International Journal of Engineering Research ISSN:2319-6890)(online),2347-5013(print)
Volume No.3 Issue No: Special 1, pp: 92-96 22nd March 2014

Optimization of Surface Roughness and MRR in Turning Operation Using Extended Taguchi Method

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Abstract— **This study investigated the multi-optimization of the turning process on AISI1045 steel material with CNMG cutting tool for an optimal parametric combination to yield the minimum surfaces roughness with the maximum MRR using a combination of a Grey relational analysis (GRA) and the Taguchi method. In view of the fact, that traditional Taguchi method can't solve a multi-objective optimization problem: To overcome this limitations Grey relation theory has been coupled with Taguchi method. Nine experimental runs based on an Orthogonal array of the Taguchi method were performed to drive objective functions to be optimized within the experimental domain the signification of the factors on the overall quality characteristics of the cutting process was also evaluated quantitatively using the Analysis of Variance ANOVA method. Optimal results verified through additional experiments.**

.Keywords— Turning parameters, Grey relational theory, Taguchi method, ANOVA, Material removal rate.

I. Introduction

Today's manufacturing industries are very much concerned about the quality of their products. They are focused on producing high quality products in time at minimum cost. Surface finish is one of the crucial performance parameters that have to be controlled within suitable limits for a particular process. Therefore, prediction or monitoring of the surface roughness of machined components has been an important area of research. Cutting parameters such as speed, feed and depth of cut strongly influence the surface roughness of the machined component. The estimation of the surface roughness and MRR by dynamic simulation of the system is very difficult because determination of the machine tool parameters is not easy and parameters including damping and stiffness change in the course of time.

Therefore, this study applied a Taguchi L_9 orthogonal array to plan the experiments on the turning process. The three controlling factors, including the cutting speed (*V*), the depth of cut (*d*) and feed rate (*f*), were selected. The Grey relational analysis is then applied to examine how the cutting factors influence the cutting force (*F*), the surface roughness (*Ra*) and the material removal rate (MRR). An optimal parameter combination was then obtained. Through analyzing the Grey relational grade matrix, the most influential factors for individual quality targets of the turning process can be identified. Additionally, an analysis of variance (ANOVA) was also utilized to examine the most significant factors for the *F*, *Ra* and MRR in the turning process.

II. Introduction to Grey-Based Taguchi Method

In a Grey relational analysis, experimental data, i.e., measured features of the quality characteristics, are first normalized, ranging from zero to one. This process is known as Grey relational generation. Next, based on normalized experimental data, the Grey relational coefficient is calculated to represent the correlation between the desired and the actual experimental data. Then overall Grey relational grade is determined by averaging the Grey relational coefficient corresponding to selected responses. The overall performance characteristic of the multiple response process depends on the calculated Grey relational grade. This approach converts a multiple-response process-optimization problem into a single-response optimization situation with the objective function of the overall Grey relational grade.

The optimal parametric combination is then evaluated, which would result in the highest Grey relational grade.

III. Experimental Procedure And Test Results

Experimental setup

The cutting experiments were carried out on an experimental lathe setup wsing CNMG carbide inserts for the machining of the AISI 1045 (of diameter 32mm and 150mm length) required for conducting the experiment have been prepared first. Three numbers of samples of same material and same dimension have been made. After that, the diameter of each samples have been measured accurately with the help of a high a high digital vernier caliper. Then, using different levels of the process parameters three specimens at 9 different levels have been turned in lathe accordingly; machining time for each sample has been

calculated accordingly. After machining, the diameter of each machined parts have been again measured precisely with the help of the digital vernier caliper. Then surface roughness and surface profile have been measured precisely with the help of a portable stylus-type profilometer, Talysurf (Taylor hobson, surtronic 3+, UK).

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ISSN:2319-6890)(online),2347-5013(print)
22nd March 2014

Four parameters design was performed as shown in table. Note that is not an obstacle for the methodology followed. The standard ($L_9(3^4)$) orthogonal matrix experiment was used table

Table 3.1 machining parameters for experimentation

Factors	Level 1	Level 2	Level 3
Cutting speed (rpm)	250	350	400
Feed (mm/rev)	0.034	0.051	0.069
Depth of cut (mm)	0.2	0.6	1
Tool nose radius(mm)	0.4	0.8	0.4

Table 3.2 L9 Orthogonal Array (OA)

Exp.No	Run order	A	B	C	D	Speed (rpm)	Feed (mm/rev)	Depth of cut(mm)	Tool nose radius
1	3	1	1	1	1	250	0.034	0.2	0.4
2	2	1	2	2	2	350	0.051	0.6	0.4
3	1	1	3	3	3	400	0.069	1	0.4
4	4	2	1	2	3	350	0.034	1	0.8
5	6	2	2	3	1	400	0.051	0.2	0.8
6	5	2	3	1	2	250	0.069	0.6	0.8
7	8	3	1	3	2	400	0.034	0.6	0.4
8	7	3	2	1	3	250	0.051	1	0.4
9	9	3	3	2	1	350	0.069	0.2	0.4

Experimental Result:

Table 3.3 Experimental data

Surface Roughness Ra in µm	Surface Roughness Rq in µm	Surface Roughness Rz in µm	MRR in (mm^3/min)	Time Taken in sec
3.613	4.5	22.8	129.41	268
5.43	6.78	33.79	446.336	124
6.98	8.74	43.86	1422.42	8505
4.94	6.01	27.49	635.63	187
4.14	5.16	26.13	296.858	112
4.69	5.86	29.3	550.098	132.5
4.3	5.49	27.8	466.392	170
5.68	7.11	35.5	735.176	180.5
4.69	5.85	29.13	339.988	93.5

Table 3.4 Normalized data

SI NO	Ra in µm	Rq in µm	Rz in µm	MRR (mm3/min)	Time Taken sec
Ideal	1.000	1.000	1.000	1.000	1.000
1	1.000	1.000	1.000	1.000	0.319
2	0.665	0.663	0.674	0.289	0.689
3	0.517	0.515	0.519	0.090	1.000
4	0.730	0.748	0.829	0.203	0.457
5	0.872	0.872	0.872	0.435	0.763
6	0.769	0.768	0.777	0.235	0.645
7	0.839	0.819	0.820	0.277	0.502
8	0.635	0.632	0.642	0.176	0.473
9	0.769	0.768	0.782	0.380	0.214

An average of three measurements of the surface roughness (R_a, R_q, R_z) was taken to use in the multi-criteria optimization. Also the MRR was calculated using eq .

$$MRR = \left[\frac{\pi D^2}{4} - \frac{\pi d^2}{4}\right] * F * rpm \quad --(13)$$

Where

D= Diameter of work piece before cutting.

d= Diameter of work piece after cutting

Table 3.5 Check for correlation between the responses

SI NO	Correlation between responses	Pearson correlation coefficient	Comment on correlation on component
1	Ra and Rq	0.998	Both are correlated
2	Ra and Rz	0.963	Both are correlated
3	Ra and MRR	0.836	Both are correlated
4	Ra and time	-0.538	Both are correlated
5	Rq and Rz	0.974	Both are correlated
6	Rq and MRR	0.84	Both are correlated
7	Rq and time taken	-0.545	Both are correlated
8	Rz and MRR	0.77	Both are correlated
9	Rz and time	-0.575	Both are correlated
10	MRR and time	-0.459	Both are correlated

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Table 3.6: Eigenvalues, eigenvectors, accountability proportion (AP) and Cumulative accountability proportion (CAP) computed for the responses

	ψ1	ψ2	ψ3	ψ4	ψ5
Eigen value	4.0637	0.6389	0.264	0.0325	0.0008
eigenvector	0.486	0.171	0.21	0.575	-0.600
	0.488	0.164	0.212	0.278	0.783
	0.479	0.081	0.419	-0.750	-0.162
	0.436	0.241	-0.851	-0.164	-0.034
	-0.327	0.938	0.107	-0.047	-0.005
AP	0.813	0.128	0.053	0.007	0.000
CAP	0.813	0.941	0.993	1.000	1.000

Table 3.7: Principal components in all L9 OA experimental observations

SI NO	ψ1	ψ2	ψ3
Ideal Sequence	1.562	1.595	0.097
1	1.7847	0.9562	0.0241
2	0.8424	0.989	0.365
3	0.4644	1.175	0.4653
4	1.0571	0.7929	0.5355
5	1.208	1.1839	0.4444
6	1.0131	0.9825	0.5193
7	1.1574	0.883	0.5114
8	0.8472	0.7511	0.4376
9	0.9909	1.2705	0.4264

Table 3.8 Quality loss estimates $\Delta_{0i}(k)$ (for principal components)

Si No	ψ1	ψ2	ψ3
1	0.2227	0.6388	0.0729
2	0.7196	0.606	0.268
3	1.0976	0.42	0.3683
4	0.5049	0.8021	0.4385
5	0.354	0.4111	0.3474
6	0.5489	0.6125	0.4223
7	0.4046	0.712	0.4144
8	0.7148	0.8439	0.3406
9	0.5711	0.3245	0.3294

Table 3.9 Individual grey relational coefficients for the principal components

S.	ψ_1	ψ_2	ψ_3
1	1	0.7036	1
2	0.6082	0.7261	0.5995
3	0.4685	0.8865	0.4971
4	0.7321	0.6098	0.4441
5	0.8545	0.896	0.5155
6	0.7028	0.7215	0.4553
7	0.8092	0.6582	0.461
8	0.6105	0.5896	0.5217
9	0.6889	1	0.5324

Table 3.10 Calculation of overall grey relational grade

SI NO	$\Gamma_{0,\square}$	S/N Ratio
1	2.7036	8.6388
2	1.9338	5.7282
3	1.8521	5.3532
4	1.786	5.0376
5	2.266	7.1052
6	1.8796	5.4813
7	1.9284	5.7039
8	1.7218	4.7196
9	2.2218	6.9341

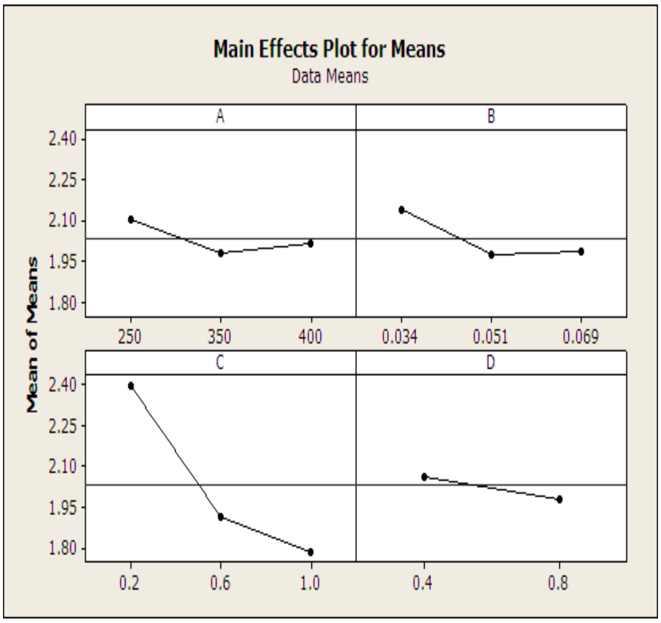

Fig 3.1: S/N ratio plot for grey utility grade

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III. CONFORMATION TEST:

After evaluating the optimal parameter settings the next step is to predict and verify the enhancement of the quality characteristics using the optimal parametric conditions by the conformity test. Again experiment was conducted for optimal parameter setting and S/N ratio were found and the Table 7.9 reflects the satisfactory results of conformity test.

The estimated grey relation grade $\hat{\gamma}$ using the optimal level of the design parameters can be calculated as: $\hat{\gamma} = \gamma_m + \sum_{i=1}^{o}(\hat{\gamma}_j - \gamma_m)$

Where γ_m is the total mean Grey relation grade , $\hat{\gamma}_i$ is the mean Grey relational grade at the optimal level, and o is the number of the main design parameters that affect the quality characteristics. Good agreement between actual and the predicted results has been observed.

Table 4.1 conformity test

	Optimal process condition	
	Prediction	Experiment
Factor level	$A_1B_1C_1D_1$	$A_1B_1C_1D_1$
R_a in µm	----	3.998
R_q in µm	----	5.23
R_z in µm	---	24.78
MRRR in mm^3/min	---	205.3
Time taken	----	240
S/N ratio of overall	8.245	9.738
Mean of overall utility	2.60	4.88

The results show that using the optimal parameter setting ($A_1B_1C_1D_1$) cause a lower surface roughness and time taken and higher MRR were obtained.

IV. ANALYSIS OF VARIANCE

The ANOVA response was calculated (MINITAB 15 software) and it shown. Usually, the change of the turning parameter has a significant effect on the performance characteristics when the *F* value is large. The ANOVA for the overall grey relation grade is shown in Table

Table 6.1 ANOVA table for overall grey relation grade

Source	DOF	Seq SS	Adj MS	F-test	P-Value	% of contribution
A	2	0.2193	0.196	0.12	0.9	2.335289169
B	2	2.6645	0.3322	0.36	0.764	28.37381665
C	2	5.4178	5.289	5.6	0.286	57.6932497
D	1	0.1861	0.1861	0.2	0.732	1.9817479
Error	1	0.903	0.9303			9.615896579
Total	8	9.3907				100

Table 8.2 ANOVA Table for surface roughness R_a

Source	DOF	Seq SS	Adj MS	F-test	P-Value	% of contribution
A	2	0.3727	6.1864	0.61	0.671	4.72682
B	2	2.1419	1.0709	3.51	0.353	27.1649
C	2	4.528	2.2564	7.4	0.252	57.4269
D	1	0.5523	0.5523	1.81	0.407	7.00462
Error	1	0.3051	0.3051			
Total	8	7.8848				100%

Graph representations

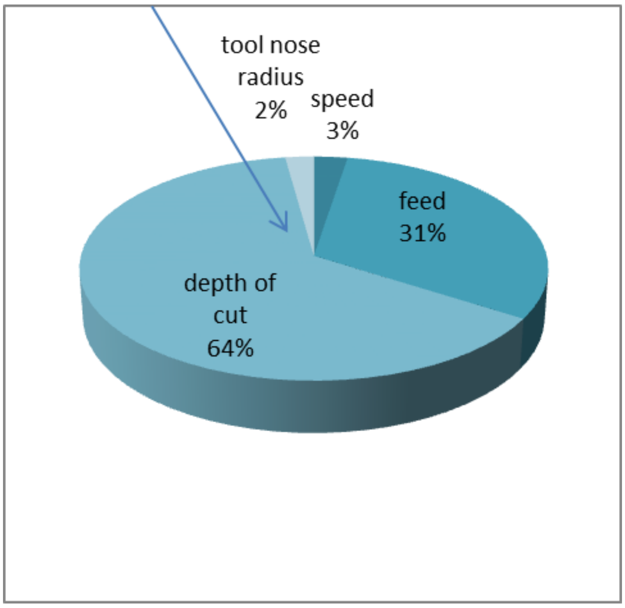

Fig 6.1 ANOVA response for overall Grey relation grade

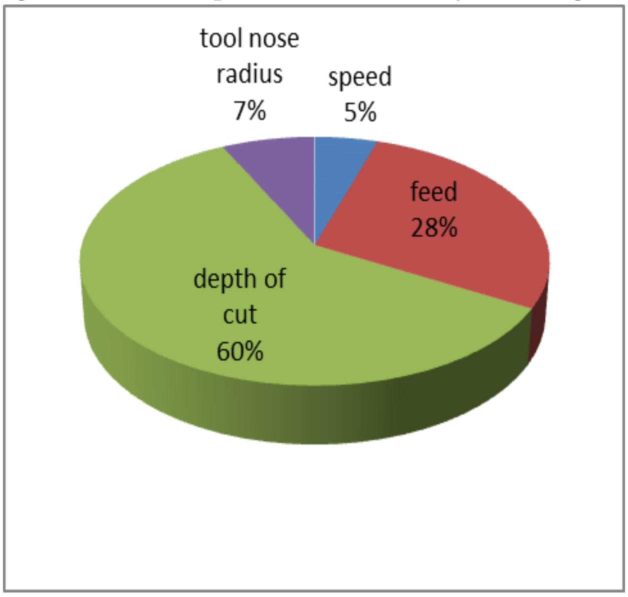

Fig 6.2 ANOVA responses for surface roughness R

V. CONCLUSIONS

In this study, the Grey-based Taguchi method was applied for the multiple performance characteristics of turning operations. A grey relational analysis of the material-removal rate, the cutting force and the surface roughness obtained from the Taguchi method reduced from the multiple performance characteristics to a single performance characteristic which is called the grey relational grade. Therefore, the optimization of the complicated multiple performance characteristics of the processes can be greatly simplified using the Grey-based Taguchi method. It is also shown that the performance characteristics of the turning operations, such as the material removal rate, the cutting time and the surface roughness are greatly enhanced by using this method. The aforesaid extended Taguchi method can be applied for continuous quality improvement of the product/process and off-line quality control.

According to this analysis, the most effective parameters with respect to the material-removal rate, the cutting force and the surface roughness are the feed rate, the depth of cut and the cutting speed and tool nose radius. The percentage contribution indicates the relative power of a factor to reduce the variation. For a factor with a high percentage contribution, there is a great influence on the performance. The percent contributions of the cutting parameters on the material-removal rate, the cutting force and the surface roughness are shown in Table 9.2. The depth of cut has high influence (57.69%) on Grey relation grade and feed has (28.37%) of influence on Grey relation grade. the cutting speed were found to be the second- and third-ranking factors respectively.

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