



Investigate effect of machining parameters on geometric form and orientation controls (2^3 design)

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Abstract

This study investigates the impact of machining parameters such as spindle speed, feed rate, and depth of cut on Face Milling of Aluminium 6061. Aluminium 6061 is commonly used in manufacturing due to its cost-effectiveness. A total of 2^3 full factorial designs with four central factors were employed to conduct reliable experiments. The response parameters chosen include Flatness, Straightness, Parallelism, which govern the form and orientation control of Geometric Dimensioning & Tolerancing (GD&T). The spindle speed, feed rate, and depth of cut influence flatness, straightness, and parallelism. Controlling machining parameters is crucial to achieve desired levels of flatness, straightness, and parallelism. Predictive modelling can assist in selecting optimal process parameters. ANOVA analysis was performed to determine the significance of input parameters. Flatness, straightness, and parallelism were measured using a coordinate measuring machine. The predicted values from the model closely match the experimental values.

Keywords: Speed; Feed; Depth of Cut; Flatness; Straightness; Parallelism; Analysis of variance.

Introduction

GD&T concept emphasizes the integration of various functions in a manufacturing organization. It could be a symbolic language used by engineers and producers to describe items and facilitate communication between entities that co-produce the product. The language can also be utilized for essential communication of accurate portion designs and their proper execution. GD&T was made to ensure proper get-together of mating parts, move forward quality, and reduce rework and related costs^{1,2}.

Flatness controls are regularly utilized on surfaces that can rest on a planar surface without moving forward and in reverse significantly. Geometric control can be confirmed by dial pointer, CMM, or other strategies³. In this work, the measurement control uses a coordinate measuring machine.

Amit Joshi and colleagues utilized the Taguchi method to investigate the effects of various parameters on the surface finish of aluminium cast heat treatable alloy during end milling. By varying spindle speed, depth of cut, and feed rate, they analysed the impacts. Their variance examination results indicate that the feed rate is the primary influencing factor in modelling surface finish⁴. D. Baijic and others studied the effects of cutting speed, feed rate, and depth of cut on surface roughness during face milling. They employed regression analysis and neural networks to predict surface roughness based on experimentally determined data^{5,6}. Patel and team explored the influence of Material Removal Rate (MRR) during the flashing operation of precision steel ball fabrication using a 2^3 -

replicate experimental design. They developed a model based on fuzzy logic^{7,8}. Schmitz and colleagues presented a case study quantifying the relative contributions of geometric, thermal, contouring, and cutting force errors to part errors for a circle-diamond-square work piece geometry under selected cutting conditions typical of high-speed milling⁹. Woo and co-authors examined high-speed cutting characteristics using the design of experiments¹⁰. Abdelilah et al. discussed the selection of cutting tools during milling operations¹¹.

Research Novelty and Managerial Implications: Conducting the research across different materials (metals, polymers, composites) and understanding how machining parameters affect geometric form and orientation controls. By controlling geometric form and orientation more precisely, manufacturers can improve the quality and consistency of their products.

The rest of the article is structured as follows: Section 2: Experimentation; Section 3: Analysis of variance; Section 4: Regression model and Section 5: Conclusion.

Methodology

Selection of work piece material, machine and cutting tools: The test work piece material is Al6061. Its typical composition along with its few mechanical properties are shown in Table-1. It is the most widely used material due to its less cost. Machinability tests were carried out on the Vertical Machining Centre [VMC 430].

Table-1: Component composition and mechanical properties of Al6061.

Components	Chemical composition %
Magnesium	0.8-1.2
Silicon	0.4-0.8
Iron	Max. 0.7
Copper	0.15-0.40
Titanium	Max.0.25
Manganese	Max.0.15
Chromium	Max.0.15
Others	0.04-0.35
Aluminium	Remainder
Mechanical Properties	
Ultimate Tensile Strength	310 MPa
Yield strength	275 MPa

Experimental Procedure, Measuring Techniques and Results: Experimental trials were conducted on Aluminium blocks measuring 50 mm x 50 mm x 40 mm. Machining parameters such as Spindle speed, Feed, and Depth of cut were selected as input variables for experiments following a 2³ full factorial design with four Center points. The levels of these input variables are detailed in Table-2 and illustrated in Figure-

1. The Aluminium work-piece block was securely clamped using a hydraulic vice. Initial machining was performed on all sides of the block before the face milling process was executed on each face. Measurement data for flatness, straightness, and depth of cut were obtained using a hexagon Coordinate Measuring Machine (CMM). Carbide inserts with a 32 mm diameter were utilized for machining the workpieces, and a 4 mm probe diameter was employed in the hexagon CMM. Table 3 presents the responses corresponding to coded factors and treatment combinations utilizing the 2³ full factorial design with four centre points¹².

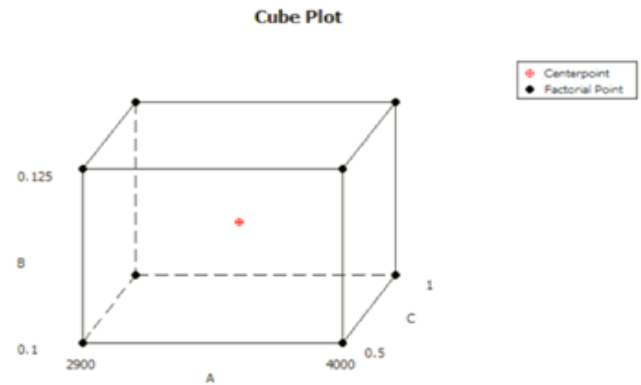


Figure-1: Factors and levels.

Table-2: Factors and levels

Factors	Coded Factors	Low Level (-)	High Level(+)	Centre Points
Spindle Speed (rpm)	A	2900	4000	3450
Feed (mm/min)	B	0.1	0.125	0.1125
Depth of Cut(mm)	C	0.5	1.0	0.75

Table 3:Experimental data for different treatment combinations.

Labels	A	B	C	Flatness	Straightness	Parallelism
1	-	-	-	0.001	0.001	0.002
a	+	-	-	0.003	0.003	0.001
b	-	+	-	0.001	0.001	0.003
ab	+	+	-	0.001	0.003	0.001
c	-	-	+	0.003	0.001	0.005
ac	+	-	+	0.004	0.003	0.004
bc	-	+	+	0.001	0.002	0.002
abc	+	+	+	0.002	0.003	0.015
Center points	0	0	0	0.007	0.004	0.121
	0	0	0	0.002	0.003	0.115
	0	0	0	0.002	0.002	0.115
	0	0	0	0.003	0.004	0.112

ANOVA-Analysis of variance study

To identify significant factor, individual factor effect on response analysis of variance (ANOVA) is performed. In a factorial experimental design is used to investigate the effect of

independent variables on dependent variables. Table 4,5 and 6 shows ANOVA table for flatness, straightness and parallelism respectively.

Table-4: ANOVA table flatness.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	0.00000850	0.00000850	0.00000283	0.50	0.708
2-way interaction	3	0.00000100	0.00000100	0.00000033	0.06	0.978
3-way interaction	1	0.00000050	0.00000050	0.00000050	0.09	0.786
Curvature	1	0.00000600	0.00000600	0.00000600	1.06	0.379
Residual Error	3	0.00001700	0.00001700	0.00000567		
Pure Error	3	0.00001700	0.00001700	0.00000567		
Total	11	0.00003300				

Table-5: ANOVA table Straightness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	0.00000850	0.00000850	0.00000283	3.09	0.189
2-way interaction	3	0.00000100	0.00000100	0.00000033	0.36	0.786
3-way interaction	1	0.00000050	0.00000050	0.00000050	0.55	0.514
Curvature	1	0.00000417	0.00000417	0.00000417	4.55	0.123
Residual Error	3	0.00000275	0.00000275	0.00000092		
Pure Error	3	0.00000275	0.00000275	0.00000092		
Total	11	0.00001692				

Table 6: ANOVA table Parallelism

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	0.0000654	0.0000654	0.0000218	1.53	0.368
2-way interaction	3	0.0000554	0.0000554	0.0000185	1.30	0.418
3-way interaction	1	0.0000281	0.0000281	0.0000281	1.97	0.255
Curvature	1	0.0332270	0.0332270	0.0332270	2E+03	0.000
Residual Error	3	0.0000427	0.0000427	0.0000142		
Pure Error	3	0.0000428	0.0000428	0.0000143		
Total	11	0.0334187				

Main effect and interaction effect on flatness, straightness and parallelism: A “main effect” is the effect of one of the independent variables on the dependent variable, ignoring the effects of all other independent variables. An “interaction effect” occurs when the effect of one variable depends on the

value of another variable. Figure-2,3 and 4 shows main effect plots of speed, feed and depth of cut on flatness, straightness and parallelism respectively. Figure-5, Figure-6, and 7 shows interaction effect plots for flatness, straightness and parallelism respectively.

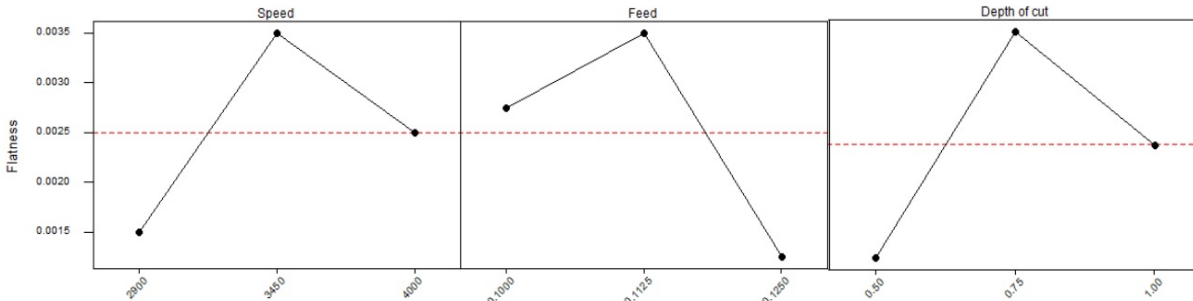


Figure-2: Parametric study on flatness.

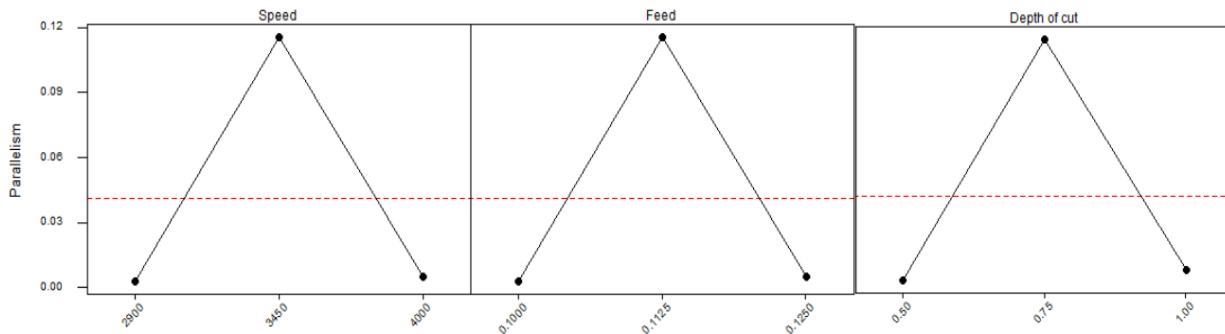


Figure-3: Parametric study on straightness

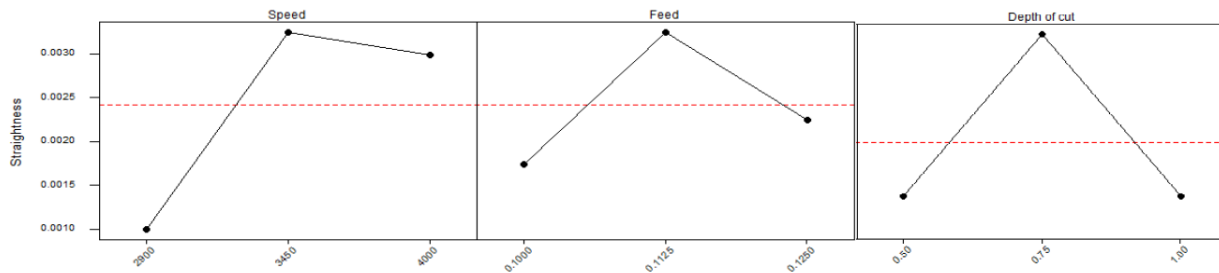


Figure-4: Parametric study on Parallelism.

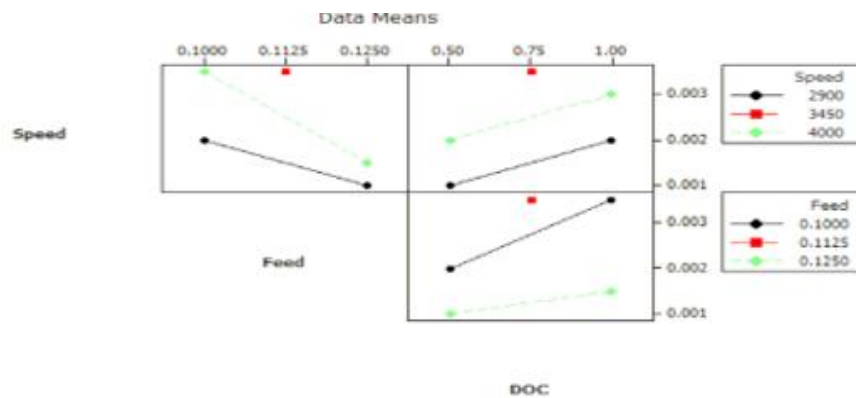


Figure-5: Interaction effect plot for flatness.

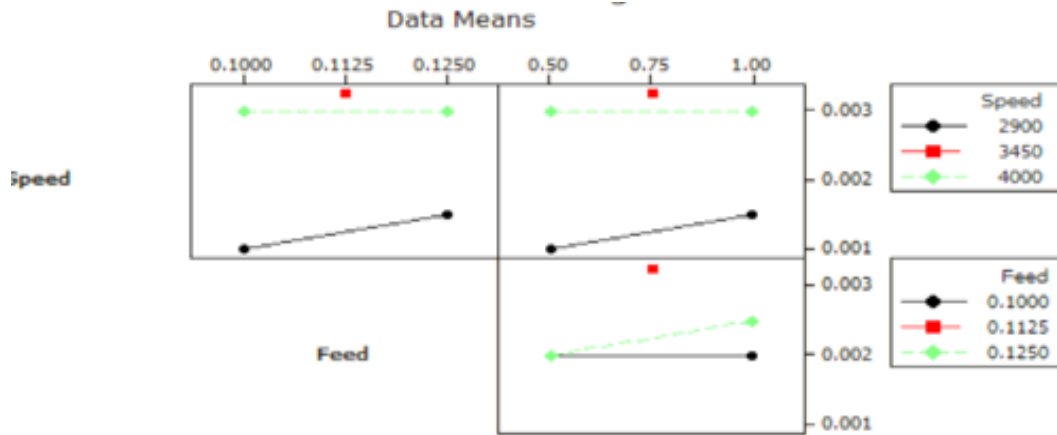


Figure-6: Interaction effect plot for straightness.

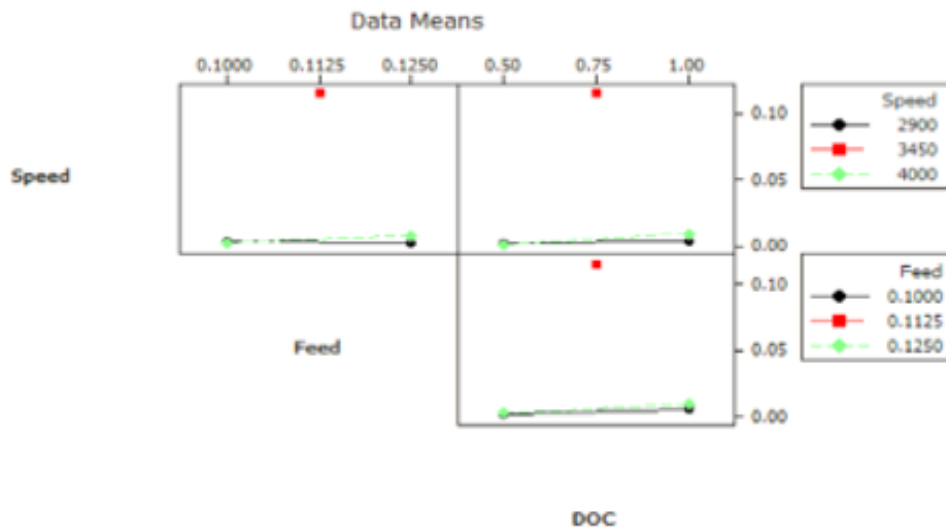


Figure-7: Interaction effect plot for parallelism.

Identification of Regression Model

The regression model broadly utilized to predict the responses is an algebraic representation of the regression line and is utilized to describe the relationship between the responses and predictor factors. Equations (1), (2) and (3) shows linear regression model for flatness, straightness and parallelism [13].

$$y = 0.002 + 0.0005 x_1 - 0.00075 x_2 + 0.0005 x_3 - 0.00025 x_1 x_2 - 0.00025 x_2 x_3 + 0.00025 x_1 x_2 x_3 \quad (1)$$

$$y = 0.002 + 0.0001 x_1 + 0.00025 x_2 - 0.00025 x_1 x_2 + 0.00025 x_2 x_3 - 0.00025 x_1 x_2 x_3 \quad (2)$$

$$y = 0.004125 + 0.001125 x_1 + 0.001125 x_2 + 0.002375 x_3 + 0.001625 x_1 x_2 + 0.001875 x_1 x_3 + 0.000875 x_2 x_3 + 0.001875 x_1 x_2 x_3. \quad (3)$$

Conclusion

From main effect plots, flatness is minimum at low level of speed and depth of cut means at higher value of feed, flatness is minimum. Flatness minimum at 2900 rpm, 0.1125 mm/rev. and depth of cut 0.5 mm. whereas, straightness and parallelism are minimum at low levels of all the independent variables. Straightness minimum at 2900 rpm, 0.1 mm/rev. and depth of cut 1.0 mm. Parallelism minimum at 2900 rpm, 0.1 mm/rev. and depth of cut 0.5 mm.

From the interaction plots for flatness and parallelism indicated that there is no interaction between the independent variables. Whereas, interaction plot for straightness shows minor interaction between speed, feed and depth of cut. Through the models are inadequate, it could be used as a means to understand that the machining parameters are influencing the geometry of the component produced.

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