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ScienceDirect
Procedia Engineering 64 (2013) 690 – 700
Procedia Engineering
www.elsevier.com/locate/procedia

International Conference On DESIGN AND MANUFACTURING, IConDM 2013

Optimization of Cutting Parameters for Cutting Force in Shoulder Milling of Al7075-T6 Using Response Surface Methodology and Genetic Algorithm

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Abstract

This paper aims at developing a statistical model to predict cutting force in terms of machining parameters such as cutting speed, cutting feed rate and axial depth of cut. Response surface methodology experimental design was used for conducting experiments. The work piece material was Aluminum (Al 7075-T6) and the tool was a shoulder mill with two carbide insert. The cutting forces were measured using three axis milling tool dynamometer. The second order mathematical model in terms of machining parameters was developed for predicting cutting force. The adequacy of the predictive models was tested by analysis of variance and found to be adequate. The direct and interaction effect was graphically plotted which helps to study the significance of these parameters with cutting force. The optimization of shoulder mill machining parameters to acquire minimum cutting force was done by genetic algorithms (GA). A Matlab genetic algorithm solver was used to do the optimization.

Keywords: Cutting force;Shoulder Mill;Response Surface Methodology;Genetic Algorithm;Optimization

1. Introduction

Shoulder mill is one of the most vital practices for shaping metal, nonmetallic components and a curved profile. It is one of the most widely used metal removal processes because of its ability to remove material faster with a good surface quality in industry and milled surfaces are largely used to mate with other in die, aerospace, automobile, biomedical products and machinery design as well as in manufacturing industries.

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doi:10.1016/j.proeng.2013.09.144

Nomenclature

V_c	Cutting speed (m/min)
f_z	Cutting feed rate (mm/tooth)
a_p	Axial depth of cut (mm)
F	Cutting force (N)
F_x	Infeed force (N)
F_y	Crossfeed force (N)
F_z	Thrust force (N)
X_i	Required coded value of variable
X_{min}	Lower limit of the variable
X_{max}	Upper limit of the variable
ϕ	Response surface
e_u	Residual
u	Number of observation
b_0	Constant
b_i	Linear term coefficient
b_{ii}	Quadratic term coefficient
bij	Interaction term coefficient
GA	Genetic algorithm

During machining, the cutting tool uses a force on the workpiece as it removes the machining allowance in the form of chips. A correct estimation of such force could avoid quality problem related to the tool deflection, chatter or fixture improving also the productivity. The optimization of a machining process necessitates accurate measurement of the cutting force by a special device called a machine tool dynamometer, which is capable of measuring the components of the cutting force in a given coordinate system. It is a useful and powerful tool employed in a variety of applications in engineering research and manufacturing. The determination of optimal cutting parameter such as cutting speed ,Axial depth cut, and feed, which are applicable for assigned cutting tools, is one of the vital modules in process planning of metal parts, since the economy of machining operations plays an important role in increasing productivity and competitiveness.

In the present work, an investigation on cutting forces is undertaken in order to study its effect on stability in end milling process together with its predictive model from machining parameters by way of response surface methodology and genetic algorithm. The literature survey pertaining to the work done by other researchers is given below.

Aladdin [1] used response surface method to predict tool life in end milling. The author found that the speed was the dominant factor in both the first and the second order models, followed by the feed and the axial depth of cut. Kovacic et al, [2] developed a genetic programming to predict cutting forces in milling. Baskar et al. [3] established a genetic algorithm (GA), hill climbing algorithm and memetic algorithm to optimize machining parameters for milling operations. The author considered the three objective functions namely minimum production cost, minimum production time and maximum profit rate for both single tool and multi-tool operations. Omar et al. [4] proposed a method to predict the cutting forces and 3D surface topography during side milling .The model incorporated the effects of tool runout, tool deflection, system dynamics, flank face wear, and the tool tilting on the surface roughness. Brezocnik et al. [5] introducted a genetic programming to predict surface roughness in end milling and established that the surface roughness was most influenced by the feed rate, whereas the vibrations increase the prediction accuracy. Ganesh babu et al. [6] carried out the effects of machining parameters on the variations of cutting forces during end milling operation of Al SiC metal matrix composite material. They showed the cutting force in tangential direction increases when the depth of cut increases. Ginting and Nouari [7] optimized the cutting coditions for end milling of aeroengine material Ti–6242S under dry condition. They also used the FEM simulation, the chip morphology, contact length at the tool–chip interface and the tribological aspects (temperature, pressure) in machining to predict the optimum cutting codition. Peng et al. [8] investigated the characteristics of high speed machining dynamic milling forces of Titanium alloy by use of polycrystalline diamond tools. They found that amplitudes increase with the increase of cutting speed and tool wear. Ghani et al. [9] Taguchi's technique used to optimization of end milling parameters. The author showed that high cutting speed, low feed rate and low depth of cut leads to better surface finish and low cutting force. Palanisamy et al.[10] discussed the dynamic cutting force model for end milling which is developed to predict the tangential cutting force and the thrust force. They concluded that the cutting forces increase with increase in axial depths of cut. Li Zeng et al. [11] presented an experimental study of the tool wear propagation and cutting force variations in the end milling of Inconel 718 with coated carbide inserts. The tool flank wear propagation in the up milling operations was more rapid than that in the down milling operations. Soo Kang et al. [12] studied an analytical cutting force model for micro end milling was proposed for predicting the cutting forces. The cutting force model, which considered the edge radius of the micro end mill, was simulated. They found that the increasing of thrust force affects the feed direction cutting force in micro end milling with a very small feed per tooth. Oktem et al. [13] both response surface methodology and Genetic algorithm utlized to optimization of cutting conditions for surface roughness. The author concluded that GA decreases the surface roughness value in the mold cavity from 0.412 μm to 0.375μm corresponding to about 10%. Campatelli et al. [14] analysed the effect of feed per tooth and cutting speed on the cutting coefficients in order to create a model to predict reliably the cutting force with different process parameters. The experimental tests showed that the shearing cutting coefficient is influenced not only by the instantaneous chip thickness, or the feed per tooth, but also by the cutting speed, this contribution have a smaller effect respect to feed per tooth. Milfelner et al .[15] developed a genetic equation to predict the cutting force for ball end milling process. The authors indicated that intelligent production system will lead to decrease in manufacture cost and manufacture time, flexibility in machining parameter selection, and development of product quality. Zhang et al. [16] analyzed the tool wear and the cutting forces variation during high-speed end-milling Ti-6Al-4V alloy. The experimental results showed that the major tool wear mechanisms in high-speed end-milling Ti-6Al-4V alloy with uncoated cemented tungsten carbide tools are adhesion and diffusion at the crater wear along with adhesion and abrasion at the flank wear. Fnides et al. [17] developed a mathematical model for cutting forces and surface roughness in turning of hot work steel. The authors pointed that tangential cutting force was very sensitive to the variation of cutting depth what affects the cutting forces, surface roughness was very sensitive to the variation of feed rate and that flank wear has a great influence on the evolution of cutting force components and on the criteria of surface roughness. Yung Kuang Yang et al. [18] used a design of experiments to optimize parameters of a computer numerical control in end milling for high-purity graphite under dry machining. The author concluded that the feed rate was found to be the most significant factor affecting the groove difference and the roughness average in end milling. The literature showed above exposes that not much work has been stated on prediction and optimization of cutting force in shoulder mill. In this work, the main objective is to develop a model based on response surface methodology to the cutting force in terms of machining parameters such as cutting speed, cutting feed rate, and axial depth of cut. The mathematical model aided us to study the direct and interaction effect of each parameter. Additionally, the statistical model developed was utilized to optimize the machining parameters to obtain minimum cutting force using genetic algorithm.

2. Experimental design

Response surface method is the most effective method to study the result obtained from factorial experiments. It is an effective tool for modelling and studying the manufacturing problems. It delivers more information with fewer numbers of investigations. It is an investigation strategy for exploring the limits of the input parameters and emerging experiential statistical model for the measured response, by approximating the relationship existing between the response and input process parameters. The limit of the process parameters has to be defined in response surface method and the first experimentation was done to recognize the machining parameters that affect the cutting force and to discover the range of the selected cutting parameters. In the present study, cutting speed, cutting feed rate and axial depth of cut has been considered as the cutting parameters. The response cutting force F equation (1) can be expressed as a function of machining parameters cutting speed *(V_c),* cutting feed rate *(f_z) and* axial depth of cut *(a_p)*

$$F = \phi\,(V_{ciu}, f_z, a_p) + e_u \qquad (1)$$

Where ϕ is the response surface, e_u is the residual, u is the Number of observations in the factorial experiment and i_u represents level of the i^{th} factor in the u^{th} observation. When the mathematical form of ϕ is unknown, this function can be approximated acceptably within the experimental region by polynomials in terms of the machining parameter variable. Box and Hunter [25, 26] proposed the central composite rotatable design for fitting a second-order response surface based on the criterion of rotatability. The selected design plan chosen consists of 20 experiments. It has three factors-five levels central composite design consisting of 20 sets of coded condition (Table1).

Table 1. Parameters and Levels in Shoulder Milling

Parameters	Notation	Units	Levels				
			-1.682	-1	0	1	1.682
Cutting speed	V_c	m/min	100	130	160	190	220
Cutting Feed	f_z	mm/tooth	0.06	0.07	0.08	0.09	0.10
Depth of cut	a_p	mm	0.5	1	1.5	2	2.5

The design for the above experiment comprises of a full replication of 2^3(=8) factorial design plus six center points and six star points. These correspond to first 8 rows, the last six rows, and rows from 9 to 14, respectively. For Full replicate, the extra point included to form a central composite design, α becomes $2^{(k-1)/4}$=1.682. The upper limit of the parameter is coded as 1.682; lower limit, as −1.682. In this matrix, twenty experimental runs provide ten estimates for the effect of three parameters. One estimate for the mean effect of all the three parameters, three linear estimates for main effects, three quadratic estimates due to main effects, and three estimates for the two factor interactions are included. Thus the design matrix has allowed the estimation of linear, quadratic and two-way interactive effects of the selected machining parameter variables on cutting force. In the present work, shoulder mill of cutting tool insert, cutting speed, feed rate, and depth of cut have been considered as the machining parameters for cutting condition monitoring, and the cutting force is measured as a response variable (Table 2). In conducting the experiment, the upper limit of a factor was coded as +1.682 and the lower limit as −1.682. The coded values for intermediate values were calculated from the following relationship

$$X_i = \frac{1.682(2X-(X_{max}+X_{min}))}{(X_{max}-X_{min})} \qquad (2)$$

Where X_i is the required coded value of a variable X, X is any value of the variable from X_{min} to X_{max}, X_{min} is the lower limit of the variable and X_{max} is the upper limit of the variable. The intermediate values are coded as −1, 0, and 1.The coded values for intermediate values have been calculated using Eq. 2.

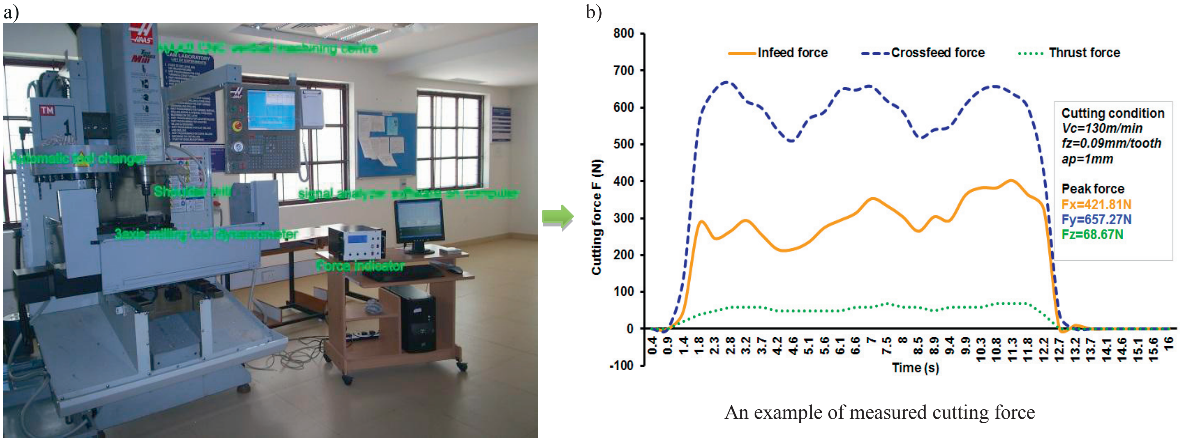
Table 2. Experimental Design-Central Composite Design Matrix and Measured Value of Response

Test no.	Control factors			Infeed force F_x		% Error	Crossfeed force F_Y		% Error	Thrust force F_Z		% Error
	V_c	f_z	a_p	Observed value	Predicted value		Observed value	Predicted value		Observed value	Predicted value	
1	-1	-1	-1	342.97	328.604	-4.189	381.81	385.23	0.895	58.67	55.993	-4.563
2	1	-1	-1	235.44	240.372	2.095	343.35	356.342	3.784	49.86	47.707	-4.319
3	-1	1	-1	412.81	430.682	4.329	657.27	669.992	1.936	68.67	68.255	-0.604
4	1	1	-1	161.19	152.094	-5.643	399.73	392.184	-1.888	36.24	35.445	-2.195
5	-1	-1	1	399.16	417.094	4.493	603.19	637.13	5.628	72.67	74.188	2.088
6	1	-1	1	342.97	328.862	-4.113	589.55	608.242	3.171	39.24	40.377	2.896
7	-1	1	1	794.61	787.216	-0.931	1187	1200.41	1.129	88.29	86.451	-2.084
8	1	1	1	490.5	508.628	3.695	894.61	922.604	3.129	29.43	28.115	-4.471
9	-1.682	0	0	637.57	619.207	-2.881	803.47	775.482	-3.483	88.29	89.107	0.926
10	1.682	0	0	313.92	310.711	-1.022	538.79	517.551	-3.942	32.43	33.078	1.999

11	0	-1.682	0	264.87	265.081	0.079	382.59	394.585	3.135	54.05	57.188	5.806
12	0	1.682	0	510.12	502.112	-1.569	873.09	898.448	2.904	58.86	57.188	-2.841
13	0	0	-1.682	169.15	173.132	2.354	307.01	317.551	3.434	37.43	38.963	4.096
14	0	0	1.682	559.18	547.397	-2.107	997.01	975.482	-2.159	49.86	48.100	-3.529
15	0	0	0	461.07	464.959	0.843	637.65	646.517	1.391	41.24	43.532	5.557
16	0	0	0	473.07	464.959	-1.715	657.65	646.517	-1.692	43.24	43.532	0.674
17	0	0	0	451.07	464.959	3.079	667.65	646.517	-3.165	46.24	43.532	-5.857
18	0	0	0	483.07	464.959	-3.749	627.65	646.517	3.006	41.24	43.532	5.556
19	0	0	0	451.07	464.959	3.079	657.65	646.517	-1.693	45.24	43.532	-3.776
20	0	0	0	469.07	464.959	-0.876	627.65	646.517	3.006	45.24	43.532	-3.776

3. Experimental details

The experiments were conducted on a HAAS CNC vertical machining center with two carbide insert of shoulder mill cutter under dry condition. The work piece material was Aluminium 7075- T6 material was chosen in this study is usually employed in the aerospace industry to manufacture components that demand: lighter, harder, stronger, tougher, stiffer, more corrosion- and erosion-resistant properties. The dimension of the work piece specimen was 50 mm × 25 mm in cross section and 100 mm in length was used in this study. The cutting forces: infeed force, crossfeed force and thrust force are measured by using syscon instruments; three axis milling tool dynamometer. The data is acquired in the data acquisition software and observations are tabulated to obtain the mathematical model. The experimental setup used for conducting the experiments is shown in Fig.1a-1b.



An example of measured cutting force

Fig.1. Experimental setup used for conducting the experiments

4. Development of mathematical model

The general form of a quadratic polynomial which provides the relation between response surface y and the cutting variable x under study is given by Eq. 3.

$$y = b_0 + \sum_{j=1}^{k} b_i x_i + \sum_{j=1}^{k} b_{ii} x_i^2 + \sum_{i<j} b_{ij} x_{ij} \tag{3}$$

Where b_0 is a constant, b_i is the linear term coefficient, b_{ii} is the quadratic term coefficient and b_{ij} is the interaction term coefficient.

The values of the coefficients of the polynomials were calculated by the multiple regression method. A statistical software Minitab14 and QA Six Sigma DOE PC IV was used to calculate the values of these coefficients

[22,27]. The second-order mathematical model was established by neglecting the insignificant coefficients of the cutting force (F) Eq 4..

$$\begin{aligned}
&\textit{Infeed force } F_x && =464.959-91.705V_c+70.461f_z+111.256a_p-28.759f_z^2-37.006a_p^2-47.58V_cf_z+67.011f_za_p \\
&\textit{Crossfeed force } F_y && =646.517-76.674V_c+149.781f_z+195.58a_p-62.23V_cf_z+69.63f_za_p \qquad (4) \\
&\textit{Thrust force } F_z && =43.5316-16.6556V_c+2.7161a_p+6.2074V_c^2+4.827f_z^2-6.131V_cf_z-6.3813V_ca_p
\end{aligned}$$

The adequacy of the model was verified using the analysis of variance (ANOVA) technique (Table 3). The calculated *F* ratio of the model does not exceed the standard value for a desired 95 % level of confidence. Table 3 shows that the model is acceptable, and that the error between the experimental and predicted values is less than 5 %.

Table 3. Results of ANOVA analysis

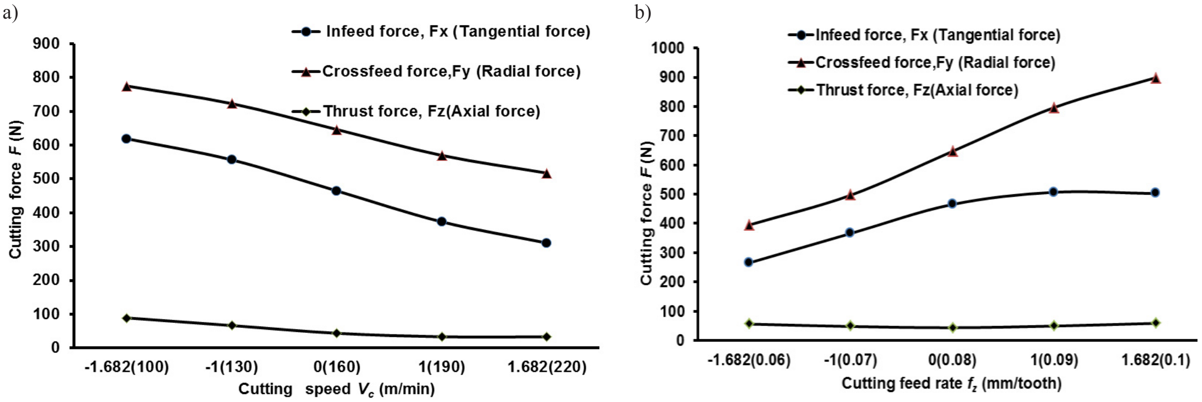
Response	Factors Df	Lack of fit-df	Pure error	F-ratio		Whether Model is adequate
				Model	Standard	
Infeed force (F_x)	9	5	5	2.80	4.77	Adequate
Crossfeed force (F_y)	9	5	5	2.09	4.77	Adequate
Thrust force(F_z)	9	5	5	0.66	4.77	Adequate

5. Results and Discussion

The mathematical model was used to predict cutting force by substituting the respective values of the machining parameters. The influence of the machining parameters of cutting force was studied using the developed model.

5.1 Main effect of machining parameter on cutting force

The direct effect of machining parameters was studied by keeping all the machining parameters at the middle level except the parameter whose direct effect was studied.Fig.2a-2c shows the effect of cutting speed, cutting feed and axial depth of cut on cutting force.



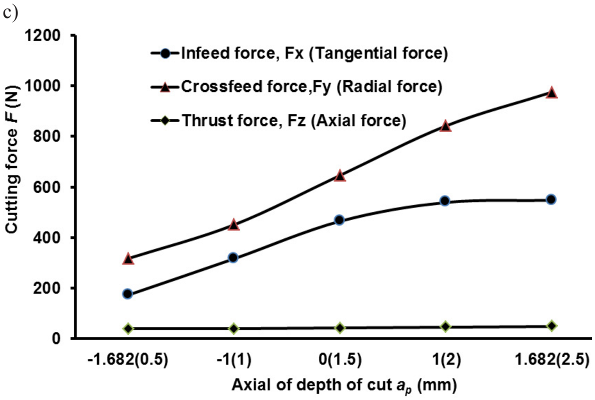
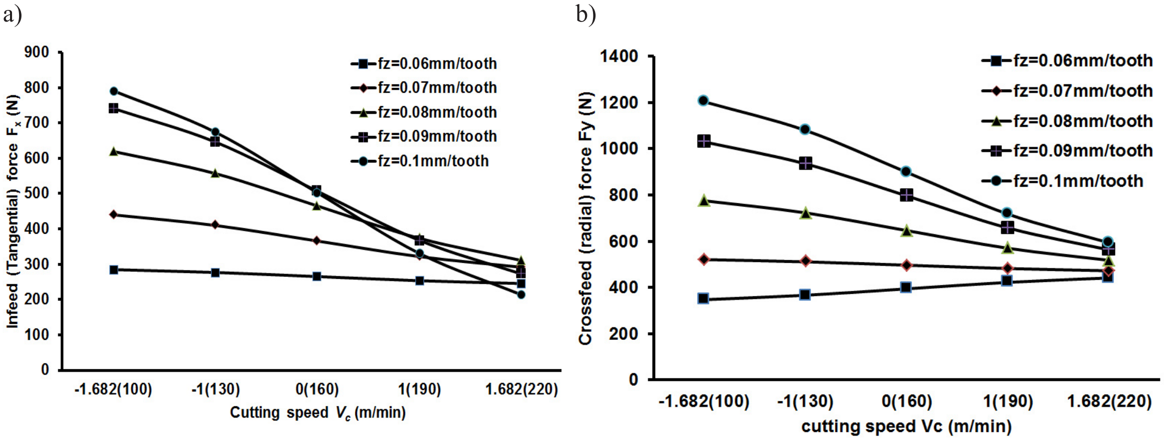


Fig.2. Main effect of a) cutting speed, b) cutting feed, c) axial depth of cut on cutting force

From the Fig.2a, it can be inferred that when cutting speed ranges from 100m/min to 220 m/min the cutting force decreases with the increase of cutting speed due to the thermal softening which changes the shear angle and thus the necessary plastic deformation. This is due to due to an increase in strain and strain rate [19]. From the Fig.2b, it can be inferred that when cutting feed ranges from 0.06mm/tooth to 0.1mm/tooth the cutting force increases with the increase of cutting speed due to that more material will have to be cut per tooth per revolution, as a consequence more energy is required [19]. Fig.2c, it can be inferred that increase in axial depth resulted in an increase of in cutting force on all levels. Higher the axial depth of more length of the flute will get engaged which results in more cutting force. Increase in axial depth of cut, the length of the contact area in the axial cutting length in the rotating direction is increased, which resulted in increased cutting force [21].

5.2. Interactive effects of machining parameters on cutting force

The change in effect of one variable when the second variable is changed from one level to another is known as interaction effect. The interaction effects of the process variables are useful in understanding the machining behaviour. In this study, the two-way interactive effects of the process variables which have strong interaction with cutting force are discussed below.



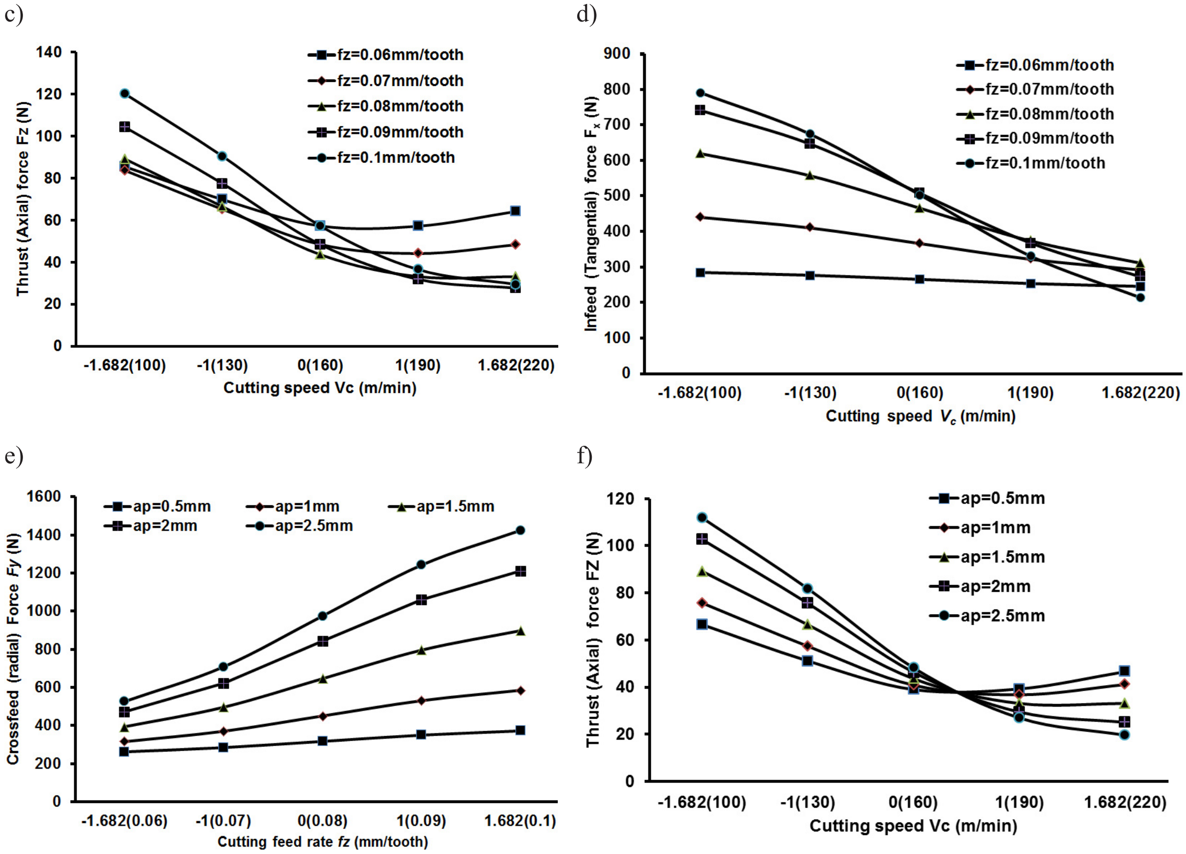


Fig.3. Interaction plot for response (cutting force)

Fig.3a-3f shows the interactive effect of cutting speed, cutting feed and axial depth of cut on cutting force. Fig.3a-3c shows the interactive effect of cutting speed and cutting feed on infeed force, cross feed force and thrust force. It has been inferred from the direct effect analysis that cutting speed has the negative effect and cutting feed has a positive effect on infeed force, cross feed force and thrust force. From Fig.3a-3c, it is observed that the cutting force (infeed, crossfeed, thrust force) increases for cutting speed at 100m/min and 220m/min as the feed is increased from 0.06mm/tooth to 0.1mm/tooth. The resultant effect is due to the instantaneous accelerating in chip thickness with the increase in the feed rate and there is an amplified in the cutting forces as the forces are in proportion with the chip area .The reason is that more material will have to be cut per tooth per rotation as the feed is raised as a consequence more energy is required [19]. Therefore, it may be concluded here that cutting speed in the range of 160m/min to 220m/min and the cutting feed in the range of 0.06mm/tooth to 0.08mm/tooth would give minimum infeed force. Fig.3d-3e shows the interactive effect of cutting feed and axial depth of cut on infeed force and cross feed force. From Fig.3d-3e, it is observed that the cutting force (infeed, crossfeed) increases for cutting feed at 0.06mm/tooth and 0.1mm/tooth as the axial depth of cut is increased from 0.5mm to 2.5mm. This is because when the axial depth of cut increases, the average chip thickness increases which in turn increases the load on the ship resulting in decreased wedge strength of the tool [21]. Therefore, it may be concluded here that cutting feed rate in the range of 0.06mm/tooth to 0.09mm/tooth and the axial depth of cut in the range of 0.5mm to 1.5mm would give minimum cutting force.

Fig.3f. shows the interactive effect of cutting speed and axial depth of cut on thrust force. It has been inferred from the direct effect analysis that cutting speed has the negative effect and axial depth of cut has a positive effect on thrust. From Fig.3f, it is observed that the infeed decreases for cutting speed at 100m/min, 130m/min and 160m/min as the axial depth of cut is increased from 1.5mm to 3.5mm. The trend changes in other two levels of cutting speed 190m/min and 220m/min. The thrust force increases for these two cutting speeds. By increasing the cutting speeds, the tendency of chatter decreases, but only up to a certain threshold value. After a certain limit, the tool will tend to deflect more, which induces vibration. Increase in axial depth of cut, the length of the contact area in the axial cutting length in the rotating direction is increased, which resulted in increased cutting force. Therefore, it may be concluded here that cutting speed in the range of 100m/min to 160m/min and the axial depth of cut in the range of 0.5mm to 1.5mm would give minimum cutting force.

6. Optimization procedure

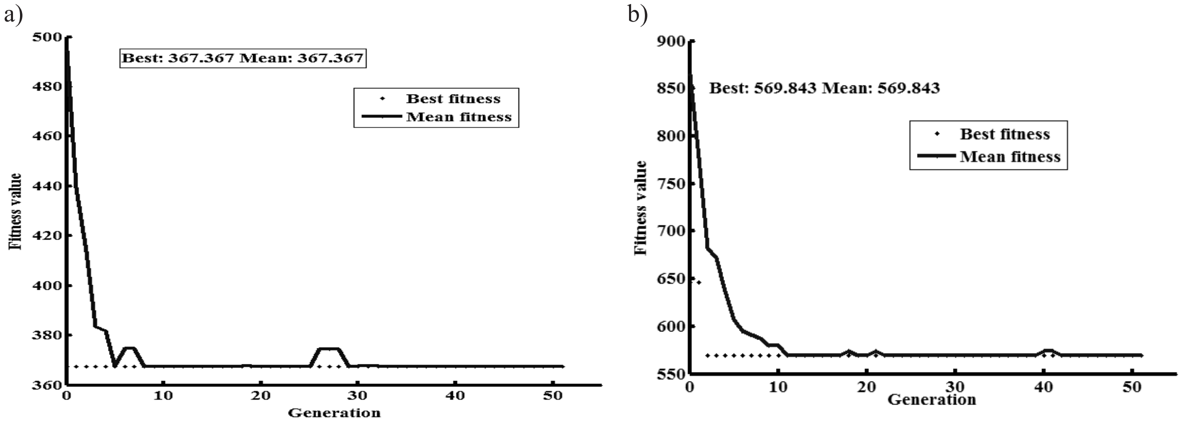
The optimal selection of shoulder mill machining parameters should rise not only the function of cutting economics, however also the creative quality to a great magnitude by minimizing the cutting force. In this work, optimum values of end mill machining parameters are determined by an optimization method. Therefore, the machining parameters of end milling are distinct in the normal optimization method that is resolved by a numerical optimization algorithm. An objective function to be minimized is essential to describe the normal optimization problem. In end milling with different cutting condition cutting force, optimization problem can be expressed in the following:

Find: V_c, f_z, a_p, *Minimize:* $F_w(V_c, f_z, a_p)$

With ranges of cutting parameters: $100\,m/min \leq V_c \leq 220\,m/min, 0.06\,mm/tooth \leq f_z \leq 0.1\,mm/tooth,$

$$0.5\,mm \leq a_p \leq 2.5\,mm \qquad (5)$$

Genetic algorithm (GA) solver, an international optimization technique, is developed to solve the optimization problem conveyed by Eq. (5). Genetic algorithm simulates the biological progression method. The result of an optimization problem with genetic algorithm instigates with a set of possible solutions or chromosomes that are randomly selected [28]. The entire set of these chromosomes comprises a population. The chromosomes progress through numerous iterations or generations. New generations are produced employing the crossover and mutation method. Crossover comprises splitting two chromosomes and then joining one-half of each chromosome with the additional pair. Mutation includes tossing a sole bit of a chromosome. The chromosomes are then gauged using definite fitness criteria and the best ones are reserved while the others are rejected. This procedure recaps till one chromosome has the best fitness and is taken solution of the problem as the optimum [23, 28]. In this work, population size of 20, Elit count 2,crossover fraction 0.8, mutation rate of 0.01,lower bound[-1.682 -1.682 -1.682], upper bound [1.682 1.682 1.682] and 100 generation are used. Optimization history only up to 51 iterations is illustrated in Fig. 4.



C)

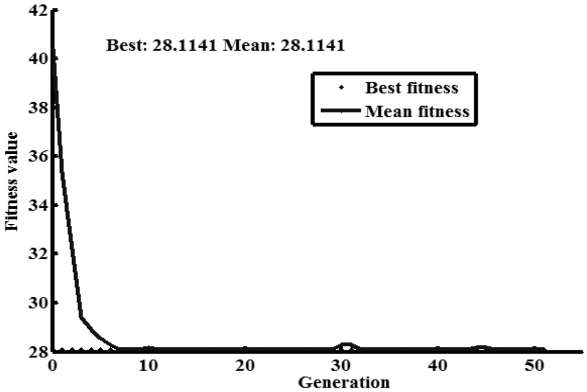


Fig. 4. Optimization history with generation for cutting force- a) Infeed force b) crossfeed force c)Thrust force

Optimization problem in Eq. (5) is resolved without any constraint to examine the effect of numerous situations on optimum values of shoulder mill machining parameters. Fig. 4 displays the results developed by running the Genetic algorithm (GA) solver for minimizing cutting force. The difference in the original curve is due to the search for the optimum solution. In Fig. 4, it is evident that the minimum cutting force occurs at the 51th generation and the value is infeed force 367.67N, crossfeed 569.843N and thrust force 28.1141N.

The optimum values of the machining of Al7075-T6 variables obtained from GA are given below:

Cutting force	V_c *(m/min)*	f_z *(mm/tooth)*	a_p *(mm)*
Infeed (tangential) force 367.367N	190	0.09	1.5
Crossfeed (radial) force 569.843N	190	0.09	1.5
Thrust (axial) force 28.1141N	190	0.09	2

7. Conclusions

In this work, response surface methodology and genetic algorithm have been utilized for establishing optimum end mill process parameter guiding to minimum cutting force during shoulder mill Aluminium 7075-T6 with different cutting condition. Shoulder mill cutting parameters cutting speed, cutting feed, axial depth of cut used to conducting experiments. A response surface methodology was developed to regression model cutting force by manipulating experimental measurements found from these cutting forces. The established RSM model was further coupled with an established genetic algorithm to novelty the optimum end mill cutting parameter prominent to the minimum cutting force value.

In addition to the results discussed above, the following conclusions can be summarized:

The cutting force of AL7075-T6 aluminium alloy can be computed efficiently through the second-order quadratic model developed in this work. The direct and interactive effects of machining parameters on cutting force within the range of investigation can be studied with ease from the central composite design.

The machining parameters for accomplishing the desired cutting force can be obtained from the mathematical model. A comparison is made between the predicted results and the experimental results and has been found that the deviation is well within the limit of 95% confidence level. We found that the cutting speed was the dominant factor in the second order models, followed by the cutting feed rate and the axial depth of cut. We also identified that high cutting speed, low cutting feed rate and low axial depth of cut leads to better low cutting force.

From this work, it is understood that it is possible to control the machining parameters and achieve the desired cutting force in AL7075-T6 aluminium alloy. Prior knowledge about the cutting force model acting on the system may help the operator in choosing the suitable machining parameters and the optimization of the machining parameters may help the manufacturer of machining tools in designing of cutting tools and to estimate the power requirement. This work will provide an engineer who designs a machining center with a tool to predict the cutting force and also provide a guideline for industrial engineers to estimate the cutting performance of high speed spindles during the design stage.

Acknowledgements

The authors thank All India Council for Technical Education, New Delhi, India for providing financial help for the experimental setup by sponsoring the above research and development project (BOR/RID/RPS-8023). The author also wishes to thank Kumaraguru College of Technology, Coimbatore and special thanks to Mr. A.Sethupathy for technical assistance in machining.

References

[1] Alauddin, M., El Baradie, M.A.,1997. Tool life model for end milling steel (190 BHN) . Journal of Materials Processing Technology 68, pp.50-59.
[2] Kovacic, M., Balic, J., Brezocnik, M., 2004. Evolutionary approach for cutting forces prediction in milling, Journal of Materials Processing Technology 155–156,pp1647–1652
[3] Baskar , N., Asokan , P., Saravanan , R., Prabhaharan , G., 2006. Selection of optimal machining parameters for multi-tool milling operations using a memetic algorithm. Journal of Materials Processing Technology 174 ,pp239–249.
[4] Omar,O.E.E.K,Wardany,T,, El,Elbestawi,M.A., 2007. An improved cutting force and surface topography prediction model in end milling, Int J Mach Tools Manuf 47,pp1263–1275
[5] Brezocnik, M., Kovacic, M. Ficko, M., 2004. Prediction of surface roughness with genetic programming. Journal of Materials Processing Technology 157–158, pp28–36.
[6] Ganesh babu, B.,Selladurai, V., Shanmugam, R.,2008. Analytical modeling of cutting forces of end milling operation on aluminum silicon carbide particulate metal matrix composite material using response surface methodology, ARPN Journal of Engineering and Applied Sciences 3(2),pp5-18
[7] Ginting , A., Nouari, M., 2007. Optimal cutting conditions when dry end milling the aeroengine material Ti–6242S. Journal of Materials Processing Technology 184 , pp319–324.
[8] Peng LIU, Jiu-hua XU, Yu-can FU., 2011. Cutting force and its frequency spectrum characteristics in high speed milling of titanium alloy with a polycrystalline diamond tool, Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering) *12(1),pp56-62.*
[9] Ghani, J.A., Choudhury, I.A., Hassan, H.H., 2004, Application of Taguchi method in the optimization of end milling parameters. Journal of Materials Processing Technology 145, pp84–92.
[10] Palanisamy, P., Rajendran, I., Shanmugasundaram, S., and Saravanan, R., 2006. Prediction of cutting force and temperature rise in the end-milling operation, J. Engineering Manufacture 220,pp 1577- 1587
[11] LI, H.Z., Zeng, H., Chen, X.Q., 2006. An experimental study of tool wear and cutting force variation in the end milling of Inconel 718 with coated carbide inserts. Journal of Materials Processing Technology 180,pp296–304.
[12] Soo Kang Ik, Jeong Suk Kim , Yong Wie Seo., 2008. Cutting force model considering tool edge geometry for micro end milling process, Journal of Mechanical Science and Technology 22 , pp293-299
[13] Oktem, H., Erzurumlu , T., Kurtaran , H., 2005. Application of response surface methodology in the optimization of cutting conditions for surface roughness. Journal of Materials Processing Technology 170 , pp11–16.
[14] Campatelli, G., Scippa, A., 2012. Prediction of milling cutting force coefficients for Aluminum 6082- T4, 5th CIRP Conference on High Performance Cutting 2012, Procedia CIRP 1,pp 563 – 568
[15] Milfelner , M., Kopac , J., Cusa, F. , Zuperl, U. , 2005 . Genetic equation for the cutting force in ball-end milling. Journal of Materials Processing Technology 164–165 ,pp1554–1560.
[16] Zhang, S., Li J. F., Sun, J., Jiang, F., 2010. Tool wear and cutting forces variation in high-speed end-milling Ti-6Al-4V alloy, Int J Adv Manuf Technol 46,pp69–78
[17] Fnides, B., Aouici, H., Yallese, MA, 2008. Cutting forces and surface roughness in hard turning of hot work steel X38CrMoV5-1 using mixed ceramic, International Journal of Scientific and Research ,2(70),pp73-78.
[18] Yung-Kuang Yang, Ming-Tsan Chuang, Show-Shyan Lin., 2009. Optimization of dry machining parameters for high-purity graphite in end milling process via design of experiments methods. Journal of Materials Processing Technology 209 , pp4395–4400.
[19] Cyril Donaldson, George, H., Lecain,. Goold, V.C., 2009. Tool Design, Tata McGraw – Hill publishing company limited.
[20] Cochran, WG, Cox, GM., 1987. Experimental designs. Wiley, New York.
[21] David, A., Stephenson and John, S., Agapiou.2006. Metal Cutting Theory and Practice.Taylor & Francis Group.
[22] DOE—PC IV Software reference manual. 1988. Quality America, Inc, USA.
[23] Deb, K., 1995. Optimization for engineering design: algorithms and examples. Prentice-Hall, New Delhi.
[24] Goldberg DE.,1989. Genetic algorithms in search, optimization and machine learning. Addison-Wesley Pub, New York.
[25] Montgomery,D.C., 2005. Design and analysis of experiments. John Wiley and Sons, New York
[26] Montgomery, D.C, PECK, E.F., 2005. Introduction to linear regression analysis. John Wiley and Sons, New York.
[27] Mini Tab Release 14 reference manual., 2004. Minitab Inc, USA.
[28] Matlab Release R2011a reference manual .,2011. Mathworks Matlab Inc,USA.