CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Rolling is the most widely used deformation process. It consists of passing metal between two rollers which compress it to reduce its thickness. A set of roller is called a stand, and in a mill there may be more than one stands. The roller in contact with the metal are called work roller. Often back up rollers are provided to increase the rigidity of the work rollers for improving the dimensional control. Steel may pass through from one stand to another for a number of times before it reaches the required thickness and shape.

Cold rolling is one of the most important processes in an integrated steel works because it improves the accuracy in controlling the sizes and produces thinner gauge products with a bright smooth surface. It is carried out at room temperature and is often used in the final stage of production. Compared to hot rolling, the sheets, strips and foils in cold rolling have better dimensional accuracy, high quality, surface finish and mechanical properties.

In the rolling mill, the term ‘web’ is used to describe materials that are manufactured and processed in continuous, flexible strip form, which is very long compared to its width and very wide compared to its thickness. The web must pass through several processing sections in the manufacturing process it attains its desired shape. All sections of the continuous process are
coupled with the web. Web handling and processing pervade almost every industry today. Web handling involves unwinding material, feeding it to a processing plant and winding it back into a roll after processing.

Continuous improvement in quality is one of the most important principles in cold rolling because the customer expects good quality products. In conjunction with the development of new technology in electronic devices, computing equipment and modelling, automation of rolling mills has been made remarkable progress in recent years.

It is essential that the web must follow a predetermined path amidst rollers in a longitudinal direction at a constant velocity and at a constant tension. Deviation from this may result in an inferior product quality that may be detrimental to further processing. With the need for increased productivity and performance in the web processing industry, accurate modelling and effective controller design for web handling systems are essential. Hence in this work, mathematical model of the web guide system has been developed ignoring the mass and stiffness of the web. This model has been approximated to First Order Plus Time Delay with Integrator (FOPTDI) transfer function model. PID controllers have been tuned using various methods and its performance evaluation has been made comparing with Internal Model Control (IMC) and Ziegler Nichols (ZN) method of tuning. Model uncertainties exist in the web and the robustness of the controller has also been verified using Kharitonov’s theorem.

1.2 OBJECTIVE OF THIS RESEARCH WORK

Control theory is widely applied in steel works, as well as the whole process, from treating the raw material to producing final products. Control techniques used to obtain consistent quality in modern mass production are necessary because this means changing the state to achieve the
desired state by carrying out appropriate operations. An automatic gauge control system of the process to be controlled, the system and the sensing system are shown in Figure 1.1. This research work deals with the design of controller for intermediate web guide in a cold rolling mill. To locate the web on the center position of roller, a PID controller has been designed using various methods. The web and guides were modeled by using geometrical relations ignoring the mass and stiffness of the web. A PID controller for the centre position control of the web has been tuned by the following methods.

![Figure 1.1 Automatic gauge control system](image)

The objectives of the present work are:

To design a controller which is differently tuned by the

(i) Equating Coefficient method (EC)
(ii) Direct synthesis method (DS)
(iii) Model Reference Control(MRC)
(iv) Dual Loop Control(DLC)
(v) Fuzzy logic controller(FLC)
The transfer function of the system FOPTDI has been simulated and compared for both servo and regulatory response in terms of evaluation criteria and the robustness of the controller has been verified by simulation.

1.3 METHODOLOGY

The design phase of designing the controller using various methods is shown in Figure 1.2. The tuning parameters for the controllers are obtained using different techniques for the transfer function of the web guide system.

![Design and testing phases diagram]

The testing phase consists of obtaining the servo and regulatory response of the closed loop system using various tuning methods and robustness of the controller has been verified.

1.4 PROBLEM FORMULATION

When material is fed through a four high single stand rolling mill, forces generated by the mill housing, payoff reel and take-up reel combine to
achieve the desired proportion of the material. The control of strip position is achieved by appropriately adjusting, for example, the screw setting and/or swiveling of the unwind tension. Proper tuning of the controller is not only essential to its correct operation but also improves product quality and reduces scrap, downtime and costs. Procedures for manually tuning conventional PID controllers are established and simple to perform under ideal conditions, but rolling mill conditions are far from ideal. The tuning procedure can be initiated by the operator or selected to begin automatically upon start-up. During tuning, the appropriate controller parameter values are determined by the program and loaded into memory. These self-tuning controllers calculate the parameter values once, when the tuning sequence is selected.

Figure 1.3 shows a strip profile or position control system on a 4-high rolling mill. The ability to predict the dynamic behavior of a rolling mill stand can prevent severe problems in dimensional quality during rolling in addition to avoiding mill hardware damage. Generally a web entering onto any roller inclines perpendicularly to align to the roller. The curved web
between the non parallel rollers is laterally vibrated because of the mass and stiffness of the web. So web should be guided before rewinding through intermediate guides, which is accomplished by the shifting and swiveling of the rollers as shown in Figure 1.4. In industrial application, the displacement of the web is measured in the middle of the two parallel rollers due to difficulty of installing sensors. The general roll loading conditions combine bending, shear, and flattening deflections are shown in Figure 1.4.

![General roller loading conditions combine bending, shear, and flattening deflections](image)

**Figure 1.4** General roller loading conditions combine bending, shear, and flattening deflections

In this work, a self-tuning controller has been used that continuously updates the PID parameter values, thus compensating for changes in the process and product. The general web position controller is shown in the Figure 1.5. Displacement of the web from its centre position is being measured and controlled by position controller.
Figure 1.5 General web position controller

This type of self-tuning controller is relatively easy to implement and is applicable to complex processes with a wide variety of characteristics involving unknown parameters, the presence of time delays, time varying process dynamics and stochastic disturbances. In order to produce a strip profile of desired properties throughout the strip, it is required to position the web at the desired location. Hence position of the web controller has to be tuned properly.

The flow diagram of the developed work is shown in Figure 1.6. In method -I and method -II it has been discussed about the equating coefficient method for PI and PID controller for the transfer function of the FOPTDI system.
The mathematical model of the displacement type web guide of the cold rolling mill has been approximated to FOPTDI model and then simulated. PID controller in series with a lead/lag compensator has been designed for control of closed loop processes using direct synthesis method has been discussed in method III. The required form of the controller has been designed based on the process to design, the desired output behavior of the closed loop can be specified as a trajectory model and the parameters of the PID controller are tuned using model reference control method in Method -IV and dual loop control method has been discussed in method V. Fuzzy logic based tuning of PID controller has been described in Method-VI.

To design a stabilizing PI and PID controllers are of great importance for industrial applications since the controllers are used extensively in the process industries because of their robust performance and simplicity. Indeed 90% of the control loops are PID. A number of performance measures have been introduced so far in respect of dynamic response to step input and steady-state error to both step and higher order inputs. In many of the control schemes, the system parameters are automatically adjusted to keep the system at an optimum level of performance under varying inputs and varying conditions of operation. These systems
require performance index which is a function of the variable system parameters. Other desirable features of a performance index are its selectivity. That is its power to clearly distinguish between the optimum and non-optimum system, its sensitivity to parameter variations. A number of such performance indices are used in practice, the most common being the Integral Square Error (ISE), is given by,

\[ ISE = \int_0^\infty e^2(t)dt \] (1.1)

It is well known that ISE converges to a limit as \( t \to \infty \). Minimizing of ISE by adjusting system parameters is a good compromise between reduction of rise time to limit the effect of large initial error, reduction of peak overshoot and reduction of settling time to limit the effect of small error lasting for a long time. Another easily instrumented performance index is the Integral of the Absolute magnitude of Error (IAE)

\[ IAE = \int_0^T |e(t)|dt \] (1.2)

In this work, the two evolution parameters represented in equations (1.1) and (1.2) has been taken for analysis and simulated.

1.5 BACKGROUND STUDY

Steel is the most useful and cost effective metal. The automation in the steel manufacturing is continuing, hence steel makers expect that more techniques can be incorporated in the processes, particularly after computer technologies came into development.

Tension variations beyond certain tolerance levels affect processes and causes damage to the web. This can result in wrinkles and may even lead
to breakage of the web. The two main types of tensions that need to be maintained closely are the longitudinal tension and the lateral tension. The reasons for variations in longitudinal tension can be numerous. These can be categorized into two main types. The disturbances which have their sources external to the system and those that are due to the noise signal in the process itself. Some of these disturbances are periodic in nature (they repeat at regular intervals) and others aperiodic.

Different web tension magnitudes are typically present in each processing section. Severe tension variations in these sections may lead to degradation of product quality or even the rupture of the material during processing. This results in significant economic loss and negative impacts on the process line of productivity. In order to minimize the potential for loss, it is necessary to control the tension within a predefined range in a moving web processing section.

There are many intermediate web guides in cold rolling mills process such as Continuous Galvanizing Line (CGL), Electrical Galvanizing Line(EGL). The main functions of the web guide are to adjust the centre line of the web (strip) to the centre line of the steel process. So they are called Centre Position Control (CPC). Rapid speed causes large deviation between the centre positions of the process line, also too much deviation is not desirable; the difference between the centre position of the strip and the process line should be compensated. In general, the CPC of the web is obtained by the hydraulic driver and electronic controller.

A continuous process system manufactures the web which is a flexible long strip such as steel, paper, printed textiles and plastic products. Productivity in this process is related to the length and the speed of the process. Increasing productivity causes a problem with the lateral movement of the web so that a device for compensating web position should be installed in the middle of the process.
Linear controller is likely to perform poorly, because of the non-linearity in the system which cannot be properly compensated. There are more non-linearities in the control system whose discontinuous nature does not allow linear approximation. These non-linearities include columb friction; valve hysteresis, reactor dead zones, backlash and so on. These effects cannot be derived from linear model. In designing linear controllers, it is usually necessary to assume that the parameters of the system model are reasonably well known. However, many control problems involve uncertainties in the model parameters. A linear controller based on inaccurate or obsolete values of the model parameters may exhibit significant performance degradation or even instability. Nonlinearities can be intentionally introduced into the controller part of control system so that model uncertainties can be tolerated.

Cold rolling mills can be divided into three different main categories depending on the thickness of the strip that they roll: sheet mill, tin mill and foil mill. These categories are used to obtain the surface finish, the mechanical and physical characteristics desired by the customer. The temper mill only slightly reduces the thickness of the input material.

Metal plate, sheet, or strip such as steel, aluminum, or copper is manufactured on hot and cold rolling mills having various configurations of the rollers and with varying numbers of individual rolling stands. For large-scale production of hot rolled and cold rolled carbon steel and aluminum sheet different stand configurations are widely employed. The stand configurations for the most common types of hot and cold reduction mills given as below.

1.5.1 The Two-High Mill

It is a mill that consists of two work rollers mounted on top of each other and that are pressed together with great force as shown in Figure 1.7(a). The strip is passed one or several times through the gap between these rolls to
obtain the desired thickness. For all different types of mill, the roll-chocks and bearings are placed at the edge of the rolls, which is by necessity outside the edge of the strip. Therefore, due to the high roll-separating force that arise in the roll-gap and that must be overcome by adding a force at the bearings, the rolls tend to bend around the strip edges during rolling. To handle this, the rigidity of the work rolls must be increased, which is easily accomplished by increasing the diameter. A problem with this is that with a larger diameter, the contact area towards the strip is increased and an even higher roll-separating force arises. Hence, the rollers in a two-high mill often have a very big diameter. Nowadays the two-high mill type is not used to a great extent, but for temper mills it is still common.

1.5.2 Three - High Mills

These type of three high mill is mainly used in hot rolling. Since there are three rolls, it can be used in reversing mills without changing the direction of rotation of the motor. The top and bottom rollers are rotating in one direction and the middle roller in the opposite direction. The three high mill configuration is shown in Figure 1.7(b).

Figure 1.7   (a) Two-high mill         Figure 1.7 (b) Three-high mill
Usually only the top and bottom rollers are driven, while the middle roller rotates by means of the friction towards the strip. The middle roller is raised or lowered together with the mill table depending on the rolling direction. In one direction the strip is passed over the middle roller and in the other direction it is passed below. Therefore, the rotation directions of the rollers are never changed.

1.5.3 Four- High Mills

In the two-high mill, the rigidity of the work rollers was increased by increasing the roller diameter. A better method is to add backup rolls on the outer side of each work roller. Then, the mill type that is obtained is called a four-high mill, or a quarto-mill as shown in Figure 1.7(c). In fact, the backup rollers enable the possibility to reduce the diameter of the work rollers and thus lowering the roller separating force, which is dependent on the contact area towards the strip. The backup rollers should be approximately square, i.e., the diameter should be as big as the roller face. Even if the roller bending is reduced with this design, there will always be bending present to some extent, since the force is applied at the roll chocks outside the strip edge. The alignment of the rollers in the horizontal direction depends on the type of process. If it is a reversing mill the rollers should be aligned with a common vertical centre point, but in a one direction mill they should have a small offset towards the exit side of the roll-bite. The reason for this is that for work rolls with a small diameter, and thus a low rigidity, the high torque in the roll-bite will cause them to deflect towards the entry side of the mill. The backup rollers are usually made of softer material than the work rollers to prevent work roll markings. The four-high mill is the most popular type of mill stand in use today since it can be used for many production steps: breakdown rolling, finishing rolling as well as temper rolling.
1.5.4 Six - High Mills

In a four-high mill, the roll bending around the strip is reduced, but not completely removed. This is further improved in a six-high mill shown in Figure 1.7(d), where there are three rollers on either side of the strip. The intermediate roller could be equipped with a side-shift mechanism with which the rollers can be moved laterally in and out over the strip edge during rolling.

A disadvantage is that a very high pressure was created between the backup roller and the intermediate roller at the end of the intermediate roller face. The solution to this is to grind a taper on the intermediate roller to get a softer gradient at the end of the roller face. The intermediate roller allows for a reduction of the work roller diameter further than can be achieved with the four-high mill, since the ratio of two adjacent roller diameters are kept low. Six-high mill that eliminates most of the roll bending at the edges by lateral movement of the intermediate rolls to let the edge coincide with the edge of the strip.
1.5.5 Y-Mills

It is a mill with a small work roll on the top-side of the strip, supported by two levels of backup rollers that form a 90° angle with respect to each other and 45° angle to the strip normal as shown in Figure 1.7(e). On the bottom-side of the strip there is a work roll that is comparable to the intermediate backup rollers in size, supported by one backup roller. The purpose of the mill was to get as small a work roller as possible with rigid backup both in the vertical and the horizontal direction. However, a mill that has work rolls of different size is likely to induce coil-set into the material since the reduction on the top side of the strip will be bigger than the reduction on the bottom side of the strip. The reason is that the smaller diameter of the top work roller will have a higher roll force per area unit.

1.5.6 Cluster Mills

To have accurate shape of the strip, the relative reduction of the strip should be uniform across the width of strip on both sides. Therefore, the work rolls must be of the same size. To be able to utilize small work rollers of equal size that are supported in both the horizontal and vertical direction, a six-high mill with rollers organized in four levels was introduced and is shown in Figure 1.7(f).
The work rollers in this mill each has two backup rollers placed in 45° angle with respect to the strip normal and 90° angle with respect to each other. The construction is similar to the Y-mill, but with horizontal support on both sides and no intermediate rolls. In this mill, the smallest diameter of the work rollers that could be used was reached when the horizontal tangent of the work rolls coincided with the horizontal tangent of the backup rollers. A method to decrease the diameter even further is to insert intermediate rollers and organize the mill in a pyramid fashion.

In a cluster-mill, the top most and the bottom most backup rollers are called backup assemblies. They consist of a number of shafts with bearings that give support to the second intermediate backup rollers over their entire width, instead of at the edge-bearings as in other mill types. The number of bearings depends on the width of the mill. The backup roller diameter in a mill build for wide strips can be the same as the back up roller diameter in a mill build for narrow strips. Instead, the wide mill should have a larger number of bearings that transfer vertical support from the mill housing to the backup rollers. In other mill types, where the pressure is kept only at the edge-bearings, the backup rollers themselves must offer the vertical support. Thus, the rigidity of the rolls, i.e. the diameter, has to be increased for the mill to be capable to handle wider strips. The bearings in the backup assemblies are elliptic and can be rotated to increase or reduce the pressure over the strip at the specific position of each bearing. Each bearing is a very important control actuator. The mill, also called Sendzimir-mill, is popular for rolling hard materials today, most often in a single-stand reversing mill. Its advantages are that the small work rolls enable quick work roll replacements, better surface quality and good response to shape control mechanisms.
1.5.7 Z-High mills

The Z-high mill is a compromise between the four-high mill and the 20-high cluster-mill. In the four-high mill, the work rollers can be too big for some applications so that the roll separating force may reach too high values. On the other hand, in the 20-high mill, the work rollers for a mill of the same size can be too small, which introduces skidding. In a Z-high mill, the diameter of the work roller will be somewhere in-between the diameters of its four-high and 20-high counterpart and is shown in Figure 1.7(g). The mill can be described as a six-high mill with side-support to prevent deflections due to torque. As with the case of the Sendzimir-mill, no spot cooling is possible in the Z-high, which means that there is no control of the thermal crown. On the other hand, the stiffer mill-modulus of the Z-high offers improved gauge accuracy compared to the four-high mill.

Figure 1.7 (g) Z-mill

Figure 1.7 (h) 20-High cluster mill

1.5.8 Tandem Mills

The higher the reduction that can be made on each pass, the shorter the production time and the higher the mill output. Therefore, one naturally
strives for maximum reduction. One way to increase the reduction is to increase the roll force but with this comes problems with roll bending and increased wear of the mill. Another means is to add a new roll stand to the production line and thus create a tandem mill with twice the productivity as shown in Figure 1.7(h). Today there exist tandem mills for high strip speed with up to eight successive rolling stands, which allow for a very high strip production rate. At some point, the material must be annealed to allow for further reduction, otherwise there will be formation of cracks and eventually a strip break will occur.

1.5.9 Temper or Skin-Pass Mills

Temper or skin pass mills are used to improve the flatness and surface finish of strips that have already been reduced to the desired thickness. In these mills there is only a slight reduction of the thickness, and because of this the roll separating force is light and it is sufficient to use a two-high rolling mill. It is used to improve the flatness and surface quality of the strip as well as the mechanical properties around the yield point of the material before delivery.

1.5.10 Pre-Stressed Mills

In a conventional rolling mill, the roller separating force that arises when the strip is passed through the rollers is transferred via the backup rollers and their bearings to the mill house. In a pre-stressed mill, the two backup rolls are connected to each other by an element, pre-stressed to a value that is greater than the maximum roll separating force. The advantages of this type of mills are, greater accessibility to the rolls and the roll bite, more rigid strip guides and so on.
1.6 COLD FORMING

For many applications, the products of hot forming are not satisfactory as per Elvers et al (1994). In particular, cold forming is used for the production of thin strip. Additionally, cold rolling is sometimes applied for the production of wires and tubes. However, by far the most important application is the production of cold rolled strip. The advantages of cold forming are,

- Production of thinner strip than by hot rolling
- Production of blank surface with little depth of roughness
- Production of strip with narrow gauge tolerance and even surface over width and length
- Good control of strengthening
- Control of physical characteristics

In cold rolling, usually no heat is applied to the work piece before forming. Only some special steels like spring steel, tool steel, tempering steel or alloyed steels may be subjected to heat treatment before pickling and rolling. However, frictional energy at the contact surfaces of the work piece is converted to heat. This heat may increase temperatures in rapid adiabatic processes over 100°C. The processing of steel in cold rolling mills differs considerably from the production in hot rolling mills. The raw material is first descaled (usually pickled, sometimes shot blasted and pickled), then cold rolled and heat treated. Further treatment steps include slitting, skin-pass rolling, coiling and packing.

Cold rolling mills usually consist of a number of mill stands arranged in alignment as in Figure 1.8. Long metal products with different cross-sections, such as strips or bars, are produced basing on the principle of multistage shaping as they proceed through mill stands sequentially. The
cross-sections of work pieces, such as blooms, billets or slabs, are reduced in each stand under high pressure.

**Figure 1.8 Tandem rolling mills**

To meet the dimension requirements, such as thickness, width, flatness and shape, Automatic Gage Controllers (AGC) are employed to control the roll gap and pressure. Automatic Speed Regulators (ASRs) are used to control the mass flow passing the rolling mills. A single stand in tandem rolling mills with dimension and yield regulation systems is schematically illustrated in Figure 1.9.

**Figure 1.9 Single stand in tandem rolling mill**
According to the rolling processes of a work piece, the operation modes of a stand fall into four categories. Initially, no work piece passes and the stand n works in an idle mode as shown in Figure 1.10.

![Figure 1.10 Idle mode](image)

When a work piece passes, the stand n is engaged on the upstream stand n-1, but has not entered the downstream stand n+1 yet, stand n is in a run-in mode as shown in Figure 1.11.

![Figure 1.11 Run-in mode](image)
Following the normal mode in which the work piece passing stand n, is engaged on both the upstream stand n-1 and the downstream stand n+1 as in Figure 1.12.

![Figure 1.12 Normal mode](image)

The run-out mode refers to the state when the work piece passing stand n is engaged on the downstream stand n+1 and leaves the upstream stand n-1 as in Figure 1.13.

![Figure 1.13 Run-out mode](image)

A specific problem associated with tandem rolling mills is the presence of tension, a longitudinal force inside the work piece resulting from
the inequality of mass flow of the rolled material between two adjacent mill stands. Tension can cause undesired product deformation such as cross-sectional reduction or cobbling. On the other hand, to optimize the performance of AGC and ASR, it is desirable to keep tension constant by means of additional control action. However, interaction effects, i.e., activities of AGC and ASR, such as adjusting the roller gap and stand speed, will incur tension variation and in turn tension maintenance activity, such as adjusting stand speed, will worsen the gage and speed control, and will complicate the situation.

Despite the advancements of numerous metal rolling technologies over the past half century, intense global competition and the requirements for increasingly thinner, higher quality rolled metal products continue to force metal producers to seek new ways to outperform one another. The need to maximize rolling mill utilization times to achieve profitability, and the significant costs associated with capital upgrades, mean that the application of innovative rolling technologies presents the most attractive near-term solution for many metal producers to improve quality and productivity.

Knowledge of plant performance aids the owner in deciding whether the facility performs well. Obtaining an overall view of the plant performance and finding the weak links is a demanding task. A decrease in performance may have a variety of reasons, for example incorrect controller tuning, incipient faults in the system or poor operating practices. The objective of the performance monitoring is to enable tracing and fixing the problem before they cause poor-quality products to be manufactured and excessive financial losses.

Control system technology and control parameters are described in relation to the control process of cold rolling. Automatic control systems are preferred to manual control for ensuring higher strip quality. Automatic control is more efficient and produces fewer defective strips. It can provide a
process automation system with adaptive control and intelligent adjustment of control parameters.

Optimal dynamic performance is maintained under different process conditions by using control algorithms. Several types of controller are used in rolling mills. Feedback is applied to the variables in order to tailor the output to the required set point values. Tolerance between the actual value at the output and the set point value are calculated and the difference is applied to the controller. The controller changes the work roller gap, which is regulated by position or alternatively by a roll force control loop in the thickness control method. A correction value consistent with the saved entry position deviation is computed and forwarded to the position guide control system when the strip reaches the work roll gap. The general flow chart depicts the step by step procedure of the entire rolling process is shown in Figure 1.14.

![Figure 1.14 Step by step procedure of the rolling process](image-url)
Hot rolled steel always has a layer of scale of variable structure on its surface, depending on the conditions of hot rolling. In order to achieve good surface quality and better frictional behaviour, the strip has to be descaled before cold rolling. Descaling is usually done chemically (continuously by pickling) only or in combination with mechanical means (stretching, levelling abrasive blasting, rolling). Pickling removes oxides and mill-scale from the surface of steel. Unalloyed steel is usually pickled by the action of an inorganic acid, generally sulphuric or muriatic acid, diluted with water. For stainless steels there is no single acid that is able to remove all types of scale layers. However, most commonly for the pickling of stainless steels nitric acid / fluoric acid mixtures are used. Furthermore, electrolytic pickling enhances the descaling of alloyed steels that are otherwise hard to pickle. Pickling can be carried out by push pickling or by continuous pickling installations.

Startup-times of new plants and shutdown-times during modernizations have to be kept at a minimum while the guarantees for product quality, plant availability and throughput are more and more ambitious. For cold rolling mills this means that not only the strip thickness and shape must be kept within certain tolerances and the process speed should be maximized, but also that off-gauge lengths have to be kept at a minimum. One key-issue for achieving these goals in multi-stand (tandem) cold rolling mills is the accurate synchronization of all mill drives. For those standard industrial applications P or PI controllers are widely used. Good control performance can be achieved since the processes are mostly linear and PI control allows to optimize the control loops in a straight-forward way. Once those systems are running properly, strip can be threaded into the mill and the technological control functions such as position control, strip thickness, strip tension force and shape control can be set-up step by step. Those control
loops are superimposed to the basic control loops so that there is a cascaded control structure.

Owing to the necessity of large magnitudes of applied forces to achieve strip thickness reductions in the rolling process, elastic deflections of the mill housing, rolls, bearings and other components occur simultaneously with the elastic-plastic deformation of the rolled strip.

These dimensional quality criteria are strongly related to the resulting deflection profile of the contact interface between the working rolls and the strip. In the absence of corrective measures, the non-uniform natural deflection at the roll-strip interface causes an uneven strip thickness reduction. Hence, a strip with an initially rectangular cross-sectional thickness profile will typically possess a non-rectangular thickness profile after rolling.

1.7 LITERATURE SURVEY

In particular, a wide web cannot be guided by means of flange and pulley because of undesirable distortion or damage of the edge. Markey (1957) researched the edge position control of webs in the steel industries. Feiertag (1967) studied steering and displacement type web guides in the rolling process.

Shelton (1968) first order model presents the dynamics of a moving web that includes the relation of the lateral velocity to the longitudinal velocity and the input error. Shelton and Reid (1971) had derived the first order and second order model through geometrical by taking the elasticity of webs into account, and represented dynamic behaviour by regarding web as Euler beam. Using modified initial conditions, Young and Reid (1993) represented transfer function based on the second order model.
Brandenburg (1977) studied the longitudinal dynamics of a moving web, but did not consider the tension in the entering span. In this method the effects of small changes in area that result from strain changes, temperature changes, and register errors are described.

Proportional Integral Derivative (PID) control approach is the primary feedback control law used in industry. For tension feedback control, however, because of the significant variations in system dynamics, PID alone has been shown to be inadequate. Reid and Lin (1993) proposed the fixed-gain and variable-gain PID control of web tension in the winding section. For variable gain PID, the control parameters are continuously updated based on the diameter of the roller, which is a major contributor to the system dynamics and uses pole placement techniques.

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Ian Postlethwaite and John Geddes (1994) presented a paper which considers the application of robust multivariable control based on $'H_\infty'$ optimization, to the problem of gauge control in a tandem cold rolling mill. The work has been undertaken as part of a collaborative research project between CEGELEC Projects Ltd., Rugby, and the University of Leicester. For the test coil under consideration the simulation results indicate that $'H_\infty'$ optimization can contribute to high quality rolled product, and offers potential for significant improvement in product quality over existing schemes. Better attenuation of the lower frequency (skid chill) disturbances was obtained with the 31" controller in terms of peak to peak variation in exit gauge, and
furthermore the 31” design produced significantly less undershoot in response to skid chill.

Proper tuning of the controller is not only essential to its correct operation but also improves product quality and reduces scrap, downtime and costs. The control of strip thickness is achieved by appropriately adjusting, for example, the screw setting and/or the unwind tension. Nicolas Soler (2008) implemented an adaptive self-tuning gauge control system on a cold-rolling aluminum mill, using an 80286-based micro computer system. The mill process had been modeled as a second order system with one input (unwind tension reference) and one output (gauge error). The model parameters were estimated on-line using a recursive least squares estimation algorithm. The inputs to the estimator were correlated in time so the estimator is not affected by the gauge measurement transport delay. Based on the estimated model parameters and a pole-placement design, a control signal is calculated. The regulator structure used was a filtered version of a discrete PID controller.

Cold rolling mill process in steel works uses stands of rolls to flatten a strip to a desired thickness Sungzoon Cho et al (1997). The accurate prediction of roll force is essential for product quality. Two multilayer perceptrons have been trained, one to directly predict the roll force and the other to compute a corrective coefficient to be multiplied to the prediction made by the mathematical model. Both networks were shown to improve the accuracy by 30–50%. One difficulty was when promoting the use of the neural network the inability to estimate the monetary savings resulting from the improved quality and decreased off-gauge.

The hydraulic Automatic Gauge Control (AGC) of cold rolling mill is directly related to the quality and effectiveness of cold rolling aluminum sheet strips. Traditional PID control becomes difficult to satisfy the necessity of improving the control performance of cold rolling mill. A new variable
structure control (VSC) based on a co-ordination optimization algorithm has been developed. Based on steady state error in VSC, an optimized boundary layer width tuning rate is designed and added to the nonlinear control term of VSC. The tuning rate of boundary layer width of sliding mode phase plane is optimized through a co-ordination optimization algorithm (Ringwood 2000). Simulation results verify the effectiveness of the proposed VSC. Recently, some methods have been used to solve such paradoxical problem.

Han and Jingqing Han (1994) developed a new methodology for web tension regulation based upon a unique Active Disturbance Rejection Control (ADRC) concept. In this approach the disturbances have been estimated using an Extended State Observer (ESO) and compensated during each sampling period. The proposed ADRC control system consists of the ESO and a nonlinear PD controller. It is designed without an explicit mathematical model of the plant. This controller is designed to be inherently robust against plant variations. Once it is set up for a class of problems within a predetermined range of variation in system variables, no tuning is needed for start up, or to compensate for changes in the system dynamics and disturbance. This method is particularly suitable for web tension regulation applications because of its robustness and disturbance rejection capabilities.

Reviews of the problems in tension control of webs were discussed by (Barmish 1994; Wolfermann 1995). Tension in a web span is controlled in an open loop fashion by controlling the velocities of the rollers at the either end of the web span. The dancer subsystem was used as a tension measurement device or as a device to attenuate tension disturbances. When the dancer subsystem is used as a tension measurement device, the displacement of the dancer roller is measured and the tension in the span is inferred from the measured displacement.
In order to meet increasing demand for the high precision of strip thickness, various types of Automatic Gauge Control (AGC) methods have been developed for hot or cold mill processes. Lin and Lan (1993) derived a mathematical model for a typical single-stand rolling mill and design Proportional- Derivative (PD) controllers for regulating strip tension. In order to reduce the effects of periodic thickness deviation of the entry strip which was caused by the roll eccentricity etc., also proposed a thickness controller based on the Internal Model Control (IMC) principle. They also analyzed so-called BISRA (British Iron and Steel Research Association) AGC method can be combined with the proposed thickness controller in the presence of modelling error.

Steel sheet gradually passes through a series of rollers at constant speed. The rollers are oriented at different angle to increase the deformation of the sheet until the desired geometry is obtained. The sheet metal panel undergoes plastic deformation and residual stress. The methods to minimize these problems were investigated by Fei-chin Jan and Olapido Onipede (1999). To effectively mesh the plate and the rollers at critical locations, an adaptive mesh was used.

Gerhard Rath (2000) derived a linear mathematical model for the rolling process, which describes the interaction of the required influencing variables. The approach found here leads to numerically efficient algorithms, which are necessary to run in a real-time environment. With the help of these linear descriptions, the essential elements for the thickness control were investigated. A computer simulation programme that can analyze the dynamic behaviors of tandem cold rolling process without laborious experiments in actual mill was developed. In this work, a simulation programme was developed to analyze the transient rolling characteristics on the basis of general cold rolling theories and dynamics of rolling mill. The simulation
results with actual mill data showed that the developed simulator has enough accuracy in calculation of dynamic characteristics of tandem cold rolling process.

Cold rolling process is a highly nonlinear system in which many uncertain parameters are involved. Minsuk Shim et al (2001) designed fuzzy controller for the flatness controller by the heuristic approach that is based on the operator’s experience and knowledge gained in the experiments. It has been demonstrated that the fuzzy control with the error-decomposition network met the desired flatness requirement without overshoot, but with faster response. The simulation is based on the estimated model of the No. 1 Cold Roll Mill at Pohang Works, POSCO, Korea and plans are under way to implement the automatic flatness control system in a real plant in future.

The web tension control problem is very challenging and important because the system dynamic is a function of many process variables that often vary over a wide range. Yi Hou (2001) proposed the novel nonlinear PD controller and used in conjunction with the Active Disturbance Rejection Control (ADRC). Two internal compensation methods are used to improve web tension control performance. A simulation of real industrial application is used to provide realism. The results show the effectiveness of the proposed tension controller in coping with large dynamic variations commonly encountered in web tension applications. The newly developed web tension control approach described in this work is ready for hardware testing and implementations.

Using fuzzy logic controller Jingrong Liu (2002) aimed at maintaining constant tension between two adjacent stands in tandem rolling mills. Based on modelling the rolling stand as a single input single output linear discrete system, which works in the normal mode, the element settings and parameter selections in the design of the fuzzy controller are discussed.
With the inclusion of supervision and concern for conventional control criteria, the parameters of the fuzzy inference system are tuned by a backward propagation algorithm or their optimal values are located by means of a genetic algorithm.

The robust stability of control system with parameter variations has been a focus of attention of researchers in recent years since the well-known Kharitonov et al (2003) has been published. It focuses on the problem of robust stabilization of an uncertain plant whose parameters belong to the given real interval.

Mathematical model for cold rolling and temper rolling process of thin steel strip has been developed by Won-Ho Lee (1999, 2002) using influence function method. By describing roll gap phenomena and considering more influence factors, this model offers significant improvement in accuracy and robustness. After calibration, the model was installed in the plant together with the data acquisition system to make parallel comparison and calculations. The strip elastic deformation at the entry and exit are taken into consideration.

The complex kind of disturbances that are experienced by the web processing lines may be considered to encompass basic disturbances and can be categorized as step disturbance, ramp disturbance and sinusoidal disturbance. Dale et al (2004) has compared periodic tension disturbance attenuation in web processing lines. Generally a disturbance can be compensated by controlling the speed of the master speed driven roller.

Yanwei Huang et al (2004) analyzes the rolling process composed of the rolling force model and the rolling mill elastic model with the existence of “algebraic loop”, which causes to obtain the analytical solution difficultly. To eliminate the “algebraic loop”, the simplified linear
model based on sensitivity has been developed by the linearization of the rolling process. The simulations results indicate that the proposed controller has the better control performance and higher control thickness precision.

Design of control systems with time delay is very important since most real processes are represented by time delay models. Designing and stabilizing PI and PID controllers are of great importance for industrial applications since the controllers are used extensively in the process industries on account of their robust performance and simplicity; indeed 90% of the control loops are PID. Sang Min Kim and Byoung Joon Ahn (2004) modeled a web guide based on second order system. In this method PID controllers were designed and their gains tuned by the ZN method, the ‘$H_\infty$’ based model-matching method, and the CDM (Coefficient Diagram Method). Also the sinusoidal disturbance at the roller and load pressure variation at the hydraulic driver, controller performance were verified by computer simulation where the CDM proved to be the most robust against disturbance and parameter variation.

Flatness Sensing inter Stand Looper (FLatSIL) and self tuning PI control system for improving the flatness of hot strip in finishing mill processes was described by Jeong Ju Choi et al (2004). The FLatSIL measures the tension along the direction of the strip width by using segmented rolls. The flatness control system is operated by using tension profile. Simulation and experiment shows that the GMV S-T shows better performance than the fixed PI flatness control system.

Luis (2006) presented a method based on neural networks to represent the cold rolling process. The representation uses the sensitivity factors to determinate the variations of its main parameters. The sensitivity equations have been obtained by differentiating a neural network previously trained. The procedure to obtain the sensitivity expressions through a neural
network was presented. The neural representation, based on sensitivity factors, allows calculating the output thickness considering the rolling load, which can be measured directly from the process. This fact can eliminate the thickness sensor, usually X-ray, placed in each stand of a rolling mill.

A set of optimizing alternatives for a heavy continuous rolling mill was developed by Pittner and Simaan (2006). The simulation approach was developed which would enable the designers and analyst to foresee the behaviour of systems in normal and also emergency situations.

The digitizer and G-code were used to programme and the fitting and interpolation method were adopted for the smoothing process of the trajectory, which was recorded during the teaching process (Bo You et al 2006). The cold rolling efficiency, flexibility, reliability and precision of the system have been guaranteed for the use of the digitizer, G-codes and PLC, and the process of the digitizer trajectory. The cold rolling mill controlled by this system can be widely used to produce steel pipes with great length, high precision and good surface finish, which are used for mechanical structure, pressing equipments and etc.

The high-speed tandem cold rolling mill is the typical complicated electro mechanical system. Since the request to the quality of cold rolling sheet strips is higher and higher Wang Yiqun et al (2007) considered compensation of the tension vibration to eliminate the thickness deviation because of the tension vibration. The computer control strategy of the feed forward AGC is researched, and the control strategy adapting the distributed computer control system is provided. All strategies have been applied, and favourable control results are gained.

Several techniques exist for evaluation or prediction of the strip gauge in the rolling gap. Pavel Ettler and Josef Andrysek (2007) have
presented a technique consists of mixing several well known techniques to utilize all available information for weighted gauge prediction. The main idea of the proposed solution was to predict the strip thickness in the rolling gap by combination of several methods relying on existing signals.

In multi-stand cold rolling mills an accurate synchronization of the mill drives is necessary for a good product quality and for a safe process operation. During the standard commissioning procedure the control performance of each drive is optimized individually. Based on a model of the drives and the strip tension force the control performance of the coupled drives is analyzed. A linear observer is proposed by Nicolas Soler et al (2008) to support the standard PI speed controllers. The observer used only a few parameters to cover all operating points of a tandem cold rolling mill. The presented feed forward control based on a disturbance observer improves the speed control performance of multi-stand cold rolling mills especially at low speed. The structure is very simple and only few parameters are necessary. The decentralized observer can easily be integrated into classical control structures.

Controlling the tandem cold rolling of metal strip is a significant challenge to the control engineer. This is due to mostly complex interactions between the process variables, nonlinearities that change with process conditions, and long speed-dependent time delays. A new control strategy (John Pittner and Simman 2008) based on solving a state-dependent algebraic Riccati equation point wise establish a control law for a Multi Input Multi Output (MIMO) controller that is augmented by appropriate trimming functions considered. Simulation testing showed that the tolerance in mill exit thickness compares favourably to the tolerances using existing techniques.

Garber et al (2007) developed a new methods of cold rolling process modeling process which is highly recommended for development of
rolling mill control system. They will ensure increased rolling speed; upgrade the quality of cold rolled sheets and save energy in production. It has been determined that in order to control the rolling process effectively, the determination of neutral position exact position in the deformation zone of the working stand is of vital importance. For that purpose a solution was found to contact interaction between strip and roll based on the elastic and plastic model of the zone.

High precision, simple and effective control strategies are very important for the hydraulic AGC system of cold rolling mill. A fuzzy neural networks control was developed by Yang Yong and Zhang Xinning (2008) and applied to the screw-down mechanism control of hydraulic AGC system of cold rolling mill. For the complex control problems, it is also desirable to integrate neural networks into fuzzy control so as to simplify and automate the specification of linguistic rules. The successful applications of RBF neural networks with logical neurons AND/OR improve the abilities of both the self-taught and the representation of the hydraulic AGC system, especially to simplify and automate the specification of linguistic control rules in the design of fuzzy controller.

Frantisek Durovsky et al (2008) developed mathematical model of rolling process used at cold mill rolling on tandem mills in metallurgy. It is based on the modified Bland-Ford model. The rolling process is analyzed according to process data measured on the mill and get immeasurable variables necessary for rolling control and optimal mill pre-set for next rolled coil. Identification of friction coefficient on a single rolling mill stand was developed using genetic algorithm. Genetic Algorithm was used to find an actual value of friction coefficient between rolls and steel strip on the current rolled coil. The time elapsed for off-line model computation for one rolling mill stand was less then 50 seconds.
Cold rolling process is a multivariable, nonlinear, time varying, large time delay, high-precision control system and its control mechanism is extremely complicated. Du Tai-hang et al (2009) put forward a method which combines structure of fuzzy control and PID control to analyze both static and dynamic performance of the system. Simulation results show that the fuzzy adaptive PID controller achieved good results in the controlling tension between cold-rolling tracks.

Cold rolling production scheduling problem is an extremely difficult process. Based on rolling feature of continuous tandem cold rolling mill, Haijun Chen et al (2009) developed Particle Swarm Optimization (PSO) algorithm schedule optimization procedure for tandem cold rolling mills, based on computer powerful data processing capacity. PSO algorithm was used to optimize the objective function to obtain the optimal solution. It makes the reasonable distribution of tandem cold rolling power, gives full play to equipment capacity and improves the production efficiency.

Controlling the tandem cold rolling of metal strip is a significant challenge to the control engineer. This is due to mostly complex interactions between the process variables, nonlinearities that change with process conditions, and long speed-dependent time delays. A new control strategy described by Bingji Li (2009) was based on solving a state-dependent algebraic Riccati equation point wise to establish a control law for a MIMO controller that is augmented by appropriate trimming functions. Tolerance in mill exit thickness compares favourable to the tolerances using existing techniques.

As strip rolling work is performed through the roll, the quality of a roll which contacts a product directly influences product quality and productivity. The improvement in roll performance is intensely needed. Takami et al (2009) developed the high speed steel roll manufactured by the
CPC process (Continuous Pouring process for Cladding) in order to provide a fast improvement in a life of roll.

Rudiger Holz et al (2007) presented a method for a continuously operating tandem mill with combination of open and closed-loop controls. The drop in thickness was measured after the first and the last stand (stand 5) avoiding form waves in cold rolling of brass in a two-stand tandem mill. A technology package including new and enhanced physical model approaches for simulating the cold rolling process was developed and the analysis shows that the form waves exclusively occur through insufficient lubrication conditions. By improving the lubricant and direct application of an additive, in the first pass, the form waves are avoided and this enables a clearly higher rolling speed and thus a clear improvement of the plant's output capacity.

Indeed, Bhattacharya et al (1993, 1995) point out that a significant deficiency of control theory at the present time lacks non-conservative synthesis methods to achieve robustness under parameter uncertainty. Hyeunhun et al (2010) have derived PID controller for the lateral displacement of a moving web by using steering guide system. In this work, mathematical model is built under the principle that the web in the entering span aligns itself perpendicularly to the roller. Simulations and experimental work for the lateral of the web with a long span dryer using the steering guide system is described.

The simulation software LAteral motion and COntrol SIMulation (LACOSIM) is also designed and implemented to control the lateral position error of a web in roll-to-roll (R2R) systems by Zhu et al (2003). Fuzzy control logic is developed and verified by the simulations with step input errors. A mathematical model is described first to explain the lateral dynamics of a moving web. Based on the model, simulation software named LACOSIM is designed and implemented to simulate the lateral dynamics and also to control
the lateral position error of a web in R2R systems. In spite of developing modern control theories, control loop has been constructed with a PID controller in various fields because of its simple structure, stable response to widespread processes, relatively efficient performance and convenience for the operator.

During the process of strip cold rolling, the gauge and shape of wide strip are two key factors which determine the quality of product. The flatness and profile are used to describe the strip shape, while the crown and edge drop are two key parameters determining the profile of strip. In this year, the rolling technology develops quickly and lots of research works focus on this topic. Zhang and Yin (2000) give optimal design system based on genetic algorithms for the rolling parameters of tandem cold strip mill. Some other works were also achieved (Yang and Dou 2007; Wang and Tieu 2000; Bilkhu 2001; Morari 1998) but most of these works focus on hot rolling and part of them are theoretical analysis on cold rolling.

In spite of developing modern control theories, control loop has been constructed with a PID controller in various fields because of its simple structure, stable response to widespread processes, relatively efficient performance, and convenience for the operator. Up to now, much research of techniques to tune PID gains have been undertaken (Clement and Chidambaram 1997a,b; Ziegler and Nichols 1942). However, in order to obtain further improvements in performance and stability against disturbances and parameter uncertainties, research of synthetic tuning skills of gains are required. The coefficient diagram method (CDM) is one of gain-tuning techniques (Battacharyya et al 1995).

Bontolini (1996) presented a measure to make chattering happening on the visual derivation of control value to smooth chattering. Chen et al (2002) proposed an on-line manner of adjusting the width of the boundary
layer based on the state norm for an uncertain linear system. Feng et al (1999) set up a mathematical relationship between the steady state error and the width of the boundary layer, which not only reduces chattering, but also satisfies the specified steady state error.

Hydraulic Servo System (HSS) has advantages of quick response, large output, as well as high precision (Knohl and Unbehauen 2000). The hydraulic AGC system of cold rolling mill uses the merits of hydraulic servo system. The hydraulic servo system is typically nonlinear because of pressure-flow characteristics, threshold, hysteresis, friction, the servo amplifier, nonlinearities of A/D and D/A converters, and so on. The loop gain and the hydraulic damping vary due to the load of the actuator. As a result, the hydraulic AGC system imperatively needs more advanced control techniques with stronger robustness and higher precision.

Chun and Jung (1998) study the optimization performances between immune algorithm and other heuristic algorithms in rolling process. Yang and Dou (2007) study the load distribution optimization helpful to shape control of hot strip mills. give optimal design system based on genetic algorithms for the rolling parameters of tandem cold strip mill. Some other works were also achieved (Spooner and Bryant 1976). But most of these work focus on hot rolling, part of them are theoretical analysis on cold rolling.

Fleck et al (1992) presented the model based on roll deformation when rolling thin hard strip of thickness down to foil thickness. In this method the rolls were bending and the flattening had been reduced at the edges so that the diameters of the rolls were increased. This over rolling means harder material and could result in cracks. A strip suffering from cracked edges, into which high tension is applied, runs an increased risk of strip breakage. After a strip break, the mill needs to be cleaned from strip and damaged parts need to be replaced. The time for this depends on strip properties and the type of mill
but in bad cases is up to several hours. This is very costly for the producer which is why cracked edges must be eliminated. Another problem is the necking of the strip that according to results from the elevation of temperature in the roll-bite. The strip width is practically the same on both sides of the roll-bite, but the high energy consumption during the thickness reduction will cause the temperature to be higher on the exit side. Therefore, as the strip is cooling, the strip width will contract according to the temperature coefficient of the material. To compensate the problem, the producer must choose a raw material wider than the final strip dimension specification and use a shearing machine to remove the bad parts of the strip and make the width uniform.

Cold rolling mill control systems have previously been studied using static models (Bryant et al 1973; Chicharo and Tung 1990; Gunasekera et al 1998; Kim et al 2002; Zarate 2005 and Goodwin et al 2000). Previous research has focused on quality control (Dahlquist 2006) presented mathematical equations to describe the cold rolling mill and discussed process control. Numerical methods were used for prediction and identification of models. Postlethwaite et al (1998) studied the gauge control problem in tandem rolling mills. They performed a powerful multivariable analysis using the $H_\infty$ loop shaping method of McFarlane and Glover. Nonlinear simulation showed that this method provided improvements over a courier industrial controller.

Lee (2002) studied models of a cold rolling mill, constructed a mathematical model and used multivariable data analysis to analyze the results. Design of the control system in a cold rolling mill with multiple controllers is a complex task which requires knowledge of the system performance, potential problems and compatibilities. The selection of controllers to achieve the stability, accuracy, safety and reliability of the system is critical. The controller system can be designed using existing
modules such as estimators, adaptation systems, identifiers, delay blocks, calculators and displays.

Takami et al (2009) designed a simple, capable and reliable controller which can be used in a single stand cold rolling mill in a magnetic core factory. This fast and accurate control system uses a PID controller, smith predictor, kalman estimator, saturation operators and a delay function which enables accurate control of exit thickness with good fit around the set point. It is able to tolerate disturbances in the input or output of the system, and to control the thickness by controlling the spray valves.

In the present work, to control the position of the web, the transfer function model of the web guide of the cold rolling mill system has been developed. PID controller has been designed using various methods like equating coefficient, direct synthesis method, optimization method, model reference control, dual loop control, fuzzy logic control, and its robustness has been verified by using kharitonov’s method to determine the stability range of the controllers.

1.8 ORGANIZATION OF THE THESIS

Chapter 1: Includes the introduction about the work undertaken and the literature reviewed. Also incorporates the background study of the cold rolling process and problem statement.

Chapter 2: Comprises the mathematical model of the web guide of the cold rolling mill.

Chapter 3: Includes the different tuning methods for controlling the transfer function of the web guide of the cold rolling mill.

Chapter 4: Fuzzy logic based PID controllers have been discussed.
Chapter 5: Depicts the robustness analysis of controller.

Chapter 6: Reveals the overall conclusion of the work and future scope followed by references.