International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

Multi-Objective Optimization of Milling Process by Using Grey Fuzzy Logic Hybrid Approach

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Abstract: ***Cutting force investigation of the milling machine is one of the major areas for designs/manufacturing. In the present work influence of cutting parameters (speed, feed, and depth of cut) on cutting forces and Material removal rate (MRR) has been analyzed in a Milling machine. During the current study grey fuzzy logic method hybrid optimization technique is utilized to determine the optimal settings of milling process parameters with an aim to improve cutting force and material removal rate (MRR). Taguchi design of experiment techniques a total of 8 tests were carried out, optimum level for MRR and cutting force were chosen from the three levels of cutting parameters considered. Experimental were conducted on tool dynamometer and the influence of cutting parameter was studied using analysis of variance (ANOVA) based on adjusted approach. Grey relational analysis (GRA) combined with fuzzy-logic is used to determine grey fuzzy reasoning grade (GFRG). In the using for GFRG value the optimum level of machining parameters are calculated.***

Keywords: Cutting Force; Material Removal Rate; Grey-Fuzzy logic; Taguchi design of experiment; Milling Machine

1. Introduction

Cutting force is considered as one of the influencing parameters in determining the accuracy and productivity of the part produced and performance of the tool that is used for the production. There is a high demand of components of aluminium alloys of better finishing in the aerospace industries in order to increase their performance by avoiding presence of some stress concentrators in the surface, such as micro cracks, scratches, or striations produced during machining. The unique properties such as the high specific stiffness and strength, high mechanical strength, high damping, good corrosive resistance and low thermal expansion of the fibre-reinforced composite materials have enabled their use in automotive, machine tool industries, aerospace, sporting equipment industries [1].

In the recent years, fuzzy-logic-based multi-criteria decision making approaches have become very popular in optimization of all conventional and nonconventional machining and other manufacturing processes. Increasing the productivity and the quality of the machined parts are the main challenges of manufacturing industries. This objective requires better management of the machining system. This literature includes information on hard materials, soft materials, and soft and abrasive materials used in turning, coating materials for cutting tools, wear observed during turning operations and surface finish of the machined work piece. The machining with titanium-nitride coated carbide tool at 0.18 mm/rev and DOC of 1.5 mm resulted in greater amount of both tangential (Pz) and axial force (Px) than that uncoated carbide tools. There was not variation of forces for both types of tool at lower feed rate of 0.095 mm/rev. Machining of Steel 3 type required lesser force compared to other two grades of cast austenitic stainless steel [2]. Machining at low cutting speed and at high feed rates the chip of low curl radii was obtained with high chip thickness [3]. The chip curl radius and chip thickness increases with increase in the cutting speed. At lower cutting speed the chips obtained is of yellow color, brittle color chips are obtained at higher speed [4-5]. With increase in both cutting speed and the feed rate there occurred a transition of chip to segmented type from continuous type [5-9].

The influence of cutting parameters (speed, feed, and depth of cut) on cutting forces and surface finish has been analyzed, under the different variable with different responses. 27 experiments based Taguchi design was used to study cutting force (Fx, Fy and Fz) and Material removal Rate (MRR) of mild steel work-piece. During the current study grey fuzzy logic method hybrid optimization technique is utilized to determine the optimal settings of milling process parameters with an aim to improve cutting force and material Taguchi design of experiment techniques a total of 8 tests were carried out, optimum level for MRR and cutting force were chosen from the three levels of cutting parameters considered.

1. Experimental Set-Up

In this unit detail methodology of the experiment has been described. The detail aspect of machine tool used, equipment facilities, work piece material, cutting tool, machining parameters and experimental set-up has been discussed. The Milling Machine is shown in Figure1.

Figure 1: Miiling Machine

2. Design of Experiment

The present experimental investigation deals with the analysis of the experiment by the Taguchi methodology. Based on the main effects plots obtained through Taguchi design, a total of 8 tests were carried out, optimum level for MRR and cutting force were chosen from the three levels of cutting parameters considered. Machining parameters and their levels are shown in Table 1. The range of each parameter is set at three different levels, namely low, medium and high. Mathematical models were deduced by software Minitab in order to express the influence degree of the main cutting variables such as cutting speed, feed rate and depth of cut on cutting force components experiments with combination of different cutting parameters were randomly repeated. The 3^3= 27 experiments of settings were done to analyse the response that is the Cutting force and Material removal rate.

Table 1: Machining parameters and their levels

Parameters	Symbol	Levels		Unit
		Low	High	
Feed	F	16	40	mm/min
Speed	S	45	90	RPM
Depth of Cut	d	0.1	0.2	mm

3. Methodology

Table 2 presents' experimental results of cutting force components (Fx, Fy and Fz) and MRR for various combinations of cutting regime parameters (cutting speed, feed rate and depth of cut) according to Taguchi design. The results indicate that the lower cutting forces were registered at the higher cutting speeds.

Table 2: Observation table

RN	C.Pt	B	S	F	d	Fx	Fy	Fz	MRR
1	1	1	45	16	0.1	957	74	1041	5.42
2	1	1	90	40	0.1	545	215	924	7.35
3	1	1	90	16	0.2	178	168	557	6.54
4	1	1	45	40	0.2	1426	89	1149	5.75
5	1	2	90	16	0.1	619	176	511	6.68
6	1	2	45	40	0.1	1170	97	1257	5.94
7	1	2	45	16	0.2	962	49	990	5.37
8	1	2	90	40	0.2	178	197	957	6.95

This can be related to the temperature increase in cutting zone and leads to the drop of the work piece yield strength and chip thickness. The results also show that cutting forces increase with increasing feed rate and depth of cut because chip thickness becomes significant what causes the growth of the volume of deformed metal. That means increasing of cutting speed with lowest feed rate and depth of cut leads to decreasing of cutting force component.

3.1. Grey Relation Analysis

Grey Relational Analysis is an effective method in which analysis being done among the sequence groups requires that all sequences satisfy comparability conditions, for instance, non-dimension, scaling, and polarization attributes. Normally, two different types of comparability equations are used for generating the comparable sequence as follows:

(1) Higher the better: (Higher objective value is better)

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

(2) Lower the better: (Lower objective value is better)

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

Where $x_i^*(k)$ and $x_i(k)$ the normalised data and observed data, respectively, for i^{th} experiment using k^{th} response.

And also the Grey relation coefficient can be calculated by using Equation 3.

$$\zeta_i(k) = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_i(k) + \zeta\Delta_{max}} \quad (3)$$

Where Δ_i (k) is the k^{th} value in Δ_i different data series, Δ_{max} and Δ_{min} are the global maximum and global minimum values in the different data series, respectively. The distinguishing coefficient ζ lies between 0 and 1, which is to expand or compress the range of GRC.

4.2. Fuzzy Logic System

Fuzzy logic is a mathematical theory of inexact reasoning that allows modeling of the reasoning process of human in linguistic terms. The fuzzy logic control allows the existence of uncertainty in handling parameter values. Fuzzy logic system (Mamdani system) comprises of a fuzzifier, membership functions, a fuzzy rule base, an inference engine, and defuzzifier. Next, the inference engine (Mamdani fuzzy inference system) performs fuzzy reasoning on fuzzy rules to generate a fuzzy value. Finally, the defuzzifier converts fuzzy predicted value into a single equivalent Multi Performance Characteristics Index (MPCI).

4.3 Optimization of multiple quality characteristics with Grey-Fuzzy logic

Grey-Fuzzy logic is used to convert multiple responses into a single characteristic index known as Grey-Fuzzy Reasoning Grade (GFRG) for optimisation. Grey-fuzzy logic method is generated and applied. It precedes fuzzy rules approach rather than making a traditional GRG estimation for grey relational analysis. At first, the experimental values of MRR, Fx, Fy and Fz are normalised in the range of 0 to 1 for all the experimental run by using Equation 1 and 2 respectively. Here the weightage of all three responses are considered relatively equal. Then, the Grey Relational Coefficient (GRC) of each response is calculated by using Equation 3.

In fuzzy logic system, the fuzzifier uses the membership functions to fuzzify GRC of each performance characteristic. In this paper four inputs and one output fuzzy logic system are shown in Figure 2. The inference engine (Mamdani fuzzy inference system) performs fuzzy reasoning with fuzzy rules to generate a fuzzy value. These fuzzy rules are presented in the form of if-then control rule. For each rule, the three inputs are assigned in the fuzzy subsets of Small, Medium and Large and the corresponding membership functions, μx_1, μx_2 and μx_3, respectively. The output is assigned to any of the five fuzzy subset (Very small, Small, Medium, large, Very large) membership functions µY. The number of rules yielded from the present study is eight and the membership function of the input and output are indicated in Figure 3. Fuzzy rules are directly derived based on the fact that larger-the-better characteristic. By tracking maximum-minimum compositional operation, the fuzzy reasoning of these rules yields a fuzzy output. Finally, the defuzzifier converts fuzzy predicted value into a GFRG. This GFRG values are shown in Table 3.

Table 3: Computing GRC and grey fuzzy reasoning grade (GFRG)

SN.	Nfx	Nfy	Nfz	N MRR	GRC fx	GRC fy	GRC fz	GRC MRR	GFRG
1	0.624	0.151	0.710	0.025	0.571	0.371	0.769	0.339	0.5244
2	0.294	1.000	0.554	1.000	0.415	1.000	0.333	1.000	0.622
3	0.000	0.717	0.062	0.591	0.333	0.638	0.411	0.550	0.482
4	1.000	0.241	0.855	0.192	1.000	0.397	0.675	0.382	0.622
5	0.353	0.765	0.000	0.662	0.436	0.680	0.395	0.596	0.482
6	0.795	0.289	1.000	0.288	0.709	0.413	0.634	0.413	0.482
7	0.628	0.000	0.642	0.000	0.574	0.333	1.000	0.333	0.622
8	0.000	0.892	0.598	0.798	0.333	0.822	0.359	0.712	0.5743

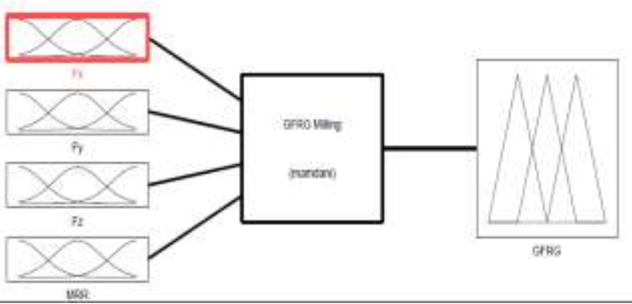

Figure 1: Three input and one output fuzzy logic control

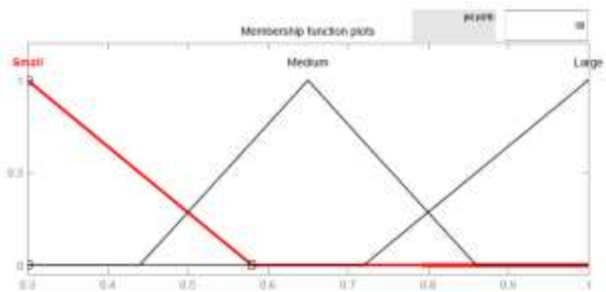

Figure 2: Membership function for input (Fx, Fy, Fz and MRR)

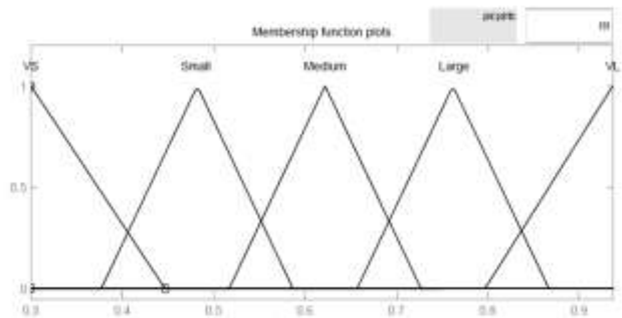

Figure 3: Membership function for output (GFRG)

The result of Analysis of Variance (ANOVA) of GFRG that is shown in Table 3, it represent speed, feed and depth of cut not significantly effect for Multi-performance characteristics, all insignificant factor is donated the star in column P. In this ANOVA is measurement of sum of square deviation, and the total mean of square of GFRG. Also describe that probability of each process parameter and the residual error.

Figure 4: Fuzzy rules

The graphical representation of main effect plot for GFRG is shown in Figure 5 and this graph presented that the optimal Milling parameter (S= 45 rpm F=40 mm/min and d= 0.2mm).

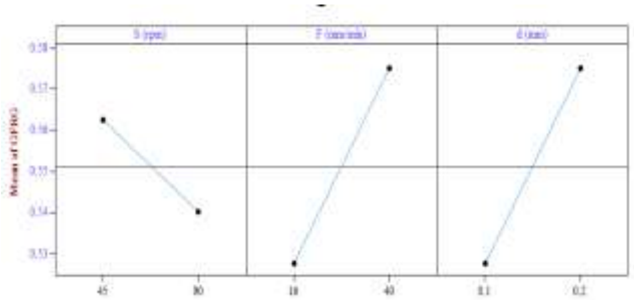

Figure 5: Main effect plot for GFRG

4. Conclusions

Taguchi Design method is found to be a successful technique to perform trend analysis of Cutting Force and MRR in metal cutting in milling with respect to various combinations of design variables (cutting speed, feed rate, and depth of cut). Response model for Fz is more precise than first Response model for Fx and second Response model for Fy in predicting the power consumption.

Grey-fuzzy relation analysis was adopted to optimise the Milling process with multiple performance characteristics, Fx, Fy, Fz and MRR. The optimal milling parameter settings were found to be S= 45 rpm F=40 mm/min and d= 0.2mm for maximum MRR and forces, simultaneously.

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