

Optimization of Cutting Parameters in Turning Process

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ABSTRACT

Predicting the main cutting force during turning is of great importance as it helps in setting the appropriate cutting parameters before machining starts. Again, optimization of cutting parameters is one of the most important elements in any process planning of metal parts as economy of machining operation plays a key role in gaining competitive advantage. This paper presents an experimental study of main cutting force in turning of AISI 1040 steel and developing a model of the main cutting force during turning using Response surface Methodology (RSM) as well as optimization of machining parameters using Genetic Algorithm (GA). The second order empirical model of the main cutting force in terms of machining parameters have been developed based on experimental results. The experimentation has been carried out considering three machining parameters: cutting speed, feed rate and depth of cut as independent variables and the main cutting force as the response variable. The formulated model has been validated against new set of experimental values using Mean Absolute Percent Error (MAPE) method. The Genetic Algorithm approach is also used to optimize the cutting parameters to keep the main cutting force to a minimum.

KEYWORDS: Response Surface Methodology, Genetic Algorithm, Mean Absolute Percent Error, Main Cutting Force

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INTRODUCTION

The most emerging needs of the modern metal cutting operation are to increase the material removal rate with better surface finish and high machining accuracy. These objectives can be achieved by reducing cutting temperature in the cutting zone. In metal cutting process, high cutting temperature and its detrimental effects are generally reduced by proper selection of process parameters. The selection of optimal cutting parameters is a very important issue for every machining process in order to enhance the quality of machined products, to reduce the machining costs and to increase the production rate. The cutting parameter optimization is also necessary in minimizing the cutting force during machining as the high cutting force can result many adverse conditions, like-reduction in tool life, high power consumption, greater surface roughness, poor surface finish etc.

Optimization of process parameters in machining operations has been an area of interest for many researchers since 1950 when Gilbert presented an analytical procedure for determining the optimum cutting speed in a single pass

turning operation. The selection of optimal cutting parameters in machining is a difficult task which involves the development of machining models and optimization algorithm able to optimize these models. Several mathematical models have been developed to establish the relationship between the cutting performance and the cutting parameters. Optimization of cutting parameters in turning which will ultimately minimize the cutting force requires a model in terms of those parameters. Optimization of cutting parameters involves the use of optimization algorithms and other numerical optimization techniques to optimize the machining models. An optimization problem consists of optimizing one or multiple objective functions while satisfying several constraints. Those objectives are often conflicting and incomparable like- the increase of rate of feeding brings about the growth of the production rate but also increases the cost of the operation due to excessive tool wear and decreases the surface quality because of greater roughness. However various optimization techniques for selecting process variables were developed. Vijayakumar et al. [1] used the ant colony algorithm for solving multi-pass turning optimization problems. The machining parameters are

determined by minimizing the unit product cost, subject to various practical machining constraints. It has been established from this research that the ACO can obtain a near optimal solution in an extremely large solution space within a reasonable computation time. Saravanan et al. [2] applied simulated annealing (SA) and genetic algorithm (GA) to determine the optimal machining parameters for continuous profile machining with respect to the minimum production cost subject to a set of practical constraints. The constraints considered to this problem are cutting force, power constraints and tool tip temperature. It has shown that SA has performed slightly better than GA.

Sardiñas et al. [3] proposed a multi-objective optimization technique, based on genetic algorithms to optimize the cutting parameters in turning processes: cutting depth, feed and speed. The proposed model used microgenetic algorithm in order to obtain the non-dominated points and build the Pareto front graph. Two conflicting objectives, tool life and operation time, are simultaneously optimized in this research. This research also remarks the advantages of multi-objective optimization approach over the single -objective one. Kolahan and Abachizadeh [4] also developed a simulated annealing algorithm to optimize machining parameters in turning operation on cylindrical work pieces. The turning operation usually includes several passes of rough machining and a final pass of finishing. Seven different constraints are considered in a non-linear model where the goal is to achieve minimum total cost. The weighted total cost consists of machining cost, tooling cost and tool replacement cost. Their computational results show that the proposed optimization procedure has considerably improved total operation cost by optimally determining machining parameters. Srikanth and Kamala [5] proposed a real coded genetic algorithm (RCGA) and its advantages over the existing approach of binary coded genetic algorithm. The results obtained, conclude that RCGA is reliable and accurate for solving the cutting parameter optimization. Saha [6] used genetic algorithm (GA) to obtain the optimum cutting parameters by minimizing the unit production cost for a given amount of material removal for the multi-pass face milling process. The cutting parameters optimized were: cutting speed, feed and depth of cut. Car et al. [7] employed Genetic algorithm to obtain optimal cutting parameters in CNC turning that yield minimum machining time and minimum production cost. Ganesan et al. [8] applied Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) to determine the optimal machining parameters with respect to the minimum production time for continuous profile machining. The results obtained from GA and PSO are compared and it was found that PSO generates better results than GA. Using this technique machining time can be further minimized. Xie and Guo [9] combined genetic algorithms (GAs) with a pass enumerating method in selecting the cutting parameters that will minimize the unit production cost (UC) in multi-pass turnings. In the pass enumerating method, the number of all possible rough cuts is calculated in order to divide the whole complicated problem

into several sub-problems. The results show that the optimization approach can find the better results than other algorithms proposed previously to significantly reduce the UC.

Sahoo [10] used Response Surface Methodology (RSM) to develop a predictive model of surface roughness in terms of machining parameters in turning based on experimental results and then used Genetic algorithm (GA) to optimize the machining parameter that results minimum surface roughness. Madhu et al. [11] used artificial neural network (ANN) to optimize cutting parameters for surface roughness prediction in CNC turning. This research also concluded that ANN is a reliable method and it can be readily applied to different metal cutting processes with greater confidence. Korat and Agarwal [12] used Taguchi techniques to optimize the effects of cutting parameters on surface finish and MRR of EN24/AISI4340 work material in CNC turning. The orthogonal array, signal to noise ratio and analysis of variance were employed to study the performance characteristics in turning operation. This research concluded that it is possible to increase machine utilization and decrease production cost in an automated manufacturing environment. Savadamuthu et al. [13] proposed an optimal fuzzy control scheme designed by the Taguchi-genetic method in optimizing cutting parameters in turning. The orthogonal array, the signal-to-noise ratio, and the analysis of variance are employed to study the performance characteristics in turning operations of AISI 1030 steel bars using TiN coated tools. An Adaptive Neuro Fuzzy Inference System (ANFIS) is proposed in this paper to control a constant cutting force turning process under various cutting conditions which consists of two parts: predictor and the fuzzy logic controller. The step size of the predictor and the scaling factors of the fuzzy controller are adjusted for ensuring stability and obtaining optimal control performances. The genetic method is applied to search for the optimal control parameters of both the predictor and the fuzzy controller. Pansare et al. [14] employed Ant colony optimization algorithm (ACO) to obtain optimum turning parameters for minimum surface roughness value in multi-pass turning operation. The cutting process had roughing and finishing stage and the relationship between the parameters and the performance measures were determined using multiple linear regression, this mathematical model is used to determine the optimal parameters. The experimental results showed that the proposed technique is both effective and efficient. Davis et al. [15] optimized the cutting parameters (depth of cut, feed rate, spindle speed) in turning EN24 steel (0.4% C) with hardness 40+2 HRC by using Taguchi method. In this research, turning operation was carried out on EN24 steel by carbide P-30 cutting tool in dry condition.

The objective of this paper is to develop a model of main cutting force (P_z) during turning in terms of the cutting parameters: cutting speed (V_c), feed rate (S_0) and depth of cut (t) using the RSM method and then obtain the optimal value

of the cutting parameters using a Genetic Algorithm (GA) approach. The optimal value of cutting parameters is so selected that will minimize the main cutting force required in turning and thus reduce the power consumption, tool wear, chatter and vibration and thus improves surface finish. The next section describes the methodology used for model formulation and optimization. The following section contains the formulated model of cutting force using RSM technique and then cutting parameters are optimized using GA in the next section. The last section involves the findings and conclusion of this research.

METHODOLOGY

This section is divided into two parts: “Model Formulation” section describes the RSM methodology for developing the cutting force model and “Computing Methodology” section describes the GA approach for the optimization of cutting parameters.

Model Formulation

To develop the model of the main cutting force (P_z) in terms of the cutting parameters: speed, feed rate and depth of cut in turning, Response Surface Methodology (RSM) is used in Minitab16 software in this research. Response surface method is found to be a successful technique to perform the trend analysis of cutting force with respect to various combinations of design variables including the cutting speed (V_c), feed rate (S_0) and depth of cut (t). It is a combination of experimental and regression analysis and statistical inferences. The concept of the response surface involves a dependent variable (P_z) called the response variable and several independent variables. If all of these variables are assumed to be measurable, the response surface can be expressed as-

$$P_z = f(V_c, S_0, t) + e \quad (1)$$

Where, ‘e’ is the error which is normally distributed with zero mean according to the observed response.

In this research a second-order model is used to predict the main cutting force (P_z) because the first-order model only includes the main effects (individual) of the variables and often the curvature in the true response surface is so strong that the first-order model with interaction effect is inadequate to predict the response surface. Thus, the second order equation can be used to represent the response surface for K-number of factors which can be expressed as,

$$P_z = b_0 + \sum_{i=1}^k b_i X_i + \sum_{i,j=1}^k b_{ij} X_i X_j + \sum_{i=1}^k b_{ii} X_i^2 \quad (2)$$

Where, b_0 is the free term, the coefficients $b_1, b_2, \dots, b_k$ are linear terms, $b_{11}, b_{22}, \dots, b_{kk}$ are the quadratic terms, and $b_{12}, b_{13}, \dots, b_{k-1, k}$ are the interaction terms. Replacing the general variables of the above equation by the conventional denotation and considering the interaction effect of the parameters along with main effects can be represented by,

$$P_z = b_0 + b_1 V_c + b_2 S_0 + b_3 t + b_{12} V_c S_0 + b_{13} V_c t + b_{23} S_0 t + b_{11} V_c^2 + b_{22} S_0^2 + b_{33} t^2 \quad (3)$$

Where, b_0 = constant, independent of all parameters which contains environmental factors, tool and workpiece material properties constant.

The data for main cutting force (P_z), cutting speed (V_c), feed rate (S_0) and depth of cut (t) have been collected from turning of a round bar of AISI-1040 steel having a diameter of 40 mm and length 30 cm in a lathe machine using uncoated carbide tool as the cutting tool in a dry machining environment. This operation have been performed in a lathe machine in which 20 feed rates are possible ranging from 0.029-0.412 mm/rev and the rpm ranges from 46-2000. The uncoated carbide insert used here has the following tool geometry:

- Back rake angle: -5°
- Side rake angle: 0°
- Principal cutting edge angle: 9°
- Side cutting edge angle: 10°
- End clearance angle: 8.5°
- Side clearance angle: 10°
- Nose radius: 2.5 mm

Four cutting speeds (V_c) and four feed rates have been used in this research which are given in the following [table 1](#).

Table 1. Cutting speed and feed rate values

Cutting speed (V_c), m/min	Feed rate (S_0), mm/rev
66	0.12
85	0.16
110	0.20
144	0.24

These four values of cutting speed and feed rates are combined to generate sixteen combinations of experiments. These sixteen experiments have been performed and the corresponding main cutting forces (P_z) values are found. The experimental values have been used in the RSM method to estimate the values of the coefficients of [equation \(3\)](#). In this research, the depth of cut (t) has been kept fixed at 1.5mm. So, the main cutting force becomes the function of only the cutting speed (V_c) and feed rate (S_0). Thus, depth of cut (t) will not appear in the expression of the main cutting force. Again, after developing the model, validation of the model has been performed using different sets of cutting parameter values.

In the “Formulated model” section, a model for the main cutting force (P_z) has been formulated and deviation of the