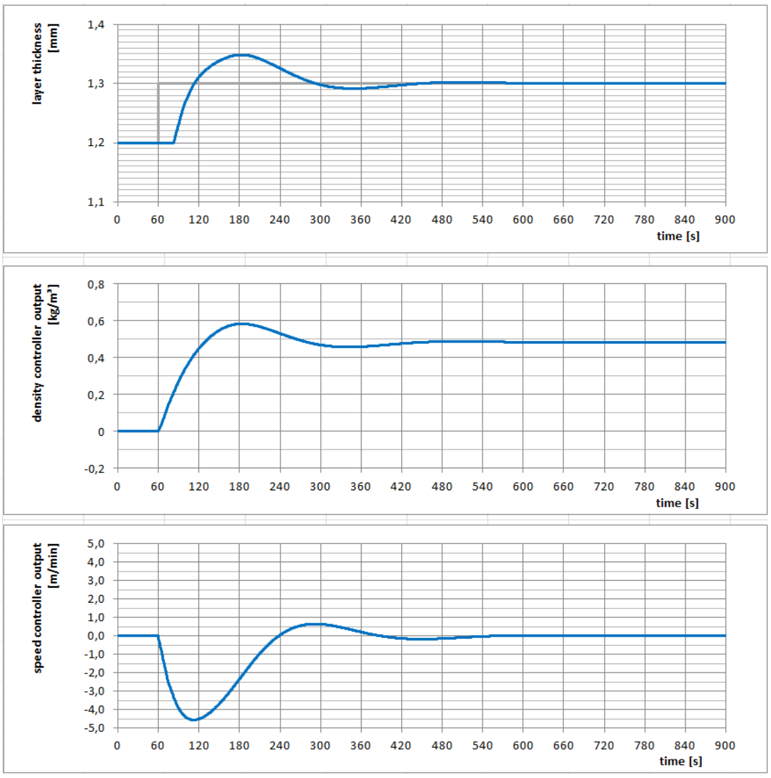

Figure 6: thickness control by density and felt speed variation, overshooting thickness

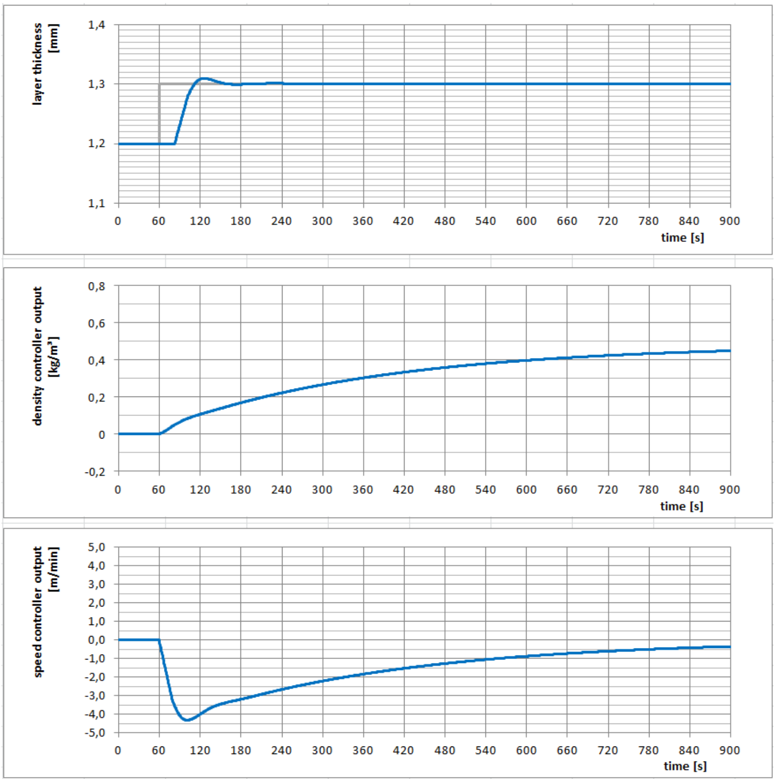

Figure 7: thickness control by density and felt speed variation with pilot speed control

PRACTICAL APPLICATION AND CONCLUSION

To compare the system behaviour on different layer thickness controller concepts, the graphs in figures 3 to 7 show the system reaction to a spontaneous change in setpoint layer thickness. On the board machine in reality this applies when changing the sheet thickness to be produced or when changing the number of turns on the forming roller for a certain sheet thickness.

Besides this, the process is usually disturbed by a variety of other influences, such as

- changes in the performance of the involved pumps, leading to deviations in the slurry density in the homogenizer
- changes in flocculants dosing causing altering layer generation and dewatering
- changes in consistency and properties of the return slurry coming back from the recuperator tank
- changing dewatering properties of the mix
- changes in return slurry consistency and content

To compensate these and other undesirable influences on the layer thickness and to achieve a fast and automatic adjustment of the slurry density it is advantageous to implement a fast reacting thickness control system into the process. Sophisticated controllers have several parameters to adjust. The described method of mathematical modelling and simulation allows finding optimised parameters to achieve the desired system behaviour. Implementation of an additional pilot speed feed forward control into the PLC system can enhance the control system performance.