MATERIAL REMOVAL RATE PREDICTION USING CIRCULAR INTERPOLATION BASED ON TAGUCHI METHOD IN MILLING OPERATION

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ABSTRACT
This paper presents generate tool path and getting G-codes for complex shapes depending on mathematical equations without using the package programs that using linear interpolation. Circular interpolation (G02, G03) was used to generate tool path and this need to define the tool radius and radius of curvature in addition to define the cutting direction if it is clockwise or counter clockwise. In addition many other factors had been considered in the machining process of the proposed surface to find the best tool path and G-code. Side step, feed rate and diameter had been studied as machining factors affecting tool path generation process. The impact of the machining parameters on the Material Removal Rate was determined by the use of analysis of variance (ANOVA) that detect more influence for side step (75%).From this study, it has been learned that less side step (0.6) mm and feed speed (2000) mm/min and high value for diameter (12) mm is better tool path to be used in machining operations to give high Material Removal Rate. This study would help engineer and machinist to select the best tool path for their product.

Keywords:
Tool path generation, Surface roughness, radius of curvature, Artificial Neural Network.

INTRODUCTION

The demand of low tolerances and better quality products has forced manufacturing industry to continuously progress in quality control and machining technologies. One of the fundamental metal cutting processes is end milling which is one of the most popular and efficient operations for removing metal from the material surfaces highly used in automotive parts, moulds/dies, electronic devices, medical components, and other engineering applications **[1]**. End milling operation is associated with surface roughness and Material Removal Rate due to some requirements such as machining efficiency, high quality surfaces, dimensional accuracy, and the process reliability **[2].** Quality of a product is directly evaluated with its surface roughness attribute since functional attributes of a product such as contact, wearing, heat transmission and coating could be affected by surface roughness **[3].**

A lot of research has been conducted for determining optimal cutting parameters in machining processes. However, Different cutter paths in face milling operations can be used with end mills.

Gershon E, et al. (1994)[4] presented an algorithm to adaptively extract ISO curves. It is adapted and enhanced to generate milling tool paths for models consisting of trimmed surfaces. They used 3 axis milling. The tool paths generation does not find gouge locally and combine the advantages of both prior approaches. The researchers found that algorithm has been used to compute gouge avoiding tool paths for automatically milling free form surfaces without requiring the introduction of auxiliary check and drive surfaces

Akeel S, (2006)[5] presented an algorithm to make an efficient and accurate three dimensions surface interior data depending on primary initial data based on approximation and interpolation techniques. The researcher used mathematical algorithm to generate three dimensions surface design using three approximation different methods (Hermite technique, Bezier technique, and B-Spline technique) presented. A new method of surface generation which extends the conventional Lagrange interpolation (1D) to generate (3D) surface deign is presented in his work. Comparison is made between the two proposed techniques of surface generation approximation and interpolation depending on several standard functions; sin-cosine, exponential, parabola, fractional functions and polygon.

Tahseen F. Abbas (2008)[6] presented an algorithm that generates NC tool path for parametric surfaces depending on the accuracy of a desired surface. A designed surface was represented by sufficient control points, by using these control points, the surface was represented depending on Bezier technique to generate reliable surface. The proposed algorithm includes two functions, forward step function that computes the maximum distance between cutter contact points and the given surface tolerance and side step function which calculates the maximum distance between two adjacent tool paths with a given scallop height.

The aim of this study is to generate tool path and G-codes for complex shapes depending on mathematical equations and investigate optimum cutting characteristics of AL-Alloy 7024.The cutting parameters to be utilized are side step, feed speed, and cutting speed.

TOOL PATH GENERATION

Free form surfaces are relatively difficult to machine due to their complex geometry. Free form surfaces machining primarily has two phases, the first phase roughing and the other finishing. The present work focuses on generating tool paths for the finishing operation. Given any arbitrary free form surfaces and G-code machine have been generated to machine that surface using ball-end milling cutters on a 3-axis CNC machine. Tool path planning has been done on the offset surface

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Circular Interpolation for Forward Step

Circular arc interpolation is essential in manufacturing of curve contours. Thus, the problems of how to determine the parameters of the circular arcs and how to minimize the number of arcs according to desired interpolation accuracy.

Radius of Curvature and Normal Vector Calculations

Calculations have been made, which include the radius of the curvature and normal vector for each point of the surface through mathematical equation that adopted in the present work and using the ready-made surfnorm in MATLAB program and function as later.

$T = \acute{P}(u)$ Tangent …..(1)

$N = \acute{\acute{P}}(u)$ Normal.. (2)

$ķ = \frac{|TxN|}{|T|^3}$ …... (3)

$R = \frac{1}{ķ}$ radius of the curvature …. (4)

where, tool-path generation methods are classified as either the cutter contact based method or the cutter location based method depending on the type of tool path generation surface.

Cutter Contact and Cutter Location detection

The cutter contact point can be defined as the points that are located on the tool path, where there is instantaneous contact between the tool and the manufactured part. While the cutter location points are a fixed point on the tool which is taken as tool reference in moving along the tool path as shown in figure (1).

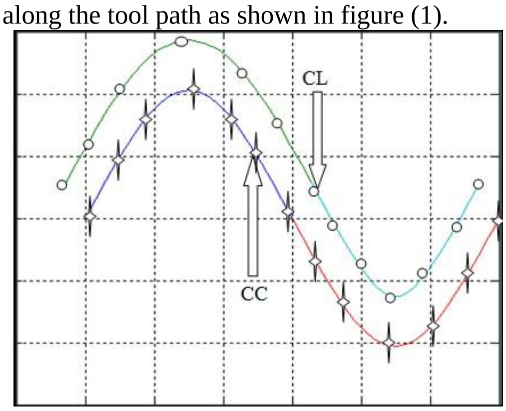

Figure (1): Cutter contact and cutter location points

To reduce machining errors, cutter contact points can be converted to cutter location points in order to compensate. The cutter location point is always placed along the normal direction of the point on the surface in 3-axis CNC milling machine using ball cutter. Thus, a cutter location point can be obtained from a cutter contact point and the surface normal of the point [7].

$Pcl = Pcc + r.n$ … (5)

where:

Pcc = cutter contact point

Pcl = cutter location point

r = *radius of cutter*

n = normal vector that can be calculated as follows:

$t = \frac{T}{|T|}$ unit vector for tangent …. (6)

$b = \frac{TxN}{|TxN|}$ …. (7)

n = t x b …. (8)

Side Step Estimation

The distance between two adjacent tool-paths is called the side-step. The side-step varies along the machined surface and the un-machined region between two adjacent tool paths is the scallop height. Typically, the desired value of the scallop height is given, from which the side-step is calculated

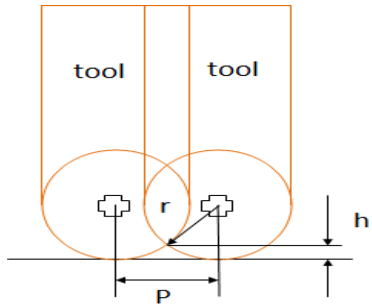

Figure (2): The workpiece machined showing the side steps

From figure (2):

$$h = r - \sqrt{r^2 - \left(\frac{P}{2}\right)^2}$$

$$P = 2\sqrt{r^2 - (r-h)^2} \quad \text{…… (9)}$$

where,
P= side-step length in physical domain,
r = cutter nose radius, h = scallop height [7].

Were, Nine tool paths types had been generated and MATLAB program had been used to facilitate the calculations according to flow chart figure (4) then the text file that created by MATLAB file will be opened in program CIMCO edit V5 as shown in figure (3) which include the G02 and G03 (circular interpolation) so as to simulate the tool path that generated from the equations and program that built in the present work.

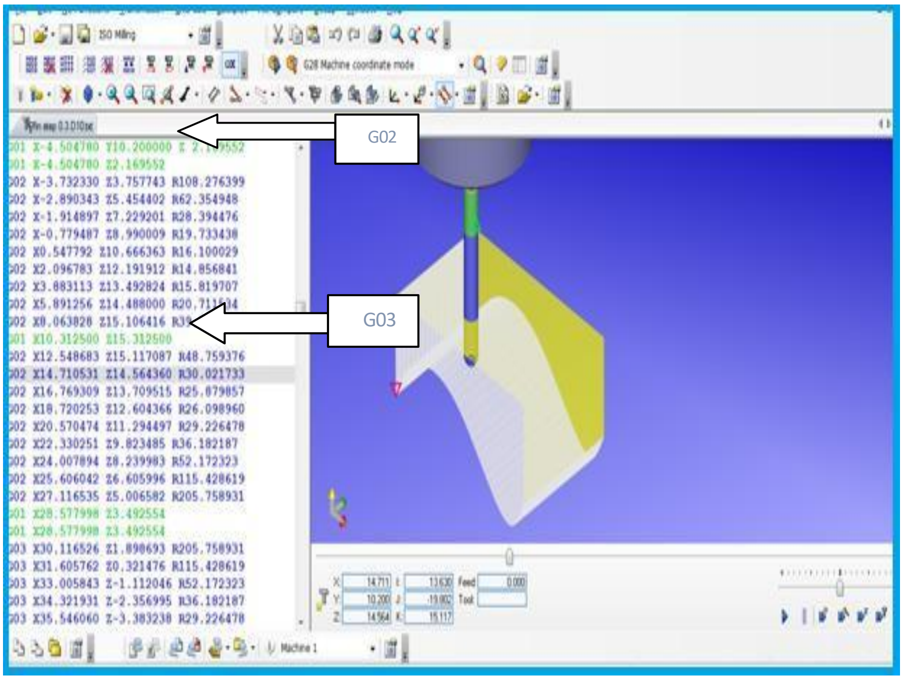

Figure (3): Windows of CIMCO edit V5

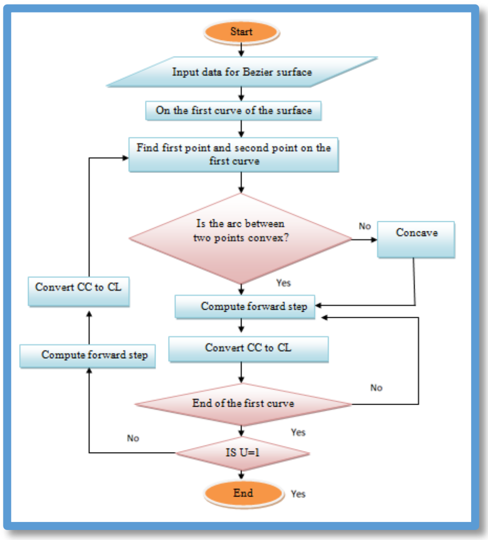

Figure 4: Flow chart of tool path in MATLAB.

Experimental set-up and procedure

Taguchi method

In this technique, the term (mean) refers to the output characteristic, (signal) to the desirable value and the term (noise) is the standard deviation. The determination of *S/N* ratio differs according to aims of function, i.e., a characteristic value. There are two characteristic values in the present work as "Larger is Better (LB)" and "Smaller is Better (SB)". Generally, the signal to noise (S/N) ratio represents the response of the data output in the Taguchi design of experiments [10].

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}(y_i^{\;2})\right] \quad ; \qquad i\text{=1, 2, and 3, to n......................(10)}$$

This equation is used to find the S/N ratio. The quality characteristic for MRR higher is the better type in case of compression or negative MRR. Therefore, the S/N ratio is given by:

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\left(1/y_i^{\;2}\right)\right] \quad ; \qquad i\text{=1, 2, and 3 to n......................(11)}$$

Where *n* is the number of (input), and y_i the measured characteristic value (output). The unit of *S/N* ratio is decibel.[8]

CNC machine

CNC machine type (C-TEK) used to implement the practical part. The workpiece with dimensions (30×60×40 mm) used in the experiment was Aluminum alloy (7024).The percentages of chemical composition are given in **Table (1)** to cut surface with depth 15 mm.

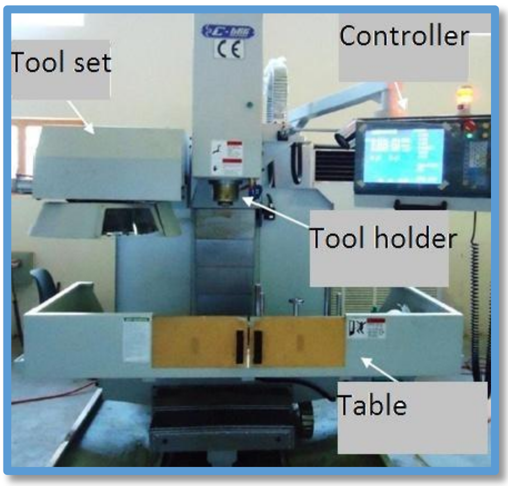

Figure (5): CNC C-TEK milling machine.

Table (1): Chemical composition of Aluminum 7024.

Cu%	Mg%	Si%	Fe%	Mn%	Cr%	Ni%
2.14	1.55	0.163	0.422	0.216	0.090	0.012
Ga%	Pb%	Zn%	Ti%	V%	Other%	AL%
0.010	0.071	4.93	0.038	0.007	0.132	90.219

Design of experiments

The design of experiments has an important role on the number of experiments needed. Therefore, cutting experiments should be well-designed. The total number of cutting experiments is (9 experiments) based on three levels three parameters (3^3). A full factorial design was performed to obtain MRR values. The parameters were side step, feed and diameter. The levels of cutting parameters are listed in **Table (2).**

Table (2): Cutting conditions

No	Parameter	Symbol	Level 1	Level 2	Level 3	Units
1	Side step	P	0.2	0.4	0.6	mm
2	Feed	f	1000	1500	2000	mm/min
3	diameter	D	8	10	12	mm

The final distribution of the experiments according to Taguchi orthogonal array for their levels and final result of MRR are shown in **Table (3)**. In addition to the predicted values by the program Minitab16 depending on the Taguchi method.

Table (3): Experimental design for the work

No	**Side step**	**Feed**	**diameter**	MRR measured (gram/sec)	MRR predicted (gram/sec)
1	**1**	**1**	**1**	4.285	5.0649
2	**1**	**2**	**2**	6.000	4.3602
3	**1**	**3**	**3**	7.334	8.1939
4	**2**	**1**	**2**	13.100	13.9599
5	**2**	**2**	**3**	11.582	12.3619
6	**2**	**3**	**1**	9.880	8.2402
7	**3**	**1**	**3**	25.210	23.5702
8	**3**	**2**	**1**	13.157	14.0169
9	**3**	**3**	**2**	17.964	18.7439

Metal removal rate (MRR)

The amount of metal removed by a single discharge is proportional to the diameter of crater and depth of which the melting temperature is reached. The spark is consider as a uniform circular temperature source on the electrode surface .The material removal rate of the workpiece will be measured by dividing the weight of workpiece before and after machining against the machining time that was achieved [9].

$$MRR = \frac{WPVB - WPWA}{MT} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where:

MRR= Material removal rate (g/min)

WPVB= Weight before machining (g).

WPWA= Weight after machining (g).

MT = time of machining (min).

CONCLUSION

The regarding between predicted and measured for material removal rate as shown in **Fig(6**), it is indicate there is an agreement in more values between two bar charts , in **Fig(6),** the comparison of the experimental data and the prediction value for Material Removal Rate. The independent of the independent values able to predict the dependent values coefficient prediction R^2 (which are taken from the program and are considered as an indication of the viability of the program on prediction) pieces are 93.9% for mean material removal rate. The mean of S/N ratio and these characteristics are shown for each characteristic. To study the designed parameter and to indicate the conditions are the main purpose of used the analysis of variance (ANOVA), which significantly affects the quality characteristic. This analysis use to find out the contribution of parameter in controlling the output of the milling process. The “P%” value in **Table (4)** shows the effectiveness for all condition toward affecting the related response characteristics within the limited range. From **Table (4),** it is contain the side step is the more significant parameter for maximum MRR, and feed is the next significant parameter for maximum MRR.

Table (4): ANOVA for third region.

Source of variance	Degree of freedom, υ	Sum of squares ,ss	Variance, V	F ratio	P (%)
Side step,p (mm)	**2**	**251.1**	**125.55**	**20.75207**	**75.04**
Diameter (mm)	**2**	**23.9**	**11.95**	**1.975207**	**7.15**
Feed speed, f (mm/min)	**2**	**47.5**	**23.75**	**3.92562**	**14.19**
Error ,e	**2**	**12.1**	**6.05**		**3.61**
Total	**8**	**334.6**			**100**

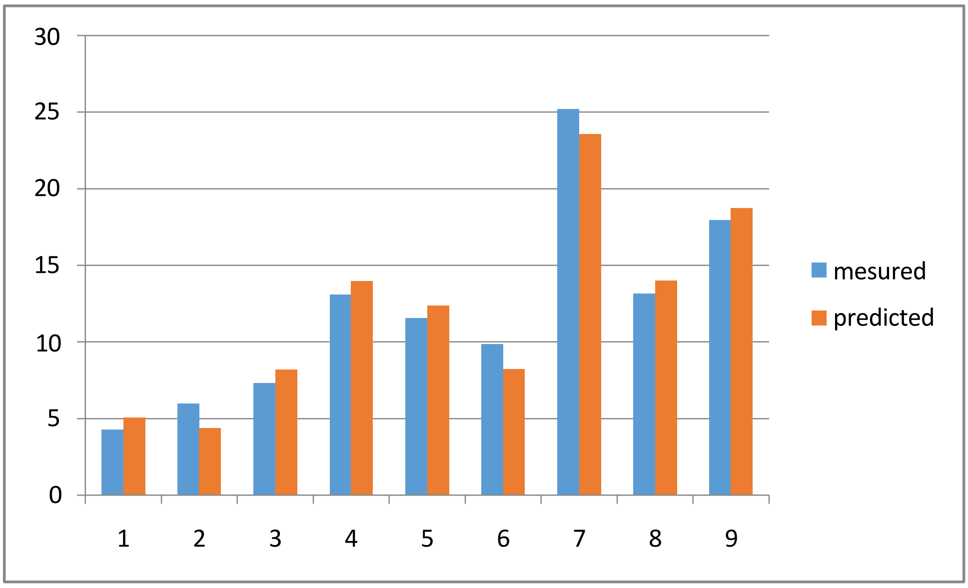

Fig (6: The diagram of the measured and predicted material removal rate for the experimental data.

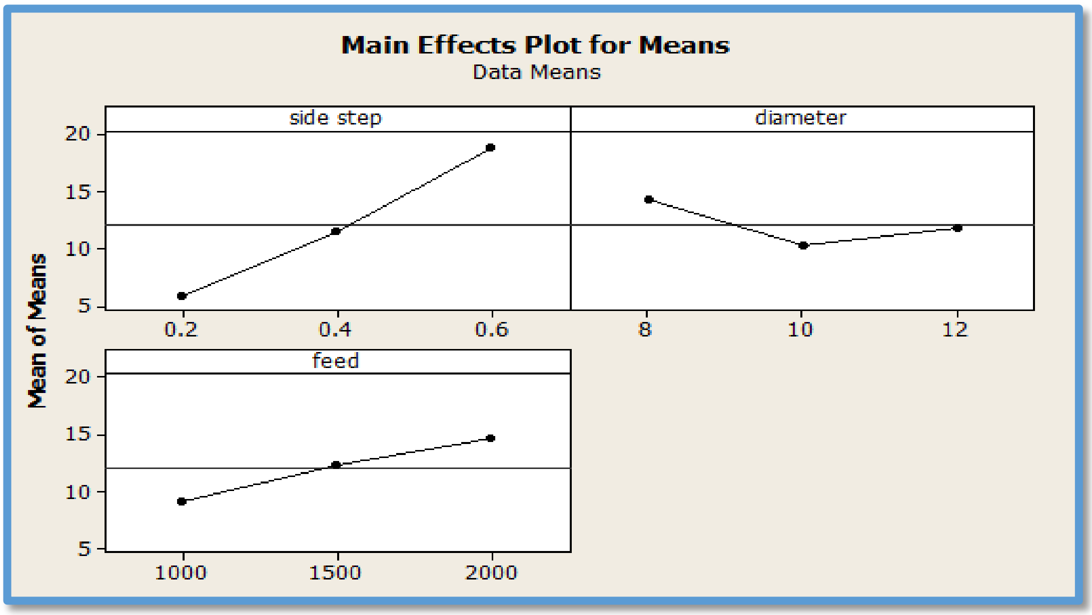

Fig (7): Main effects Plot for means (MRR)

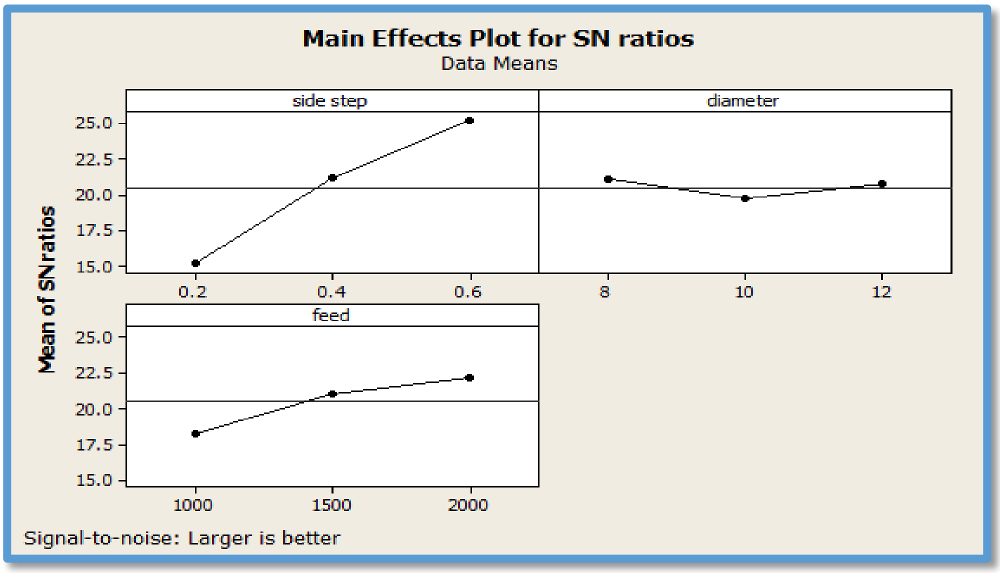

Fig (8): The mean S/N ratio plot for (MRR)

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