

Process Parameter Optimization Using Taguchi Technique for Slitting Process

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Abstract— Sheet metal is one of the most important semi finished products used in the steel industry, and sheet metal forming technology is therefore an important engineering discipline within the area of mechanical engineering. The development of new sheet metal forming processes, tooling and so on has up till now to a large extent been based on experience, rules of thumb and trial-error experiments without or with only little use of scientifically based engineering methods. As mentioned above, experience is not enough, and trial-error experiments are very expensive with regard to both money and time. There is therefore great need for the development of both theoretical and experimental engineering methods. In this case, Taguchi method was selected to design of experiment using the statistical software version 7 which enables the problems to be tackled effectively; the punching process has been chosen to form the sheet metal. The objective of the project is to determine the optimize parameters. The parameters to be considered in this study are punching tonnage, the sheet thickness, the sheet length and the sheet width.

Keywords—Recoiler, Anova, Camber,Slitting, Skin-pass

I. INTRODUCTION

Mechanical shearing is still the most economical process for mass production, although other cutting techniques as for instance laser beam cutting are available because nowadays industry requires a higher output together with a higher and more constant quality, there is a need for a more fundamental knowledge of the shearing process [21].

In Slitting process the sheets are slitted by shearing mechanism in which the width of an original or master coil is reduced into multiple narrower coils. A wide range of materials and thicknesses can be slit, ranging from thin foils to thick plate. Normally, the outside edges of the master coil are trimmed. This creates an accurate register cut, providing a reference point from which the other cuts can be made [20].

Slitting line consists of four basic devices:

- The uncoiler, or pay-off reel, which tightly grips the master coil on its inside diameter using an expandable mandrel. The coil is fed into the slitter by either rotating or joggling the mandrel.
- The slitting arbor consists of two parallel arbors mounted with rotary cutting knives. These knives partially penetrate the coil stock causing a crack or fracture on both sides of the stock, separating the material.
- A tensioning device, which is placed between the slitter and the subsequent recoiler. A tensioning device is needed because the master coil is crowned or larger in diameter in the center of its width than at the edges. Without a tensioning device the slit material from the center of the master coil would take up more quickly while the outboard strips would hang loosely.
- The recoiler, which takes up the slit coils on a driven, expandable mandrel. The recoiler mandrel is fitted with separator discs which prevent interleaving of the narrower coil widths. The slitting process is schematically shown in figure 1

One basic rule of the slitting process is to slit the starting flat strip in a straight line, in the longitudinal direction. However, the stresses created by the forming, compounded with the residual stresses in the starting material, frequently force the product to deviate from a straight line. The most frequently used terms to describe the deviations after they exit from the last pass are:

Camber - in the horizontal direction

Bow - in the vertical direction

Twist - shaped in a spiral form [28]

To correct these problems, skin-pass mills are used at the exit end of most slitting processes.

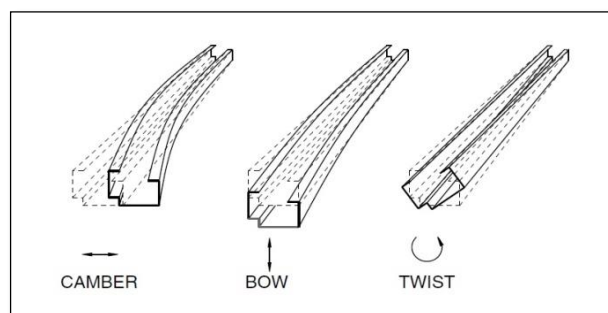
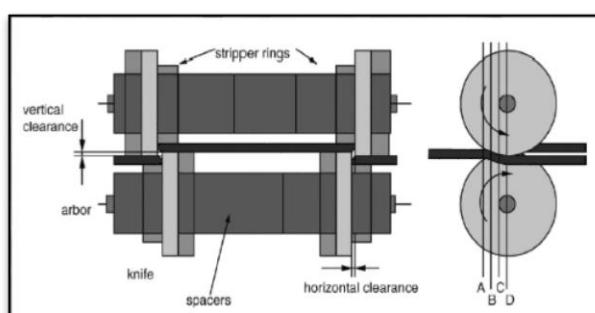


Figure 0: Slitting process [21]

Figure 1 : Deviation from straightness [28]

Figure 1.2 shows some major defects which will occur during slitting of the strips. This project focused only on minimization of Camber formation. Side loading has a big impact on blade life and cut quality. The pressure needed to keep the top blade in contact with the bottom band varies depending on the material being slit. It is important that the side loading always be set as light as the process will allow.

- The side loading pressure must be heavy enough to enable the bottom band to drive the top blade. Yet excessive side loading causes faster blade wear.
- The heavier the basis weight, the more side loading needed. Heavier papers create more lateral force on the blade.

Theory of Slitting Process Line

A slitting line consists of a un-coiler, a slitter and a re-coiler. The un-coiler, slitter and re-coiler are driven by separate motors. Depending on the way the un-coiler, slitter and re-coiler are driven; different modes to drive the material through the slitter knives can be distinguished. Which mode is chosen depends on the material, the sheet thickness and the number of slits.

A. Straight mode slitting

In this mode the driven recoiler pulls the material from the uncoiler through the slitters. It is called pull-through slitting, when the uncoiler and slitter are driven only to feed the material to the recoiler. In driven slitting the slitter is also driven during the process. The motors must now be synchronized to maintain a constant speed of the material as it moves through the line. The advantages of driven slitting are the ability to slit thin sheets and an improved edge quality for all thicknesses.

B. Free loop mode slitting

In free loop slitting, the material is allowed to form a free loop between the slitter and the recoiler. A tensioning device in front of the recoiler is needed now, to produce well wound coils. This method makes it possible to process poorly shaped coils. Shape defects (length variations such as buckles, twists and thickness variation across the width) and internal stresses in the incoming coil influence the result of the slitting process. Therefore, a leveler or a temper mill can be added to the slitting line, to correct defects in the incoming coil, which ensures a better quality of the slitted strips.

Introduction to Camber

Camber is the deviation of the strip edge from a straight line in the horizontal plane. The inside concave edge of the strip is shorter than the outside convex edge. During the roll forming process, the strip is straightened. In figure 3.2 the shorter edge (marked "S") will be under tension and the longer edge (marked "L") will be compressed. Depending on the conditions, the compressed edge may become wavy. It has not been recognized for long time that camber is a possible contributor to product problems. However, roll formers are now requesting tighter camber tolerances because rolls cannot be designed to compensate for camber. Special devices such as automated camber correctors for narrow strips and special levelers for wider strips can eliminate or minimize the effect of camber. Excessive camber also creates problems when the strip is pre-punched in a long pre-punching/notching die. Because the punches are set in a straight line, the hole distance from the edges will vary according to the camber in the strip. During roll forming, the strip is straightened; therefore, holes pre-punched in a straight line will be on a radius similar to the radius of the camber in the strip. In the case of thin, narrow strips, the guide in the pre-punching die may straighten the strip during punching. Thicker, wider or higher strength cambered strips may get stuck in the pre-punching die, which has a guide built to the maximum strip width tolerance. If the strip guides are made wider, then the tolerance on the hole locations from the bend lines will be looser.

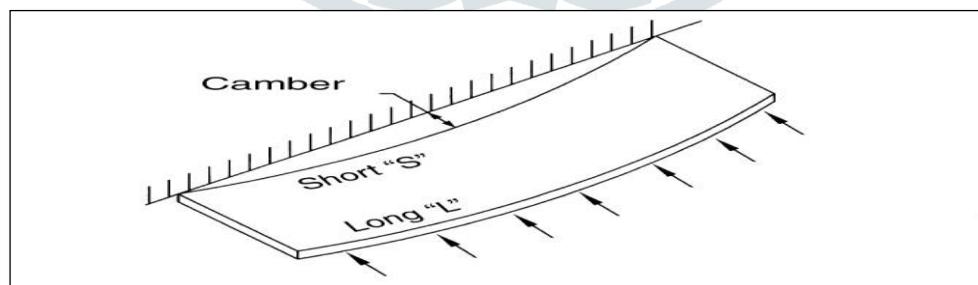


Figure 0: Shape defects in slitting [28]

Slitting will not eliminate camber in the strip. Actually, dull slitting knives, applying more force than required or creating burr, may induce camber in the formerly straight material. There are the two types of camber are generated during slitting process as shown in figure 3.3

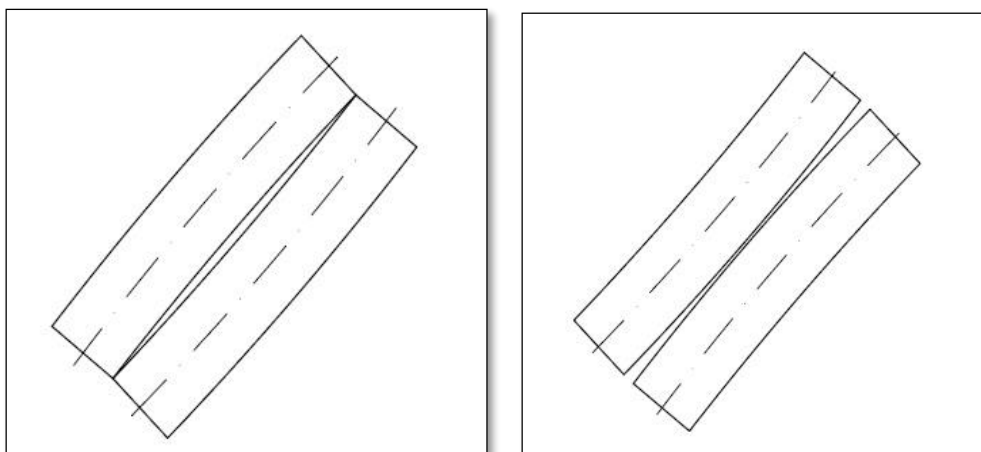


Figure 4: Slittingstrip edge having camber towards center line and curving away from the center line [28]

Existing Slitting Setup

The picture shows the existing slitting process setup at Keshav metals Pvt. Ltd. This setup is only for Hard Rolled material. If Cold Rolled material was tried to slit on this setup, many issues are formed during slitting. One of the major issue is camber generation and marking on the strip edges. To overcome these problems new set-up was built. In this project some modification and optimization had done in slitting process line.

The uncoiler is used to feed sheet metal automatically to the line. The tiles opening and closing is made by a hydraulic cylinder. The machine can be fitted with a pressure arm. This device helps to introduce or rewind the coil. Optional accessory: In the event that it is necessary to use the additional tiles, they have to be sliced over the fixed tiles according to the image.

MODIFIED SLITTING PROCESS LINE

From study of existing set-up some modifications has done by using the optimization technique. After analyzing the results of existing process and percentage of reduction the process is to be modified with some new arrangements. In the first stage the modifications are listed with CAD drawing and in second stage optimization is done by using Taguchi method.

CAD Drawing

Drawing of the slitting process is prepared by using the CAD software Unigraphics NX 8.0 software which is developed by SIEMENS. 2D drafting is shown in the following figure 4.1



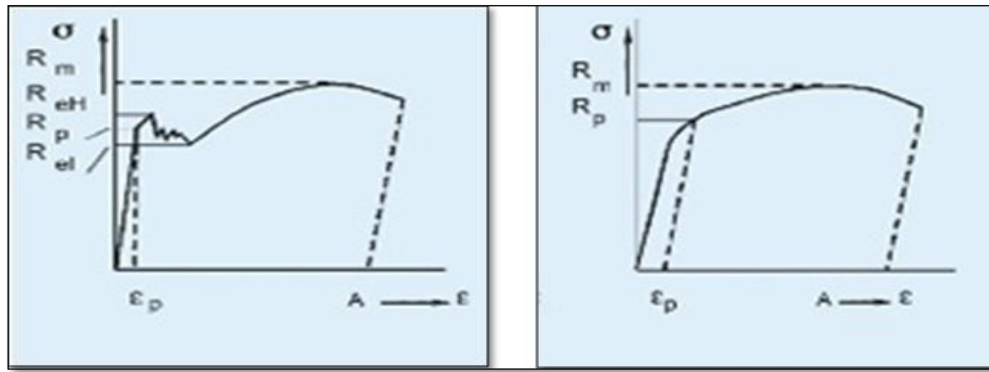
Figure5 :CAD Drawing Using UGNX Software

Modifications in Slitting Process

1) Skin-Pass Arrangement

Our single skin-pass mills are independent rolling facilities which usually follow the batch-annealing stage and can be implemented very flexibly. They can process both hard strip and ultra-mild strip. They also provide the perfect finish for cold-rolled stainless steel strip. Cold rolled steel strip is something we encounter every day in one place after another. Surface effects, whether high-gloss, mat or other communicates an impression of beauty and elegance. In addition to the aesthetic effect, the surface of steel strip is of technical importance. For example, the correct surface roughness ensures that painted surfaces have a permanently perfect visual appearance. Other properties of cold-rolled steel strip remain unnoticed by us. However, they are indispensable for industrial further processing.

Let us take a beverages can, for example, which is fashioned out of thin tinplate in a single deep drawing operation. To produce it economically, not only is the right surface quality needed but above all a defined deformation behavior. Through more precise adjustment of the necessary properties, it has been possible to reduce the weight of the beverages can by 30 % over the past 25 years. The decisive process step for this is skin-passing upon completion of the cold strip manufacture. It produces the exact mechanical and geometrical properties that the customer needs for his applications. Figure 4.2 shows skin pass mill.



Before skin-pass

After skin-pass

Figure 6: Strength of strip [11]

Advantages of Skin-Passing:

The objective of skin-passing is to attain the correct yield points and the desired surface characteristics.

1. Definition of the yield points:

Skin-passing causes the unsteady yield-point range, known as the Luders band, to be transformed into a defined yield point. This serves to improve the flow behavior during the deep-drawing operation and to prevent unwanted lines of stress.

2. Setting of the strip roughness:

Setting the desired roughness of the strip surface will, for example, enhance the yield of the deep drawing process or improve the adhesion of paints.

3. Achievement of perfect strip flatness:

Strip flatness is an important property for the firms which perform further processing. This is because good flatness values allow trouble-free operation of their plant and equipment.

If the product has a twist in one direction, then the straightener must rotate it in the opposite direction beyond the yield limit to create a permanent deformation. If the angle of the correcting rotation is right, then after spring back the product will exit straight without twist. One basic rule of the roll forming process is to bend the starting flat strip in a straight line, in the longitudinal direction. However, the stresses created by the forming, compounded with the residual stresses in the starting material, frequently force the product to deviate from a straight line. The most frequently used terms to describe the deviations after they exit from the last pass is camber-in the horizontal direction. To correct these problems, skin-pass are used at the exit end of most slitting machines.

2) PU Rubber Spacers

Stripper rings have three functions:

1. To force the slit multi from between the knives as it leaves the slitter head.
2. To support the strip be flat during slitting
3. In some machines, stripper rings double as pinch rolls to drive the material through the arbors.

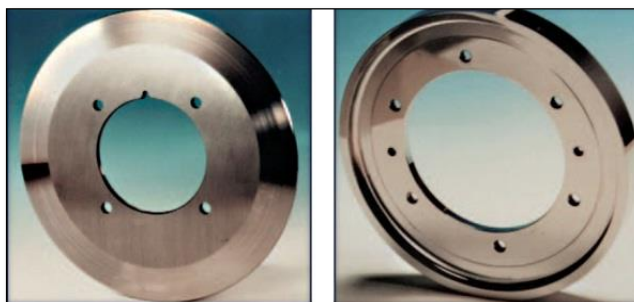
There are many kinds of strippers:

Natural Rubber Compounds or polymer rings: These can be either separate from or bonded to the metal spacers.

Steel rings: These fit loosely over spacers and are supported by backup rolls. Steel stripper rings are generally used in high precision slitting of very light guage material. The slitting machine must be design to accept steel stripper rings which are shown in figure 4.4

3) Slitting Knives and Horizontal Cutter Clearance

There are many different top knife blade bevel options available. Factors for consideration are the material being slit, speed of operation, and side load force required. Double hollow ground bevel blades are good for slitting light materials and adhesives. They offer less area for sticky substances to adhere. They are somewhat speed limited but produce much less dust because of the lessened path the slit edge must travel in contact with the blade. Edge cut profile is typically very clean. There is no question that top (male) knife blade surface finish is an important factor for quality slitting. The rougher the blade surface the more potential for web edge damage. It is extremely important that when CPM-10V runs against D2, CPM-10V'shardness should be in the 58-60 RC range.



Flat Blades

Dished Blades

Figure 7: PU stripper rings

Figure 8: Types of blades

Types of blades are shown in figure 4.5 the clearance between upper and lower shear blades determines the quality of the cut edge, and can influence shearing force. Excessive clearance results in heavy burr and where soft steels are being sheared, increased distortion of the cut edge. In extreme cases the work piece can be pulled between the blades, causing overloading or blade damage. Optimum clearance varies with both the mechanical properties and the thickness of the work piece but since most shears are used to shear a range of steels, a compromise clearance setting is usually required. It is common practice to set blade clearance at 10% of work piece thickness. Where a range of thickness is sheared on the one machine, clearance is set 10% of the mean thickness range which can be accommodated by a single clearance setting.

4) Hold Down Arm cum Tensioning Mechanism

The tension pad is composed by a main structure and a mobile arm. The arm opening and closing is performed automatically with two hydraulic cylinders. The pressure to tighten the bands is made by a pressure air hose. The pressure is controlled by the control provided for this purpose. The machine is equipped with the upper and lower felts which are, where bands will touch and should be replaced when, by the use, are damaged. At the entry of the tension pad, there is the shaft which has separator disks that acts as band guides. The disks roller support is articulated so the adding or removing disks action can be done in an easy way.

Repeat this operation each time is necessary to add or remove separator disks. If it is necessary to remove or change the separator disks, first unscrew the disks and put them all together next to the articulated support and then extend the extensible device to hold the roller with the disks. The introduction of the strips is done manually. For, this mobile arm of the tension pad must be open. Adjust the separator discs to the wanted strip width using for that the rule located in the machine. After that, fix the discs using the screws to block them. Pass the strip manually through the tension pad and introduce it into the mandrel. Once the strip is introduced into the mandrel, close the mandrel holding the strip. After closing the tension pad, inflate the hoses with the proper air pressure, making sure that the strips are cantered properly in separating discs.

Experimental Procedure

Taguchi methods which combine the experiment design theory and the quality loss function concept have been used in developing robust designs of products and processes and in solving some taxing problems of manufacturing [5]. The degrees of freedom for three parameters in each of three levels were calculated as follows:

Degree of Freedom (DOF) = number of levels - 1

For each factor, DOF equal to:

For (A); DOF = 3 - 1 = 2

For (B); DOF = 3 - 1 = 2

For (C); DOF = 3 - 1 = 2

L9 orthogonal array was selected by using following formula, which has nine rows corresponding to the number of tests, with three columns at three levels. L9 OA has eight DOF, in which 6 were assigned to three factors (each one 2 DOF) and 2 DOF was assigned to the error.

Formula for selection of orthogonal array is:

$$N_{Taguchi} = 1 + N_v (L - 1) \dots \dots \dots \text{Eq. (4.1)}$$

Where,

$N_{Taguchi}$ = Number of Experiments to be conducted

N_v = Number of parameters

L = Number of levels

L9 Orthogonal Array:

In L9 array 9 rows represent the 9 experiment to be conducted at 3 levels of the corresponding factor.

Input Factors:-

- 1) Speed of Re-coiler (A),
- 2) Speed of Cutter (B),
- 3) Horizontal Clearance (C).

Responses measured:-Camber in mm.

The trial of experiments was performed on 1.5mm thick cold rolled cold annealed sheet. For the purpose of observing the degree of influence of the process parameters in slitting, three factors, each at three levels, are taken into account, as shown in Tables 4.2.

Table1: Level values of input factor

Sr. No.	Factors	Levels		
		1	2	3
1	Speed of Re-coiler (A)	410	640	960
2	Speed of Cutter (B)	348	544	816
3	Horizontal Clearance (C)	0.2	0.3	0.4

Table 4.3 shows nine experiments were carried out considering three process parameters. In L9 array 9 rows represent the 9 experiment to be conducted at 3 levels of the corresponding factor. The camber values corresponding to each experiment were shown in Table 4.3.

Table2: Taguchi L9 array for camber

Experiment No.	Speed of re-coiler	Speed of Cutter	Horizontal Clearance	Camber in mm
E1	410	348	0.2	0.35
E2	410	544	0.3	0.5
E3	410	816	0.4	0.43
E4	640	348	0.3	0.24
E5	640	544	0.4	0.54
E6	640	816	0.2	1.5
E7	960	348	0.4	0.2
E8	960	544	0.2	1
E9	960	816	0.3	1.3

RESULT AND ANALYSIS OF EXPERIMENTS

Analysis of Signal to Noise ratio (S/N)

In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristics and the term 'noise' represents the undesirable value for the output characteristics. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available, depending on the type of characteristics: lower is better (LB), nominal is the best (NB), or higher is better (HB). Smaller is better S/N ratio was used in this study, because lower parameter of camber was desirable. The quality characteristics of the smaller is better is calculated according to the following equation [10].

Table 3: Analysis of experimental data using S/N ratio

Expt. No.	Camber (mm)	S/N Ratio (dB)
E1	0.35	9.1186
E2	0.50	6.0206
E3	0.43	7.3306
E4	0.24	12.3958
E5	0.54	5.3521
E6	1.50	-3.5218
E7	0.20	13.9794
E8	1.00	0.0230
E9	1.30	-2.2789

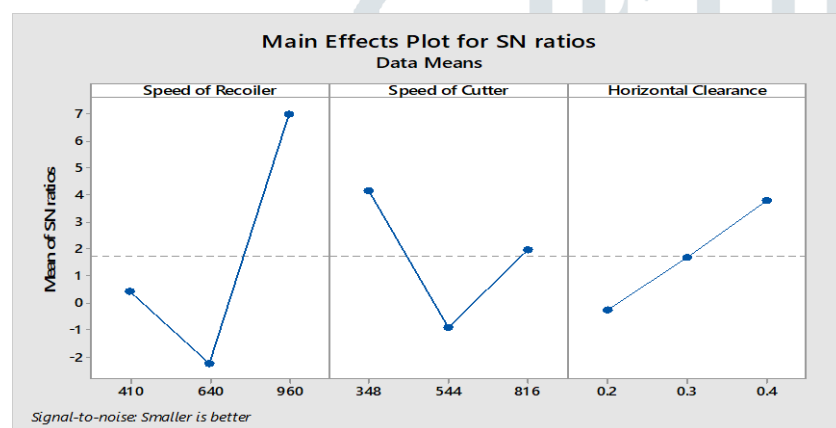
The camber response table for the speed of Recoiler, speed of cutter and horizontal clearance was created in the integrated manner and the results are given in Table 5.2 by using standard commercial statistical software package MINITAB 17. Regardless of the category of the performance characteristics, a greater S/N value corresponds to a better performance.

Table 4: Response table for signal to noise ratios (Smaller is better)

Level	Speed of Re-coiler	Spees of Cutter	Horizontal Clearance
1	7.4900	11.8313	1.8656
2	4.7420	3.7909	5.3792
3	3.9002	0.5100	8.8874
Delta	3.5898	11.3213	7.0218
Rank	3	1	2

Delta (Δ) represents the overall change in a value. In Taguchi designs, delta is the difference between the maximum and minimum mean response across levels of a factor. Often, delta is considered the difference between an initial and end value, irrespective of fluctuations that might occur between these points. Here in above table Delta is the difference between the maximum and minimum average signal-to-noise ratios for the factor. The Rank is the rank of each Delta, where Rank 1 is the largest Delta.

The optimal level of the slitting parameters is the level with the smallest S/N value. Based on the analysis of the S/N ratio, the optimal slitting performance for the camber was obtained at 640 speed of Recoiler (level 2), 544 speed of cutter (level 2) and 0.2 mm horizontal cutter clearance (level 1). Fig. 5.1 shows the effect of the process parameters on the camber values.

**Figure 9: Effect of process parameters on camber**

The effect of process parameters on the camber values was shown in Fig. 5.1 The camber is minimum at intermediate speed of Recoiler, speed of cutter and increases with increase in horizontal cutter clearance.

Analysis of Variance

ANOVA is a statistically based, objective decision-making tool for detecting any differences in the average performance of groups of items tested. ANOVA helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of the experimental errors at specific confidence levels.

The ANOVA results are illustrated in Table 5.3

Table 0: Analysis of variance for camber

Source	DOF	Adj SS	Adj MS	F-Value	P-Value	%C
Speed of Re-coiler	2	0.000290	0.003902	9.10	0.062	13.67%
Speed of Cutter	2	0.001630	0.000800	39.00	0.002	55.31%
Horizontal Clearance	2	0.002104	0.000604	18.70	0.030	26.04%
Error	2	0.000058	0.000015	-	-	4.35%
Total	8	0.004082				

Statistically, there is a tool called an F test, named after Fisher, to see which design parameters have a significant effect on the quality characteristic. In the analysis, the F-ratio is a ratio of the mean square error to the residual error, and is traditionally used to determine the significance of a factor.

The P-value reports the significance level (suitable and unsuitable) in Table 5.3. Percent (%) is defined as the significance rate of the process parameters on the camber. The percent numbers depict that the speed of recoiler, speed of cutter and horizontal cutter clearance have significant effects on the camber. It can be observed from Table 5.3 that the speed of recoiler (A), speed of cutter (B) and horizontal cutter clearance (C) affect the camber by 13.67%, 55.31% and 26.04% in the slitting process of cold rolled cold annealed material respectively. A confirmation of the experimental design was necessary in order to verify the optimum cutting conditions.

Here, the experiments were conducted involving only quantitative factors, therefore it is required in this experiment to relate the output (response) with the input variables (factors) in order to predict the output or optimize the process. A regression analysis generates an equation to describe the statistical relationship between one or more predictors and the response variable and to predict new observations. Linear regression usually uses the ordinary least squares estimation method which derives the equation by minimizing the sum of the squared residuals. Here, regression equation is used to find the optimum camber at process parameters. The correlation between factors (speed of Recoiler, speed of cutter and horizontal cutter clearance) and camber on the slitting process for Cold Rolled Cold Annealed material were obtained by multiple linear regressions.

The standard commercial statistical software package MINITAB was used to derive the models of the form:

$$\text{Camber in mm} = 0.060 + 0.000707 \text{ Speed of Recoiler} + 0.001720 \text{ Speed of Cutter} - 2.800 \text{ Horizontal Clearance} \dots\dots\dots (\text{Eq.5.2})$$

EXPERIMENTAL VERIFICATION

In this method of optimizing slitting process line the experimental verification had done to validate the modified process. The validation was done at the customer end whether they satisfied or not with this camber minimized method. These are some datasheets which used to comparing the status of camber after modification and before modification was done. From the survey it was found that to overcome the punching issues the requirement of customers was so precise, they allow camber below 1.5mm in 1000mm strip.

CONCLUSIONS

The camber-free method was successfully implemented by proper selection of horizontal cutter clearance at first stage, which was near to maximum shear point. Focus and taking care of speed of cutter and re-coiler, horizontal cutter clearance leads for a better quality of camber free Cold Rolled Cold Annealed slitted sheets and with maximum production.

The trial of experiments was performed on 1.5mm thick cold rolled cold annealed sheet. There were three optimum parameter settings corresponding to the one response factors. The combination of input factor levels, for optimum setting is given in table 8.1

Table 0.1: Optimal combination of process parameter

Physical Requirement	Optimal Combination		
	Speed of Re-coiler	Speed of Cutter	Horizontal Clearance
Minimum Camber	640	544	0.2

By using this optimum combination of parameters for slitting of Cold rolled Cold Annealed 1.5mm thick sheet the camber less production have taken successfully. The optimal combination parameter was; Speed of Re-coiler: 640rpm, Speed of Cutter: 544rpm and Horizontal Clearance: 0.2 mm.

The condition of maximum 1.5mm camber within 1000mm of sheet length was achieved by this optimized and modified setup with less rejection and higher productivity rate upto 70%.

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