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A new approach to minimization of the surface roughness and cutting force via fuzzy TOPSIS, multi-objective grey design and RSA

Arif Gok

Department of Mechanical Engineering, Faculty of Technology, Amasya University, Turkey

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ABSTRACT

Surface roughness affects the strength of parts during contact and working performance. Therefore, generating optimum surface roughness values are crucial to obtain high productivity in the manufacturing of turning geometries. This study presents a new method of choosing optimal cutting parameters. The first aim of this study is to investigate turning of ductile iron using fuzzy TOPSIS and grey relational analysis of optimum cutting parameter values. The second aim of the study is to determine using response surface analysis of mathematical model depending on cutting parameters of average surface roughness, maximum roughness, and main cutting force and feed force in turning. The adequacy of the developed mathematical model is proved by ANOVA. The results indicate that the depth of cut was the dominant property on the surface roughness and cutting forces.

1. Introduction

The turning process is the most widespread method among the metal cutting methods. It is also the most common machining operation performed in automotive, aerospace, aircraft, medical and other application industries. In this study, surface roughness is desired to obtaining the most excellent while obtaining the smallest cutting forces. Requirements of higher surface roughness and manufacturing efficiency have led to a great deal of research aimed at controlling the cutting parameters. Cutting parameters are reflected on surface roughness and surface texture of the product. Surface roughness and cutting forces, which are used to determine and to evaluate the quality of a product, are two of the major quality attributes of a turning product [1]. Minimal surface roughness and cutting forces are important due to increased consumer demands of quality, low-cost products, minimum friction, maximum lubrication, and minimum wear. It is a characteristic that could influence the performance of mechanical parts and production costs [2]. Process modeling and optimization are two important issues in manufacturing products. The manufacturing processes are characterized by a multiplicity of dynamically interacting process variables [3]. Because surface roughness and cutting forces are affected by variation parameters, modeling them are difficult. In recent years, various statistical, experimental and simulation studies based on design and analysis of experiment methods for the modeling of surface roughness and cutting forces occurred in turning of various materials were conducted. Some of the literature studies are given below:

Asilturk and Neseli [2] have worked on the multi response optimization of CNC turning parameters via Taguchi method-based response surface analysis. Lalwani et al. [4] studied the effect of cutting parameters in turning on cutting forces and surface roughness. They carried out a number of experiments based on RSM. As a result, linear and quadratic models have been formed to explain the relation between the parameters. In parallel to this study,

E-mail address: arif.gok@amasya.edu.tr

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Abouelatta and Madl [5] worked on the surface roughness prediction based on cutting parameters and tool vibrations in turning operations. Neseli et al. [6] worked on optimization of tool geometry parameters for turning operations based on the response surface methodology. Yang and Tarng [7] worked on optimization of cutting parameters for turning operations so that both the optimal cutting parameters were demonstrated and the basic cutting parameters affecting cutting performance in turning were defined. Kurt et al. [8] worked on the optimization of cutting parameters for the finish surface and the accuracy of hole diameter during dry drilling. In this way, optimum cutting conditions with the process optimization were obtained.

Recently, the optimizing of cutting parameters is attracting the interest of researchers to improve quality and minimize cost. However, most methods for choosing optimal parameters do not evaluate each parameter. It is aimed to keep the values of surface roughness and cutting forces at the minimum and to control unwanted machining results, such as poor surface roughness. At the same time, finding surface roughness and cutting forces values are important for keeping production within the appropriate tolerances and decreasing production costs. First, the optimum cutting parameters that result in surface roughness and cutting force at lower values in turning are proposed via Fuzzy TOPSIS and Grey relational analysis. Next a surface roughness and cutting force prediction model depending on the cutting parameters are generated using Response Surface Analysis.

2. Design of experiments

2.1. Cutting parameters

Process parameter optimization has been widely used in turning operations. The literature investigation and accordance with ISO 3685 determined the turning parameters and their levels for the experiment [6]. Three different variable parameters were used for operations. These were; cutting velocity (V_c), feed rate (V_f) and depth of cut (a_p). Cutting velocity, feed rate and depth of cut values were borrowed from the reference catalogues of tool manufacturer (Sandvik Company) (Table 1). An orthogonal array of $L_{16}(3^4)$ for experimental design was chosen and four different levels to each cutting parameter were appointed (Table 2).

2.2. Response surface methodology

Response Surface Analysis (RSA) focuses a well-known up to date approach to the optimization of the input parameters models based on physical experiments, simulation experiments and experimental observations. These approximated models need to be assessed statistically for their adequacy, and then they can be utilized for an optimization of the initial model [2]. The response surface analysis problems have a functional relation between responses and independent variables, and this relation can be explained using the second-order polynomial model in below [9].

$$\eta = \beta_0 + \sum_{i=1}^{k}\beta_i X_i + \sum_{i=1}^{k}\beta_{ii} X_i^2 + \sum_i \sum_j \beta_{ii} X_i X_j + \varepsilon \tag{1}$$

where η is the estimated response, β_0 is constant, β_i, β_{ii} and β_{ij} represent the coefficients of linear, quadratic, and cross-product terms, respectively. X reveals the coded variables. The common approach in the RSM is to use regression methods based on least square methods.

Table 1
Assignment of the levels to factors.

Factors	Level 1	Level 2	Level 3	Level 4
Cutting velocity, V_c (m/min) – A	50	100	150	200
Feed rate, V_f (mm/rev) – B	0.05	0.075	0.1	0.125
Depth of cut, a_p (mm) – C	0.5	1	1.5	2

Table 2
The orthogonal array $L_{16}(3^4)$ based on the Taguchi method.

Exp. no.	Control factor levels		
1	50	0.050	0.5
2	50	0.075	1.0
3	50	0.100	1.5
4	50	0.125	2.0
5	100	0.050	1.0
6	100	0.075	0.5
7	100	0.100	2.0
8	100	0.125	1.5
9	150	0.050	1.5
10	150	0.075	2.0
11	150	0.100	0.5
12	150	0.125	1.0
13	200	0.050	2.0
14	200	0.075	1.5
15	200	0.100	1.0
16	200	0.125	0.5

2.3. Grey relational analysis (GRA)

While the Taguchi method is designed to optimize single response characteristic, the Grey relational analysis optimizes multiple outcomes. For this reason, the Grey Relational Analysis method is complex [10,11]. In GRA, the optimization process is carried out in the following three phases.

In the first step, the measured values of average surface roughness (R_a), maximum roughness (R_t), main cutting force (F_c) and feed force (F_f) ranging from zero to one are normalized. This process is known as Grey relational normalization [12]. Typically, "lowest-is-the-best" quality characteristic for the surface roughness has been selected and is expressed as follows [11]:

$$x_i(k) = \frac{\max y_i(k - y_i(k))}{\max y_i(k - \min y_i(k))} \tag{2}$$

Here, $x_i(k)$ refers to the value at the i series and k row after normalization, min $y_i(k)$ refers to the minimum value at the i series, max $y_i(k)$ refers to the maximum value at the i series and $y_i(k)$ refers to the original value at the i series and k row.