A NOVEL INVESTIGATION ON COLD ROLLING CONTROL SYSTEM TO OPTIMIZE OF CONTROL DESIGN

Kourosh Mousavi Takami[1], Erik Dahlquist[2], Jafar Mahmoudi[2]
[1]PhD Student in MDH, TDI researcher, ACECR, IRI; [2]Prof. in Mälardalen University, Västerås, Sweden
Corresponding Author: K.M. Takami, IST Dep., Box 883, SE 721 23Mälardalen University, Västerås, Sweden;
Kourosh.mousavi.takami@mdh.se

Abstract. The main aim of cold rolling is reduction of strips to the desired final thickness. As the cold rolled strip is being manufactured from hot rolled strip, the uniformity of width, thickness, hardness, etc. are all now intended for improvement. To reach to this target, need to abound control system to reach the higher quality of slabs. It should satisfy the several factors, as regards geometrical, mechanical, chemical and surface properties.

Process control has taken advantage of new measurement equipments, new control actuators and algorithms. Automation and automatic process control can advance the quality further than what is achievable by manual control. This is an important desideration in rolling industry that rolling of slabs needs advanced and optimized process control to increase the productivity and reduction of the variations in the final properties.

A typical cold rolling stand performs one step in a chain of processes in the cold rolling mill, which can include pickling, rolling, annealing, temper rolling and downstream processes. All these processes contribute to the final properties of the strips. When the main process or the main objective is well controlled, it is important to continue with the other processes. In continuous annealing furnaces, the temperature controls the mechanical properties, but temperature differences and bending around rollers change the flatness. Temper rolling needs the same flatness control as other cold rolling processes. Cooling and lubrication can affect several properties of the strips.

Precise general control of the strip in a cold steel rolling mill will be discussed in this article.

Typically, the rolling process is modelled with numerical techniques. But these are not appropriate for a controller design, because they are too difficult. Thus, a linear mathematical model for the rolling process is presented here, which describes the interaction of the required influencing parameters. The attempt leads to numerically professional algorithms, which are essential to run in a real-time situation. With the help of these linear descriptions, the vital elements for the control are investigated. Modern rolling mills are equipped with a servo-hydraulic gap adjustment system, eccentricity control of the rolls, thickness, speed, force and tension controls.

A model to optimize of the control design process and increasing of accuracy is presented. In this way using the process transfer function in system at different control mode like to thickness, flatness, shape and etc designed a PID and PI optimized controller with using of the best optimization method, final properties increased. The measurements are used to verify the model approach and to detect the most significant sources of disturbances.

A new linearised numerical model for the rolling process which is suitable for closed loop control has been developed. The model is based on the calculation of the operating point using an available numerical method, followed by determining the partial derivatives at the operating point with respect to all input parameters. Finally, the partial derivatives are combined using superposition to describe the behaviour of the complete system. In this manner, the changes in the output parameters can be determined for small changes in the input parameters. This calculation is numerically efficient and suitable for use in closed loop control.

Moreover, we describe the roll eccentricity problem and the possibilities to perform compensation. Due to the great variety of solutions, a classification of the methods will be sketched. The basic properties of these classes are discussed. Then, a special solution is presented, which has proved its worth already in a practical application. The investigation of its properties is proposed to be typical for the whole class, to which the method belongs.

Finally measurement data which can be used to verify the new model will be performed. The model has been incorporated as a simulation system developed by the authors who enable the simulation of a multi-pass single stand rolling process. To get practical information about the rolling process, a data logging system was developed and installed in Sura AB for data collection.

1 Introduction

Two different keys methods in control system design are analysis and synthesis. Analysis is related to the impact that a given controller has on a given system when they interact in feedback while synthesis inquires how to create controllers with certain properties. Main focus of this job covers analysis. For a given controller and plant connected in feedback, to find that is the loop stable or not, it needs to answer: What are the sensitivities to various disturbances? , What is the impact of linear modeling errors? , How do small nonlinearities impact on the loop? [1,3]. It also need to investigation of several analysis tools; specifically: Root locus and Nyquist stability analysis to answer to some questions.

Here need to introduce the fundamentals of SISO feedback control loop analysis. Feedback introduces a cyclical dependence between controller and system: the controller action affects the systems outputs and the system outputs affect the controller action. For better or worse, this has a remarkably complex effect on the emergent closed loop. However, it is obvious that well designed, feedback can: make an unstable system stable; increase the response speed; decrease the effects of disturbances and decrease the effects of system parameter uncertainties, and more. In other hand, poorly designed, feedback can: introduce instabilities into a previously stable system; add oscillations into a previously smooth response; result in high sensitivity to measurement noise; result in sensitivity to structural modelling errors, and more [2].

Individual aspects of the overall behavior of a dynamic system include: time domain: stability, rise time, overshoot, settling time, steady state errors, etc. and frequency domain: bandwidth, cut off frequencies, gain and phase margins, etc. Some of these properties have rigorous definitions, others tend to be qualitative. Any property or analysis can further be prefixed with the term nominal or robust; nominal indicates a temporarily idealized assumption that the model is perfect; robust indicates an explicit investigation of the effect of modelling errors. Variations in output thickness can arise from the: variations in the thickness/hardness of the incoming beam and eccentricity in the rolling cylinders. Feedback control is necessary to reduce the effect of these disturbances. Because the roll gap cannot be measured close to the mill stand, the rolling force is used instead for feedback. The input thickness disturbance is modeled as a low pass filter driven by white noise. The eccentricity disturbance is approximately periodic and its frequency is a function of the rolling speed. A reasonable model for this disturbance is a second-order band pass filter driven by white noise.

Authors in this article tried to find the best controller to achieve the accurate and desired value of final properties. But question is that how can define the best controller? Authors to answer this question collected the data with using of instrumental sensors that installed on the cold rolling mill. Set point and desired value defined by producer, transfer function of the system achieved by machines manufacturer or automation system designer or have to find by authors and finally using the set point, desired value in the final production and transfer function of system can find the proper controller. After that, to study on effect able parameters on system and noises should be tried. Using the real time output of mill, desired value or reference value the best constant and parameter in controller can be estimated.

2 System Model and controllers designing

Figure 1 shows a modern proposed control system with installed measuring devices to sense of variables and transfer to data base using modern transmitting equipments like optic fiber and other data acquisition systems. Feedback, feed forward, position, mass flow, wedging and other modern control systems will be discussed and optimized during this paper. To achieve the best set point and reach to high quality final product needs to define optimized constants in controllers. It analyzes and changes by different values and signals behavior due to this change will be discussed. One of the main parts of control diagram is the system transfer function. System behavior to input and noise depend to transfer function of system. Based on TF's controller will be designed and optimized with optimum choice of constants and controller. In most of this report due to lack of TF, it set to a constant value. In next step of job, Surahammars Bruk AB cold rolling TF will be used to analyzing of the model and controller. [4]

To reach the control model needs to define physicals formulae. According to conventional defined formulae this job will be done. The exit thickness h is obviously related to the gap between the rolls, which is, in turn, related to the unloaded position of the backup rolls s (also called the unloaded screw position) and the input thickness H. More specifically, the force on the rolls is given by $F = M(h - s)$. However other equation related to the force is defined by: $F = W(H - h)$. Consequently; $h(M + W) = Ms + WH \rightarrow \mathbf{h} = \frac{M}{M+W}s + \frac{W}{M+W}\mathbf{H}$. In this simulation, due to lack of transfer function (TF) of system, above constants set with: $\frac{M}{M+W} = \mathbf{1/3}$ and $\frac{W}{M+W} = \mathbf{2/3}$, these are depended to the reduction rate.

Because of impossibility to measure of exit thickness of slab immediately after leaving from the roll gap, it can be measured in advance the line, this make a delay to the system and should be consider in the control design of rolling mill.

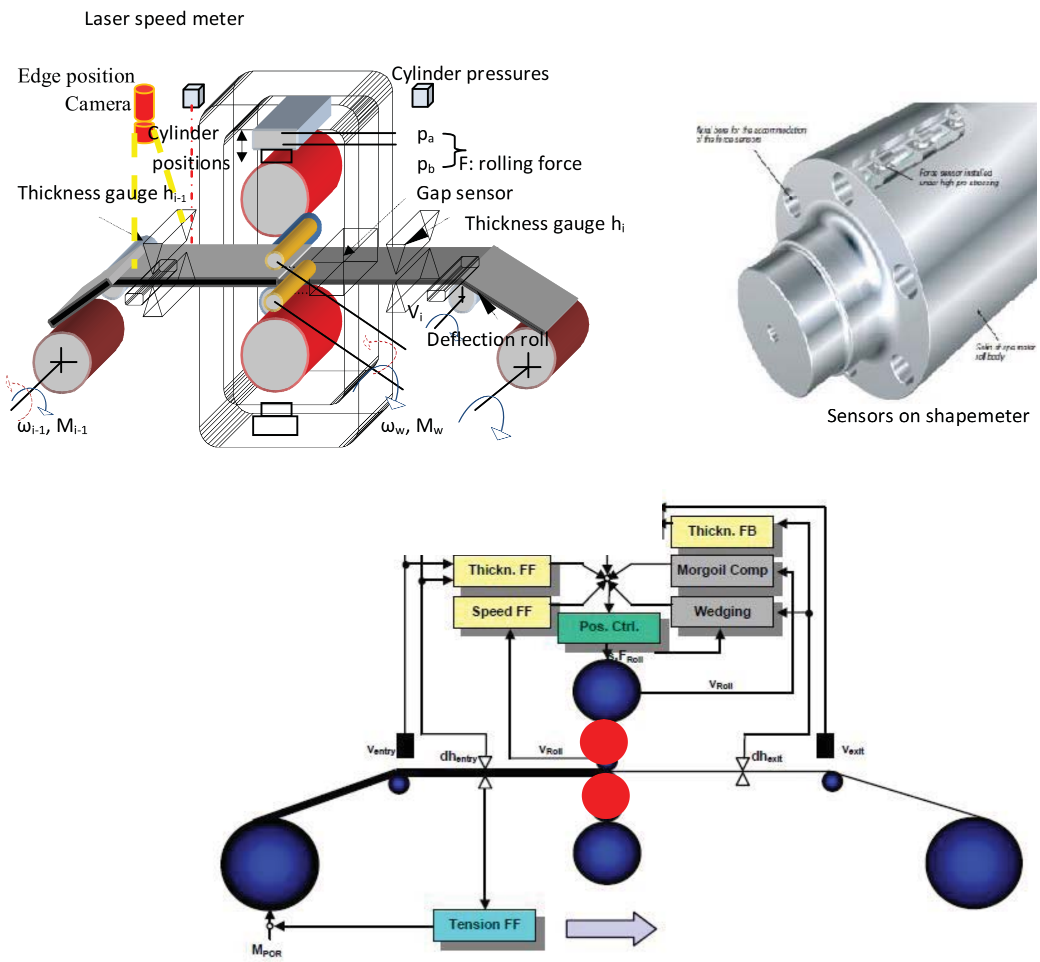


Figure 1. Control Concept with thickness gauge, laser speed measurement and with tension feed-forward [5]

This delay time depends to slab's speed in the exiting side, then should be assumed a times delay like 1 second to cover it. (We know intuitively that a measurement delay is undesirable, since the control system is working with information which is not current). This leads us to the following model for the closed loop system that TF is not activated here because of the lack of that. Switch in this model is a virtual switch and is like a logical operator, OR.

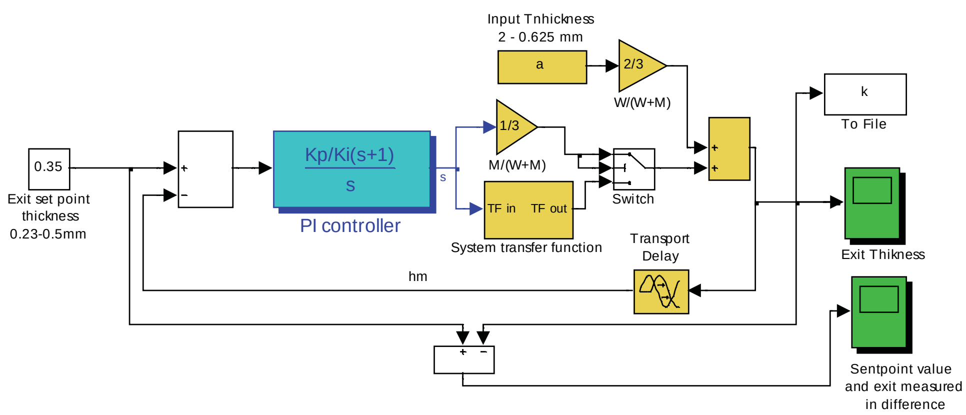


Figure 2. Control diagram

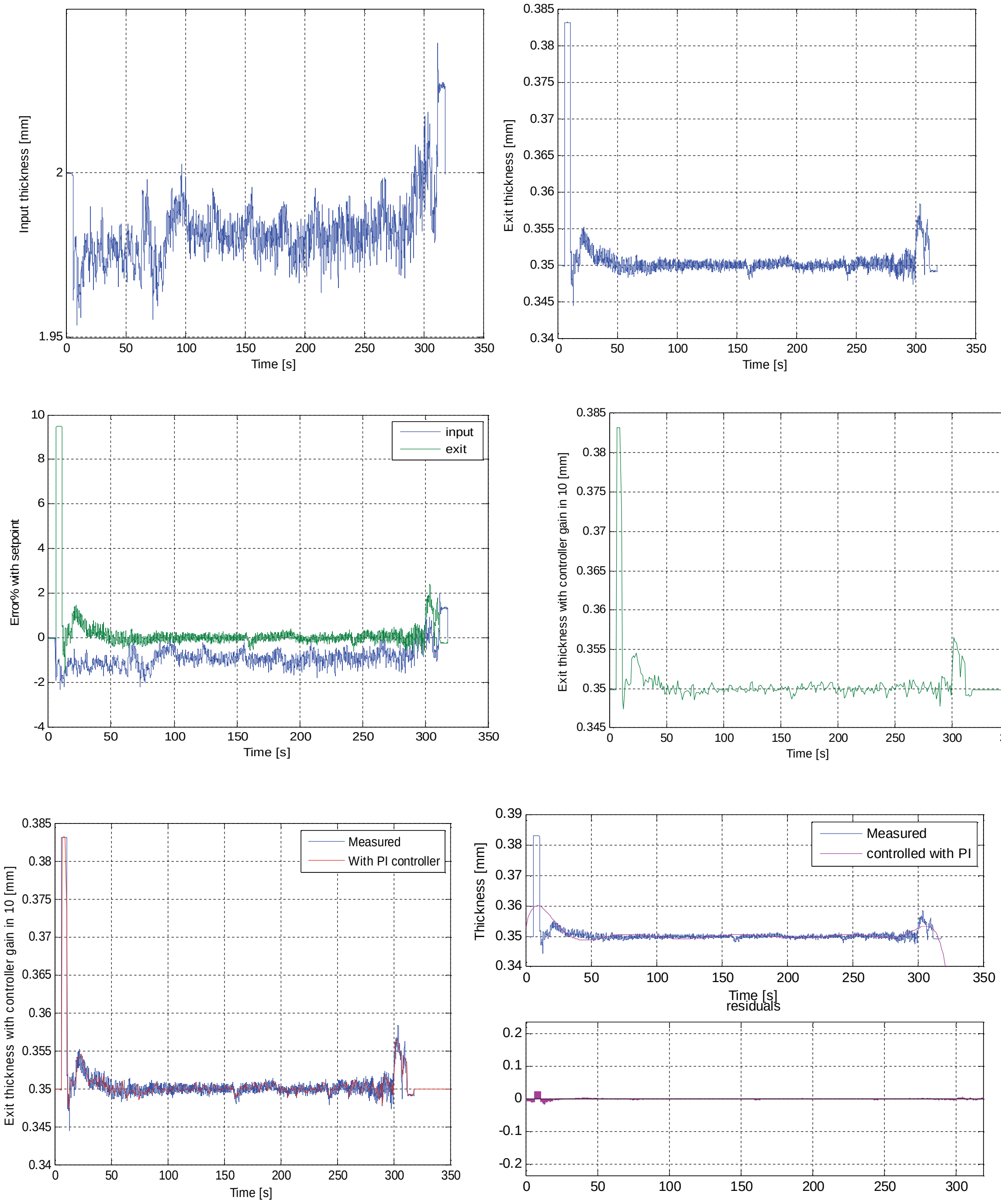


Figure 3. Resulted curves

The controller is$C(s) = (K_p/K_i)(s+1)/s$, that (K_p/K_i) called gain, in the controller. To run the model, $k_p = 0.25$ and $k_i = 2.5$ are set to provide a reasonable response. These are illustrated in figures 3. There is also a 11 ms time constant associated with changing the screw position *s* which is not shown in the above diagram. Tos tudy on controller effect can change the thickness *H*, the controller parameters k_p and k_i and the amount of measurement noise in the system. When change the input thickness, shows the "disturbance" approaching, and it only takes effect when it reaches the rolls. To overcome on the effects of time delay Smith predictors can often be used. The following diagram shows the Smith predictor. Since time delays are very common in real world control problems, it is important to examine if one can improve on the performance achievable with a simple PID controller. This is especially important when the delay dominates the response. For the case of *stable* open loop plants, a useful strategy is provided by the Smith predictor. The basic idea here is to build a parallel model which cancels the delayHere also set the controller on$C(s) = (K_p/K_i)(s+1)/s$. To run the model with proposed configurations set the $k_p = 0.7$ and $k_i = 7$.

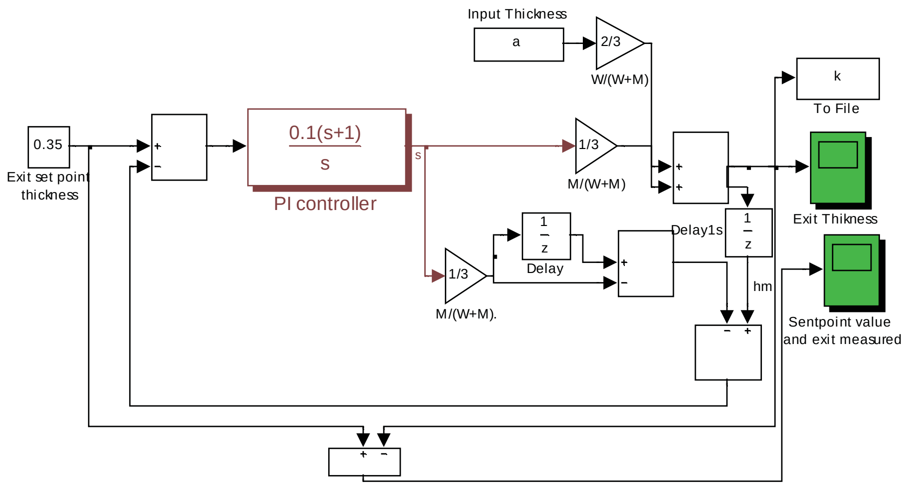
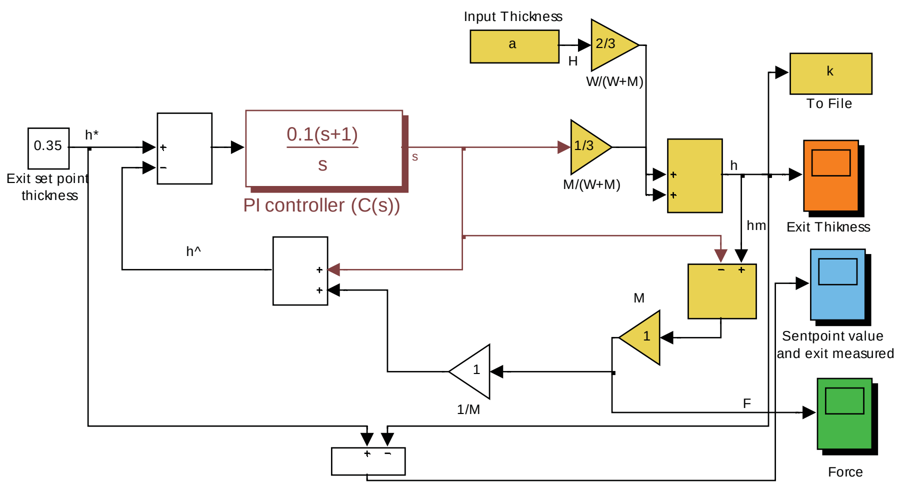


Figure 4. Control diagram with smith predictors

Control model analyzed by change in set point of output and input thickness and so gain of controller and concluded that: With change the set point to 0.3, the delay has no effect on the set-point response due to the Smith Predictor. Input thickness changed to 0.5 but the time delay still affects the disturbance response. With increasing the controller gain to try and increase the system's response speed observed that the system still goes unstable for a high enough gain, but it can handle higher gains than before. The Smith predictor definitely improves the set-point response, but does nothing for the disturbance response. This delay in the disturbance response is a problem because the disturbance affects the product (as much as two meters of steel could be deformed because of this). The Smith predictor also allows higher controller gains (and therefore faster responses) without the system going unstable, but the closed loop system is now more sensitive to modeling errors.

2.1 Soft Sensors

Using the force on the roll can guess the exit thickness of cold rolling system with avoiding of the time delay. This device is known as BISRA gauges. Because of that $F = M\,(h - s)$, force can measure and then estimate exit thickness with$\hat{h} = \frac{F}{M}+s$. Figures 5 show the control diagram of this system.



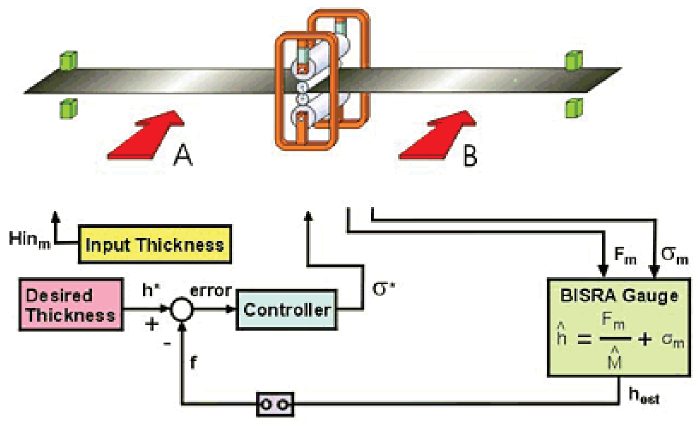


Figure 5. Control diagram of system with using of force to exit thickness measurement.

The control parameters can be chosen as k_p = 10 and k_i = 100. By eliminating the delay in the system, we allow much faster responses (with time constants as low as 10ms). Since such fast responses would not be easily visible in real-time.

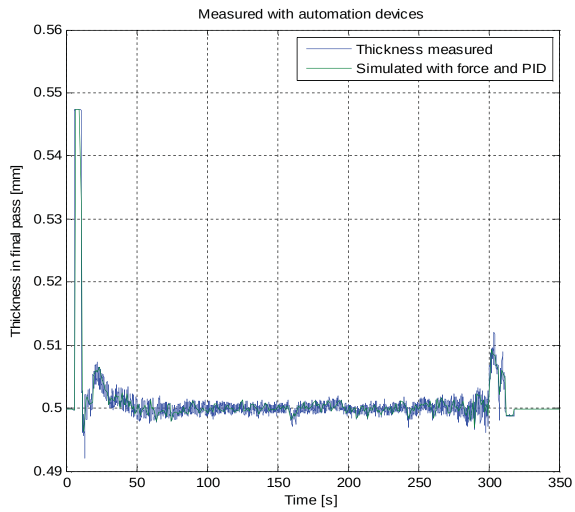


Figure 6. Result of simulation thickness with and without PID controller with force loop

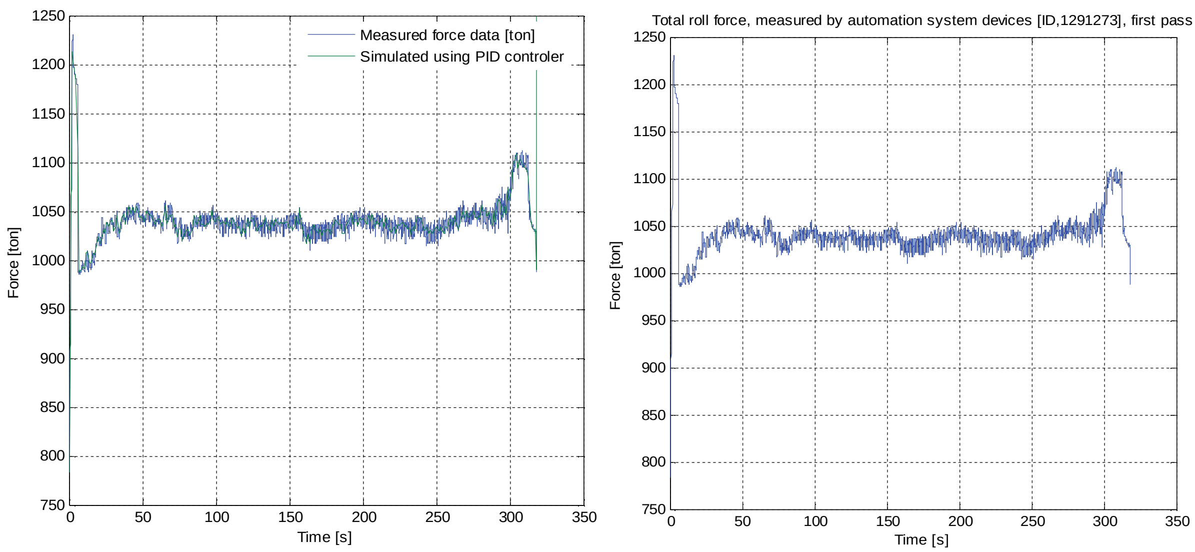


Figure 7. Result of simulation force with and without PID controller with force loop

With run the simulation found that the system's response is much faster now, but the sinusoidal variations are much larger. With change the set point to 0.3 observed that the delay has no effect on the set-point response.

With change the input thickness to 0.5 found that the delay now has no effect on the disturbance response. Increase the controller gain to try and increase the system's response speed lead to the gain must be much higher for the system to go unstable, meaning that this system can have a larger closed-loop bandwidth. Results showed in figures 6 and 7.

It has most likely observed that now the system's response speed is now very fast. However, the sinusoidal variations in the output have increased in size to the point where they can no longer be ignored. (Previously, the time delay was our main concern.). The sinusoidal variations in exit thickness are due to the fact that the rolls are not perfectly round, but contain various "bumps" or imperfections. These imperfections are known as the eccentricity of the roll. Eccentricity is a periodic signal, since it will repeat each time the roll completes a revolution. This periodic signal can be expressed as a Fourier series (i.e. in terms of sinewaves). For simplicity, the eccentricity was modelled as a single sinewave in the simulations (which corresponds to an elliptic roll). The model of the system can then be modified to include the effect of eccentricity. The eccentricity signal e is defined such that a positive value indicates that the roll is wider than normal. Thus, when the roll is wider, the force on the roll will increase, since $F = M\ (h - s + e)$. We then find that the exit thickness is given by $h = \frac{M}{M+W}s + \frac{W}{M+W}H + \frac{M}{M+W}e$. Note that the eccentricity signal is attenuated by a factor of $\frac{M}{M+W} = 1/3$ in the uncontrolled, open-loop system (i.e. the effect of eccentricity on the output is one third of the input value). The actual system is shown in the control model in figure 8. This has severe implications for the BISRA gauge, since the estimated exit thickness is actually: $\hat{h} = \frac{F}{M} + s = h + e$. So the controller thinks that the eccentricity variations are disturbances in the output and compensates for them. This explains why the eccentricity appears unattenuated on the output of the system.

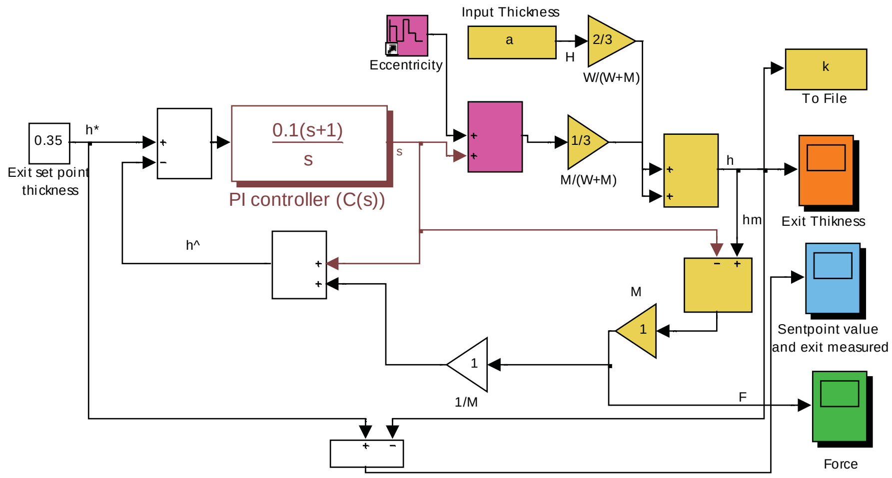


Figure 8. Control diagram

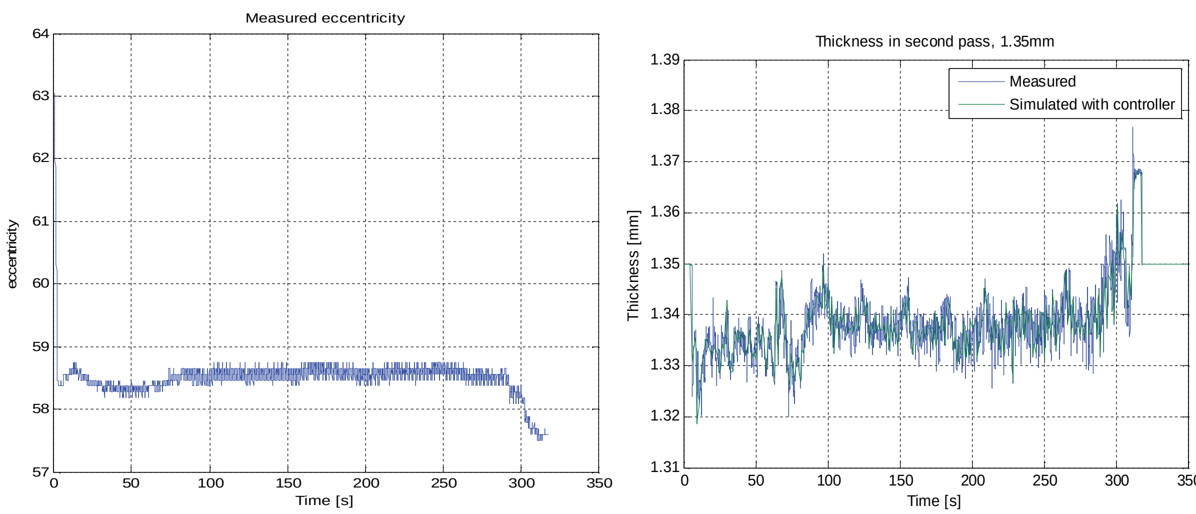


Figure 9. Result of simulation

Next, we look at the use of a Kalman filter (another "virtual sensor", "soft sensor" or "observer") to estimate the eccentricity and remove it from the thickness measurement.

2.2 Observers

To estimate roll eccentricity, we view the output of the BISRA gauge (which is h + e) as the eccentricity e plus some noise. Before using an observer to estimate the roll eccentricity, is needed to model it. As before, this model is chosen to be a single sinewave of period 200ms. A suitable "system" for this sinewave of frequency w is $\begin{bmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\omega^2 & 0 \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} u.$

The output of this "system" is simply x1 (so C = [1 0]). We can then design an observer $= [J_1 \quad J_2]^{-1}$, for this system to estimate the state variables of the system: $\dot{\hat{x}}(t) = (A - JC)\hat{x}(t) + Jy(t)$. The closed loop characteristic polynomial of this observer is: $s^2 + J_1 s + J_2 s + \omega^2$ and using this equation with the desired characteristic polynomial can place the observer poles at the desired locations. Alternatively, with using of the Kalman filter equation to find the optimal J it is possible. As a starting point, can be chosen $J_1 = 120$ and $J_2 = 0$. Once there is this estimate of eccentricity (i.e. the estimated x1), it can subtract it from the output of the BISRA gauge to give the new estimate of exit thickness: $\hat{h} = h + e - \hat{e}$. To improve performance further, then emulate disturbance feedforward by subtracting the estimated eccentricity from the controller output u. This lead to the following model for the closed loop system:

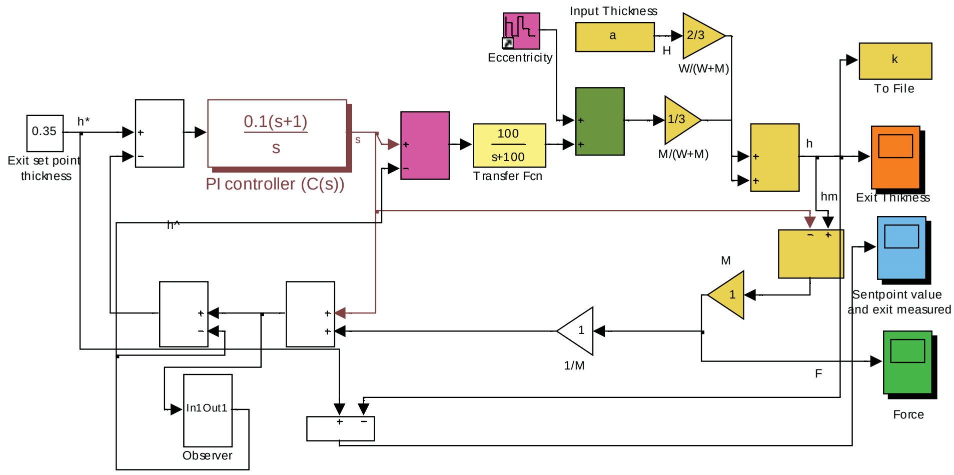


Figure 10. Control diagram

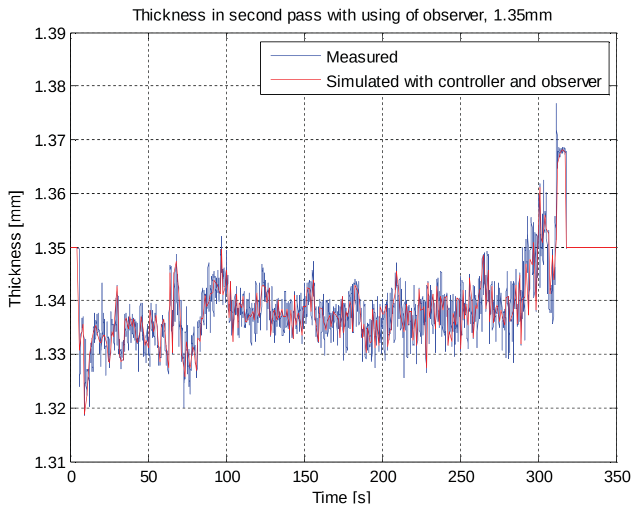


Figure 11. Result of simulation

The control parameters have been chosen as kp = 20 and ki = 200. With run the simulation in MATLAB, Simulink, The system's response is as fast as in the previous case and the sinusoidal variations are almost no-existent. The set point changed to 0.3 and the input thickness set to 1.35 and this lead to that the delay has no effect on the set-point or disturbance responses (but the sudden change causes the eccentricity estimate to be incorrect. Redesigned the observer using the Kalman filter equation and the result shows better observer performance can be achieved, but the effect of the rapid output changes on the eccentricity estimate cannot be removed. This simulation shows that with the observer, the roll eccentricity effect is enormously reduced. Actually, for an eccentricity of 0.03, the effect on the output is 0.0024, which represents a 92% reduction, which is quite respectable considering the uncontrolled system, performs a 66% reduction. The effect of the eccentricity signal could only be zero if (1) had an always perfect estimate of eccentricity and (2) could subtract the estimated eccentricity directly from s (which is not possible since can only control u). Thus, the filtering effect of the time constant of the screw position means that the eccentricity will always have some effect.

It may have observed the oscillation in both the set-point response and the disturbance response. This is due to the inaccuracies of the eccentricity estimation at these points (a fact easily observed from the graph of estimated eccentricity). The observer will see a change in its input signal, and will take some small amount of time to correct for this.

As it have seen with the progression of these simulations, as it delve deeper into the control problem, it can achieve better performance using more sophisticated methods from control science. However, with each solution comes a new limit on performance (which is better than the previous limit), and hence a new problem to be solved. As it may have guessed, the Kalman filter solution (allowing increased system bandwidth) is by no means the final solution - there exists a phenomenon known as the "hold-up effect" which prevents the system from achieving the promised 10ms response time.

2.3 Rolling Mill Shape Control

2.3.1 System Description

Cold rolling mills are an abundant source of control problems. Typically, the stand consists of a small diameter work roll and a larger backup roll on each side of the steel strip. Significant amounts of energy are required to achieve the desired thickness reduction. Much of this energy appears as heat on the work roll, which is removed with cooling sprays. This leads to non-uniform thermal expansion across the work roll, referred to as thermal camber. The problem of keeping the roll edge flat is called shape control. Numerous cooling sprays are located across the roll, and the flow through each spray is controlled by a valve. The cool water sprayed on the roll reduces the thermal expansion. The interesting thing is that each spray affects a large section of the roll, not just the section directly beneath it. This leads to an interactive MIMO system, rather than a series of decoupled SISO systems.

2.3.2 Rolling Mill Shape Control

2.3.2.1 A review on the strip shape

Slabs can be bended around it when it entered between the rolls and tolerate forces for making a reduction. This phenomenon likes to make a thicker part in the middle and thin in the edges. Due to thinner in edges, it is seen wavy edges. Roll deflection named this phenomenon that rolls bended around the sheet.

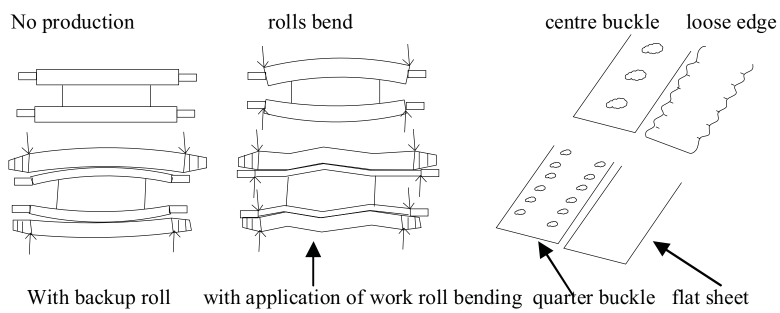


Figure13. Basic Types of Sheet Shape **Figure 12.** Roll shapes

Using the backup rolls with a larger diameter to support of rolls can stiff the works; however, it cannot solve the main problem. Some hydraulic jacks to force to the works rolls used behind their, this force balanced the weight of the top half of the roll stack. To getaway the loose edges make this over pressings by bending the rolls. For roll balance and roll bending duties separate hydraulic cylinders used by mill designer in this system. Not only this didn't remove the problem but also another problem crated in improvement it. In this way buckles move from the edges to points a quarter of the across the sheet on both side of slab due to the different fulcrum points of the application of the various forces; this named as quarter buckle in industry. Figure 11 and 12 show the problems. Other problem in this area is roll heating. Roll separating force is needed in reduction process and energy needs to turn the rolls. Problems related with bending of rolls made by this forces. Due to reduction heat generated in the strip, in the center of sheet this heat is more than of other parts, it gradually tapers off towards the edges. Expansion in metal is made when it is heated. This heating's made by roll turning and sheet reduction in thickness. Therefore, the rolls are going to expand in the center of the sheet. This attempts to get rid of some of the "rolls bending around the sheet effect", but if left unchecked could lead to that the sheet to become thin in the center and show signs of buckles in this area, named as center buckles. Any way with increasing of mill speed, heat generation rate will being increase and it lead to accelerated roll expansion and named as thermal crown. Control of this phenomenon has two ways, either slows the mill down or spray coolant on the work rolls. Due to multi jobs of coolant for cooling the rolls, lubricant to reduction process that allows the roll separating force to reduce to a lower value and it cleans debris consisting mainly of metal fines and oxides, its material is important to choose. The lubrication effect causes the rolls' surface wear at a lesser rate than if coolant were not used. By making the reduction process more efficient, the lubrication portion of the coolant lowers the amount of heat generated into the rolls. On a steel temper mill a 2% reduction can be made at, say for example, 400 tons of separating force when no coolant is used. If a lubricant is applied, the reduction, at the same 400 tons can be as high as 30%. Coolant should be sprayed in related zones to control purposes. With high coolant flow, rolls can cool and make them contract in that zone, with low volume of coolant, it allow that zone to heat up and expand. It means in conjunction with the reduction cooling rate changes, (that makes the rolls bend), and the roll bending forces to control the buckles. It is necessary that the high flow zone to be in the location of the buckle, and the low flow zone to be in the location with no buckle. In view of the fact that rolling is a dynamic operation, the buckles move from edge wave, (also named as loose edges), to full center, to quarter buckle and back again. Periods where the buckles are so small, the sheet looks flat, may be occurred. To control of this process, the sprays have to be continuously adjusted. The tendency to create of buckles increases and more adjustment is needed than when rolling heavy gauges, when the sheet thickness lowers. The same is valid for mill speed, when mill speed an increase, more adjustment is needed than when have the low mill speeds. Figure 12 shows these different types of sheet shape.

2.3.3 System Model

The model for the system is shown in the block diagram below, where **U** vector of spray valve positions and **Y** is the roll thickness vector. (The bold lines indicate vectors rather than single signals).

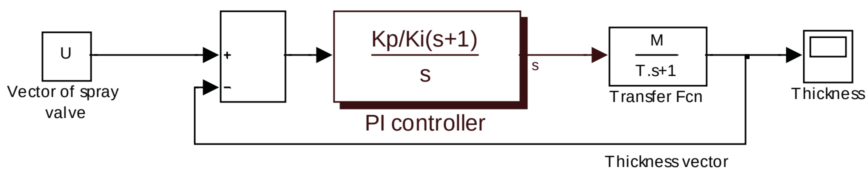


Figure 14. Control diagram

The sprays affect the roll as described by the matrix **M** below. The parameter $\propto$ represents the level of interactivity in the system, and is determined by the number of sprays present, and how close together they are.

$$M = \begin{bmatrix} 1 & \propto & \propto^2 & \ldots\ldots\ldots. \\ \propto & 1 & \ldots\ldots\ldots\ldots\ldots & \\ \propto^2 & \ldots\ldots\ldots\ldots\ldots\ldots\ldots & & \\ \ldots\ldots\ldots\ldots..1 & & & \propto \\ \ldots\ldots\ldots\ldots..\propto & & & 1 \end{bmatrix} \quad M^{-1} = \begin{bmatrix} \frac{1}{1-\propto^2} & \frac{\propto}{1-\propto^2} & 0\ \ldots\ldots\ldots.0 & \\ \frac{-\propto}{1-\propto^2} & \frac{1+\propto^2}{1-\propto^2} & \ldots\ldots\ldots\ldots\ldots & \\ 0\ \ldots\ldots\ldots\ldots\ldots & & \ldots\ldots\ldots\ldots\ldots\ldots.\ 0 & \\ \ldots\ldots\ldots\ldots\ldots\ldots & & \frac{1+\propto^2}{1-\propto^2} & \frac{-\propto}{1-\propto^2} \\ 0\ \ldots\ldots\ldots & 0 & \frac{-\propto}{1-\propto^2} & \frac{1+\propto^2}{1-\propto^2} \end{bmatrix}$$

Using this matrix to decouple the system amounts to turning off surrounding sprays when a spray is turned on.

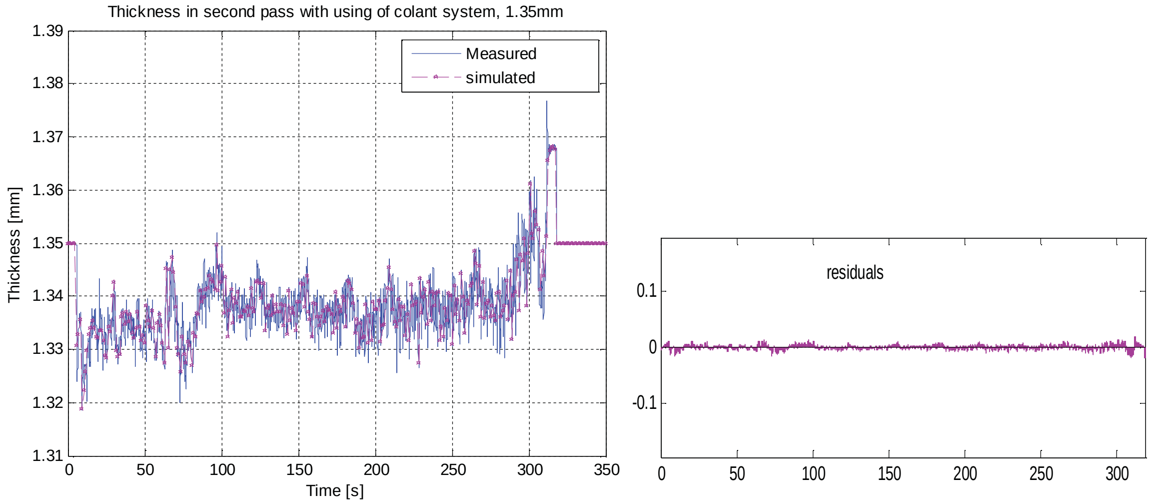


Figure 15. Simulated results

So we can decouple the system simply by multiplying the control vector by this inverse. This set up is shown in the block diagram below.

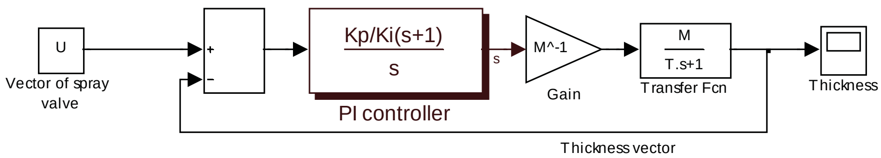


Figure 16. Control diagram

The controller is then a set of simple PI controllers linking each shape meter with the corresponding spray. (It assumes the shape meters measure the shape of the rolls perfectly). It may at this stage seem that adding more sprays will give finer control of the roll shape. However, as more sprays are added, α approaches 1. The system is then less robust, since the matrix **M** is almost all 1s, and the inverse of **M** has very large numbers. The system is then very sensitive to errors in the estimation of alpha, due to the large gains present in $\mathbf{M}^{-1}$. In practice, the set point is fixed, but output disturbances occur. Applying step set-point changes is similar to applying step output disturbances, as a very similar type of response would be seen. The decoupling method works extremely well. The highly interactive system becomes completely decoupled, allowing control using simple PI controllers.

2.3.3.1 Saturation Effects

The previous simulations assumed that the spray valves could be opened infinitely, and also assumed that the sprays could somehow suck water back into the spray when required. Clearly, these are not realistic assumptions, since the valves have physical saturation levels. The block diagram of the system with this actuator saturation in place is shown in figure 17.

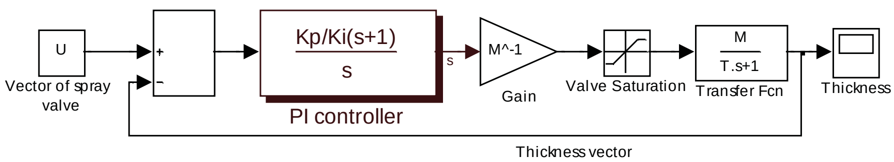


Figure 17. Control diagram

The saturation can cause integrator windup in the PI controller. Note that *C(s)* is diagonal with the same entry on each diagonal. M^{1} is non-dynamic and can be commuted with *C(s)*. This gives the anti-windup arrangement shown in figure 18.

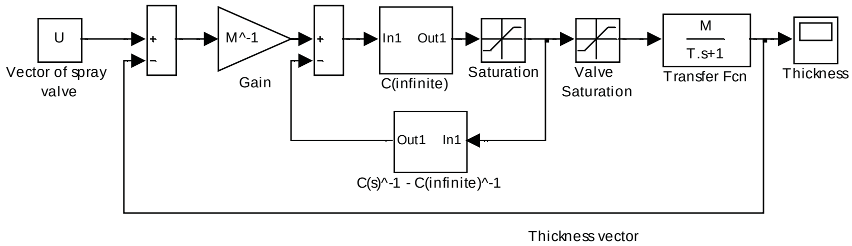


Figure 18. Control diagram

This controller form reduces the overshoot in the step response, but interferes with the decoupling, since the saturation occurs after the matrix inversion. It is almost identical to the previous simulation, except the decoupling mechanism is always enabled.

The saturation of the spray valves interferes noticeably with the decoupling. This suggests that a more sophisticated control strategy is needed to overcome these difficulties. The problem is that the saturation does not allow the decoupling matrix to work effectively. One method of overcoming this would be to scale the error for each PI controller, so that the controller output is never larger than the saturation limit. This ensures that the decoupling will work, since the valve saturation will have no effect on the control signal (since it is already within the saturation limits). However, such a control strategy is difficult to implement. This highlights the difficulties posed by non-linearity's in MIMO systems.

3 Conclusion

Design of control system in cold rolling mill with abundant controller is a complicated job. First designer have know about system performances, system problems and system compatibilities. Choosing of controller to achieve the stability, final accuracy, safety and reliability of system is other option in designing. Using the existence operator in system like estimators, adaptation systems, identifier, delay blocks, calculator and displayer could obtain the best design of controller system. Authors in this paper found and designed the simple, capable and reliable controller which is used in single stand cold rolling mill of magnetic core production factories. It showed that with using of PID controller, smith predictor, Kalman estimator, saturation operators and delay function can reach to fast and accurate system. These controllers' helps to find the accurate thickness in exit with good best fit to output set point, cancel the disturbances in input or output of system, and control the shape with control of spray valves.

4 References

[1] Erik Dahlquist: *Process technology and process simulation.* November 2006, Malardalen University Press, Västerås, Sweden, (Book)

[2] Graham C. Et al., *control system design.*

[3] Kourosh Mousavi Takami, Erik dahlquist: *process control report in cold rolling mill*. Malardalen University, Västerås, Sweden.

[4] Surahammars Bruks AB, www.sura.se

[5] Kourosh Mousavi Takami, Jafar Mahmoudi, Erik Dahlquist, Magnus Lindenmo, *Process control in steel core production to optimize of power dissipation in electrical machines and transformers*, submitted in SSSEC2009 conf., Stockholm, Sweden