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INVESTIGATING THE EFFECT OF TOP ARM ANGLE ON MATERIAL REMOVAL RATE AND CUT QUALITY (TAPER) IN BANDSAW CUTTING OPERATION

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ABSTRACT

Cutting of raw material is a basic process to cut material to required length for further operations. But compared to other cutting off processes, like hacksawing, parting, shearing etc., bandsawing process has not attracted researchers. Now a days bandsaw machines are used to cut the material instead of hacksaw due to the demand of fast and accurate cutting to feed the CNC machines for subsequent operation. Looking to the increased use of bandsaw in industries, optimization of its cutting parameter becomes vital for researcher to study and suggest appropriate optimal combinations. In the present study “Material removal rate (MRR)” and “cut quality (Taper cutting)” are focused to optimize. With the help of Taguchi method experiments are planned and response parameters are recorded. An approach to use Taguchi and “Grey relational analysis” together to optimize process parameters for multiple response in bandsawing operation is discussed in the present work. The results show that speed and top arm angle has significant effect on the response parameters. The significance and contribution of individual parameter to the response is calculated using ANOVA. Detailed experimentation and result analysis is presented in this study.

Key words: *Bandsaw machine, Top arm angle, Material removal Rate, Cut quality (Taper), Taguchi method, Grey relational analysis, ANOVA.*

1. Introduction

Majority of raw materials needs 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 is 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 [1].

Now a day, the way CNC machines become the vital equipment for any product manufacturing, demand of faster cutting of raw material has increased 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. HaciSeglam [1], 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 has experimented to investigated the effect of these parameter on tool wear. The study indicates that cutting speed, cutting length and material hardness has significant effect on teeth wear and feed rate has minimum effect. M.M. Ahmad et al. [2], 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 decreases as the cutting speed increases. Whereas the feed has reverse effect on the cutting and thrust force. Workpiece breath does not have significant effect on cutting and thrust force. M. Sarvar et al [3], 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. [4-5], have studied the influence of force, power and specific

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cutting energy on wear of teeth in band sawing process. In both the work, it is observed 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 [6], reviewed various optimization methods used for metal cutting process 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 modeling techniques”, “Taguchi method, Response Surface design Methodology (RSM), Iterative mathematical search technique”, Heuristic search technique etc.

Looking to the robustness of design of experiment method (DOE), various industries have started applying it for process and product improvement. N. Alagumurthi et al.[8] have used “design of experiment (DOE) technique to optimize process parameters for grinding process. Julie Z. Zhang etal. [9] “have used Taguchi method to find optimum parameters for end milling process”. H. K. Dave et al. [19] “have used Taguchi method to find optimum process parameters for turning process”.

Due to limitation of DOE/Taguchi technique to optimize only one response parameter at a time, various multiple response optimization techniques gain importance among the researchers. Out of various such techniques “Grey relational analysis (GRA) found more suitable for optimization of process parameters” and hence become popular among the researcher to optimize multiple responses of various manufacturing processes [7,8,9]. The technique is applied for prediction and optimization of drilling process [12, 26], TIG welding process [13], Laser welding process [14], Laser micro turning process [15], Friction stir welding process [18], Grinding process [19], Electro discharge machining process (EDM) [18], Laser cladding process [19], Turning process [22, 23], Micro EDM process [24], Wire EDM process [26] and many more.

With reference to 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 material removal rate (MRR) and cut quality (Taper) in bandsawing operation. In today’s competitive market everyone is focusing to reduce the process cost and hence to reduce the final product cost. Improvement of MRR increases the productivity and hence reduces cost per cut. Cut quality, taper cutting not only increases the second operation time but also result in wastage of costly raw material. These leads to increase in product cost. Hence in the present study MRR and cut quality are considered as a response parameter.

After rigorous literature review, it is found that all the existing machines does not have facility to change the top arm angle in one machine. Authors had discussion and personal observation that, machine manufacturer decides the top arm angle based on cutting capacity of the machine, it is also observed that machines having higher degree of inclination gives somewhat more output compared to lower inclination angle. Due to fixed top arm angle and to the best of knowledge to the authors, change in top arm angle is not reported. Hence it is decided to develop the machine having flexibility in changing the top arm inclination in the same machine and study its impact on various responses like, material removal rate and cut quality.

The present investigation has been focused on application of Taguchi method for planning experiment matrix to perform band sawing operation. The independent controlling factors selected are top arm inclination angle, speed and feed, each factor set at three levels for present investigation. “Grey relational analysis” method is used to analyze effect of the above independent controlling factors on the multiple characteristics response factors viz. material removal rate (MRR) and cut quality (Taper). With this combined approach an optimal process parameter combination has been obtained.

2. Experiment Setup and Procedure

The experiments are carried out on a hinge type metal cutting bandsaw machine with a bimetal metal cutting bandsaw blade. Details of test set up are shown in Fig. 1. Specifications of machine, bandsaw blade and work piece material are listed in Table 1,2 & 3 respectively.

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 replaceable and is used to change the inclination of the top arm. Blade guide (4) twist the blade and make it right angle in the

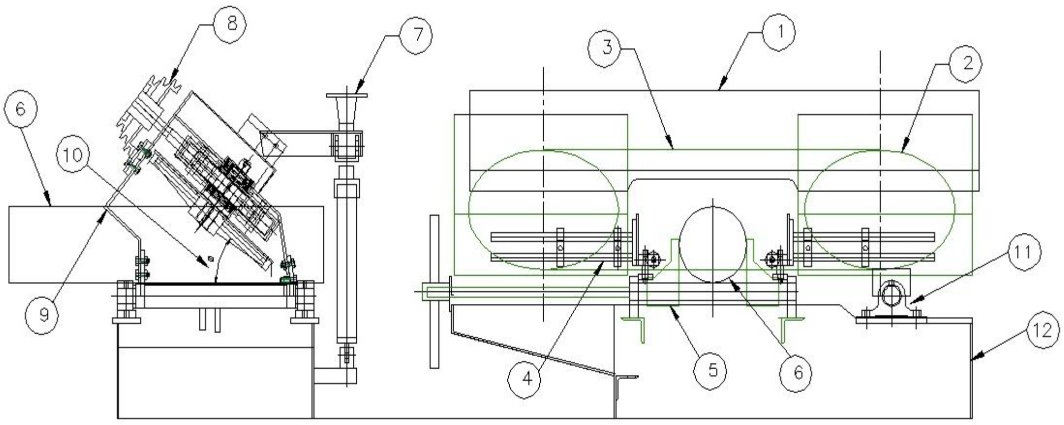

Fig.1 Bandsaw machine outline1. Top arm assembly, 2. Band wheel, 3. Blade, 4. Blade guide,5. Vice, 6. Workpiece, 7. Feed control valve, 8. Step pulley, 9. Inclined plate, 10. Ø = Top arm angle, 11. Hinge, 12. Base Tank

cutting zone to ensure straight cutting. Vice (5) is used to clamp the workpiece during cutting process.

Based on Taguchi's design of experiments [30,31,32], 27 (3^3) test runs are designed to analyze the (MRR) and Cut quality (Taper). Factors and their levels are selected based on the preliminary experiments, blade manufacturer's catalog and machine specifications. Cutting speed is selected with reference to blade manufacturer's catalog, feed depends upon the workpiece material and cutting speed. Table-4 shows the factors and their levels. Experiment matrix and response results are reported in Table -5 [7]. MRR is calculated by measuring the time taken to complete the cut and Cut quality (Taper) is calculated by measuring the thickness of the cut sample from top and bottom end and taking difference of both the values.

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
Blade size (mm)	3000 x 27 x 0.9

3. Grey relational analysis

Grey relational analysis is a one of the multi response optimization technique. Various multi response optimization methods are in use at industries and research organizations. ANN, Fuzzy set theory, Genetic Algorithm etc. are also multi response optimization techniques but they require large data set to optimize the process. GRA approach can be efficiently applied to complex metal cutting process with fewer data set. Bandsawing also falls under the complex metal cutting process, hence GRA approach is used for the optimization of MRR and Taper in the present work.

Deng [25] has suggested Grey relational analysis (GRA) for multi response characteristics. Two sequences can be correlated with grade value using this analysis. The procedure of grey relational analysis has been laid down by Deng [25]. The same has been used by many researchers in their investigations [7,12-29, 22-27]. In present work, emphasis has been given to the grey relational analysis in association with Taguchi technique.

3.1Data normalization

Normalization of data is required when the range of data and unit in one data sequence differ from the other. It is also required when the range of "sequence" is scattered in large range or when the directions of the characteristics in the sequence are different. Data is processed using various standard methods suggested by researchers and mentioned in one-line space between the first and subsequent author group (if any). The content of the header is given in the header of the present document. literatures, depending on the characteristics of the original data [23 –25, 29]. As MRR has characteristic as “larger the better”, normalization of data is carried out using Eq. (1) [29].

$$x_i^*(k) = \frac{x_i^0(k) - min\, x_i^0(k)}{max\, x_i^0(k) - min\, x_i^0(k)} \quad (1)$$

Table 3. Raw Material Standard data [33]

S. No.	Grade	Range	%C	% Mn	%Si	% S	%P	% Cr	%Mo
1	EN 19	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

Parameter (Factor)	Level 1	Level 2	Level 3
Top arm Angle (A) (Degree)	30	40	50
Speed (B)(m/min)	22	38	60
Feed (C) (Valve Position)	1	2	3

Same way Cut quality, i.e. taper of the face, has “lower the better” characteristic, normalization is carried out using Eq. (2) [29]:

$$x_i^*(k) = \frac{max\, x_i^0(k) - x_i^0(k)}{max\, x_i^0(k) - min\, x_i^0(k)} \quad (2)$$

Where $x_i^0(k)$ is original value of the result, $x_i^*(k)$ is normalized value of that result, max $x_i^0(k)$ is the largest value of $x_i^0(k)$, min $x_i^0(k)$ is the smallest value of $x_i^0(k)$ all among $x_i^0(k)$s.

3.2 Calculations of Grey relational coefficients (GRC) and grades (GRG)

GRC is calculated for the k^{th} performance characteristics in the i^{th}trial calculated using Eq. (3):

$$\xi_i(k) = \frac{\Delta_{min} + \zeta\, \Delta_{max}}{\Delta_{oi}(k) + \zeta\, \Delta_{max}} \quad (3)$$

Where,

“$0 < \xi\, (x_i^0(k), x_i^*(k) \leq 1$

$\Delta_{0i}(k) = |x_i^0(k) - x_i^*(k)|$

$\Delta_{max} = max|x_i^0(k) - x_i^*(k)|$

$\Delta_{min} = min|x_i^0(k) - x_i^*(k)|$

ζ is the distinguishing coefficient, $\zeta \in [0,1]$”

Once the GRC is obtained, the GRG (is obtained using Eq. (4).

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi_i(k) \quad (4)$$

Where n = Number of response parameters.

Table 5: Experiment matrix and results

	Input parameters			Response results	
Exp.no.	Top arm Angle (Degree)	Speed (m/min)	Feed	MRR (mm^3/min) *	Cut Quality (Taper) (mm)*
1	30	22	1	595	0.02
2	30	22	2	1024	0.025
3	30	22	3	1119	0.035
4	30	38	1	699	0.015
5	30	38	2	1306	0.015
6	30	38	3	1395	0.03
7	30	60	1	1061	0.01
8	30	60	2	2554	0.015
9	30	60	3	2828	0.035
10	40	22	1	995	0.03
11	40	22	2	1150	0.035
12	40	22	3	1312	0.05
13	40	38	1	1183	0.025
14	40	38	2	1394	0.015
15	40	38	3	2830	0.04
16	40	60	1	1306	0.01
17	40	60	2	2697	0.03
18	40	60	3	3564	0.03
19	50	22	1	1169	0.02
20	50	22	2	1402	0.03
21	50	22	3	2600	0.035
22	50	38	1	1395	0.025
23	50	38	2	2923	0.02
24	50	38	3	3520	0.025
25	50	60	1	3318	0.015
26	50	60	2	3446	0.02
27	50	60	3	4205	0.02

Correlation between the original and comparability sequences is represented by “Grey relational grade”. The test run, which has higher “grey relational grade”, that combination of variables is considered near to optimal solution. [22-29].

3.3Grey Relational Analysis methodology

As mentioned in the previous section, first step of the “grey relational analysis” (GRA) is the data normalization. As mentioned in section 3.1, original sequence of MRR is normalized using the Eq. (1), as “higher is the better” is the characteristic for MRR and original sequence of cut quality (Taper) is normalized using Eq. (2), as “lower is the better” is the average of the results characteristic for Taper. Data normalization is carried out for value between zero to one. Similarly, the “grey relational coefficient” (GRC) is computed using Eq. (3). “The distinguishing coefficient ζ is set between zero and one”. In present case, it is taken as 0.5, as MRR and Cut quality (Taper) has same importance in bandsawing process. After calculating GRC, the GRG is computed with the help of Eq. (4). The normalized values, GRC and GRG are listed in Table 6.

Based on the value of GRG, response table (Table-7) is generated using Taguchi method [30,31]. Table 6 shows average GRG for each factor level. As per the GRA, highest value of GRG is considered as optimal value of that parameter. As discussed in section 3.2, the test run which give, highest value of GRG, that combination is considered as near to optimal solution. With reference to this values of GRG mentioned in response Table 7, the optimal combination of process parameter will be A3-B3-C3. Behavior of each parameter is explained graphically in the Fig.4. (Trial version of Minitab was used)

4. Results & discussion

4.1Material removal rate

The experimental findings of MRR are listed in Table 5 for the various level of process parameters and Table 10 shows the ANOVA results. From the Table 10 it is clear that Cutting speed has the highest significance on MRR with a contribution of 37.67%, followed by Feed with 32.5 % and Top arm angle with 28.74%. Fig.2 shows “that material removal rate increases with increase in the value of all the three process parameters”. Also the p-value of all these factors is less than 0.05 (Table-10), hence all the factors can be considered as significant for MRR.

Table 6.Grey relational analysis coefficient and grade calculations for 27 runs

Exp. Run	Normalized Reference Sequence		Deviation Sequence		Grey relational Co-eff		GRG	Order
	MRR	Taper	MRR	Taper	MRR	Taper		
1	0.000	0.750	1.000	0.250	0.333	0.667	0.500	16
2	0.119	0.625	0.881	0.375	0.362	0.571	0.467	21
3	0.145	0.375	0.855	0.625	0.369	0.444	0.407	26
4	0.029	0.875	0.971	0.125	0.340	0.800	0.570	12
5	0.197	0.875	0.803	0.125	0.384	0.800	0.592	11
6	0.221	0.500	0.779	0.500	0.391	0.500	0.446	23
7	0.129	1.000	0.871	0.000	0.365	1.000	0.682	5
8	0.543	0.875	0.457	0.125	0.522	0.800	0.661	6
9	0.618	0.375	0.382	0.625	0.567	0.444	0.506	15
10	0.111	0.500	0.889	0.500	0.360	0.500	0.430	24
11	0.154	0.375	0.846	0.625	0.371	0.444	0.408	25
12	0.199	0.000	0.801	1.000	0.384	0.333	0.359	27
13	0.163	0.625	0.837	0.375	0.374	0.571	0.473	20
14	0.221	0.875	0.779	0.125	0.391	0.800	0.596	10
15	0.619	0.250	0.381	0.750	0.568	0.400	0.484	18
16	0.197	1.000	0.803	0.000	0.384	1.000	0.692	3
17	0.582	0.500	0.418	0.500	0.545	0.500	0.522	14
18	0.822	0.500	0.178	0.500	0.738	0.500	0.619	9
19	0.159	0.750	0.841	0.250	0.373	0.667	0.520	13
20	0.223	0.500	0.777	0.500	0.392	0.500	0.446	22
21	0.556	0.375	0.444	0.625	0.529	0.444	0.487	17
22	0.221	0.625	0.779	0.375	0.391	0.571	0.481	19
23	0.645	0.750	0.355	0.250	0.585	0.667	0.626	8
24	0.810	0.625	0.190	0.375	0.725	0.571	0.648	7
25	0.754	0.875	0.246	0.125	0.670	0.800	0.735	2
26	0.790	0.750	0.210	0.250	0.704	0.667	0.685	4
27	**1.000**	**0.750**	**0.000**	**0.250**	**1.000**	**0.667**	**0.833**	1

As the feed increases depth of cut per tooth increases, hence MRR increases, it correlates with the results of research work carried out by M. M Ahmad etal. [2]. Along with feed as the cutting speed increases, number of teeth passing, number of time through the cross section also increases and that leads to increase in MRR. 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 MRR. Based on this the optimal combination of process parameter found is A3-B3-C3 (Table -9), i.e. Top arm angle as 50^0, Speed as 60 m/min and feed with valve position as 3 (Fig 2).

4.2Confirmation test for MRR

Once one has obtained the optimal combinations of parameters, results are verified through confirmation test. The estimated mean of the response characteristics. MRR, can be calculated for the optimum value of cutting parameters using equation (5). Three trials were performed at optimum level (A3-B3-C3), and material removal rate is computed and listed in Table 11. As listed in the table value of “material removal rate" is improved from 1312 to 4204 mm3/min. The improvement with reference to initial process parameter [16,18] is found as 68.8 % for MRR and same is listed in Table 11.

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

Where,

T = Overall mean of process parameter

η_i = Average value of significant parameter.

Table 7. Response table for Grey grade [7,13]

Parameter	Level 1	Level 2	Level 3
Angle (A)	0.576	0.561	0.656
Speed (B)	0.514	0.595	0.684
Feed (C)	0.591	0.599	0.603

Table 8. ANOVA Results for GRG [7,13]

Factors	SS	DF	MS	F	% Contribution	p-value
Angle (A)	8.762	2	4.381	7.58	23.83	0.004
Speed (B)	26.794	2	13.40	23.19	72.88	0.000
Feed (C)	0.054	2	0.027	0.05	0.15	0.955
Error	11.555	20	0.578		3.14	
Total	47.165	26	18.386		100	

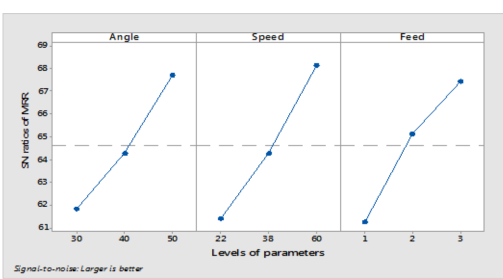

Fig. 2 Response Diagram for SN ratio of MRR

Table 9: Response table for MRR [18]

LEVEL	ANGLE	SPEED	FEED
1	61.85	61.42	61.25
2	64.27	64.29	65.13
3	67.7	68.12	67.45
DELTA	5.85	6.71	6.19
RANK	3	1	2

4.3 Cut quality (Taper)

Table 5 shows the experimental results of cut quality (Taper) for the various level of process parameters and Table 13 shows the ANOVA results. From the Table 13 it is clear that feed has the highest significance on Taper with a contribution of 52.86 %, followed by Speed with 24.73 % and Top arm angle with 17.81 %. Also the p-value of all these factors is less than 0.05 (Table-13), hence all the factors can be considered as significant for taper.

From the graph shown in Fig. 3 it is clear that lowest value of top arm angle, highest value of cutting speed and lowest value of feed give minimum taper, i.e. good cut quality. As discussed in the previous section, combined effect of top arm angle and feed increases MRR 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. In case of cutting speed, as the speed is higher the resting time of the blade in the cross section will be minimum and hence minimize the scope of blade deflection in the cutting zone. This helps in reducing taper cutting. Based on this the optimal combination of process parameter found is A1-B3-C1 [Table-12], i.e. Top arm angle as 30^0, Speed as 60 m/min and feed with valve position as 1 (Fig. 3).

4.4Confirmation 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 (V). Three trials were performed at optimum level (A1-B3-C1), and taper is measured and listed in Table 14. As listed in the table value of "cut quality (Taper)" is improved from .05 mm to 0.012 mm. The improvement with reference to initial process parameter [18,20] is found as 76 % for taper and same is listed in Table 14.

4.5 Optimal band sawing parameters using GRA

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

As discussed in the previous section 3.2, combination of parameters giving highest value of average of three reading GRG can be considered as optimal solution. In the present study exp. Run 27, has highest value of GRG. Hence the optimal combination of the parameters can be A3-B3-C3, which is matching with the combination of response table 6.

Table 10. ANOVA Results for MRR [18]

SOURCE	SS	DF	MS	F-VALUE	% CONT.	P-VALUE
ANGLE	155.45	2	77.725	28.79	28.74	0.000
SPEED	203.75	2	101.875	37.74	37.67	0.000
FEED	176.27	2	88.135	32.65	32.59	0.000
ERROR	53.99	20	2.699		1.00	
TOTAL	589.45	26	270.435		100	

Table 11: Comparison of results

Sl.no.	Parameter combination	Level of individual parameter	MRR mm^3/min
1	Initial design [16,18]– based on Orthogonal array	A2-B1-C3	1312
2	Optimal design – based on Grey theory	A3-B3-C3	4204[#]
	Final Gain Final gain in %		2892 68.80 %

Table 12. Response table for Cut quality (Taper)[16]

LEVEL	ANGLE	SPEED	FEED
1	34.05	30.34	35.22
2	30.76	33.18	32.84
3	32.8	34.08	29.53
DELTA	3.29	3.75	5.69
RANK	3	2	1

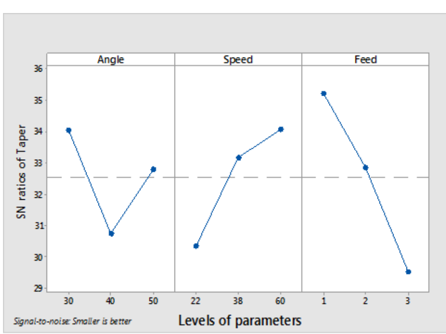

Fig. 3 Response Diagram for SN ratio of Taper

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 [30,31]. Table 8 reports the results summary of ANOVA of GRG, one can conclude that the speed has highest contribution on the multiple response characteristics with 72.88 % and top arm angle has second highest contribution with 23.83 %, feed has least contribution with 0.15 %. The p-value for speed and top arm angle is less than 0.05 and hence they are considered as significant for the multiple characteristic, whereas feed has p-value greater than 0.05, hence it will not be considered as a significant parameter.

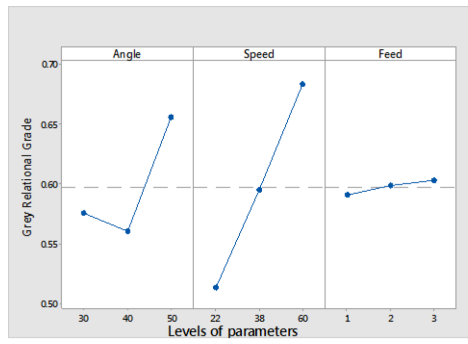

Fig. 4 Response Diagram for GRG

From response diagram of GRG (Fig. 4), it is clear that the highest value of all the three parameters gives better MRR and minimum taper. As discussed in the previous section 4.1, combined effect of top arm angle and feed increases MRR. Also discussed in the previous section 4.3, that if the feed is higher and speed is low, it leads to higher taper values due to deflection of the blade in the cutting zone. As we have highest speed as an optimum parameter for better MRR and minimum taper cutting, it justifies the cutting phenomena. In the present study the optimal parameters obtained are highest top arm angle (500), speed (60 m/min) and feed (Valve position 3) (Table 7).

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.

4.6Confirmation test for GRA

Once one obtained the optimal combinations of parameters, results are verified through confirmation test. The estimated mean of the response characteristics, i.e.

Table 13. ANOVA Results for Cut quality (Taper) [18]

SOURCE	SS	DF	MS	F-VALUE	%CONT.	P-VALUE
ANGLE	49.52	2	24.76	3.88	17.82	0.038
SPEED	68.76	2	34.38	5.38	24.73	0.013
FEED	146.97	2	73.49	11.51	52.86	0.000
ERROR	127.73	20	6.39		4.59	
TOTAL	392.98	26	139.02		100.00	

Table 14. Comparison of results

Sr.no.	Parameter combination	Level of individual parameter	TAPER mm
1	Initial design [16,18] – based on Orthogonal array	A2-B1-C3	0.05
2	Optimal design – based on Grey theory	A1-B3-C1	0.012#
	Final Gain Final gain in %		0.038 76 %

Table 15: Comparison of results (GRA)

Sl.No.	Parameter combination	Level of individual parameter	MRR mm3/min	Cut Quality (Taper) mm
1	Initial design [16,18] – based on Orthogonal array	A2-B1-C3	1312	0.05
2	Optimal design – based on Grey theory	A3-B3-C3	4204#	0.02#
	Final Gain Final gain in %		2892 68.80 %	0.03 60 %

grey relational grade, can be calculated for the optimum value of cutting parameters using equation (5). Three trials were performed at optimum level (A3-B3-C3), and material removal rate and taper were computed and listed in Table 15. As listed in the table value of "material removal rate" is improved from 1312 to 4204 mm^3/min and taper is reduced from 0.05 to 0.02 mm. The improvement with reference to initial process parameter is found as 68.8 % for MRR and 60% for Taper and same is listed in Table 15.

5. Conclusion

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

- For the individual response parameter, MRR, highest value of all the three, top arm angle (50^0), speed (60 m/min) and feed (3), input parameters leads to maximum MRR and for cut quality, lowest value of top arm angle (30^0), highest value of speed (60 m/min) and feed (1) leads to minimum taper.
- Both the response, MRR and Taper, optimum values are of reverse nature and hence GRA approach applied to optimize the combined characteristics. From the experiment results it is found that proposed approach is effective.
- Based on GRA 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 and feed as valve position 3.

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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Nomenclature

Symbol	Meaning
$xo(k)$	Original reference
	sequence
$xi(k)$	Sequence for comparison
m	Total number of experiment to be
	considered
n	Total number of
	observation data
$Xi^0(k)$	Original Sequence
$Xi^*(k)$	Sequence after data pre processing
	Largest value of $Xi^0(k)$
Max. $Xi^0(k)$	Smallest value of $Xi^0(k)$
Min. $Xi^0(k)$	Distinguishing coefficient
ζ	Grey relational analysis
GRA	Grey relational
GRC	coefficient
	Grey relational grade
GRG	

