Multi-Objective Optimization of Machining Parameters for dry CNC Turning of 16MnCr5 Steel using Grey Relation Analysis

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Abstract- The aim of this research work is to investigate the effects of Machining parameters such as cutting speed, feed rate and depth of cut on surface roughness, and MRR in CNC dry turning of 16MnCr5 material with the help of Grey Relation Analysis. Experimental work has been carried out based on L_9 orthogonal array design with three machining parameters. Optimal cutting conditions were determined using the Grey Relation Grade which was calculated for each experiment. Minimum surface roughness and maximum material removal rate were produced corresponding to optimum values of machining parameters obtained from GRA. Result of this study shows Depth of cut has highest dominant factor for surface roughness followed by speed and feed rate.

Keywords: Surface Roughness, MRR, Turning, GRA, GRG

1. INTRODUCTION

In production of a machine part the most important consideration is quality of product, machining time and cost associated to production. For turning operation the most important characteristic of final product on which quality of product depends is surface roughness because stress concentration and friction offered by this product is directly depends on surface roughness. An industry always wants to produce minimum surface roughness. Material removal rate is a other important parameter which decide machining time and total cost of production. For a good turning operation material removal rate should be high. R. Sreenivashu et al. [1] applied grey relation analysis for surface roughness in drilling operation of Al6061 alloy. They finally concluded point angle is highly dominating factor followed by drill diameter, feed rate, fluid mixture and cutting speed. A. Baruah et al. [2] Investigated to enhanced formability and reduce surface roughness in incremental sheet forming in three direction. They combine Taguchi and grey relation analysis and their result shows lubricant has dominating factor in all the three directions. L. Varghese et al. [3] Optimized the effect of machining parameters in dry turning of 11SMn30 by using grey relation analysis and finally the concluded feed has most dominating factor followed by speed and depth of cut to produce minim um surface roughness and maximum material removal rate. A. Mohanty et al. [4] performed a research work for MRR, surface roughness and microstructure in Electrochemical machining with the help of Taguchi and analysis of variance by considering electrolyte concentration, feed and voltage as factors for Taguchi design. Finally they concluded that voltage has highest effect on the MRR and surface roughness. H. Aouici et al. [5] investigated a experimental work, in which they machined AISI H11 steel by using CBN tool. They measure the values of surface roughness and tool wear. They analysed the effects of cutting time, feed rate and cutting speed with the help of RSM and ANOVA. It was found that cutting time is most dominating effect for tool wear and feed rate is highest significant factor for surface roughness. M. Tomov et al. [6] suggested mathematical models for surface roughness and models were verified with the help of different CNC lathe and inserts. R. Suresh et al. [7] performed research work on AISI 4340 with the help of Roughness Surface method. They finalised that to minimise surface roughness and cutting forces, low feed rate, high cutting speed, low depth of cut and short machining time are required and for minimum tool wear low cutting speed and low feed rate required. Y. Kevin Chou, Hui Song [8] proposed a model and they analyzed Increasing cutting speed and feed rate adversely affect maximum temperature of machined surface in new cutting tool but increasing depth of cut favourably affect the maximum temperature of machined surface. S. Z. Chavoshi et al. [9] investigated on AISI 4140 steel on lathe machine by using CBN cutting tool. They concluded that hardness has highest effect on surface roughness. [10] R. Vinayagamoorthy et al. performed a research work on multi-objective parametric optimization for precision turning by using grey relation analysis. They conclude feed has highest effect on surface roughness, cutting force, tool wear and tool temperature.

Here we are going to obtain best combination of machining parameters namely cutting speed, feed, and depth of cut for dry CNC turning of 16MnCr5 to produce minimum surface roughness and maximum possible material removal rate with the help of Grey Relation Analysis.

2. METHODOLOGY

Turning operation is performed on 16MnCr5 case hardening steel which is useful for core tensile loading application. This material is used for manufacturing of crank, cam shaft, gear, and axle. First of all factors and their levels are selected for experimental work and then select L_9 orthogonal array. 9 experiments are performed on workpiece of 200 mm length and 32 mm diameter. Turning length for is experiment remains 17 mm. CNC Midas 8i and cutting insert TNMG160408 is used for turning operation. After turning operation we measure the Ra and Rz value for surface roughness by using a surface tester SJ-201P.

MRR was calculated by using Formula-

$$MRR = \frac{(A_i - A_f)*f*N}{60} \text{ mm}^3/\text{s}$$

Table -1: Factors and their levels

Factors	Notation	Level 1	Level 2	Level 3
Speed (rpm)	N	400	600	800
Feed (mm/rev)	F	0.06	0.12	0.18
Depth of cut (mm)	D	0.5	1.0	1.5

Table -2: Orthogonal Array

Sl. No.	Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)
1	400	0.06	0.5
2	400	0.12	1.0
3	400	0.18	1.5
4	600	0.06	1.0
5	600	0.12	1.5
6	600	0.18	0.5
7	800	0.06	1.5
8	800	0.12	0.5
9	800	0.18	1.0

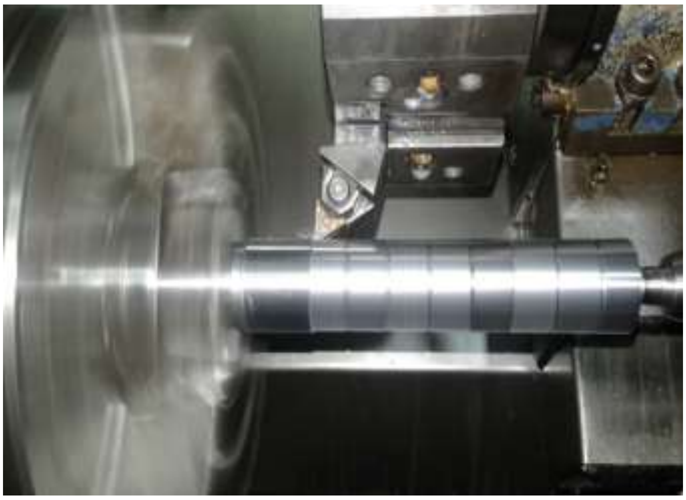

Fig -1: Turning operation

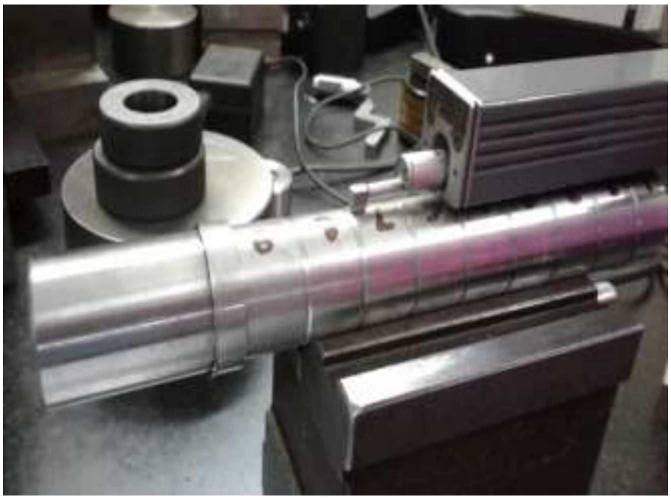

Fig -2: Surface roughness measurement

In this optimization problem surface roughness need to be minimum and MRR is need to be maximum. This is a problem of multi-objective and to solve this we select grey relation analysis method.

3. GREY RELATION ANALYSIS

Grey relation analysis is a model which is used to optimize a multi-objective problem. This system works between black and white levels of information. In grey relational analysis, black indicates having no information and white indicates having all information. Main decision making variable of GRA is grey relation grade (GRG). Data pre-processing, deviation sequence calculation and calculation of grey relation coefficient are the three steps used to calculate GRG.

3.1 Data Pre-Processing: In this we normalized experimental result between the range of 0 and 1, to transfer original sequence to a comparable sequence. Normalization is depends on our requirements.

i) Larger-the-better: This is used for MRR.

$$x_i^* = \frac{x_i(k) - x_{i\,min}(k)}{x_{i\,max}(k) - x_{i\,min}(k)}$$

ii) Lower-the-better: This is used for Surface roughness.

$$x_i^* = \frac{x_{i\,max}(k) - x_i(k)}{x_{i\,max}(k) - x_{i\,min}(k)}$$

Where,

$x_i(k)$ = Output data of ith experiment using kth response

$x_{i\,min}(k)$ = Smallest value of output data of ith experiment using kth response

$x_{i\,max}(k)$ = Largest value of output data of ith experiment using kth response

$x_i^*(k)$ = Normalized data of ith experiment using kth response

3.2 Deviation Sequence: Let $\Delta_{0i}(k)$ is the deviation sequence of reference sequence $x_0^*(k)$ and the comparability sequence$x_i^*(k)$ of ith experiment.

$$\Delta_{0i}(k) = |x_0^*(k) - x_i^*(k)|$$

3.3 Grey Relation Coefficient: It represents a relationship between the ideal and actual normalized experimental results. The grey relational coefficient is defined as follows:

$$\xi_i(k) = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{0i}(k) + \zeta\Delta_{max}}$$

Where,

$\xi_i(k)$ = GRC for kth response and ith experiment

Δ_{min} = minimum value of deviation sequence for kth response

Δ_{max} = maximum value of deviation sequence for kth response

ζ = distinguishing factor, $\zeta \epsilon(0, 1)$ and in general ζ = 0.5 used

3.4 Grey Relation Grade

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{k=n} w * \zeta_i(k)$$

Where,

γ_i = GRG for i[th] experiment

n = total number of response under consideration

w = weight factor for each response

4. RESULTS AND DISCUSSION

Higher value of GRG gives the optimum value of process parameters.

Table -3: Experimental Results

Sl. No.	Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)	Ra (µm)	Rq (µm)	MRR (mm^3/min)
1	400	0.06	0.5	4.54	5.84	1187.5
2	400	0.12	1.0	4.96	5.98	4674.7
3	400	0.18	1.5	1.76	2.31	10348.4
4	600	0.06	1.0	3.99	5.07	3506.0
5	600	0.12	1.5	1.07	1.34	10348.4
6	600	0.18	0.5	4.58	5.22	5343.8
7	800	0.06	1.5	2.05	2.50	6898.9
8	800	0.12	0.5	1.84	2.34	4750.1
9	800	0.18	1.0	1.44	1.76	14024.1

Table -4: Calculation of GRG

Sl. No.	Data Pre-Processing $x_i^*(k)$			Deviation Sequence $\Delta_{0i}(k)$			Grey Relation Coefficient $\xi_i(k)$			GRG	Rank
	Ra (µm)	Rq (µm)	MRR (mm^3/min)	Ra	Rq	MRR	Ra	Rq	MRR		
1	0.108	0.030	0	0.892	0.97	1	0.359	0.340	0.333	0.344	9
2	0	0	0.271	1	1	0.729	0.333	0.333	0.407	0.358	8
3	0.822	0.791	0.714	0.178	0.209	0.286	0.737	0.705	0.636	0.693	3
4	0.249	0.196	0.181	0.751	0.804	0.819	0.340	0.383	0.379	0.367	7
5	1	1	0.714	0	0	0.286	1	1	0.636	0.879	2
6	0.098	0.164	0.324	0.902	0.836	0.676	0.357	0.374	0.425	0.385	6
7	0.748	0.750	0.445	0.252	0.25	0.555	0.665	0.666	0.474	0.602	5
8	0.802	0.784	0.278	0.198	0.216	0.722	0.716	0.698	0.409	0.608	4
9	0.905	0.909	1	0.095	0.091	0	0.840	0.846	1	0.895	1

Consider Reference sequence $x_0^*(k)$ for each response equals to 1.

From Table -4 it is clear that maximum GRG value is 0.895 which occur for experiment number 9 means among the 9 experiments experiment number 9 produce maximum material removal rate and minimum surface roughness.

To obtain best possible combination of factors to produce maximum material removal rate and minimum surface roughness we use response table for Grey Relation Grade. To obtain GRG for each level of different factors we take mean of GRG value for a particular level of a factor by using Table -3 and Table -4.

Example: GRG value for Speed at Level 1

$$\frac{0.344 + 0.358 + 0.693}{3} = 0.465$$

GRG value for feed at Level 2

$$\frac{0.358 + 0.879 + 0.608}{3} = 0.615$$

Table -5: Response Table for GRG

Level	Speed	Feed	Depth of cut
1	0.465	0.438	0.446
2	0.544	0.615	0.540
3	**0.702**	**0.658**	**0.725**
Delta	0.237	0.220	0.279
Rank	2	3	1

Table -5 shows the rank of factors according to their effect on response. A factor which has high delta value shows low rank value.

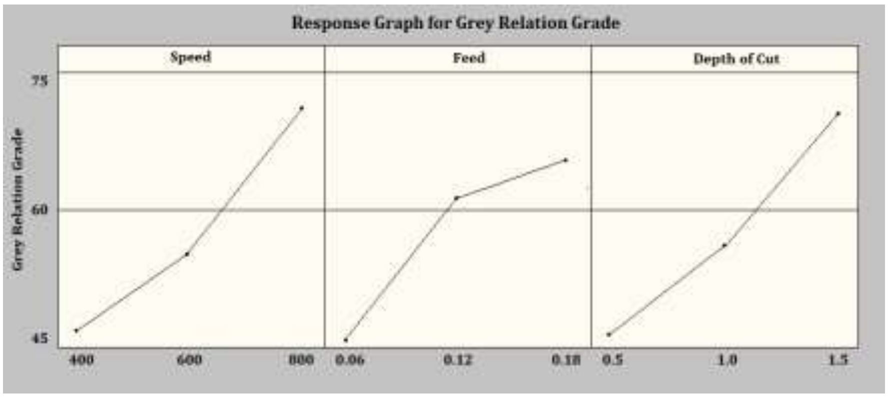

Fig -3: Response Graph for GRG

5. CONCLUSIONS

On the basis of presented research work, we can made following conclusions-

- Depth of cut has highest effect on material removal rate and surface roughness followed by speed and Feed rate has lowest effect on material removal rate and surface roughness.
- Maximum material removal and minimum surface roughness is obtained at speed 800 rpm, feed 0.18 mm/rev and depth of cut 1.5 mm.

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