An Initial Study of Taguchi Method based Optimization of Cold Rolling Mill Parameter to Improve Quality and Productivity of Steel

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Abstract: **Taguchi Method is a statistical approach to optimize the process parameters and improve the quality of products that are manufactured. This paper focuses on initial study of rolling parameters of cold rolling mill and its optimization of process parameters based on Taguchi Method of Design of Experiment. The purpose of a cold rolling mill is to successively reduce the thickness of the metal strip and/or impart the desired mechanical and micro structural properties. Optimization for cold rolling mills rolling parameters are continuously being improved due to today's stringent high throughput, quality and low scrap loss requirements for products to make process robust. Rolling parameter set up or rolling scheduling is an important aspect in the operation of cold rolling mills. The optimized rolling parameters lead to improved thickness, surface finish and shape performance of the products.**

Keywords: Optimization, Taguchi method, orthogonal array & cold rolling mill.

I. INTRODUCTION

Rolling is the process of plastically deforming metal by passing it between hot or cold rolls. It is most widely used forming process, which provide high production and close control of final product [1]. The metal is subjected to high compressive stresses as a result of friction between the rolls and metal surface. Rolling processes can be mainly divided into hot rolling and cold rolling. The initial breakdowns of ingots into blooms and billets is done by hot rolling this is followed by further hot rolling into plate, sheet, rod, bar, pipe, rail. The purpose of a cold rolling mill is to successively reduce the thickness of the metal strip and/or impart the desired mechanical and micro structural properties. The cold rolling of metals provides flat product such as sheet, strip, and foil with good surface finishes and increase mechanical strength with close control of product dimensions. Tandem type rolling mills used for larger scale production, whereby the strip undergoes a single pass through a train of rolling stands before being wound into coil form. The single stand type rolling mills are usually operated as “reversing” mills, whereby the strip is successively wound and unwound in coil form as it is repeatedly passed back and forth through the single mill stand. Reversing mills are generally used for smaller scale production of the cold rolled products.

II COLD ROLLING MILL

The function of rolling mill is to reduce ingoing strip at room temperature by 50 to 90%. The reduction of strip thickness is caused by compressive stresses in contact region between work roll surface and strip. Cold rolling Mill s are **2-High 4-High 6-High 4-High Tandem 2-High Z-High 12-High 20-High (Temper) 6-High (Cluster)** employed as secondary rolling operations to achieve more precise dimensional, metallurgical, and mechanical properties. Of all the rolling stand configurations, the 4-high variety is the most widely used both in single stand and multi stand tandem mills. Rolling mills stand consists of work rolls, back up rolls, bearings, housing for containing these parts and a drive for applying power to the rolls and controlling the speed. In 4HI Cold rolling mill configuration consists of two work rolls and two back up rolls. The back up rolls provides rigid support to to prevent work roll bending & flexure. There are two hydraulic Jacks mounted on top of the housing on either side which provide rolling force of back roll housing and adjust roll gap. The strip coil fed to mill via tension reel on either side of mill stand. As the strip exists the mill stand it wound tight on tension reel on other side which is and expanding mandrel that maintain contant tensio

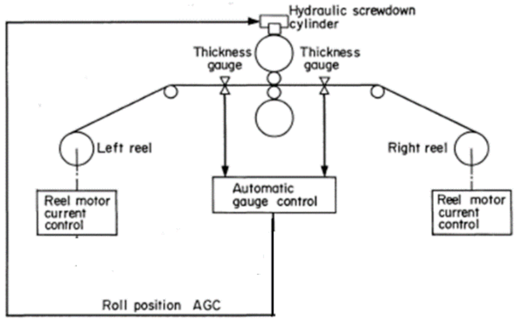

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Fig. No. 1 Schematic representation of Single stand 4 HI reversing cold rolling mill

during rolling process while reel on entry side maintain back tension during rolling.

At heart of the rolling process is the deformation of strip in roll bite. One of the most important component s in the deformation due to rolling force which has dominating effect on the accuracy of thickness and flatness of the rolled strip. Principal parameter affecting resistance to deformation are work hardening and friction at roll bite. Generally roll force can be represented as function of work roll diameter, strip width, material chemical composition, metallurgical characteristics, friction, work hardening, strain, strain rate, reduction, entry and exit tension (Bland & Ford , 1948 and 1951)[2]. In practice rolling force is measured using load cells.

Rolling parameter setting or scheduling is an important aspect in the operation of Reversible cold rolling mills. It defines reductions in each pass, tensions (Forward & Backward), rolling forces, roll torque (Mill top & bottom drive motor current), mill maximum speeds. Rolling schedule or setting parameter is a set of these rolling parameters.

Due to the heavy roll force of applied necessary 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. As a direct consequence of these individual component deflections, two important dimensional quality criteria of the rolled strip arise – 1) thickness profile, and 2) flatness.

Since rolled metal strip is used in many applications requiring strict adherence to tolerances, such as in the aerospace, automotive, construction, container, and appliance industries, it necessary to optimized rolling parameter in order to obtain productivity and quality metals. Various Process models for cold rolling mills have been intensively developed in the last years, hoping to increase quality of steel strip and productivity of rolling processes. Nevertheless, characteristics are only achieved using process sufficiently to be robust. The availability of robust & accurate models is associated for cold rolling process optimization has been intensely explored in the literature. Rolling Parameter generation or pass schedule is an important aspect in the operation of Single stand reversing cold rolling mills.

III.CONCEPT OF OPTIMISATION

An optimization problem begins with a set of independent variable or parameters, and include condition and restrictions that defines acceptable value of variables or parameters that minimizes or maximizes objective function to achieve best result from given situation. Basically, classical optimization process parameter design is used where process is technically unknown, it is complex and not easy to use. Especially, a large number of experiments have to be carried out when the number of the process parameters increases.

Evolutionary Optimization is computer programs designed to search optimal or near optimal solution are obtained too many kind of problem. Genetic algorithm one of the popular evolutionary optimization extensively used for optimization problem.

IV.TAGUCHI METHOD OF DESIGN OF EXPERIMENT:

Taguchi methods to quality control have been used to optimize the process parameters of engineering experiments [3]. This approach has been unique and powerful quality improvement discipline that differs from traditional practices. The Taguchi approach has successfully applied in several industrial applications. Parameter design to determine levels that produces the best performance of product/ process under study. The optimal condition is selected so that the influence of uncontrollable factors (Noise factor) causes minimum variation of system performance. Noise factor of process variability that are used to indentify control factors and the combined optimal level which minimizes that variability. Signal to noise ratio (S/N Ratio) are also used to measure the effect of Noise on the system. A Robust (Insensitive) system will have a high S/N ratio.

Popularly known Factorial design of experiments is laying out experiments when multiple factors are involved. This method helps the researcher to determine the possible combinations of factors and to identify best combination. However it is costly and time taking to run number of experiment to test all combination. Taguchi approach develop rules to carry out experiment, which further simplified and standardized the design of experiment with minimizing number of factor combination that would required to test for the factor effect. Bendell & Pridmore (1989)[5].

Basically, classical process parameter design is complex and not easy to use. A large number of experiments have to be carried out when number of process parameters increases. The Taguchi method uses special design of orthogonal arrays to study the entire process parameter with small number of experiments. Proper choosing of orthogonal which satisfies the problem conditions is the only job experiment designer.

V IDENTIFICATION OF PROCESS PARAMETRS:

There are various control parameters during cold rolling process such as Entry Coil Thickness, Exit Coil thickness, Front tension, Back Tension, Total Roll Force, Mill Drive motor current, Total reduction, Number of pass, Material to be rolled, Width of the strip, Coefficient of friction, Flatness of the strip, Gauge variation, Rolling Speed.

The parameters (Variables) can be divided in to following categories.

A. Independent Variables.

1. Controllable Independent Variables
2. Uncontrollable Independent Variables

B. Dependent Variables. / Performance

1. Variables or Output variables

Following variables are Dependent Variables.

I. Output Strip Thickness.
II. Output Strip Flatness.
III. Productivity
IV. Power Consumption.

Following are Main Objective of the Optimization of experiment
1. Lowest strip thickness variation.
2. Strip profile (Flatness)
3. Maximum mill speed.

Following are constraints for optimization.
1. Maximum Roll force as per Mill Specification.
2. Maximum Mill motor current limited to drive current capacity of drive motor.
3. Forward and Backward tension limited to drive current capacity of reel motor.
4. Maximum Mill speed capacity limited drive motor RPM.

In reversible cold rolling mill rolling parameters can be divided into Output parameters and input parameters.
Following are the output parameters affecting product quality and productivity
1. Output strip thickness variation.
2. Flatness & shape of output strip.
3. Total Power consumption.
4. Chattering mark on strip.

Following are the input parameters
1. Entry tension.
2. Exit tension.
3. Percent % Reduction in each pass.
4. Rolling speed.
5. Coolant % (Coefficient of friction).
6. Work roll Bending pressure.

Table no. 1 Material data

Entry th	Exit th	Reduction	No of pass	Material	Width
3.05mm	0.98mm	67.869%	8	WT41	1252mm

Table no.2 Typical Pass schedule

Pass No.	En th	Ex th	Reduction	En tension	Bk tension	width	Roll Force	Motor load	Speed
	mm	mm	%	Kg	Kg	mm	Ton	Amps	mpm
1	3.05	2.63	13.770	11360	1800	1252	750	2100	610
2	2.63	2.296	12.710	11360	9315	1252	774	2270	279
3	2.296	1.992	13.242	11360	10494	1252	769	2250	225
4	1.992	1.728	13.242	11360	9315	1252	821	1990	322
5	1.728	1.499	13.242	11360	9699	1252	810	2060	261
6	1.499	1.301	13.242	9082	6055	1252	906	2500	391
7	1.301	1.128	13.242	4921	6152	1252	794	1590	307
8	1.128	0.97	14.039	4921	6152	1252	810	2060	261

Objective function are
1. Minimize Output strip thickness variation.
2. Flatness & shape of output strip.
3. Minimize power consumption.
4. Maximize production rate.

VI PASS SCHEDULE / PARAMETER SETTING

The basic procedure for the scheduling of cold rolling mills is usually based on past experience, on trials or on rules of thumb [4].

1. Based on the coil data and stand thickness reduction pattern in each pass; a reduction at each pass is allocated. The coil data includes strip material grade such as yield strength, strip width W, strip entry thickness H and strip exit gauge h. The patterns vary with total mill reduction rate and work roll stand conditions (namely, shot-blast or bright rolling mode).
2. Maximum Forward & Backward tension stresses depend on the strip width, nominal yield stress deviation of the coil material, and the mill exit thickness at each pass.
3.Total roll force (Sum of Drive side & Operator side) is depend on various factor like stand Reduction, material grade, coefficient of friction between roll & strip and width of strip.
4.The Rolling torque (Mill top & bottom motor drive current) is depend on formula is a function of the work roll surface (namely, shot-blast or bright rolling mode), stand Reduction, material grade, coefficient of friction between roll & strip and width of strip.
5.Rolling speed is depend on the Rolling torque (Mill top & bottom motor drive current) every mill motor has limitation on maximum current.
6.The total roll force and roll torque are limited to the corresponding maximum values due to the mechanical design limits imposed by manufacturers of the rolling mill and electrical drive motors.
7. The power at each pass is estimated, based on the results of the roll speed and the roll torque in each pass.
8. The validity of the rolling parameters is checked to ensure that none of the rolling parameters has exceeded the mill capability; for instance, the limitations of the physical capability of the rolling mill (Max rolling force & rolling speed), and electrical requirements (Mill motor & tension reel motor current).
9. The mill speed is free to vary from pass to pass at the discretion of the mill operators.

Considering the above aspect of pass schedule is made. A typical pass schedule is shown in table no. 1&2.

VII. DESIGN OF EXPERIMENT:

During 1st pass material fed to mill from uncoiler and coiled on tension reel on the exit side. Due to limitation of uncoiler unit there is a limitation on back tension. Hence it is not possible to optimize rolling parameter in 1st Pass. In second pass strip fed from exit tension reel to Mill and coiled on tension reel on entry side. In designing of experiment for Optimization of rolling parameter would start consider from second pass. There are various control input factors in a pass such as reduction, entry tension, exit tension, coefficient of friction, strip width, material to be rolled. Rolling speed, roll bending pressure, input thickness, and output thickness. For optimization control parameter strip width, material, input and output thickness (Total reduction) are kept unchanged. For Application taguchi design of experiment for optimization of rolling process parameter factors are forward tension in kg, backward tension in kg, rolling speed in mpm and roll bending pressure, The levels are decided, then accordingly to this array can be produced.

There are certain assumptions for design of experiment to be carried out for batch of coils, coefficient of friction will be constant as long as width, work roll diameter, work roll surface, coil material and percentage of oil in the coolant sprayed remain constant. In our experiment we are not varying coefficient of friction for optimization and since it is very difficult to measure coefficient of friction between work roll and strip and it is depend on % rolling oil in coolant keeping other factors remain same.

Factors Input variable	Levels
Entry tension	3
Exit tension	3
Rolling speed	3
Bending pressure	3

Table No.3 shows the factors and levels for each input factors

Factor	Levels		
	1	2	3
Exit/Forward tension (Kg)	Tex1	Tex2	Tex3
Entry/Backward tension (Kg)	Ten1	Ten2	Ten3
Mill Speed (mpm)	N1	N2	N3
Bending Pressure (kg/cm2)	BP1	BP2	BP3

Table No.4 Factors and there Levels in Design of experiment.

For optimization purpose surface roughness of work roll remain unchanged and % rolling oil in coolant is unchanged from levels as decided from one coil to other coil. Levels of others factors such as entry & exit tension, bending pressure and rolling speed are also decided Table.

In our experiment there are 4 factors and 3 levels. The matrix experiment selected for this project is L9 available in standard orthogonal array.

Output variables are Thickness variation (Thv), Flatness (Flv), Power consumption (Pc) & Production rate (Pr). For each experiment reading of output variables are recorded for 2nd pass keeping same material data and rolling schedule. Thickness variation are recorded as % of strip of total length within acceptable tolerance range specified for the product after completing pass. The main objective of the cold rolling operation is to maximize % of the length of rolled strip within acceptable limit is the better performance.

Objective Function: Larger -the-Better

The following S/N ratios for the larger the better case could be calculated

$$S/NRatio = -10\log\left(\sum\left(\frac{1}{y^2}\right)/n\right)$$

Optimization using Taguchi based experiment shall be done for single response such as to minimize thickness variation of cold rolled strip. A suitable orthogonal array selected and experiment conducted in Single stand reversing cold rolling Mill. After conducting experiment thickness variation measured and signal to noise ratio calculated. With help of graphs, optimum parameter values were obtained and confirmation tests shall also be conducted to validate the optimum parameter settings.

VII. SCOPE OF THE WORK

Taguchi's DOE or ANOVA, Orthogonal Array shall be used to conduct the experiments. The parameters selected for controlling the process are forward and backward tension, rolling speed and roll bending pressure. From the results of the experiments, DOE models shall be developed to study the effect of process parameters on thickness variation. Taguchi method is generally used in optimizing process parameters of single response problem. But optimizing of a single response results in the non-optimum values for remaining response like flatness, production cost. So, multi characteristics response optimization may be the solution to optimize multi response simultaneously Cold rolling process is one of the widely used producing thin gauge cold rolled strips. The output characteristics such as strip thickness variation, strip flatness, production rate and production cost are equally important. Hence for need to devise method which fulfill the required output characteristics.

Table No. 5 Matrix Experiment

Experiment No.	Input variables				Output variables			
	Tex	Ten	N	Pb	Thv	Flv	Pc	Pr
1	Tex1	Ten1	N1	Pb1				
2	Tex1	Ten2	N2	Pb2				
3	Tex1	Ten3	N3	Pb3				
4	Tex2	Ten1	N2	Pb3				
5	Tex2	Ten2	N3	Pb1				
6	Tex2	Ten3	N1	Pb2				
7	Tex3	Ten1	N3	Pb2				
8	Tex3	Ten2	N1	Pb3				
9	Tex3	Ten3	N2	Pb1				

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