Impact Factor (SJIF): 5.301

International Journal of Advance Research in Engineering, Science & Technology

e-ISSN: 2393-9877, p-ISSN: 2394-2444

Volume 5, Issue 3, March-2018

"OPTIMIZATION OF SURFACE QUALITY FOR TURNING OPERATION USING GREY BASED TAGUCHI TECHNIQUE"

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ABSTRACT*-Surface finish is an important quality characteristic of any manufactured part. Machining process is often employed to improve the surface finish. In this study, different experiments of turning operation will be performed on mild steel samples by HSS SPCT using different values of cutting parameters like cutting speed, depth of cut and feed rate using design of experiments on CNC lathe. Eighteen such experiments will be performed and the surface finish data will be recorded as per* L_{18} *orthogonal array. This data will be used to calculate the grey relational coefficients and then the grey relational grade which are then used to calculate S/N ratios. The values of S/N ratios are used predict the optimal parameters for turning operation. Confirmation tests will be used to confirm the predicted results.*

Keywords: *Cutting parameters, Turning operation, Grey Based Taguchi Technique, ANOVA Analysis.*

I. INTRODUCTION

Surface roughness has become the most significant technical requirement and it is an index of product quality. In order to improve the mechanical properties like, fatigue strength, corrosion resistance, a reasonably good surface finish is desired. Nowadays, the manufacturing industries specially are focusing their attention on dimensional accuracy and surface finish. In order to obtain optimal cutting parameters to achieve the best possible surface finish, manufacturing industries have resorted to the use of handbook based information and operators' experience. This traditional practice leads to improper surface finish and decrease in the productivity due to sub-optimal use of machining capability.

Metal cutting is one of the most significant manufacturing processes in material removals and turning is the most commonly used method for metal cutting. Turning operations are evaluated based on the performance characteristics such as surface roughness, material removal rate, tool wear, tool life and cutting force. These performance characteristics are strongly correlated with cutting parameter such as cutting speed, feed rate and depth of cut. It is an important task to select cutting parameter for achieving high cutting performance. There is need to operate this machines are efficiently as possible in order to obtained required payback. Achieving desire surface quality is of great importance for the functional behavior of the mechanical parts. Very few research attempts have been done to estimate significant effect of surface roughness for the CNC machining process.

1.1 Factors Affecting The Surface Finish:

Whenever two machined surfaces come in contact with one another the quality of the mating parts plays an important role in the performance and wear of the mating parts. The height, shape, arrangement and direction of these surface irregularities on the work piece depend upon a number of factors,

In order to identity the process parameters affecting the selected machining quality characteristic of turned parts, the cause-effect diagram was constructed as shown in figure 1.

1) The identified process parameters are the cutting tool parameters

a) Tool geometry
b) Tool material

2) Physical and mechanical properties, the cutting parameters

a) Cutting speed
b) Feed rate
c) Depth of cut

3) Work piece-related parameters

a) Hot-worked
b) Cold-worked

4) Environment parameters

a) Dry cutting
b) Wet cutting

The following process parameters were thus selected for the present work:

a) Cutting speed (A)
b) Feed rate (B)

c) Depth of cut(C),
d) Work material – mild steel and carbide cutting tool on automated CNC lathe.
The selection of parameters of interest was based on some preliminary experiments and earlier studies by the authors.

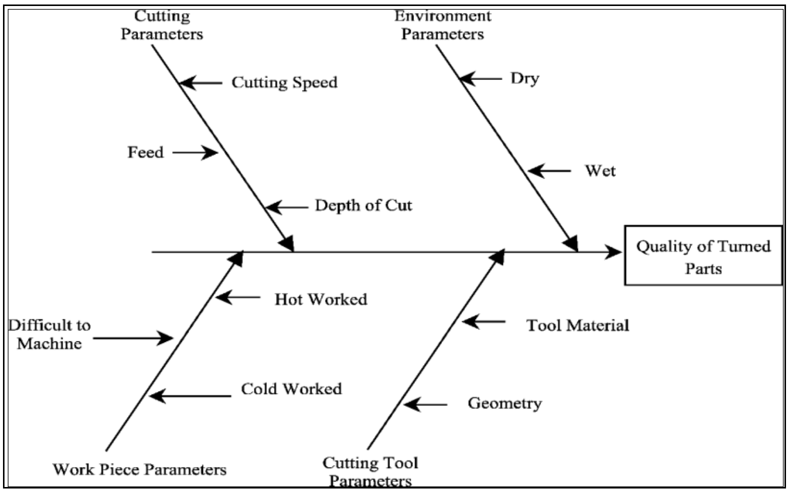


Figure 1: Cause–effect diagram of a turning process.

1.2 Adjustable Cutting Factors In Turning:

The three primary factors in any basic turning operation are speed, feed, and depth of cut. Other factors such as kind of material and type of tool have a large influence, of course, but these three are the ones the operator can change by adjusting the controls, right at the machine.

Speed:
Speed always refers to the spindle and the work piece. When it is stated in revolutions per minute (rpm) it tells their rotating speed. But the important feature for a particular turning operation is the surface speed, or the speed at which the work piece material is moving past the cutting tool. It is simply the product of the rotating speed times the circumference of the work piece before the cut is started. It is expressed in meter per minute (m/min), and it refers only to the work piece. Every different diameter on a work piece will have a different cutting speed, even though the rotating speed remains the same.

$$v = \frac{\pi DN}{60} \text{ m/min,}$$

Here, v is the cutting speed in turning, D is the initial diameter of the work piece in mm, and N is the spindle speed in RPM.

Feed:
Feed always refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. On most power-fed lathes, the feed rate is directly related to the spindle speed and is expressed in mm (of tool advance) per revolution (of the spindle), or mm/rev.

$F_m = f \times N$ mm/min

Here, Fm is the feed in mm per minute, f is the feed in mm/rev and N is the spindle speed in RPM.

Depth of Cut:
Depth of cut is practically self-explanatory. It is the thickness of the layer being removed (In a single pass) from the work piece or the distance from the uncut surface of the work to the cut surface, expressed in mm. It is important to note, though, that the diameter of the work piece is reduced by two times the depth of cut because this layer is being removed from both sides of the work.

$$d_{cut} = \frac{D-d}{2} \text{mm}$$

Here, D and d represent initial and final diameter (in mm) of the job respectively.

II. LITERATURE REVIEW

Various researches have used new combined Taguchi's and Grey relational analysis approach in various manufacturing processes especially machining to determine cutting parameters to optimize various quality characteristics like-surface finish, cutting force, feed force, cutting tool life etc.

Dave H K et.al, conduct the experiment for optimization of process parameter on milling machine is carried out using a combination method and Grey relational analysis method. Speed, feed and depth of cut are taken as input process parameter and cutting force and power are selected a target value. All the three in put parameter are taken at four different levels and sixteen experimental run are performed based on L16 OA method after experiment conducted it is found that feed has maximum influence on the target Characteristic.

S. S. Panda et.al, conduct the experiment to predict the surface roughness of drilled whole and drilled flank wear by using combine grey based Taguchi method. Experiment have been conducted on a drilling machine with four in put parameter like speed, feed rate, thrust force and feed vibration. Result of this study illustrates that Grey relational analysis procedure a simple and straight forward. This method is reliable and could able to implement that have more than to response.

S Balasubramanian et.al formulated the experiment to optimize process parameter for wire electro discharge machining WEDM, by using grey based Taguchi method. WEDM is extensively used in tool and die Industry. The main objective of this study is to obtain higher material removal rate and lower surface roughness. Wire feed rate. Wire tension applied current pulse off time, pulse on time and get voltage are the six control factor taken each four level. The experimental result confirms that process is effectively able to implement for desired goal.

Chorng – JyhTzeng et.al, formulate the experiment to investigate to optimization turning operation parameter using the grey analysis network. Nine experimental run based on $OA_8$of Taguchi method was performed. This surface property of roughness average and roughness maximum as well as the roundness were selected as the quality target. By analyzing the gray relational grade matrix the degree of influence of each controllable process factor on to individual quality target can be found. The depth of cut was identified to be most influence on the roughness Average and cutting speed is the most influence factor to the roughness maximum and roundness. Additionally analysis of variance is also applied to identify the most significant factor. The depth of cut is the most significant controllable factors for the operation.

Harisingh et.al, conduct design of experiment for determining the optimal value of feed force during turning operation when machining EN24 steel with TiC coated tungsten carbide inserts. The optimal setting of cutting parameter has been accomplished using Taguchi's parameter design approach. In their experiment they found that the percentage contribution of depth of cut 55.15% and feed rate 23.33% is much higher than that of cutting speed which is only 2.63%

III. TRADITIONAL TAGUCHI'S DESIGN

In the early 1950, Dr. Genichi Taguchi, "the father of quality Engineering" introduced the concept of quality control techniques known as Taguchi parameter design. Taguchi's method of design of experiment offer simple and systematic approach to optimize a performance quality and cost. Taguchi optimization methodology for the design of experiment is made up of three main phases.

- The planning phase
- The conducting phase
- Analysis phase

It provides a simple, efficient and systematic approach to optimize design for performance, quality, and cost. The methodology is valuable when the design parameter is qualitative and discrete. Taguchi parameter design can optimize the performance characteristics through the setting of design parameter and reduce the sensitivity of the system performance to source of variation.

This approach helps to reduce the large number of experimental trials when the number of process parameters increases. Most of the works have been published so far focused on single response performance characteristic optimization by using Taguchi approach. But the Taguchi approach is designed for optimizing the single response problems. It is not fit for optimizing the multi response problems. Optimization of a single response results the non-optimum values for remaining responses. In solving many of problems in engineering, it is necessary to consider the application of multi-response optimization, because the performance of the manufactured products is often evaluated by several quality characteristics/ responses.

3.1 Grey Relational Method:

The natural phenomena have given us numerous difficult problems. We are confronted with numerous such Grey systems: the social system, environmental system, economy system, human anatomical system. To ensure continuation of our very existence, it is imperative that we investigate and understand this system. However given our present knowledge or scientific information we have to simplify much of complex embodiment of this system. Such a model can only be at best homomorphic to or vaguely resemble the original system.

3.2 Grey Based Taguchi Method:

Experimental design based on Grey based Taguchi methodology is a powerful and effective approach to achieving this goal. The methodology involves identification of controllable and uncontrollable parameters and the establishment of a series of experiments to find out the optimum combination of the parameters which has the greatest influence on the performance and the least variation from the target of the design. This chapter covers step 1 to step 4 of the Taguchi's methodology.

The integrated grey based Taguchi method combined the algorithm of Taguchi method and Grey relational analysis to determine the optimum process parameter for surface roughness. The grey relational analysis theory makes used of this to handle uncertain systematic problem with only partial not information. This theory is adopted for solving the

complicated interrelationships among the multiple responses. The grey relational coefficient can express the relational ship between the desired and actual experimental results. The grey rotational grad is obtain the evaluated the multi response. Optimization of the complicated response can be converted into optimization single grad relational grade.
The integrated grey based Taguchi method combines advantages of both grey relational analysis and Taguchi method. This method was successfully applied to optimize the multi response complicated problems and manufacturing processes. Furthermore the S/N ratio of each quality characteristic and ANOVA is performed to see which process parameters statistically significant.
Taguchi parameter design can optimize the performance characteristics through the setting of design parameter and reduce the sensitivity of the system performance to source of variation.

3.3 Grey Relational Analysis:

The Grey relational analysis based on the Grey system theory can be used to solve the complicated inter-relational ship among the multi response effectively. In a Grey system some information is known and some information is known. It is the applied in optimization of manufacturing process with multi responses.

IV. DATA PRE-PROCESSING

The data pre-processing is the first stage in grey analysis. Data pre-processing is a means of transforming the original sequence to a comparable sequence. Depending on the characteristic of the data sequence, there are various Methodologies of data pre-processing available for this analysis.
Experimental data y_{ij} is normalized as Z_{ij} for the i^{th} performance characteristic in j^{th} experiment can be expresses as:

For S/N ratio with smaller the batter condition:

$$Z_{ij}=\frac{\max yij-yij}{\max(yij)-\min(yij)}$$ where, y_{ij} Experimental response data

4.1 Grey Relational Coefficient andGrey Relational Grade:

Grey relational coefficient:

Following the data pre-processing, a grey relational coefficient can be calculated using the pre-processed sequences. The grey relational coefficient is defined as follows.

$y_{ij}=\frac{\Delta min+\xi\Delta max}{\Delta oi+\xi\Delta max}$ where, ξ=Grey relational coefficient (0.5)

Grey relational grade:

The grey relational grade is expressed as:

$\bar{y}=\frac{1}{k}\sum_{i=1}^{m} y_{ij}$ where, m = no of Experiment k = no of quality Characteristic

The higher grey relational grade implies the batter product quality. On the basis of grey relational grade, the factor affect can be estimated and the optimum level for each controllable factor can also be determined.

4.2 Selection of Noise Factors And Control Factors:

In this study, the controllable factors are speed (A), feed rate (B) and depth of cut (C) which were selected because they may be potentially affecting on surface finish. These factors are controllable in present work. Noise factors are those that are either too hard or uneconomical to control even though they may cause unwanted variation in performance. Based on in the Taguchi methodology, such as smaller-the-better, larger the-better, and nominal-the-best. For example, smaller-the-better is considered when measuring fuel consumption of an automobile or shrinkage of a plastic component. In present work smaller value of surface roughness is desirable. Thus the smaller the batter methodology was employed for the data processing in traditional Taguchi method and data pre-processing in Grey relational method.

Lower the Better

If the Lower value for a characteristic Y is best then designer should maximize the S/N Ratio i.e.:

$$(S/N)_{LB} = -10 \log \frac{1}{r}\sum_{i=1}^{r} y_i^2$$

Where, r = number of measurement in one trial (in this case r = 1)
Y_i = ith measured value in trial.

The S/N ratio for each level of process parameter is computed based on the quality characteristic in single response problems. However optimization of multi response cannot be straight forward as in the optimization of a single response. The higher S/N ratio for one response may correspond to the lower S/N ratio for another response. To overcome that limitation combine Grey based Taguchi approach are proposed by research.

4.3 Selection of levels of control factors:

The levels selected for the current study are shown in the table 1.

Table1: Selected experiment factors and there level.

Factor	Level 1	Level 2	Level 3
Feed rate (A)	0.2	0.4	0.6
Depth of cut (B)	0.4	0.8	1.2

Cutting Speed (C)	100	125	150

4.4 Selection of orthogonal array:

There are 18 basic types of standard Orthogonal Arrays (OA) in the Taguchi parameter design. Since, three factors were studied in this present work, three levels of each factor were considered. Therefore, by using full factorial equation L^f (where, L- Level and f- factor) the Orthogonal Array OA_{27} was preferable from research but in this study we used fractional factorial orthogonal array design and choose OA_{18}. The layout of this OA18 shown in table 2 and also in table 3 each run will have single response collected, which were conducted for analysis in this study.

Table: 2 Level wise representation of Exp.

Factors/T.C.	A	B	C
1	1	1	1
2	1	1	2
3	1	2	3
4	1	2	1
5	1	3	2
6	1	3	3
7	2	1	1
8	2	1	2
9	2	2	3
10	2	2	1
11	2	3	2
12	2	3	3
13	3	1	1
14	3	1	2
15	3	2	3
16	3	2	1
17	3	3	2
18	3	3	3

Table: 3 Actual combi. of factors for the Exp.

Factors/T.C.	A	B	C
1	0.2	0.4	100
2	0.2	0.4	125
3	0.2	0.8	150
4	0.2	0.8	100
5	0.2	1.2	125
6	0.2	1.2	150
7	0.4	0.4	100
8	0.4	0.4	125
9	0.4	0.8	150
10	0.4	0.8	100
11	0.4	1.2	125
12	0.4	1.2	150
13	0.6	0.4	100
14	0.6	0.4	125
15	0.6	0.8	150
16	0.6	0.8	100
17	0.6	1.2	125
18	0.6	1.2	150

V. CONDUCTING THE EXPERIMENTS

In present work the CNC lathe (ACE Designer Ltd) with 5.5 KW spindle power and maximum spindle speed of 2500 RPM is used to perform the machining operation. The work material is Mild-Steel in form of round bar with 30mm diameter and 50mm cutting length. Carbide tool is used for machining. Three factors – speed, feed rate and depth of cut are considered to be the influence parameter to affect the surface roughness during turning operation on computer numerical control (CNC) lathe. Three levels of each factor have been considered.

The 18 experiments, shown in Table 4 were randomly run on the CNC lathe. After the data were collected and record in table 4 the S/N ratio of each experimental run was calculated based on lower is better S/N ratio equation.

Table: 4 Experimental set up and response table.

Experiment No.	Feed rate (A) mm/rev.	Depth of cut (B) mm.	Speed (C) mm/min.	Avg. response Value.	Avg.S/N Value.
1	0.2	0.4	100	2.65	-8.464
2	0.2	0.4	125	4.16	-12.381
3	0.2	0.8	150	2.67	-8.530
4	0.2	0.8	100	3.39	-10.603
5	**0.2**	**1.2**	**125**	**1.52**	**-3.636**
6	0.2	1.2	150	1.73	-4.760
7	0.4	0.4	100	4.50	-13.064
8	0.4	0.4	125	2.60	-8.299
9	0.4	0.8	150	4.53	-13.121
10	0.4	0.8	100	3.15	-9.966
11	0.4	1.2	125	5.64	-15.025
12	0.4	1.2	150	6.70	-16.521
13	0.6	0.4	100	8.89	-18.978
14	0.6	0.4	125	8.39	-18.475
15	0.6	0.8	150	9.15	-19.228

16	0.6	0.8	100	9.76	-19.788
17	0.6	1.2	125	10.43	-20.365
18	**0.6**	**1.2**	**150**	**10.79**	**-20.660**

Table 5: Grey relational coefficient of average response data and S/N value

(For average response data)

Avg. resp. Value.	Data Prepro Seq.	Normalize d Sequance	Grey Rel. Grade
2.65	0.878	0.122	0.803
4.16	0.715	0.285	0.636
2.67	0.875	0.125	0.800
3.39	0.798	0.202	0.712
1.52	**1.000**	**0.000**	**1.000**
1.73	0.977	0.023	0.956
4.50	0.678	0.322	0.608
2.60	0.883	0.117	0.810
4.53	0.675	0.325	0.606
3.15	0.824	0.176	0.739
5.64	0.555	0.445	0.529
6.70	0.441	0.559	0.472
8.89	0.204	0.796	0.385
8.39	0.258	0.742	0.402
9.15	0.176	0.824	0.377
9.76	0.111	0.889	0.359
10.43	0.038	0.962	0.341
10.79	**0.000**	**1.000**	**0.333**

(For Average S/N data)

Avg. resp. Value.	Avg. S/N Value.	Data Prep. Seq.	Normalized Sequance	Grey Rel. Grade
2.65	-8.464	0.283	0.717	0.420
4.16	-12.381	0.513	0.487	0.506
2.67	-8.530	0.287	0.713	0.412
3.39	-10.603	0.409	0.591	0.458
1.52	**-3.636**	**0.000**	**1.000**	**0.333**
1.73	-4.760	0.066	0.934	0.348
4.50	-13.064	0.553	0.447	0.527
2.60	-8.299	0.273	0.727	0.407
4.53	-13.121	0.557	0.443	0.530
3.15	-9.966	0.371	0.629	0.442
5.64	-15.025	0.668	0.332	0.600
6.70	-16.521	0.756	0.244	0.672
8.89	-18.978	0.901	0.099	0.834
8.39	-18.475	0.871	0.129	0.794
9.15	-19.228	0.915	0.085	0.854
9.76	-19.788	0.948	0.052	0.905
10.43	-20.365	0.982	0.018	0.965
10.79	**-20.660**	**1.000**	**0.000**	**1.000**

5.1 Analysis of Variance:

The purpose of the analysis of variance (ANOVA) is to determine which parameters significantly affect on desired quality characteristic. Table 6 shows the results of ANOVA analysis of raw data for surface finish. From Table 6, it is apparent that the F values of factor A (Feed rate),F_A = 4.403 is greater than F0.05, 2, 11 = 2.98, so factor A(Feed rate) is significant factor affecting on surface roughness of the material and B (Depth of cut) and factor C (Speed) was not a significant factor affecting on the surface roughness of the material. Its F value =0.033 and 0.081 is less than F0.05, 2, 11 = 2.98.

Table: 6 ANOVA Table for Response data

Source of Variation	Degree of Freedom	Sum of Squares	Sum of Mean	F-Value
Feed rate	2	0.88639	0.44319	4.40333
Speed	2	0.00684	0.00342	0.03397
Depth of cut	2	0.01650	0.00825	0.08198
Error	11	1.10715	0.10065	
Total	17	2.01690		

5.2 Determination of the optimum factor-level combination:

This investigation employs the response table of the Taguchi method, to calculate average Grey relational Grades for each factor level as illustrated in table 7 & 8.

Table 7: Average Grey relational Grade for average response data.

Level	Factor A
1	**0.8178**
2	0.6273
3	0.3661

Level	Factor B
1	**0.6073**
2	0.0598
3	0.6051

Level	Factor C
1	0.6010
2	**0.6196**
3	0.5906

Table 8: Average response Grey relational Grade for S/N data.

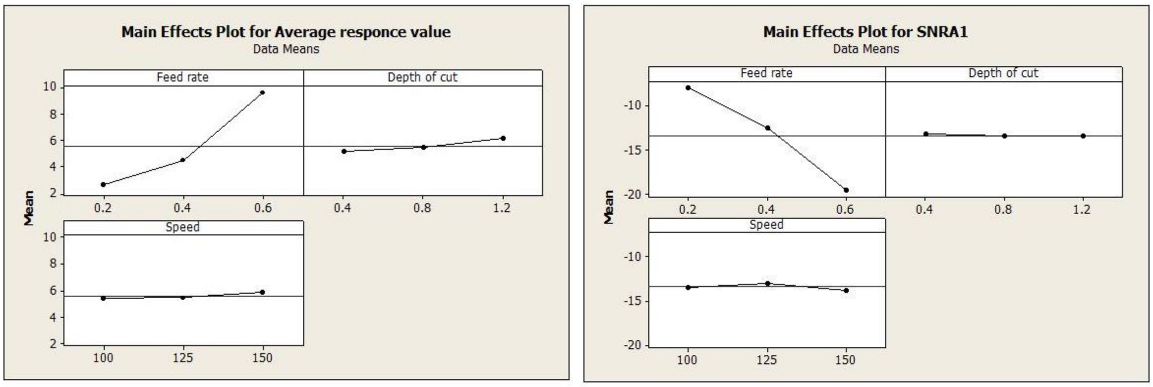
Level	Factor A
1	**0.4111**
2	0.5296

Level	Factor B
1	**0.5796**
2	0.6001

Level	Factor C
1	0.5976
2	**0.5966**

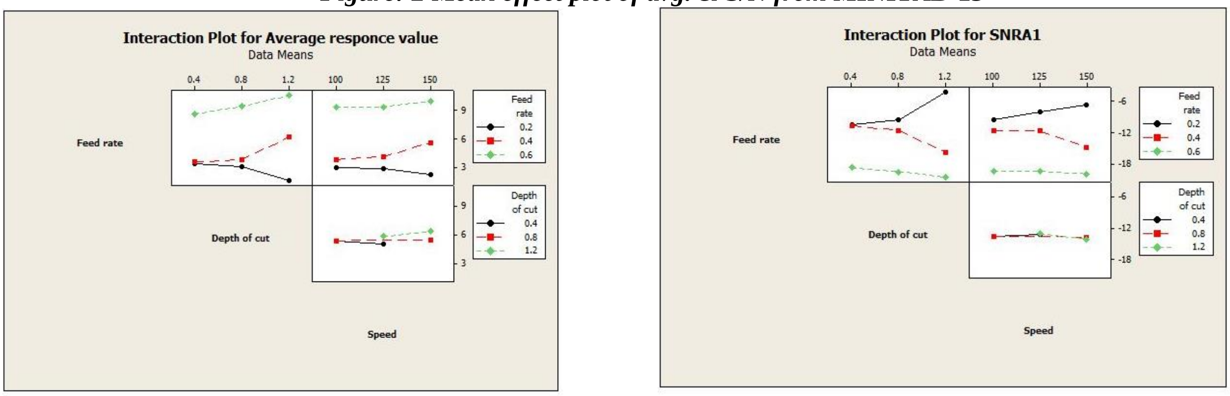
3	0.8920	3	0.6530	3	0.6360

The grey relational grade represented the level of co- relational between the reference and the comparability sequence. The higher grey relational grad implies the batter product quality. On the basis of grey relational grade, the factor affect can be estimated and the optimum level for each controllable factor can also be determined.
In this study the higher Grey relational grade means the comparatively sequence is stronger co-relation reference sequence. Based on this, one can select a combination of the level that provides the higher average response. In table 7 the combination of A_1, B_1, and C_2 show the smallest highest value of the Grey relational grad for the factor A, B, and C respectively. Similarly, In Table 8 the combination of A_1, B_1, C_2 show that smallest value of the grey relational grade for average S/N value. Therefore A_1, B_1, C_2 is the optimal parameter combination of the turning operation is chooses for confirmation test.



(A) (B)

Figure: 2 Mean effect plot of avg. & S/N from MINITAB-15



(A) (B)

Figure: 3 Interaction plots of avg. & S/N from MINITAB-15

Factor-Level Combination Figure 2&3 shows four graphs, each of which contains a curve represent the mean and the S/N ratio. The values of the graphs are from Table 7 and 8 the objective of using the S/N ratio as a performance measurement is to develop products and processes insensitive to noise factors. The S/N ratio indicates the degree of the predictable performance of a product or process in the presence of noise factors. Process parameter settings according to desired quality characteristic, S/N ratio always yield the optimum quality with minimum variance. Consequently, the level that has a smaller value determines the optimum level of each factor. For example, In Figure 3, level-1 for feed rate (A_1= 0.4111), level-1 for depth of cut (0.5796) and level-2 for speed (0.5966) has the lowest S/N ratio value, which indicated that the machining performance a such level produced minimum variation of the surface roughness. In addition, the higher grade value of surface roughness had a better machining performance. Furthermore, level-1 for feed rate (A_1= 0.8178), level-1 for depth of cut (0.6073) and level-2 for speed (0.6196) has indicated the optimum situation in terms of mean value. Therefore In this study A_1, B_1, C_2 is the optimal parameter combination of the turning operation is chooses for confirmation test.

5.5 Predicting Optimum Performance:

Using the aforementioned data, one could predict the optimum surface roughness
Performance using the cutting conditions as:
Predicted Mean for avg. response data:

Predicted Mean = $A_1 + B_1 + C_2 - 2 \times (\bar{y})$ where; $(\bar{y})$ = mean of avg. response data

$= 0.8178 + 0.6073 + 0.6196 - 2 \times 0.5438$

$= 0.9570\,\mu m$.

Similarly, the S/N ratio could be predicted as:
Predicted S/N = $A_1 + B_1 + C_2 - 2\times(\acute{\eta})$ Where, ή= mean of S/N ratio
= 0.4111 + 0.5796 + 0.5966 – 2 × (-13.4363)
= 28.4593 dB

With this prediction, one could conclude that the optimum surface finishing of the material within the above predicted optimum factor level combination the machine crates the best surface roughness with the value is equal to 0.9570 μm. A confirmation of the experimental design was necessary in order to verify the optimum cutting conditions.

VI. CONCLUSION

The grey based Taguchi method is the effective method to determine significant factors that affect an output characteristic in turning operation. In the present study, through the ANOVA, it is found that out of three parameters viz. feed rate (A), depth of cut (B) and speed(C), only the latter one proved to be the most significant factor to affect on the surface roughness of turned sample.

From the response table of the average grey relational grade, it is found that the highest value of grey relational grade for level one for feed rate (A_1= 0.8178), level one for depth of cut (0.6073) and level two for speed (0.6196) has indicated the optimum situation in terms of mean value, and as per desired quality Characteristic the smallest value of S/N of , level one for feed rate (A_1= 0.4111), level one for depth of cut (0.5796) and level second for speed (0.5966) has the lowest S/N ratio value, which indicated that the machining performance a such level produced minimum variation of the surface roughness. Hence in this study A_1, B_1, C_2 is the recommended factor level combination of the turning operation for better surface roughness.

VII. REFERENCES

1. M. Kaladhar1,*, K. V. Subbaiah2, Ch. Srinivasa Rao2 and K. Narayana Rao3, Application of Taguchi approach and Utility Concept in solving the Multi-objective Problem when turning AISI 202 Austenitic Stainless Steel, Journal of Engineering Science and Technology Review 4 (1) (2011) 55-61.
2. Yigit Kazancoglu1, Ugur Esme2, Melih Bayramoglu3, Onur Guven4,Sueda Ozgun5, multi-objective optimization of the cutting forces in turning operations using the grey-based taguchi method, Prejemrokopisa – received: 2010-06-18; sprejemzaobjavo – accepted for publication: 2011-02-02.
3. P. P. Shirpurkar, S.R. Bobde, V.V.Patil, B.N. Kale, Optimization of Turning Process Parameters by Using Tool Inserts, International Journal of Engineering and Innovative Technology (IJEIT) Volume 2, Issue 6, December 2012.
4. http://www.mfg.mtu.edu/cyberman/machining/trad/turning/geom.jpg.
5. Hari Singh1and Pradeep Kumar2, Optimizing feed force for turned parts through the Taguchi technique, SadhanaVol. 31, Part 6, December 2006, pp. 671–681.
6. http://img.springerimages.com/Images/Springer/PUB=Springer-Verlag London/JOU=00170/VOL=2004.23/ISU=34/ART=2003_1719/MediaObjects/WATER_s00170-003-1719-6flb1.jpg.
7. http://www2.mitutoyo.de/fileadmin/user_upload/pdf/prospekte/0ENGLISH/formmessgeraete_en/Surftest_SJ201_SJ301_PRE.pdf.
8. Rama Rao. S, Padmanabhan. G / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com Vol. 2, Issue 3, May-Jun 2012, pp. 192-197 192 | P a g e
9. Application of Taguchi methods and ANOVA in optimization of process parameters for metal removal rate in electrochemical machining of Al/5%SiC composites