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Application of Taguchi for Optimization of Process Parameters Inimproving Thickness Variation in Single Stand Cold Rolling Mill

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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 onapplication of Taguchi Method of Design of Experiment in optimization of process parameters in cold rolling 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. Taguchi based design of experiment applied in second pass in single stand reversing cold rolling mill to optimize rolling parameters for improving thickness variation of the steel 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 test carried out.

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

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, stripand 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

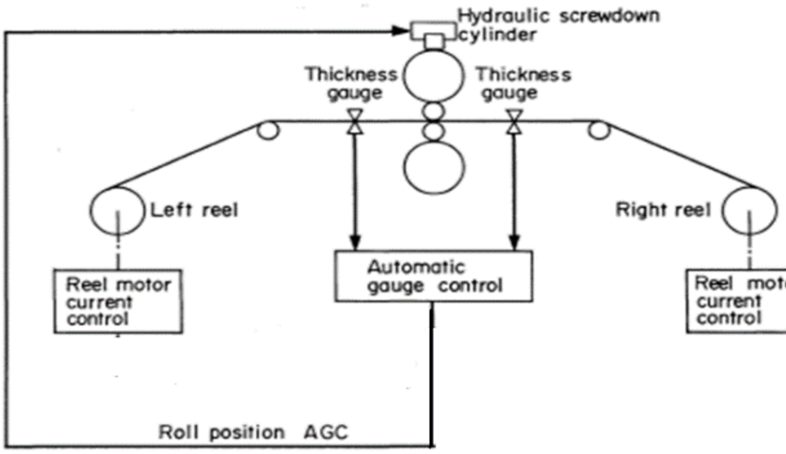

Fig. No. 1Schematic representation of Single stand 4 HI reversing cold rolling mill

At heart of the rolling process is the deformation of strip in roll bite. One of the most important 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)[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, 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. 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. Rolling Parameter generation or pass schedule is an important aspect in the operation of Single stand reversing cold rolling mill.

II. 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.

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.

III. TAGUCHI METHOF 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.

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 require to test for the factor effect. Bendell&Pridmore (1989)[8].

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.
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 output parameters affecting product quality and productivity.
1. Output strip thickness variation.
2. Flatness & shape of output strip.
3. Power consumption.
4. Production rate.

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.

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.

IV. STEPS INVOLVED IN TAGUCHI METHOD

1. The use of Taguchi’s parameter design involves the following steps [5]
2. Identify the main function and its side effects.
3. Identify the noise factors, testing condition and quality characteristics.
4. Identify the objective function to be optimized.
5. Identify the control factors and their levels.
6. Select a suitable Orthogonal Array and construct the Matrix
7. Conduct the Matrix experiment.
8. Examine the data; predict the optimum control factor levels and its performance.
9. Conduct the verification experiment.

V. APPROACH TO THE EXPERIMENTAL DESIGN.

Table no1 shows the material 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.

Entry thk	Exit thk	Reduction	No of pass	Material	Width	Weight of the coil
2.15mm	0.38mm	82.32%	8	ST29DC	1200	20 MT

					mm		

Table no. 1 Material data

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

Table no2 Typical Pass schedule

In 1st pass material fed to mill from uncoiler and coiled on tension reel on the exit side. Due to limitation ofUncoiler unit there is a limitation on back tension. Actual rolling process starts from 2nd pass hence our experiment conducted in 2nd pass. In second pass strip fed from exit tension reel to Mill and coiled on tension reel on entry side.

In accordance with the steps that are involved in Taguchi's Method, a series of experiments are to be conducted. Here, cold rolling of low carbon steel carried out in 4HI cold rolling Mill at JSW Steel coated Product, Kalmeshwar Nagpur, India has been carried out as a case study. The procedure is given below

5.1 Identify the main function and its side effects.

Before proceeding on to further steps, it is 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	Input strip thickness variation.
Exit Tension	Input strip hardness variation.
Rolling Speed	Mill chattering.
Bending Pressure	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 FactorsIn designing of experiment for Optimization of rolling parameter is consideredin 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. Since we are planning to carry out experiment keeping material input data and reduction unchanged. The control factors are entry tension (Backward), exit tension (forward) rolling speed & roll bending pressure. The noise factors are input strip thickness variation, material hardness variation and strip flatness. The levels of control factors are decided, then accordingly to this array can be produced.

5.2 Identifying the Testing Conditions and Quality Characteristics tobe observed.

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 1.350&1.450 mm.
Material: Low carbon steel Grade ST29DC
Rolling Mill: Single stand Reversing cold rolling Mill

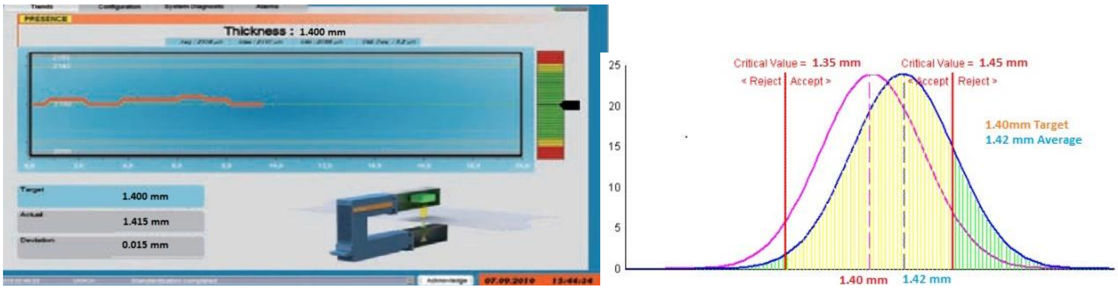
Thickness : 1.400 mm
Target 1.400 mm
Actual 1.415 mm
Deviation 0.015 mm

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 shows 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(Yellow shaded portion in normal distributioncurve).

5.3 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 betterie larger the % of length of strip within acceptable limitis 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

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

Where n= sample size and y= % of the total rolled strip thickness under acceptable tolerance limit.
Where % of the total rolled strip thickness = length of strip under tolerance limit X 100
Under tolerance limit total length of the rolled strip
More the length of the strip under tolerance limit better the performance.

5.4Identifying the Control Factors and their levels

The factors and their levels were decided for conducting the experiment, based on a "brain storming session" 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.

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

Table 3 shows the factors and levels for each input factors

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

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

5.5 Conductingthe Matrix Experiment

Experiment No.	Entry th	Exit th	Reduction	Exit tension	Entry tension	Mill Speed	Bending Pressure	Length of strip in acceptable limit
	mm	mm	%	Kg	Kg	mpm	Kg/cm2	% of Total Length
1	1.75	1.4	19.302	11000	6000	400	70	71
2	1.75	1.4	19.302	11000	6600	500	80	65
3	1.75	1.4	19.302	11000	7200	600	90	74
4	1.75	1.4	19.302	11600	6000	400	90	75
5	1.75	1.4	19.302	11600	6600	500	70	72
6	1.75	1.4	19.302	11600	7200	600	80	69
7	1.75	1.4	19.302	12200	6000	400	80	78
8	1.75	1.4	19.302	12200	6600	500	90	70
9	1.75	1.4	19.302	12200	7200	600	70	67

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

There are four control factors with 3 levels in our experiment. The most suitable orthogonal for experimentation for this project is L9 available in standard orthogonal array.The experimental layout with the selected values of the factors is shown in Table 5. Each of the 9 experiments were 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 acceptable limitof target thickness obtained from different experiments.

5.6 Examination of data

The following are the experimental results of the work carried out.

VI. Experimental Details

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 6.

Experiment No.	S/N Ratio (db)
1	37.26
2	36.25
3	37.38
4	37.5
5	37.46
6	36.77
7	37.84
8	36.9
9	36.52

Table 6 Tabulated S/N ratios

The S/N ratio for the individual control factors are calculated as given below:

$Sent1=(\eta_1+\eta_2+\eta3)$, $Sent2=(\eta4+\eta5+\eta6)$ & $Sent3=(\eta7+\eta8+\eta9)$

$Sext1=(\eta_1+\eta4+\eta7)$, $Sext2=(\eta2+\eta5+\eta8)$ & $Sext3=(\eta3+\eta6+\eta9)$

$Sn1=(\eta_1+\eta6+\eta8)$, $Sn2=(\eta2+\eta4+\eta9)$ & $Sn3=(\eta3+\eta5+\eta7)$

$Sbp1=(\eta_1+\eta5+\eta9)$, $Sbp2=(\eta2+\eta6+\eta7)$ & $Sbp3=(\eta3+\eta4+\eta8)$

For selecting the values of η_1, $\eta2$, $\eta3$ etc. and to calculate Sent1, Sent2 & Sent3 see table 6.
ηk is the S/N ratio corresponding to Experiment k.
Average S/N ratio corresponding to entry tension at level 1 = Sent1/3
Average S/N ratio corresponding to entry tension at level 2 = Sent2/3
Average S/N ratio corresponding to entry tension at level 3 = Sent3/3

j is the corresponding level each factor. Similarly Sextj, Snj and Sbpj are calculated for exit tension, speed and bending pressure. The average of the signal to noise ratios is shown in table 7. Similarly S/N ratios can be calculated for other factors.

Level	Entry tension		Exit Tension		Rolling speed		Roll bending pressure	
	Sum (Sentj)	Avg S/N ratio	Sum (Sentj)	Avg S/N ratio	Sum (Sentj)	Avg S/N ratio	Sum (Sentj)	Avg S/N ratio
1	110.89	36.963	112.6	37.533	110.93	36.977	111.24	37.08
2	111.73	37.243	110.61	36.87	110.27	36.757	110.86	36.953
3	111.26	37.087	110.67	36.89	112.68	37.56	111.78	37.26

Table 7: Average S/N Ratios for each factor

The factor effect levels corresponding to the lowest S/N ratio were chosen to optimize the condition. From these linear graph it is clear that the optimum values of the factors and their levels are as given in table

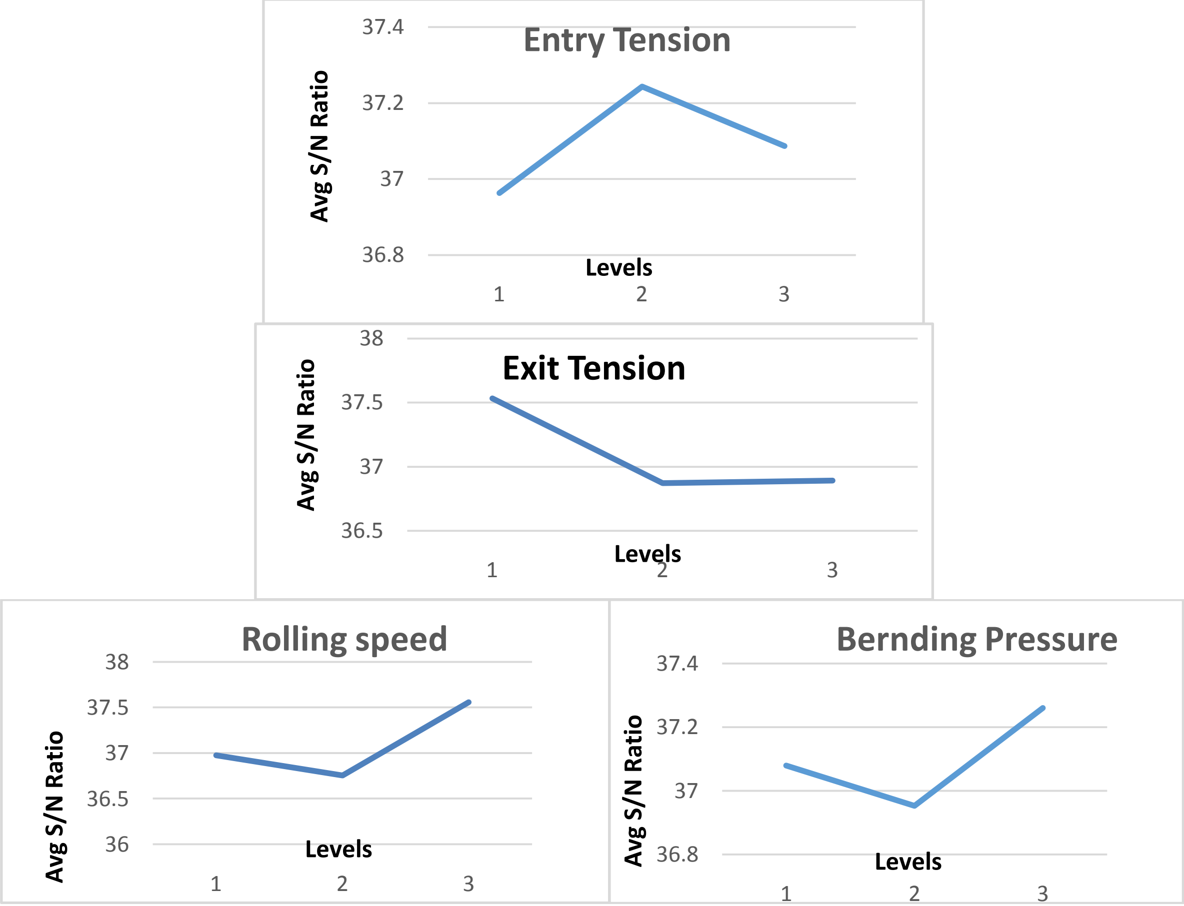

Fig 2 Charts showing parameter level v/s S/N Ratio

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

Exit Tension (Kg)	11600
Entry Tension (Kg)	6000
Rolling Mill Speed (mpm)	600
Roll Bending Pressure (Bar)	90

VII. Conduct the verification experiment.

The following table 8 shows confirmation experiments conducted by setting control factors Entry tension 12200 mpm, Entry tension 6600 Kg, Rolling speed at 600 mpm and Roll bending pressure 70 bar. Total four sets of experiments were conducted and % of length within permissible thickness variation limit values were checked. It can be seen that the results are consistent.

Experiment No.	**% Length in thickness Tolerance limit**
1	77.4
2	77.2
3	77.6
4	77.1
Mean	77.3

Table 8 Confirmation Experiment

VIII. ANOVA AND ITS SIGNIFICANCE

Analysis of variance (ANOVA) is used to evaluate the response magnitude in % of each parameter in the orthogonal experiment. It is used to identify and quantify the sources of different trial results from different trial runs.

Parameter	**DOF**	**SS**	**SS%**
Entry Tension	2	0.1182	5.49
Exit tension	2	0.8543	39.75
Rolling speed	2	1.034	48.11
Bending Pressure	2	0.1425	6.63
Noise, e		0.001	0.02
Total	8	2.148	100

Table no.9 Sum of all squares of all deviations

It can be seen from the table that for the thickness variation the contribution of exit tension(39.75%) and rolling speed (48.11%) are more significant than entry tension and bending pressure which are 5.49% and 6.63%. it is clear that effect of noise factor (0.02%) is very very low compared to the control factors.

IX. Conclusion and scope of work

For the experimental design of cold rolling process was applied Taguchi approach. Uses a special design of orthogonal arrays, only nine experiments were needed to determine the optimum condition for the cold rolling process. It can be concluded that the results are consistent.

The experiment conducted with the Taguchi method has demonstrated that the entry tension, exit tension, rolling speed & roll bending pressure are very important to control thickness variation. It was observed that exit tension and rolling speed are more significant than entry tension and bending pressure.
Scope of work:

The above experiment carried out in 2nd pass and optimum values for control factors were obtained. Similar experiment can be carried out in remaining 6 pass by carrying out 9 experiment for each pass and their optimum values for the respective pass can be obtained. Finally pass schedule based on optimum values of all eight pass can be made and final experimentation can be carry out to obtained best performance in strip output thickness.

REFERENCES

[1]. Roberts, W., *Cold Rolling of Steel*, Marcel Dekker, 1978, Chpt. 9

[2]. Vaidya V.A.” Optimization of cold rolling mill process to improve productivity and Product Quality of steel - an overview “2015 IJEDR | Volume 3, Issue 4 | ISSN: 2321-9939

[3]. Bland, D. R. and Ford, H., “The calculation o roll force and torque in cold strip rolling with tensions,” Proc. Inst. Mech. Eng., 1948, Vol. 159, pp. 144-153.

[4]. Taguchi G, Konishi S ,Taguchi Methods, orthogonal arrays and linear graphs, tools for quality American supplier institute, *American Supplier Institute*; 1987 [p. 8-35]

[5]. W.T. Foster, Basic Taguchi design of experiments, *National Association of Industrial Technology Conference, Pittsburgh, PA*, 2000

[6]. Wang, D. D., Tieu, A. K., DeBoer, F. G., Ma, B. & Yuen, W. Y. D. (2000). Toward a heuristic optimum design of rolling schedules for tandem cold rolling mills. Engineering Applications of Artificial Intelligence, 13 (4), 397-406.
[7]. Ali Heidari , Mohammad R. Forouzan Optimization of cold rolling process parameters in order to increasing rolling speed limited by chatter vibrations Journal of Advanced Research (2013) 4, 27–34.
[8]. Bendell, Disney &Pridmore, Taguchi Methods-Application in world industry, IFS 1989.
[9]. Madhav S Phadke, “Quality Engineering Using Robust Design”.