G Model
CIRPJ-407; No. of Pages 7

ARTICLE IN PRESS

CIRP Journal of Manufacturing Science and Technology xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

CIRP Journal of Manufacturing Science and Technology

journal homepage: www.elsevier.com/locate/cirpj

Assignment of weightage to machining characteristics to improve overall performance of machining using GTMA and utility concept

K. Venkata Rao [a,*], P.B.G.S.N. Murthy [b], K.P. Vidhu [c]

[a] Department of Mechanical Engineering, PBR Visvoadaya Institute of Technology and Science, Kavali, AP, India
[b] Department of Mechanical Engineering, Vignan University, Vadlamudi, Gunter, AP, India
[c] Department of Applied Engineering, Vignan University, Vadlamudi, Gunter, AP, India

ARTICLE INFO

Article history:
Available online xxx

Keywords:
Tool vibration
Tool wear
Utility value
Machining performance
Multi response optimization
Graph theory and matrix approach (GTMA)

ABSTRACT

In an automated manufacturing system, performance of machining is an important characteristic that affects the production cost especially in machining processes like milling and boring. Boring is one of critical machining processes, and therefore, it is very difficult to determine overall performance of the process. In the present work, an attempt was made to maximize overall performance of the process in order to reduce reworking and production cost. Three different performance characteristics like surface roughness, tool wear and root mean square of workpiece vibration velocity are considered to determine overall performance for boring of AISI 1040 steel with carbide tool inserts. According to User's Preference Rating, weights for the three performance characteristics are calculated using graph theory and matrix approach (GTMA). Overall performance or utility value of the machining process is calculated using utility concept. A response surface methodology (RSM) is used to optimize the process parameters for maximization of performance of the process. Weights of surface roughness, tool wear and root mean square of workpiece vibration velocity are calculated as 0.489, 0.367 and 0.184 respectively. Optimum process parameters were found to be 0.4 mm of nose radius, 170 m/min of cutting speed and 0.1358 mm/rev of feed rate.

Introduction

Boring is one of the critical machining operations having effect on performance (poor surface finish, tool life and high power consumption) due to vibration of tool and workpiece. In order to improve performance of the machining, process parameters are to be optimized. Tool wear is one of the important factors which should be controlled in order to reduce tooling cost. Poor surface quality, tool and workpiece vibration, high power consumption and noise are the direct indications of tool failure [1]. In boring, drilling and milling, vibration is the main factor that affects the tool wear and surface finish. If the appropriate values of the desirable characteristics of the product are not achieved, then it would be to reworking. Reworking would lead to additional time consumption, wastage of raw materials, lubricants used in machining and most importantly additional power which cause environmental degradation. The stringent quality levels to be achieved in precision manufacturing make the production process to be ever more exacting thus make inevitable the importance of the various variables that affect the machining process. The present work thus discuses about parameters and their optimal values that have indirect effect on the environment.

In metal cutting, the cutting tool is getting dynamic excitation due to deformation of metal that results in vibration of tool. Cutting tool vibration in external and internal turning was studied experimentally and analytically by number of researchers. In tool condition monitoring, direct or indirect monitoring methods have been applied to measure responses. Direct measurement of on-line tool wear is not easily achievable because of the complexity of measuring the signals during process [2]. In recent applications, Laser Doppler Vibrometers (LDV) is used as non-contact method to measure vibration of cutting tool or work piece accurately. The LDV is capable of giving reliable information of tool vibration. Kourosh and Gren [3] pointed that measurement of spindle and tool vibration is required to monitor the machining in high speed milling. Prasad [2] and Rantatalo et al. [4] used the LDV to measure vibrations of rotating spindle or arbor in milling machine. They concluded that the use of LDV is easy and it takes less time to measure vibration of work piece. Set up of LDV is easy when compared with set up of accelerometer.

* Corresponding author.
E-mail address: kvenkatrama@gmail.com (K.V. Rao).

http://dx.doi.org/10.1016/j.cirpj.2016.12.001
1755-5817/© 2017 CIRP.

Many authors reported on surface roughness, tool wear and vibrations of cutting tool. Lin and Chang [5] found a strong correlation between vibrations and surface roughness. They used the ratio between the frequency of vibration and the spindle rotational speed to study the effect of the relative motion between work piece and cutting tool with respect to surface roughness. Surface finish, dimensional accuracy and tool life are the three important machining characteristics that are required to be achieved by manufacturer [6]. The optimization techniques reported in the current research for the optimization of cutting parameters in machining are gray relational analysis [7], neural networks [8], Taguchi method and genetic algorithms [9–13], and response surface methodology (RSM) [14,15]. These optimization tools are having limitations in terms of computational time, understanding, availability of software, optimization accuracy level, etc. [16].

Ahilan et al. [17] developed an intelligent hybrid decision making system with neural networks to select optimum process parameters in turning process. In this system, mathematical models have been developed for surface roughness and power consumption to optimize process parameters. These models are suggested to use in automotive industries to obtain good surface quality and productivity and improve productivity. Venkata Rao and Power [18] used nontraditional optimization algorithms like artificial bee colony, particle swarm optimization, and simulated annealing to optimize process parameters in multi pass milling for maximization of production rate. In multi response optimization of process parameters using the above techniques, all the responses are given equal weightage and it is not possible to determine weightage scientifically. Then uneven optimization results are obtained due to equal weightage assigned to responses [19,20]. There are different types of methods like analytic hierarchy process, analytic network process and fuzzy systems used to calculate weights for responses but the calculation is complex and time consuming [21,22].

Based on the above literature, it was concluded that in the existing methods like Taguchi, RSM, GRA, GA and ANN, the responses are given equal weightage for multi response optimization of process parameters. But the selection of weights to the responses should be done based upon the choice of user/researcher for maximization of overall process performance. The proposed hybrid technique (Combination of Graph theory and matrix approach (GTMA) and utility concept) will calculate weights to the responses as per user/researcher preference. A new method called as 'Customer or User preference rating' has been introduced to overcome the above difficulties in calculation of weights of responses [21]. The GTMA was developed using the customer preference rating in multi response optimization. Combination of GTMA and utility concept is effectively used to calculate weights for responses in simple way [19].

In the present work, boring process parameters are optimized for multi responses of surface roughness, tool wear and root mean square of workpiece vibration velocity. The hybrid approach of Taguchi based GTMA, utility concept are used to calculate weights of responses and normalize the experimental data. A response surface methodology (RSM) was used to optimize the process parameters.

Utility concept

In this method, performance of machining process or a product is assessed by a common utility value. In assessment of machining process, machining characteristics such as surface roughness, tool vibration, tool wear, metal removal rate, cutting force, machining time etc. are taken in to consideration. In multi responses optimization, common utility values of the machining characteristics is calculated [19]. Overall utility value of component is the sum of utility value of each of the machining characteristics. Overall utility value of the product is calculated as follows:

$$U(X_1, X_2, \ldots .X_n = \sum_{i=1}^{n} w_i U_i(X_i) \qquad (1)$$

where w_i is the weight assigned to the responses, U is overall utility value, U_i is utility value of individual responses.

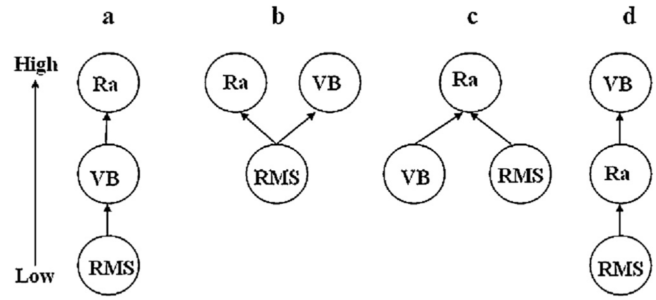

Fig. 1. Different preferences of machining characteristics by different users.

Calculation of weights

In this work, three performance or machining characteristics like surafce roughness (Ra), tool wear (VB) and root mean square of workpiece vibration velocity (RMS) are taken for optimization. Customer's or user's preference rating is considered in calculation of weights. As shown in Fig. 1, preferences of the machining characteristics are arranged according to user's preference rating. Fig. 1(a–d) are constructed according to four different users.

Preference graphs (PG)

This is the schematic preferences of three machining characteristics constructed according to four different users' preferences. In PG_1, surface roughness is given high preference and followed by flank wear and vibration. In PG_2, surface roughness and flank wear are given high preference equally. In PG_3, flank wear and vibration are given low preference equally. In PG_4, flank wear is given high preference and followed by surface roughness and vibration

$$PG_1 = \begin{bmatrix} \mathrm{Ra} & \mathrm{VB} & \mathrm{RMS} \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix} \begin{matrix} \mathrm{Ra} \\ \mathrm{VB} \\ \mathrm{RMS} \end{matrix} \qquad PG_1 = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix}$$

$$PG_3 = \begin{bmatrix} 0 & 1 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \qquad PG_3 = \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

Adjacent matrix

The adjacent matrix represents relation among the individual machining characteristics in the form of matrix as shown below:

$$PG_n = [pg_{ij}]_{M \times M} \quad (i, j = 1, 2, \ldots., m, \ldots, M) \qquad (2)$$

where n is the number of individuals, M is the number of characteristics and pg_{ij} gives the dominances of i over j in an $M \times M$.

Dominance matrix

Dominance matrices (D^n) for different PGs were calculated using adjacency matrices. The dominance matrix identifies more