OPTIMIZATION OF CUTTING RATE AND TAPER IN BANDSAWING PROCESS USING TAGUCHI AND DESIRABILITY APPROACH

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Abstract: Present work focuses on optimization of cutting rate (CR) and cut quality (Taper) using a new approach, called "Desirability Function Analysis (DFA)" in combination with Taguchi approach. Desirability Function Analysis is considered as one of the useful tool to optimize multiple characteristics objectives. In this work, "Taguchi's L_{18} orthogonal array" is used to conduct experiment to cut EN-19 material. EN19 is widely used in various engineering applications like, gears, shaft, fasteners, machine elements etc. The process parameters, top arm angle, cutting speed, feed, guide distance and blade tension are optimized for multi response consideration, cutting rate and cut quality. As per the DFA procedure individual desirability for each response parameter is calculated and then global desirability. Based on global desirability value, optimum value and contribution of each independent parameter is determined with the help of "analysis of variance method (ANOVA)". From the results it reveals that the contribution of parameters is in order of Blade tension, Top arm angle, feed, speed and distance. The results were confirmed through validation tests for the optimum values of process parameters. The results reveals that combined use of Taguchi and Desirability function proves effective for optimization of multi response objective. Detailed experiment and results are discussed in the present paper
Key words: Bandsaw machine, Cutting Rate, Cut quality (Taper), Taguchi method, Desirability function analysis, ANOVA.

1. INTRODUCTION

Raw materials need to be cut to specific length to convert in finish product through various manufacturing processes. Earlier hacksaw was used as main process to cut various raw materials. Later with the development of metal cutting bandsaw, hacksawing is replaced with bandsawing due to elimination of idle stroke and thin bandsaw blade. Continuous cutting and less kerf thickness in bandsawing, the process considered to be fast and economical compared to hacksaw. Due to variable pitch of the bandsaw blade and material of teeth, it is possible to cut various material with greater accuracy in less time (Haci Saglam, 2011).

Now a day the way CNC machines become the indispensable part of any product manufacturing, hence demand of faster cutting of raw material is increases enormously. The conventional hacksaw machines cannot full fill the demand of output per day and hence the bandsaw machines are replacing the hacksaw in every industry. But the cost of bandsaw blade and its life restrict the industry to adopt it easily. This leads to study and optimize the bandsawing process to make it economical. Haci Seglam (2011), applied Taguchi's approach along with Artificial Neural Network to estimate teeth wear of bandsaw blade. He has considered speed, feed, cutting length and material hardness as an input parameter and experimented to investigated the effect of these parameter on tool wear. The study indicates that cutting speed, cut length and hardness of material has significant effect on teeth wear and feed rate has minimum effect. M.M. Ahmad et al. (1989), investigated effect of cutting parameter and workpiece configuration on bandsawing process. Cutting speed, feed and workpiece breath are taken as independent variables to study their influence on "cutting and thrust force". The findings of the study reveal that cutting force and thrust force are inversely proportional to the cutting speed. Whereas the feed has reverse effect on the "cutting and thrust force". Workpiece breath have marginal contribution for cutting and thrust force. M. Sarvar et al (2009), have worked to investigate the influence of workpiece material on "specific cutting energy" in bandsawing and its effect on bandsawing cutting efficiency. The findings of the study indicate that the measurement of specific cutting energy is significant and helps to understand the behavior of teeth wear for different workpiece material. M. Servar et al. (2005, 2007), have studied the influence of force, power and specific cutting energy on wear of teeth in bandsawing process. In both the work, the results reveals that the wear of teeth directly affects the "cutting force" and also has significant effect on "out of square cutting (Taper)".

Indrajit Mukherjee and Pradip Kumar Ray (2006), reviewed various optimization methods used for manufacturing processes and suggested appropriate approach for the application. In this paper authors have discussed various techniques, "Statistical Regression Technique, Artificial Neural Network (ANN) and Fuzzy set theory-based modelling techniques, Taguchi method, Response Surface design Methodology (RSM), Iterative mathematical search technique, Heuristic search technique" etc.

Looking to the robustness of Taguchi approach, various industries have started applying it for process and product improvement. Julie Z. Zhang et al. (2007) have used "Taguchi" technique to find optimum parameters for end milling process. H. K. Dave et al. (2012) have used "Taguchi" technique to optimize turning process, Dave H. et al (2012) have used Taguchi technique to optimize orbital EDM process for Inconel 718 material and many more have used it for various manufacturing processes.

Due to limitation of Taguchi technique to optimize only one response parameter at a time, various multiple response optimization techniques gain importance among the researchers. Out of various techniques, Desirability Function Analysis (DFA) found more suitable for optimization of process parameters and hence become popular among the researcher to optimize multiple responses of various manufacturing processes. The technique is applied for prediction and optimization of machining process (Sait A.N. et al., 2009), drilling process (Meral G et al, 2015), fusion welding process (Adalarasan R & Santhankumar M, 2015), heat treatment process (John B, 2013), Flux cored arc welding process (Katherasan D, 2012), Wire EDM process (Garg S. K. et al, 2014) and many more.

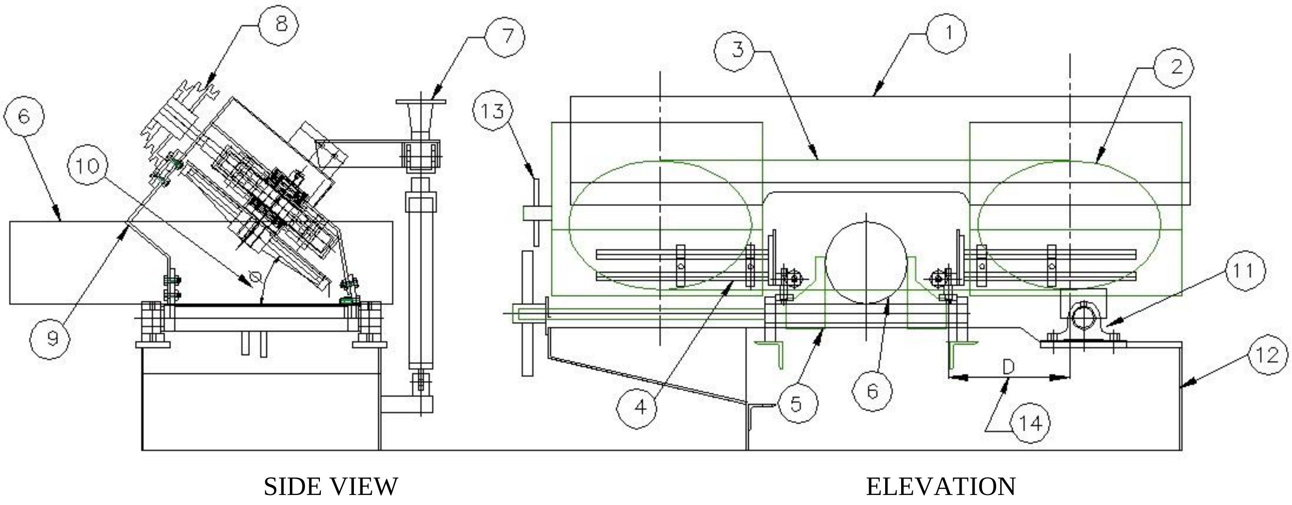

Fig.1. Bandsaw machine outline:
1. Top arm assembly, 2. Band wheel, 3. Blade, 4. Blade guide, 5. Vice, 6. Workpiece, 7. Feed control valve, 8. Step pulley, 9. Inclined plate, 10. Ø = Top arm angle, 11. Hinge, 12. Base Tank, 13. Blade tensioning handle, 14. Guide Distance - D

Based on the above literature review, it is found that researchers have considered the process parameters like, cutting speed, feed rate, workpiece material, workpiece shape, cutting length etc. to optimize teeth wear, cutting force, thrust force etc. in bandsawing.

To the best of the knowledge to the authors very less literature/study has been reported for the effect of these parameters on "cutting rate (CR) and cut quality (Taper)" in bandsawing operation. As we know in today's competitive market everyone is focusing to reduce the process cost and hence final product cost of the product. Improvement of CR is increase the productivity and hence reduce cost per cut. Poor cut quality, taper cutting not only increases the second operation time but also result in wastage of costly raw material. These leads to increase of product cost. Hence in the present study CR and cut quality are considered as a response parameter.

To the best of the knowledge to the authors no literature/study" has been reported for the effect of top arm angle, blade guide distance and blade tension in bandsawing process. Top arm angle is a machine parameter, and is important in deciding the cutting capacity of the machine. The machines available in market have fixed inclination of top arm. In the present study the machine used is made with a facility to vary the inclination of top arm, this will add range of cutting capacity of the same machine. Blade guide distance and blade tension decide stiffness of the blade in cutting zone. Blade stiffness affects the cut quality and blade penetration in the workpiece. Hence those are also considered here as process parameter to investigate their effect on cutting rate and cut quality along with other process parameters like cutting speed and feed. The present investigation has been focused on application of Taguchi method for planning experiment matrix to perform bandsawing operation. The independent controlling factors selected are top arm inclination angle, blade guide distance, blade tension, speed and feed, each factor set at three levels for present investigation. “Desirability Function analysis (DFA)” method is used to analyze effect of the above independent controlling factors on the multiple characteristics response factors viz. Cutting rate (CR) and cut quality (Taper). With this combined approach an optimal process parameter combination has been obtained.

2. TEST SETUP AND METHOD

The trials were performed on a hinge type metal cutting bandsaw machine with a bimetal metal cutting bandsaw blade. Details of test set up is shown in Fig. 1. Specifications of machine, bandsaw blade and work piece material are listed in Table 1,2 & 3 respectively. 35 mm Dia. round bar of EN-19 material was used for the cutting trials.

As shown in Fig.1, Top arm assembly (1) consist of band wheel, gear box, blade guide and is mounted on base tank (12) with hinge (11). Bandsaw blade (3), is mounted on the two band wheels and it cuts the workpiece as the top arm descends from a specific height. Feed control valve (7) control the rate of descending of top arm by changing its position. Step pulley (8) is used to vary the cutting speed of the blade in three steps. Inclined plate (9) is used to change the inclination of the top arm. Blade guide (4) twist the blade and make it right angle in the cutting zone to ensure straight cutting. Vice (5) is used to clamp the workpiece (6) during cutting process. Handle (13) is used to provide tension to the blade. Guide distance (D), is the distance from tangent of band wheel to center of blade guide bearing.

Based on Taguchi’s design of experiments, L_{18} orthogonal array (Phadke M S, 1989), (Phillip Rose, 1996), (Montgomery DC, 2004) is used and 18 test runs were planned to study the impact of various factors on Cutting Rate (CR) and Cut quality (Taper). Factors and their levels were chosen based on the preliminary trials and feedback of users. Table 4 shows the factors and their levels. Experiment matrix and response results are reported in Table 5 (Dave H et al, 2012). CR is calculated by measuring the time taken to complete the cut, divided with the volume of material removed and Cut quality (Taper) is calculated by taking the difference of the thickness of the cut sample from top and bottom values and converted in to percentage with respect to diameter.

Table 1. Machine specifications

Description	Technical data
Make	MAHAVIR
Type	Manual horizontal
Blade Motor	1 Hp
Speed range (m/min)	22-38-60
Top arm Inclination range (Degree)	30-40-50

Table 2. Blade specifications

Description	Technical data
Type	Bi metal (M42)
Pitch (TPI)	5/8
Size (mm)	3000 x 27 x 0.9

Table 3. Raw Material (EN19) Standard data [29]

Rang	%C	% Mn	%Si	%S	%P	%Cr	%Mo
Min	0.35	0.60	0.05	…	…	0.9	0.25
Max	0.45	1.00	0.35	0.06	0.06	1.2	0.35

Table 4. Factors and their levels

Factor	L1	L2	L3
Top arm Angle (A) (Degree)	30	40	50
Speed (B)(m/min)	22	38	60
Feed (C) (Valve Position)	1	2	3
Distance (D) (mm)	300	350	400
Tension (E) (Kpsi)	10	15	20

3. DESIRABILITY FUNCTION ANALYSIS

Multivariate optimization using the desirability function approach was suggested by Harrington (1965) and the same is described by Derringer and Suich in 1980. “Desirability Function Analysis (DFA)” is considered as “one of the frequently used technique in industry for the optimization of multiple characteristics” (Sait A N, 2009). In this approach the multiple responses are merged into a single response parameter and it termed as global desirability. This approach / method excludes complex mathematical calculations and it helps practicing engineers and researchers to implement with ease having brief fundamental knowledge of statistics.

3.1 Procedure followed for DFA

Step -1: “Individual desirability index (di) should be calculated for each individual responses using the formula proposed by the Derringer and Suich (1980). There are three forms of the desirability functions according to the response characteristics (Sait et al, 2009).

a. The-nominal-the best: The value of ŷ is required to achieve a particular target T. The individual desirability can be calculated as given in Eq. 1":

$$di = \begin{cases} \left(\frac{\hat{y}-y_{min}}{y_{max}-y_{min}}\right)^s, & y_{min} \le \hat{y} \le T, s \ge 0 \\ \left(\frac{\hat{y}-y_{min}}{y_{max}-y_{min}}\right)^r, & y_{min} \le \hat{y} \le y_{max}, r \ge 0 \\ 0 & \end{cases} \quad (1)$$

where the y_{max} and y_{min} represent the upper/lower tolerance limits of ŷ and s and t represent the weights.

b."The-larger-the better: The value of ŷ is expected to be the larger the better. The individual desirability can be calculated as given in Eq. 2:

$$di = \begin{cases} 0, & \hat{y} \le y_{min} \\ \left(\frac{\hat{y}-y_{min}}{y_{max}-y_{min}}\right)^r, & y_{min} \le \hat{y} \le y_{max}, r \ge 0 \\ 1, & \hat{y} \ge y_{max} \end{cases} \quad (2)$$

"where the y_{max} and y_{min} represent the upper/lower tolerance limits of ŷ and r represent the weights".

c."The-smaller-the better: The value of ŷ is expected to be the smaller the better. The individual desirability can be calculated as given in Eq. 3":

$$di = \begin{cases} 1, & \hat{y} \le y_{min} \\ \left(\frac{\hat{y}-y_{max}}{y_{min}-y_{max}}\right)^r, & y_{min} \le \hat{y} \le y_{max}, r \ge 0 \\ 0, & \hat{y} \ge y_{max} \end{cases} \quad (3)$$

Table 5. Experiment matrix and results

	Input parameters					Response results	
Exp. no.	Top arm Angle (Degree)	Speed (m/min)	Feed	Distance (mm)	Tension (kpsi)	CR (mm^3/min) *	Cut Quality (Taper) (%)*
1	30	22	1	300	10	913.37	0.071
2	30	38	2	350	15	1306.67	0.043
3	30	60	3	400	20	2886.25	0.029
4	40	38	1	350	20	1065.05	0.029
5	40	60	2	400	10	1450.71	0.057
6	40	22	3	300	15	1271.50	0.114
7	50	60	2	300	15	4065.95	0.086
8	50	22	3	350	20	2775.24	0.071
9	50	38	1	400	10	1377.53	0.086
10	30	38	3	400	15	2140.90	0.043
11	30	60	1	300	20	1197.64	0.043
12	30	22	2	350	10	1097.45	0.071
13	40	22	2	400	20	1154.50	0.029
14	40	38	3	300	10	3396.06	0.114
15	40	60	1	350	15	1300.22	0.071
16	50	60	3	350	10	5661.50	0.114
17	50	22	1	400	15	1110.10	0.043
18	50	38	2	300	20	3607.82	0.071
* Average of two readings							

where the y_{max} and y_{min} represent the upper/lower tolerance limits of ŷ and r represent the weights.

The s, t and r in Eqs. 1, 2 and 3 indicate the weights and are set to higher value if the response is required to close to the target, else set to smaller value.

Step 2: "Compute the global desirability (d_G). The global desirability (d_G) is calculated by the following Eq. 4":

$$d_G = w\sqrt{d_1^{w1} * d_2^{w2} \ldots\ldots d_i^{wi}} \quad (4)$$

"where d_i is the individual desirability of the property y_i, w_i is the weight of the property "y_i" in the global desirability and w is the sum of the individual weights.

Step 3: Determine the optimal parameter and its level combination based on value of global desirability.

The higher global desirability value implies better product quality. Therefore, on the basis of the global desirability (d_G), the optimum level for each controllable parameter are estimated."

Step 4: Identify the significant parameters and its contribution using ANOVA.

Step 5: Conduct confirmation test using optimal condition and validate the results.

3.2 Implementation of DFA

As discussed in previous section, in step-1, an individual desirability is calculated using equation 2 and 3, for cutting rate, larger the better criteria and smaller the better criteria for cut quality respectively.
After calculating individual desirability, as mentioned in step 2, global desirability is calculated using equation 4. To calculate the global desirability, weightage of quality characteristic was assumed based on the physical significance of each characteristic for bandsawing process. In bandsawing process cutting rate plays an important role as bandsawing is a first operation to be performed to cut raw material to required length and hence it should be completed within minimum time. So, the weightage considered as 0.7. Cut quality (taper) considered less significant in bandsawing as there is a second operation required to be process on the job. Also the results were well within acceptable limits and hence weightage given to taper is 0.3. Both the outputs are listed in Table 6.
"In step 3, from the values of global desirability as listed in Table 6, effect of various parameters and their optimal levels are estimated and listed in Table 7 and the parameters are plotted in fig. 2. Considering the maximum value of global desirability (Table -7)", the optimal combination is found as A3-B3-C2-D3-E3. In step 4, considering global desirability value, "ANOVA is performed to identify the significance and contribution of each parameter. The results are tabulated in Table 8".
In step 5, the optimal results were validated by conducting confirmation test. The results are tabulated in Table 15.

Table 6. Individual desirability and global desirability

Exp. Run	Individual Desirability (di)		Global Desirability (D_G)	Order
	CR	Taper		
1	0.000	0.500	0.000	15
2	0.081	0.833	0.166	7
3	0.406	1.000	0.541	2
4	0.031	1.000	0.090	13
5	0.111	0.667	0.193	6
6	0.074	0.000	0.000	15
7	0.649	0.333	0.540	3
8	0.383	0.500	0.422	4
9	0.096	0.333	0.141	8
10	0.253	0.833	0.367	5
11	0.059	0.833	0.132	10
12	0.038	0.500	0.083	14
13	0.050	1.000	0.124	11
14	0.511	0.000	0.000	15
15	0.080	0.500	0.140	9
16	1.000	0.000	0.000	15
17	0.040	0.833	0.102	12
18	0.555	0.500	0.546	1

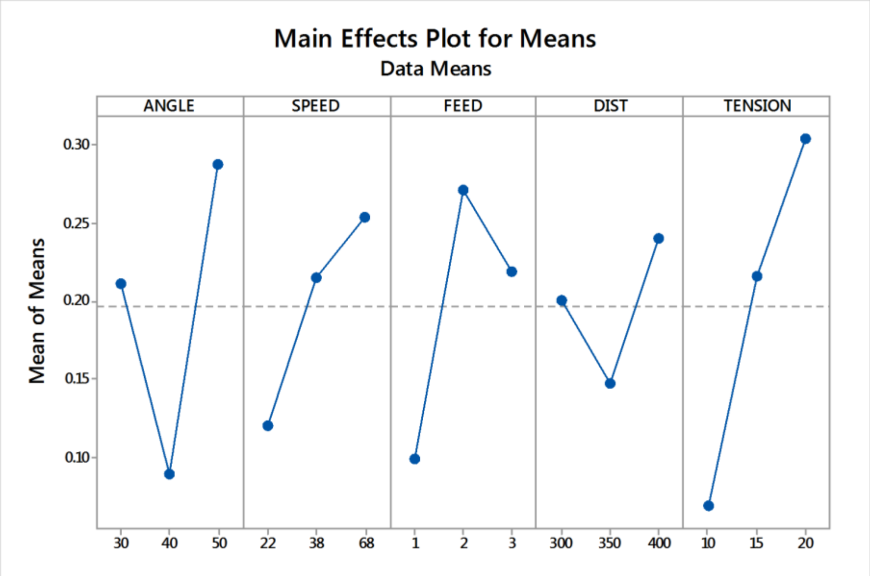

Fig. 2. Response Diagram for global desirability (d_G)

Table 7. Response table for Global desirability

Factors	Angle	Speed	Feed	Dist.	Tension
L1	0.2116	0.1203	0.0994	0.2003	0.0690
L2	0.0900	0.2150	**0.2709**	0.1479	0.2159
L3	**0.2874**	**0.2537**	0.2186	**0.2408**	**0.3042**
Delta	0.1973	0.1334	0.1715	0.0928	0.2352
Rank	2	4	3	5	1

Table 8. ANOVA Results for DFA

	Factors	SS	Df	MS	F	% Contribution
Angle	A	0.119	2	0.059	2.68	23.39
Speed	B	0.057	2	0.028	1.27	11.12
Feed	C	0.093	2	0.046	2.09	18.23
Distance	D	0.026	2	0.013	0.59	5.11
Tension	E	0.169	2	0.085	3.86	33.32
	Error	0.157	7	0.022		8.83
	Total	0.621	17	0.254		100

4. RESULTS & DISCUSSION

4.1. Cutting rate (CR)

For each experiment setting time was recorded and cutting rate was calculated for two cuts. Average of the same is listed in Table 5 for the various level of process parameters. "Based on the value of CR, signal to noise ratio is calculated (Dave H K, 2010) for each experiment run and average of each level of single factor are tabulated in Table 9 and the parameters are shown in fig. 3". The optimal levels of each factors are found as A3-B3-C3-D1-E3 (Table 9). ANOVA is also carried out for the CR to identify significance and contribution of each factor. The results are listed in Table 10. From the table it reveals that feed has highest significant with 44.42%, followed by top arm angle, 27.98% and speed as 21.02%. Distance and tension are found less significant for the cutting rate.

As the feed increases depth of cut per tooth increases, hence CR increases, it correlates with the results of research work carried out by M. M Ahamd et al. (1989). Along with feed as the cutting speed increases, number of teeth passing, through the cross section also increases and that leads to increase in CR. Because of the increase in top arm angle the vertical component of the weight of the top arm assembly increases, the same results into increase in thrust load. Thrust load helps in penetration of the blade in the material along with the feed pressure. So, combined effect of the same increases CR. Based on this the optimal combination of process parameter found is A3-B3-C3-D1-E3 (Table -9), i.e. Top arm angle as 50^0, Speed as 60 m/min and feed with valve position as 3, guide distance as 300 mm and blade tension as 20 kpsi, (Fig. 3).

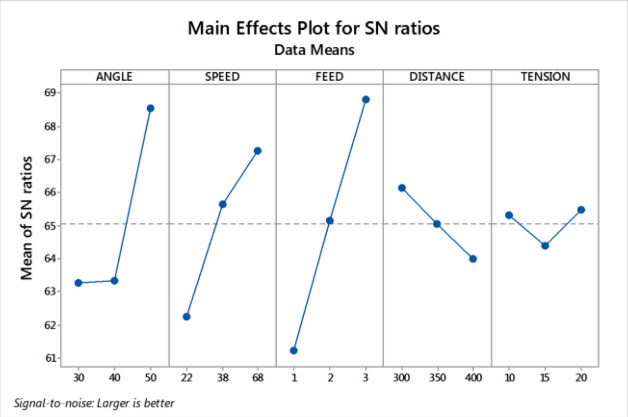

Fig. 3. Response Diagram for SN ratio of CR

Table 9. Response table for CR

Factors	Angle	Speed	Feed	Dist.	Tension
L1	63.28	62.19	61.21	**66.13**	65.28
L2	63.33	65.66	65.15	64.98	64.39
L3	**68.48**	**67.25**	**68.74**	63.99	**65.43**
Delta	5.15	5.06	7.53	2.15	1.04
Rank	2	3	1	4	5

4.2. Confirmation test for Cutting Rate (CR)

Once one obtained the optimal combinations of parameters, results are verified through confirmation test. "The estimated mean of the response characteristics CR, can be calculated for the optimum value of cutting parameters using equation (5)". Three trials were performed at optimum level (A3-B3-C3-D1-E3), and cutting rate is computed and listed in Table 11. As listed in the table value of cutting rate is improved from 913.37 mm^3/min to 5698 mm3/min. The improvement with reference to initial process parameter (J Y Kao et al, 2010) is found as 83.97 % for CR and same is listed in Table 11. The gain is quite considerable and one can say this will lead to good increase in productivity of cutting operation and definitely will help in reducing cost per cut.

$$\eta_{predicted} = T + \Sigma\left(\eta_i - T\right) \qquad (5)$$

where: "T = Overall mean of process parameter" and η_i = Average value of significant parameter.

Table 10. ANOVA Results for CR

Factors	SS	Df	MS	F	% Contr.
Angle	107.13	2.00	53.56	14.08	27.98
Speed	80.50	2.00	40.25	10.58	21.02
Feed	170.07	2.00	85.04	22.36	44.42
Distance	13.83	2.00	6.92	1.82	3.61
Tension	3.76	2.00	1.88	0.49	0.98
Error	26.62	7.00	3.80		1.99
Total	401.91	17.00	191.45		100

Table 11. Comparison of results

Sr.no.	Parameter combination	Level of individual parameter	CR mm^3/min
1	Initial design – based on Orthogonal array	A1-B1-C1-D1-E1	913.37
2	Optimal design – based on Taguchi theory	A3-B3-C3-D1-E3	5698#
	Final Gain		4784.63
	Final gain in %		83.97 %

Average of three reading

4.3. Cut quality (Taper)

For each experiment setting two cuts made and taper value is measured using digital vernier and recorded in Table 5. "Based on the value of taper, signal to noise ratio is calculated (Dave H K, 2010) for each experiment run and average of each level of single factor are tabulated in Table 12 and the parameters are shown in fig. 4". The optimal levels of each factors are found as A1-B2-C1-D3-E3 (Table 12). ANOVA is also carried out for the taper to identify significance and contribution of each factor. The results are listed in Table 13. From the table it reveals that blade tension has highest significant with 41.26%, followed by blade guide distance with 29.24%, top arm angle, 18.22%, feed with 8.23%. Speed is found less significant for cut quality.

As discussed in the previous section, effect of top arm angle increases CR due to higher thrust load, the same leads to deteriorate the cut quality. As the thrust load increases on blade, chances of blade deflection increases and it leads to taper cutting. Blade between the guides behaves like simply supported beam. Hence as the distance increases the deflection of blade will increase and hence taper will increase. Distance between guide and blade tension will decide the stiffness of the blade. Hence the value of 400 mm will provide minimum distance between guides and tension 20 kpsi will provide best stiffness. This helps in reduction of taper cutting.

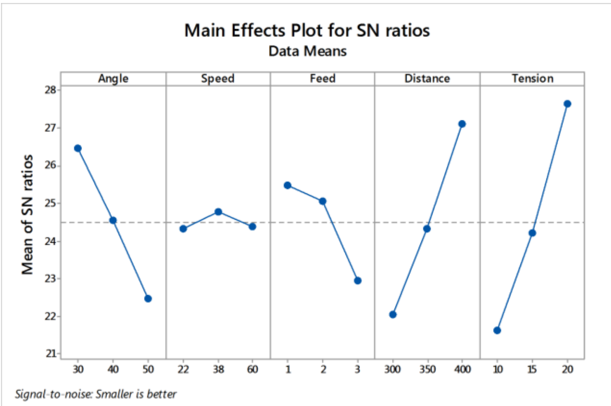

Fig. 4. Response Diagram for SN ratio of Taper

Optimal combination of process parameter found is A1-B2-C1-D3-E3 (Table-12), i.e. Top arm angle as 30^0, Speed as 38 m/min, feed with valve position as 1, guide distance as 400 mm and blade tension as 20 kpsi.

Table 12. Response table for Cut quality (Taper)

Factors	Angle	Speed	Feed	Dist.	Tension
L1	**26.47**	24.31	**25.46**	22.04	21.62
L2	24.54	**24.78**	25.05	24.31	24.20
L3	22.45	24.37	22.95	**27.11**	**27.64**
Delta	4.01	0.48	2.52	5.08	6.02
Rank	3	5	4	2	1

Table 13. ANOVA Results for Cut quality

Factors	SS	Df	MS	F	% Contr.
Angle	48.35	2.00	24.18	6.65	18.22
Speed	0.81	2.00	0.40	0.11	0.30
Feed	21.84	2.00	10.92	3.00	8.23
Distance	77.59	2.00	38.80	10.67	29.24
Tension	109.50	2.00	54.75	15.06	41.26
Error	25.44	7.00	3.63		2.74
Total	283.53	17.00	132.68		100.00

4.4. Confirmation test for Cut quality (Taper)

Once one obtained the optimal combinations of parameters, results are verified through confirmation test. The estimated mean of the response characteristics, i.e. Cut quality (Taper), can be calculated for the optimum value of cutting parameters using equation (5). Three trials were performed at optimum level (A1-B2-C1-D3-E3), and taper is measured and listed in Table 14. As listed in the table value of "cut quality (Taper)" is improved from 0.071 mm to 0.029 %. The improvement with reference to initial process parameter (J Y Kao et al, 2010) is found as 59 % for taper and same is listed in Table 14.

4.5. Optimal Bandsawing parameters using DFA

As discussed in the introduction, Taguchi method has a limitation of optimizing any one response parameter at a time, hence in the present study Desirability Function Analysis is used to optimize multiple performance characteristics. The details procedure and calculations are discussed in the previous section 3.

Table 14. Comparison of results

Sr.no.	Parameter combination	Level of individual parameter	TAPER %
1	Initial design – based on Orthogonal array	A1-B1-C1-D1-E1	0.071
2	Optimal design – based on Taguchi theory	A1-B2-C1-D3-E3	0.029#
	Final Gain		0.042
	Final gain in %		59 %

Average of three reading

As discussed in the previous section 3.2, combination of parameters giving highest value of global desirability can be considered as optimal solution. In the present study exp. Run 18, has highest value of d_G. Hence the optimal combination of the parameters can be A3-B2-C2-D1-E3.

To understand the statistical significance of the parameters for the responses and to calculate percentage contribution of each parameter analysis of variance (ANOVA) is carried out. Table 8 reports the results summary of ANOVA of global desirability, one can conclude that the blade tension has highest contribution on the multiple response characteristics with 33.32 % and top arm angle has second highest contribution with 23.39 %, followed by feed with 18.23%, speed with 11.12% and guide distance with 5.11%.

From response Table 7 and diagram of d_G (Fig. 2), it is clear that the highest value of top arm angle, speed and middle level of feed gives better CR and minimum taper. As discussed in the previous section 4.1, higher value of top arm angle, speed and feed increases CR. Also discussed in the previous section 4.3, lower value of top arm angle, feed and higher value of speed, distance and tension will give minimum taper. Hence for the optimal CR and taper cutting the combination achieved, A3-B3-C2-D3-E3, justifies the results. Due to higher speed the blade remains for minimum time in the cutting zone and hence even though the top arm descends at a faster rate due to higher feed, the blade simultaneously escaping from the cutting zone and minimize the deflection of the blade in cutting zone, hence minimize the possibility of taper cutting. Guide distance and blade tension balance the effect of higher thrust load due to of higher value of top arm angle and minimize the taper.

4.6. Confirmation test for DFA

Once one obtained the optimal combinations of parameters, results are verified through confirmation test. The estimated mean of the response characteristics, i.e. Global desirability, can be calculated for the optimum value of cutting parameters using equation (5). Three trials were performed at optimum level (A3-B3-C2-D3-E3), and cutting rate and taper were computed and listed in Table 15. As listed in the table value of cutting rate is improved from 913.37 to 4085.04 mm^3/min and taper is reduced from 0.071 to 0.043%. The improvement with reference to initial process parameter is found as 77.64 % for CR and 39.43% for Taper and same is listed in Table 15.

Table 15. Comparison of results

Sr No.	Parameter combination	Level of individual parameter	CR mm^3/min	TAPER %
1	Initial design –	A1-B1-C1-	913.37	0.071

	based on Orthogonal array	D1-E1		
2	Optimal design – based on DFA theory	A3-B3-C2-D3-E3	4085.04#	0.043#
	Final Gain		3171.67	0.028
	Final gain in %		77.64 %	39.43 %

Average of three reading

4.7. Response optimizer function

The optimal combination was not the part of experiments carried out, and hence response optimizer function of statistical software, MINITAB 17 (Trial version), is used to verify the results of confirmation test. Table 16, shows the parameter values for response optimizer analysis. The software gives interactive response optimizer graph (Fig. 5), by inserting the optimal parameters values we get the predicted results of responses (CR and Taper). We get the values for cutting rate as 3379 mm^3/min and for taper as 0.0341 %. Also the global desirability obtained is 0.7872, it is near to 1 and hence one can say that predictions are within acceptable limits. The predicted values are very close to the experiment values of confirmation test, so it reveals that optimal parameter found using DFA in combination with Taguchi method are accurate enough, that one can use these setting for estimation of response parameter with good accuracy.

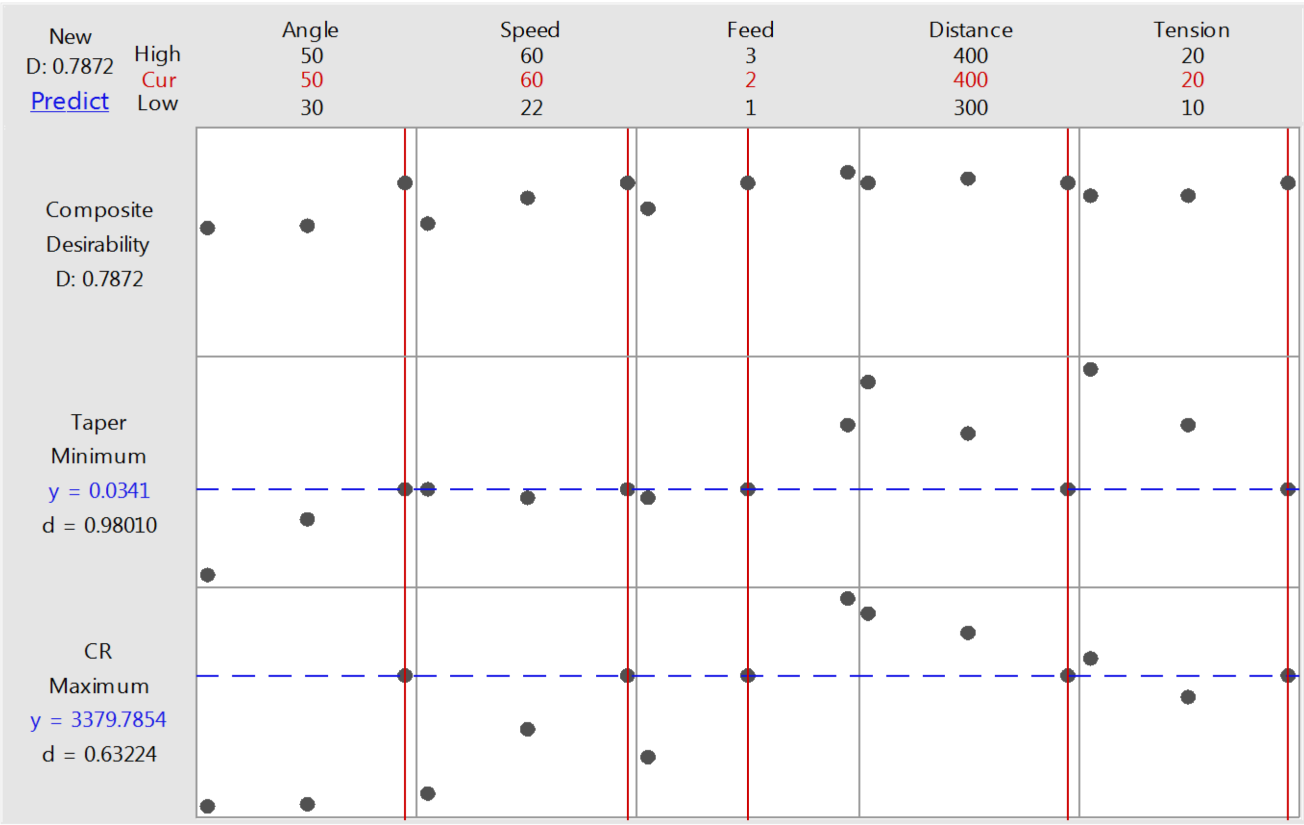

Fig. 5. Response optimizer output

Table 16. Response optimizer input values

Response	Goal	Lower	Target	Upper	Weight	Importance
Taper	Min	0.029	0.029	0.114	0.3	1
CR	Max	913.37	5661.50	5661.50	0.7	1

5. CONCLUSION

In the present study, cutting rate (CR) and cut quality (Taper) are measured for different combination of cutting parameter in bandsawing process. The results can be summarized as follows:

For the individual response parameter, CR, highest value of top arm angle (50^0), speed (60 m/min), feed (3), guide distance (300 mm) and blade tension (20kpsi) leads to maximum CR and for cut quality, lowest value of top arm angle (30^0), middle value of speed (38 m/min) lowest value of feed (1), highest value of guide distance (400 mm) and blade tension (20 kpsi) leads to minimum taper.

Both the response, CR and Taper, optimum values are of reverse nature and hence DFA approach applied to optimize the combined characteristics.

"From the experiment results it is found that proposed approach is effective".

The optimal process parameters for maximum material removal rate and minimum taper found are top arm angle as 50^0, cutting speed as 60 m/min, feed as valve position 2, guide distance as 400 mm and blade tension as 20 kpsi. Confirmation test results shows percentage improvement in material removal rate and cut quality (taper) at optimum process parameters achieved are 77.64 % and 39.43 % respectively. Results of confirmation test has also reveals agreement to the applicability of proposed approach.

Results at optimal parameter predicted using response optimizer tool of MINITAB software, are found to be in agreement to the confirmation experiment results.

Solution obtained with the present study and approach can be used for finding optimal solution of other metal cutting processes. In future, the present work can be extended for different workpiece material, workpiece shape, other process parameters, machine tools etc.

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