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Taguchi approach for optimization of process parameters in improving Quality of steel strip in single stand cold rolling Mill

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Abstract:*Thickness variation is important Quality parameters of cold rolled steel strip in cold rolling Process. Various Process models for cold rolling mills have been intensively developed, hoping to increase quality of steel strip and productivity of rolling processes. The availability of robust & accurate models is associated for optimization has been intensely explored in the literature. There is not much research done on application of Taguchi based Method in single stand cold rolling mill for optimization of cold rolling process parameters. This paper focuses on application of Taguchi Approach in optimization of cold rolling process parameters of steel. 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. AL_{27} orthogonal array was selected and total 27 experiments conducted in Single stand reversing cold rolling Mill after selecting control factors and its levels. After conducting experiment thickness variation measured and signal to noise ratio calculated. With help of graphs, optimum parameter values were obtained and confirmation test carried out.*

Keywords: *Cold rolling,Optimization,orthogonal array, Signal to noise ratio, Taguchi method, &uncoiler.*

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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] [2]. 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.

The function of cold 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 rollingstand 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. Fig 1 shows schematic representation of single stand 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 tension during rolling process while reel on entry side maintain back tension during rolling

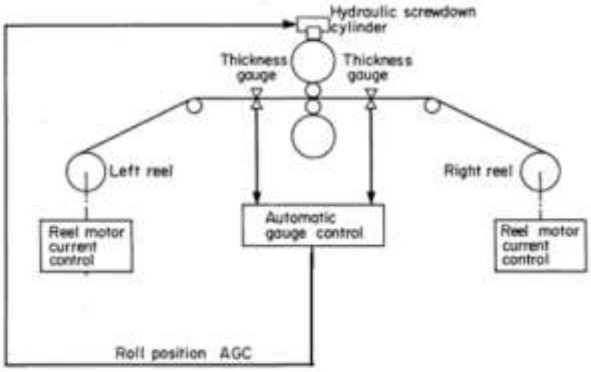

Fig. No. 1 Schematic representation of Single stand 4 HI reversing cold rolling mill

At heart of the rolling process is the deformation of strip in roll bite. One of the most important components 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)[3]. In practice rolling force is measured using load cells.

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. There are various noise factors such as input thickness variation, input material hardness variation which affects the final output thickness,itis necessary to optimized rolling process parameters in order to obtain process more robust to improve productivity and quality of steel. 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. The availability of robust & accurate models is associated for optimization has been intensely explored in the literature. There is not much research done on application of Taguchi based Method in single stand cold rolling mill for optimization of cold rolling process parameters. In the proposed study single stand reversible Mill have been taken as case study for optimization of cold rolling parameter for thickness variation. Rolling Parameter generation or pass schedule is an important aspect in the operation of Single stand reversing cold rolling mill. Pass schedule consists of number of pass with reduction in each pass. Number of pass depend on the reduction in each pass. Reduction in each pass depend on various factors.In the study the optimization carried out in 2nd pass.

1.2 ConceptOf Optimization

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.

A full factorial experiment is an experiment whose design consists of two or more factors, each with a discrete possible level and whose experimental units take all possible combinations of all those levels across all such factors. Such an experiment allows studying the effect of each factor on the response variable, as well as on the effects of interactions between factors on the response variable. A common experimental design is the one with all input factors set at two levels each. If there are k factors each at 2 levels; a full factorial design has 2k runs. Thus for 6 factors at two levels it would take 64 trial runs.

Taguchi method is a statistical method developed by Taguchi and Konishi [4]. Initially it was developed for improving the quality of goods manufactured (manufacturing process development), later its application was expanded to many other fields in Engineering.

1.3Taguchi Method of Design Of Experiment:

Taguchi methods to quality control have been used to optimize the process parameters of engineering experiments [9]. 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 identify 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.

Taguchi's S/N Ratio for (NB) Nominal-the-best.

$$\eta = 10\log_{10}\frac{1}{n}\sum_{i=1}^{n}\frac{\mu^2}{\sigma^2} \quad \ldots\ldots\ldots \quad (1)$$

Taguchi's S/N Ratio for (LB) Lower-the-better

$$\eta = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n} y_i^2 \quad \ldots\ldots\ldots \quad (2)$$

Taguchi's S/N Ratio for (HB) Higher-the-better

$$\eta = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2} \quad \ldots\ldots\ldots \quad (3)$$

1.4 Steps Involved In Taguchi Method

The use of Taguchi's parameter design involves the following steps [5]

1. Identify the main function and its side effects.
2. Identify the noise factors, testing condition and quality characteristics.
3. Identify the objective function to be optimized.
4. Identify the control factors and their levels.
5. Select a suitable Orthogonal Array and construct the Matrix
6. Conduct the Matrix experiment.
7. Examine the data; predict the optimum control factor levels and its performance.
8. Conduct the verification experiment.

II. EXPERIMENTAL SETUP

2.1ApproachTo The Experimental Design.

Table no1 shows the material data and process data for input material and output desired, depend on input and output data a roll pass schedule prepared. The basic procedure for the scheduling of cold rolling mills is usually based on past experience, on trials or on rules of thumb [6]. Table no.2 shows the typical pass schedule. Our experiment is focused on optimization control factors for 2nd pass only. The objective of the experiment is to minimize thickness variation or maximize % of strip length under specified tolerance limit of target thickness by optimizing rolling control parameters.

Table no. 1 Material and Process data

Entry thk	Exit thk	Reduction	Thickness Tolerance	No. of Pass	Material	Width	Weight of coil
2.15mm	0.38mm	82.32%	0.357-0.417	8	ST29DC	1200 mm	20MT

Table no2 Typical Pass schedule

Pass No.	Entry thk	Exit thk	Reduction	Exit tension	Entry tension	Rolling speed	Roll bending Pr.
	mm	mm	%	Kg	Kg	mpm	bar
1	2.150	1.735	19.302	12200	2000	300	80
2	1.735	1.400	19.302	12200	7200	500	80
3	1.400	1.130	19.302	12200	7200	600	80
4	1.130	0.912	19.302	12200	7200	600	80
5	0.912	0.736	19.302	10682	7121	600	80
6	0.736	0.594	19.302	8600	5734	600	80
7	0.594	0.479	19.302	4617	5772	600	80
8	0.479	0.387	19.302	3718	4647	600	80

In 1st pass material fed to mill from uncoiler and coiled on tension reel on the exit side. In second pass strip fed from exit tension reel to Mill and coiled on tension reel on entry side. In proposed study optimization of process parameterscarried out in2nd pass. Optimal process parameter were obtained in 2nd pass then it can be used as setting parameters for subsequent passes. So that in the final/last pass the thickness variation will be improved further. Hence it is important to obtain optimal control parameter setting at initial stage of rolling. From the pass schedule it is notice that all four parameters are same till 4thpass hence. Initial optimal parameter can be applied on subsequent passes up to 4thpass.Objective is to obtain optimal process parameter in 2nd pass hence our study is limited to 2nd pass only.

In accordance with the steps that are involved in Taguchi's Method, a series of experiments were conducted. Experiments were carried out on low carbon steelon 4HI cold rolling Reversible Mill at JSW Steel coated Product Ltd, Kalmeshwar Nagpur, India as a case study. The procedure is given below

2.2 Steps for Taguchi Method of experimentation

2.2.1 Identify the main function and its side effects.

Optimization of process parameters of Single stand cold rolling process:

In reversible cold rolling mill rolling process parameters can be divided into Output parameters and input parameters.

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.

Following are the output parameters affecting product quality and productivity.

1. Output strip thickness variation.
2. Flatness & shape of output strip.
3. Power consumption.
4. Production rate.

Objective function can be

1. Minimize Output strip thickness variation within acceptable limit.
2. Flatness & shape of output strip within acceptable value.
3. Minimize power consumption.
4. Maximize Production rate.

2.2.2Identify the control & noise factors, testing condition and quality characteristics.

Before proceeding on to further steps, it was necessary to list down all the factors that are going to affect or influence the thickness variation in rolling process and from those factors one has to identify the control and noise factors. The "Factors" that affect rolling operation on a cold rolling mill are listed below.

Control factors	**Noise Factors**	
Entry tension	Reduction in each pass	Input strip thickness variation.
Exit Tension	coefficient of friction	Input strip hardness variation.
Rolling Speed	work roll diameter	Mill chattering.
Bending Pressure	Material to be rolled	Input strip flatness.

After listing the control and the noise factors, decisions on the factors that significantly affect the performance will have to be ascertained and only those factors must be taken in to consideration in constructing the matrix for experimentation. All other factors are considered as Noise Factors.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. Material input data and reduction remain same during the experimentation.The factors were decided for conducting the experiment, based on a "brain storming session" and by Fishbone diagram of cause and effect study that was held with a group of people from Mill.The control factors weredecided entry tension (Backward), exit tension (forward) rolling speed & roll bending pressure. Input steel strip thickness variation was consider as the noise factor.

Quality Characteristic: Thickness variation of output strip, % of total rolled strip length under specified acceptable limit (±0.05) of the target thickness. Target thickness in our experiment is 1.400 mm and acceptable limit is LCL-1.350 &UCL -1.450 mm.

Material: Low carbon steel Grade ST29DC (carbon 0.06 max & manganese 0.30 to 0.35)

Rolling Mill: Single stand Reversing cold rolling Mill

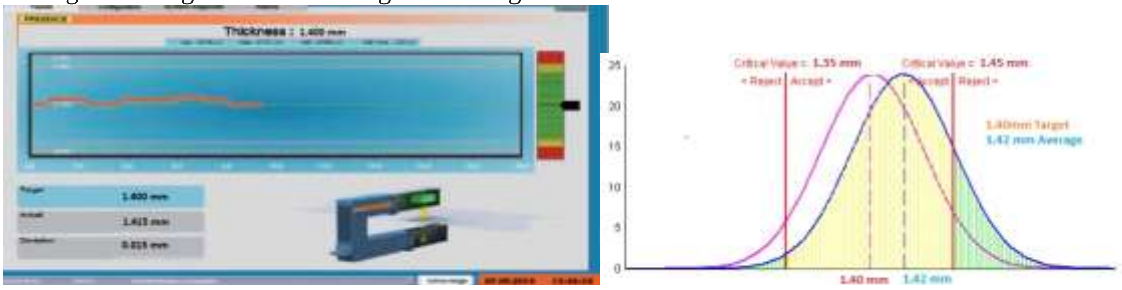

Fig No.2 Graphical representation report generated for strip thickness variation over coil length.

Testing Equipment: There are two X- Ray Gauge at two sides of the Mill stand. The x ray gauge before entering mill bite measures input gauge and X-Ray Gauge after mill stand measures output Gauge. After completion of the pass strip measurement analysis report generated, which provides output data as graphical representation of thickness about target thickness and result of the analysis like standard deviation, average thickness and % of the total rolled length within acceptable limit (UCL & LCL) (Yellow shaded portion in normal distribution curve).

2.2.3 Identify the Objective Function

The main objective of the cold rolling operation is to maximize % of the length of rolled strip within acceptable limit is the better performance. Therefore the larger the better ie larger the % of length of strip within acceptable limit(UCL & LCL)was selected for obtaining optimum rolling performance characteristics.

Objective Function: Larger -the-Better

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

S/N Ratio$=-log_{10}\left[\sum\left[\frac{1}{y^2}\right]/n\right]$ (1)

Where n= sample size and y= % of the total rolled strip thickness under acceptable tolerance limit.

$$The\ total\ rolled\ strip\ under\ specified\ limit(\%) = \frac{Total\ length\ of\ strip\ under\ specified\ limit}{Total\ length\ of\ the\ strip\ rolled}\ x\ 100$$

More the length of the strip under tolerance limits better the performance.

2.2.4 Identifying the Control Factors and their levels

The factors and their levels were decided for conducting the experiment, based on a "brain storming session" and by Fishbone diagram of cause and effect study that was held with a group of people and also considering the guide lines given in the operator's manual provided by the manufacturer of the rolling mill. The factors and their levels are shown in table 3 & 4.

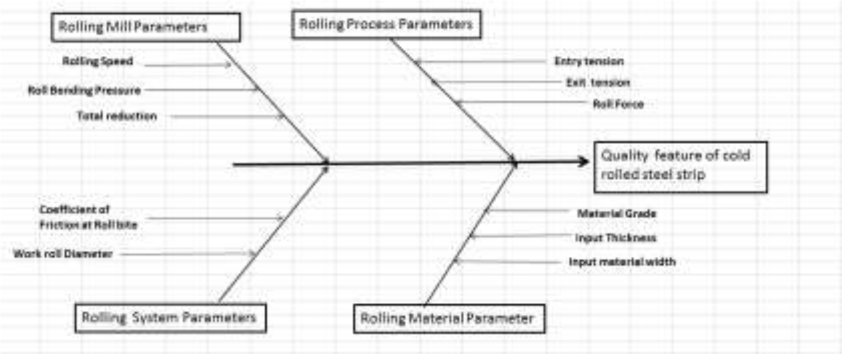

Fig 3. Fish Bone Diagram of cause of effect

Table 3 shows the factors and levels for each input factors

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

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

Factor	Units	Levels		
		1	2	3
Exit tension	Kgs	11000	11600	12200
Entry tension	Kgs	6000	6600	7200
Mill Speed	mpm	400	500	600
Bending Pressure	Kg/cm2	70	80	90

2.2.5Select a suitable Orthogonal Array and construct the Matrix

There are four control factors with 3 levels in our experiment. The suitable orthogonal for experimentation L9 standard orthogonal array was selected initially for this project.Totalnine experimentation conducted and results were recorded. Optimum parameters were obtained from the nine experiments, but as per interaction plot obtained by using L9 model shows there is a interaction among control factor, hence proposed model needed to be modified, model for such situation needs more experiments to estimate all the parameters. Next model available with four control factor with three levels is $L_{27}(3^{13})$. This Model requires Total 27 numbers of experiments;it has 13 control factors with 3 levels. For proposed study we used have L_{27}Model and kept 4 factors active and remaining 9 Factors kept it as dummy Factors.The experimental layout with the selected values of the factors is shown in Table 5.

2.2.6 Conduct experimentation

Each of the 27 experiments was conducted to account for the variations that may occur due to the noise factors. The thickness at the exit was measured using x ray gauge and thickness variation reports recorded from reports generated after finishing one complete pass. The table 5 shows the measured values of % of total length within specified acceptable limitof target thickness obtained from different experiments.

Table 5 Measured values of Thickness variation % length in acceptable limit

Experiment No.	Exit tension	Entry tension	Mill Speed	Bending Pressure	Length of strip in acceptable limit	S/N Ratio
	Kg	Kg	mpm	Kg/cm2	% of Total Length	dB
1	11000	6000	400	70	72.13	37.16
2	11600	6600	500	80	75.62	37.57
3	12200	7200	600	90	79.21	37.97
4	11600	6600	600	90	74.95	37.49
5	12200	7200	400	70	81.13	38.18
6	11000	6000	500	80	71.12	37.03
7	12200	7200	500	80	79.88	38.04
8	11000	6000	600	90	70.45	36.95
9	11600	6600	400	70	76.63	37.68
10	11600	7200	400	80	78.87	37.93
11	12200	6000	500	90	77.38	37.77
12	11000	6600	600	70	70.95	37.01
13	12200	6000	600	70	75.21	37.52
14	11000	6600	400	80	74.37	37.42
15	11600	7200	500	90	77.38	37.77
16	11000	6600	500	90	73.12	37.28
17	11600	7200	600	70	75.21	37.52
18	12200	6000	400	80	78.87	37.93
19	12200	6600	400	90	80.63	38.12
20	11000	7200	500	70	73.62	37.33
21	11600	6000	600	80	72.71	37.23
22	11000	7200	600	80	72.95	37.26
23	11600	6000	400	90	76.13	37.63
24	12200	6600	500	70	78.12	37.85
25	11600	6000	500	70	73.38	37.31
26	12200	6600	600	80	77.45	37.78
27	11000	7200	400	90	76.13	37.63

Table 8; Response table for s/n ratio for each factor

Levels	Control factors			
	Exit tension	**Entry tension**	**Rolling speed**	**Bending pressure**
	A	B	C	D
1	37.24	37.4	37.75	37.51
2	37.57	37.58	37.55	37.58
3	37.91	37.74	37.42	37.63
Delta	0.68	0.35	0.33	0.12
Rank	1	2	3	4

Table 9: Response Table for Mean Data for each control factor

Levels	Control factors			
	Exit tension	**Entry tension**	**Rolling speed**	**Bending pressure**
	A	B	C	D
1	72.76	74.15	77.21	75.15
2	75.65	75.76	75.51	75.76
3	78.65	77.15	74.35	76.15
Delta	5.89	3.00	2.86	1.00
Rank	1	2	3	4

2.2.7Examine the data; predict the optimum control factor levels and its performance

Analysis of Experimental Results

Since the objective function (% of the total length under permissible tolerance limit of thickness variation) is larger -the-better type of control function, was used in calculating the S/N ratio. The S/N ratios of all the experiments were calculated and tabulated as shown in Table 5. The factor effect levels corresponding to the lowest S/N ratio were chosen to optimize the condition. From this linear graph it is clear that the optimum values of the factors and their levels are as given in table13..

Optimum values of factors and their levels **Parameter Optimum Value**

Exit Tension (Kg)	12200
Entry Tension (Kg)	7200
Rolling Mill Speed (mpm)	400
Roll Bending Pressure (Bar)	90

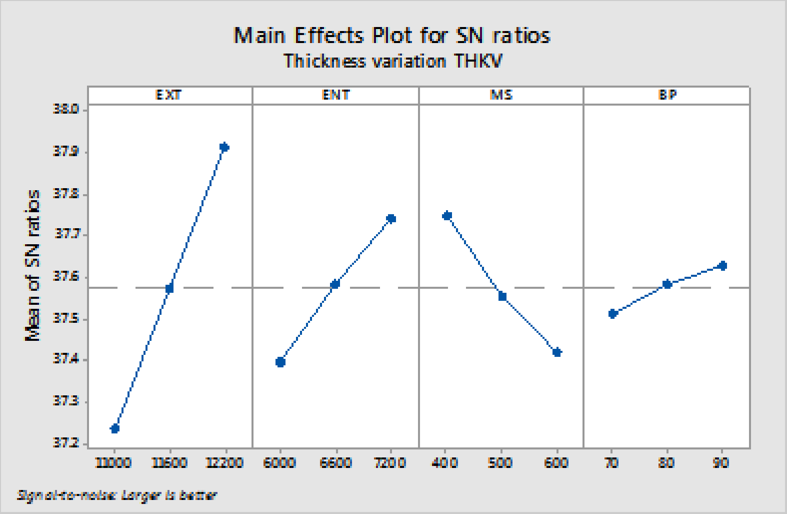

Fig 4 Main effect plot for Thickness variation

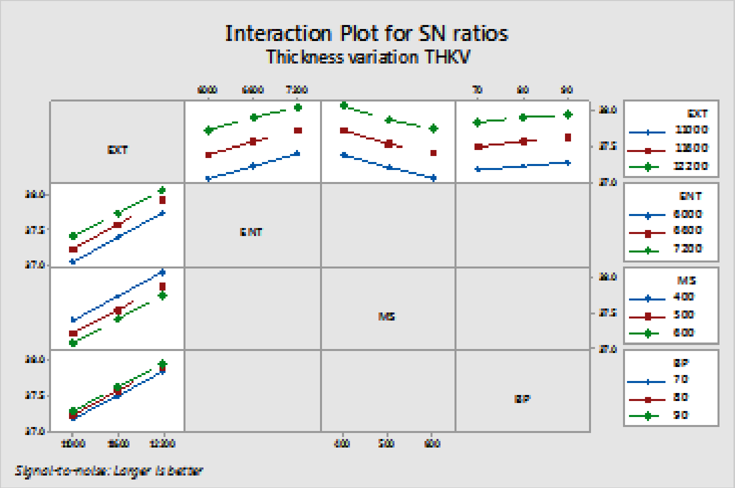

Fig 5 Interaction plot for thickness variation

Table 11 ANOVA results for Thickness variation mean values

Factors / Source	**Degree of Freedom**	**Sum of square**	**Mean square**	**F- Value**	**P-Value**	**% Contribution**
Exit Tension (EXT) A	2	156.308	78.1541	5233.54	0.000	65.42
Entry tension (ENT) B	2	40.568	20.2841	1358.31	0.000	16.98
Mill Speed (MS) C	2	37.315	18.6577	1249.4	0.000	15.62
Bending Pr (BP) D	2	4.568	2.2841	152.96	0.000	1.91
EXT+ENT	4	0.021	0.0053	0.36	0.831	
EXT+MS	4	0.034	0.0085	0.57	0.694	
EXT+BP	4	0.021	0.0053	0.36	0.831	
Error	6	0.09	0.0149			
Total	26	238.927				

From the ANOVA table of Signal to noise ratio, for 95 % confidence level, the P-value for exit tension, entry tension, Mill speed and Bending Pressure is less than 0.05 i.e. (< 0.05), hence all the input parameters are significant to thickness variation whereas, for interaction of parameters p-value is greater than 0.05 i.e. (> 0.05), hence they are not significant to thickness variation.

From this analysis, it is revealed that Exit tension is (65.42%) factor which affect the rolling process of low carbon steel. The Entry tension (16.98%) and Rolling speed (15.62%) are the not much influencing factor in determining the performance characteristics followed by roll bending pressure (1.91%) which has less significant effect on performance.

Fig no. 5 shows the interaction plot among the all the control factors which shows there is no interaction among the control factor hence selected model is correct it can able predict correct values.

Table 12 ANOVA results for Thickness variation S/N ratio

Factors / Source	**Degree of Freedom**	**Sum of square (SS)**	**Mean square (MS)**	**F- Value**	**P-Value**	**% Contribution**
Exit Tension (EXT)	2	2.06098	1.03049	4404.28	0.000	65.40
Entry tension (ENT)	2	0.53685	0.26842	1147.23	0.000	17.03
Mill Speed (MS)	2	0.49023	0.24512	1047.61	0.000	15.56
Bending Pr (BP)	2	0.06052	0.03026	129.33	0.000	1.92
EXT+ENT	4	0.00105	0.00026	1.12	0.427	0.06
EXT+MS	4	0.00020	0.00005	0.21	0.921	0.13
EXT+BP	4	0.00034	0.00008	0.36	0.821	0.11
Error	6	0.0014	0.00023			0.05
Total	26	3.15157				

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2.2.8 Conduct the verification experiment and Prediction Model

Table 13 Values of Process Parameters at Optimum Level of thickness variation

Levels	Control factors			
	Exit tension	**Entry tension**	**Rolling speed**	**Bending pressure**
	A	B	C	D
1	37.24	37.4	37.75	37.51
2	37.57	37.58	37.55	37.58
3	37.91	37.74	37.42	37.63
Delta	0.68	0.35	0.33	0.12
Rank	1	2	3	4

Table 14 Average values of response at optimal level

Level	Mean value	S/N Ratio
A3	78.65	37.91
B3	77.15	37.74
C1	77.21	37.75
D3	76.15	37.63

2.3Prediction Model:

In the present work, a mathematical model is selected to predict the thickness variation (%).In the model, thickness variation as function of exit tension, entry tension, mill speed and Roll bending pressure.The relationship between thickness variation and other input variables is model as follows [9]:

⍰ $= \gamma_m + \sum_{i=1}^{n}(\gamma_i - \gamma_m)$---- (4)

Where, µ is the predicted mean of response characteristic.

γ_m is the average value of the response

Predicted values of thickness variation at optimal setting **A3B3C1D3**

⍰ $= Y_{thkv(m)} + (\mathrm{A3} - Y_{thkv(m)}) + (\mathrm{B3} - Y_{thkv(m)}) + (\mathrm{C1} - Y_{thkv(m)}) + (\mathrm{D3} - Y_{thkv(m)})$

$Y_{thkv(m)}$ = average value of the thickness variation = 75.69

µ = 75.69+(78.65 -75.69)+(77.15 - 75.69)+(77.21- 75.69)+(76.15-75.69)
= 80.57

2.4Confidence Interval

For the 95 % confidence interval, CI is calculated as below:

$$CI = \sqrt{\frac{F_{\propto}(1,f_e)\,V_e}{n_{eff}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (5)$$

Where $F_{\alpha}(1,\ f_e)$ = The F ratio at the confidence level of (1-α) against '1' and error of freedom f_e .

α = 0.05 , V_e Error variance = 0.09 from ANOVA Table

$$n_{eff} = \frac{N}{(1+DOF\ associated\ \ with\ mean\ \ response\ )}$$

=81/ (1+8) =9,

N = Total number of results = 27*3=81

f_e =error DOF=6 (ANOVA Table Mean)

$F_{0.05}$ (1, 6) = 5.99(Tabulated F value (Ross, 1996))

Error variance Ve =0.09(from table 10)

CI =+-0.5391

The 95% confidence interval of the population is: [µ− CI] <µ< [µ+ CI]

80.03<80.57<81.10

2.5 Confirmation Test:

Once the optimal combination of process parameters and their levels was obtained, the final step was to verify the estimated result against experimental value.

The following table 15 shows confirmation experiments conducted at optimal setting control factors Entry tension 12200 kg, Entry tension 7200 Kg, Rolling speed at 400 mpm and Roll bending pressure 90 bar. Total four sets of experiments were conducted and % of length withinpermissible thickness variation limit values were checked. It can be seen that the results are consistent.

Table 15 Results of Confirmatory Experiment

Experiment No.	% in thickness Tolerance limit
1	80.4
2	81.2
3	80.6
4	81.1
Mean	80.825

Table 16 Results of Confirmatory Experiment

	Unit	Initial Result	Predicted Result	Actual Results	Error in Prediction	Improvement
Factor Level		A1B2C2D3	A3B3C1D3	A3B3C1D3		
length permissible Thickness variation	%	73.12	82.05	80.825	0.31%	10.78%

Results of confirmatory test and prediction model with confidence 95% level shows that by application of Taguchi optimization there is improvement of thickness variation by 10.78% and there is error of 0.31% in prediction model, which shows that the prediction model is suitable and appropriate.

III. CONCLUSIONS:

The Taguchi Method is successfully applied in this study to determine the optimum setting of process parameters for single response optimization of cold rolling process at 2nd pass. Single characteristic response optimization model based on Taguchi concept is used to optimize process parameters entry tension, exit tension, rolling speed & roll bending pressure on single performance characteristics such as strip thickness variation in the present case. The final conclusions arrived, at the end of this work are as follows:

From this analysis, it is revealed that Exit tension is (65.42%) factors which affect the rolling process of low carbon steel. The Entry tension (16.92 %) and Rolling speed (15.62%) are the not much influencing factor in determining the performance characteristics followed by roll bending pressure (1.09%) which has less significant effect on performance.

The best best performance characteristics was obtained from cold rolling process with the lower exit tension of 12200 kgs , Higher entry tension of 7200 kgs ,lower rolling speed of 400 m/min and medium bending Pressure of 90Kg/cm2.The predicted optimal range of Thickness variationis at 95 % confidence level.The optimal values obtained using the Taguchi based optimization models have beenvalidated by confirmation experiments.

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