Research Article

Parameter Setting for Rod Push Production Process on Multiple Responses : A Case Study in Motorcycle Parts Factory

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Abstract

The aim of this research is to study appropriate setting of parameters in the production process of Rod Push which affect quality characteristics such as diameter and surface roughness. Cycle time is also considered. The problem was done at a study plant and it was found that the actual process capability index (C_{pk}) of two quality characteristics was less than the manufacturer's standard of 1.33. Central composite design was used to examine Rod Push produced by CNC with 5 controllable process factors including three factors from rough-cutting process (spindle speed, feed rate, and depth of cut) and two factors from finish-cutting process (spindle speed and feed rate). The nuisance factor of CNC was cutting tool wear. After collecting all data, the appropriate setting was investigated. The new results indicated that the new condition yielded the better process performance index and shorter cycle time.

Keywords: DOE; Central Composite Design; Rod Push Process; CNC Turning Machine

Introduction

Rod Push is the pin in the clutch-gear of the motorcycle (as shown in Figure 1) fabricated by Computer Numerical Control (CNC) turning machine. CNC turning process are many factors; i.e. insert, spindle speed, feed rate, and depth of cut which affect quality characteristics (diameter and surface roughness) and cycle time. This research aims at setting appropriate value of the factors' parameters. Design of experiment was applied to improve quality characteristics of Rod Push directly and secondary cycle time.

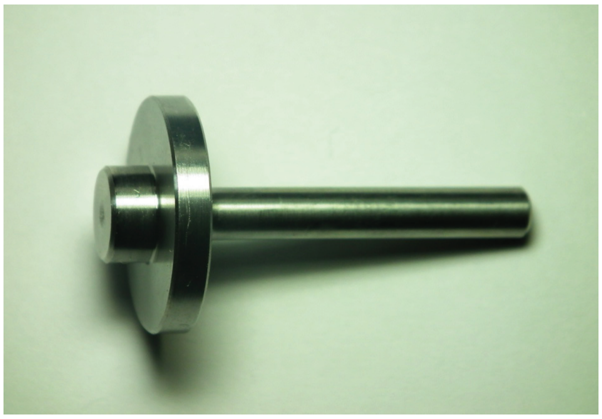

Figure 1 Rod push

Methodology

Response Surface Methodology

Response surface methodology (RSM) is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response (Montgomery, 2008).

This research applied RSM to find optimal condition of Rod Push production process. Central composite design (CCD) was used to approximate second order response surface model to analyse the optimal condition. Five factors were investigated including spindle speed of rough-cutting (A), feed rate of rough-cutting (B), depth of cut of rough-cutting (C), spindle speed of finish-cutting (D), and feed rate of finish-cutting (E), and the nuisance factor of CNC was cutting tools wear.

The research was studied whether five factors affected diameter, surface roughness, and cycle time (95% confident intervals). According to limitation of the amount of Rod Push, central composite design wherein the factorial portion of a 2^{5-1} fractional factorial design and blocking was used to reduce variance generated by nuisance factors.

The experimental plan in this study study was to divide the control factors into three levels as low (-1), medium (0), and high (+1) and increase outside range of the control factors up to ±2. This makes 33 samples to be used as summarized in Table 1.

After analysis of variance (ANOVA), it was necessary to verify the assumptions about the residual which included (i) a normal distribution, (ii) the average equal to zero, (iii) variance stability, and (iv) independence. Assumptions in regression were tested by graphical difference. (Sudasna-na-Ayudthya and Luangpaiboon, 2008)

Normal probability plot and histogram were used to test (i) that if the graph was a straight line and histogram was symmetric, then the normality assumption was satisfied

Residuals versus fits plot was used to test (ii), (iii) if the residuals randomly balance around the axis and scatter randomly on the display, suggesting that the average of residual equal to zero and variance of the original observations were stability

Residuals versus order plot was used to test (iv) if the residuals were random patterns, then residual are independence.

Result and Discussion

The commercial software, Minitab was used to determine second order response surface model and then the model was used to test the assumptions in regression model and ANOVA analysis. This step employed coefficient of determination ($R^2_{adj.}$) and lack of fit to test the fit of regression model.

Table 1 Factors and their levels for central composite design

Factor	Level of factors				
	-2	-1	0	+1	+2
Spindle speed of rough-cutting; A (rpm.)	2,250	3,000	3,750	4,500	5,250
Feed rate of rough-cutting; B (mm./minute)	0.1	0.4	0.7	1	1.3
Depth of cut of rough-cutting; C (mm.)	0.1	0.4	0.7	1	1.3
Spindle speed of finish-cutting; D (rpm.)	2,250	3,000	3,750	4,500	5,250
Feed rate of finish-cutting; E (mm./minute)	0.02	0.08	0.14	0.2	0.26

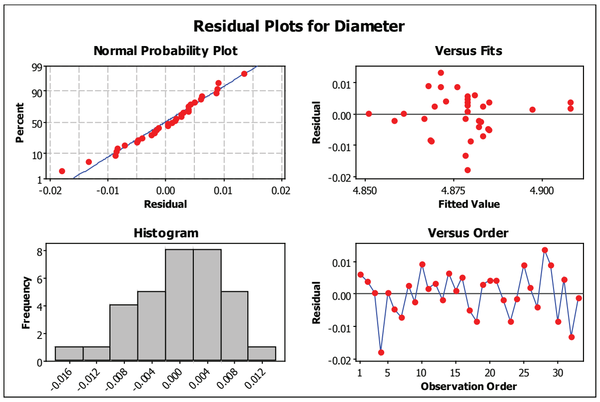

Figure 2 Assumptions in regression model testing (Diameter)

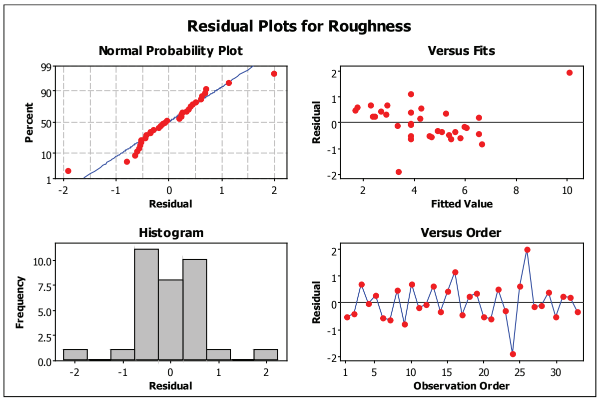

Figure 3 Assumptions in regression model testing (Surface roughness)

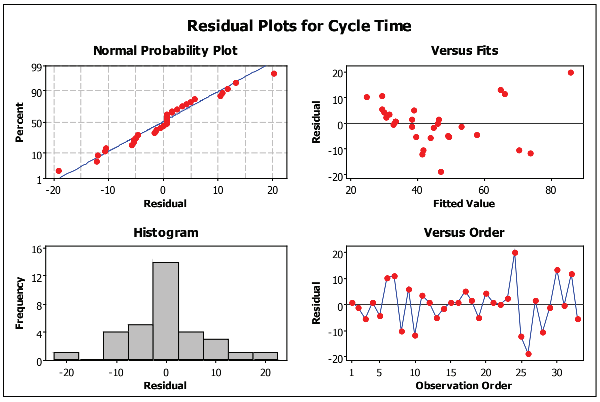

Figure 4 Assumptions in regression model testing (Cycle Time)

The assumptions tested by graphical difference in regression showed that all of three regression models were correct. The models had normal distribution with average equal to zero, variance stability, and independence (as shown in Figure 2-4).

Table 2 ANOVA Table for diameter

Source	SS	df.	MS	F	P-Value
Block	0.000003	1	0.000003	0.03	0.876
Regression	0.004521	20	0.000226	1.68	0.189
Linear	0.002839	5	0.000568	4.22	0.022
Square	0.000331	5	0.000066	0.49	0.776
Interaction	0.001480	10	0.000135	1.00	0.493
Residual Error	0.001069	11	0.000135		
Lack of Fit	0.000411	6	0.000178	2.17	0.207
Pure Error	0.000411	5	0.000082		
Total	0.006004	32			
R^2 = 75.36% R^2(adj.) = 28.31%					

Table 3 ANOVA Table for surface roughness

Source	SS	df.	MS	F	P-Value
Block	11.070	1	11.0700	7.99	0.016
Regression	56.416	20	4.3208	3.12	0.028
Linear	70.762	5	14.1524	10.21	0.001
Square	12.480	5	2.4960	1.80	0.193
Interaction	3.174	10	0.3174	0.23	0.986
Residual Error	15.241	11	1.3855		
Lack of Fit	13.118	6	2.1863	5.15	0.046
Pure Error	2.123	5	0.4245		
Total	112.727	32			
R^2 = 86.48% R^2(adj.) = 60.07%					

Table 4 ANOVA Table for cycle time

Source	SS	df.	MS	F	P-Value
Block	276.14	1	276.136	1.47	0.251
Regression	6629.42	20	331.471	1.76	0.167
Linear	4133.88	5	826.775	4.40	0.019
Square	2138.92	5	427.78	2.27	0.119
Interaction	356.63	10	35.63	0.19	0.993
Residual Error	2068.98	11	188.090		
Lack of Fit	2068.98	6	344.831	-	-
Pure Error	0.00	5	0.000		
Total	8974.55	32			
R^2 = 76.95% R^2(adj.) = 32.93%					

The results from ANOVA Table (Table 2-4) showed that either linear or square term in the regression models were significant which implied that all three models exist. All $R^2_{(adj.)}$ were high which demonstrated the appropriation of the three models showed in equation (1), (2), and (3).

However, for RSM the significances of the coefficients will not be considered in order to get the complete second order response surface models as follows:

$$\text{Diameter} = 4.87899 + 0.00092A - 0.00175B + 0.00067C - 0.00233D + 0.01042E - 0.00011A^2 - 0.00086B^2 - 0.00211C^2 - 0.00024D^2 + 0.00226E^2 - 0.00438AB + 0.00400AC - 0.00162AD + 0.00350AE - 0.00325BC - 0.00162BD + 0.00100BE + 0.00350CD + 0.00062CE - 0.00275DE \quad (1)$$

$$\text{Surface Roughness} = 3.8130 - 0.0865A - 0.2235B - 0.0823C + 0.1442D + 1.6922E + 0.0022A^2 - 0.3239B^2 - 0.1625C^2 + 0.2931D^2 +$$

$0.4185E^2 + 0.1802AB - 0.1494AC + 0.0125AD - 0.1481AE + 0.0720BC - 0.0218BD + 0.1195BE + 0.3110CD - 0.0391CE - 0.0570DE$ (2)

$\text{Cycle Time} = 33.28 - 1.96A - 6.12B - 5.87C - 1.46D - 9.71E - 1.24A^2 + 3.64B^2 + 3.39C^2 - 0.99D^2 + 6.76E^2 - 0.31AB + 0.31AC - 0.94AD - 0.56AE + 3.69BC + 1.19BD + 2.06BE - 0.19CD - 1.06CE + 0.69DE$ (3)

$$-2 \leq A, B, C, D, E \leq 2$$

The Appropriate Setting

This Research used equation (1) (2) and (3) to determine the appropriate parameters with response optimiser function in Minitab program, the appropriate parameters were A, B, C, D and E equal to 1.11, 0.60, 1.84, -0.49, and -0.46 respectively. The diameter was 4.8725 mm, the surface roughness of 2.44 micrometers (μm) and cycle time of 42.36 seconds, the composite desirability of 0.97 (as shown in Figure 5).

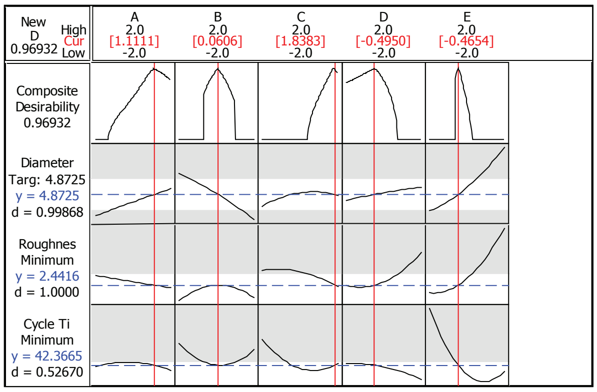

Figure 5 Optimisation plot

The appropriate parameters from Minitab program converted to the actual values which calculated as showed in equation (4) to (8).

$$\xi_A = (A * 750) + 3,750 \quad (4)$$

$$\xi_B = (B * 0.3) + 0.7 \quad (5)$$

$$\xi_C = (C * 0.3) + 0.7 \quad (6)$$

$$\xi_D = (D * 750) + 3,750 \quad (7)$$

$$\xi_E = (E * 0.06) + 0.14 \quad (8)$$

The actual value used in the production were ξ_A = 4,583 rpm, ξ_B = 0.72 mm/minute, ξ_C = 1.25 mm, ξ_D = 3,379 rpm, and ξ_E = 0.11 mm/minute.

Confirmation Test

The validation was to use the analysed parameters in actual production. The sample was randomly collected up to 20 replicates and the three response variable was recorded.

Before and after improvement were investigated as summarized in Table 5. After implement the new setting, the average of the diameter and surface roughness were closer to the target and standard deviation is reduced. The C_{pk} of diameter and the surface roughness was equal to 4.06 and 2.37, respectively (as shown in Figure 6 and 7), while the cycle time is decreased to 37 seconds (17.78% reduction).

Table 5 Comparative analysis of the before and after improvement

Responses Variable	**Before**	**After**
Diameter		
Target (mm)	4.8725	4.8725
Average (mm)	4.8821	4.8782
Standard Deviation (mm)	0.0038	0.0021
C_{pk}	0.64	4.06
Surface Roughness		
Target (μm)	2.50	2.50
Average (μm)	3.59	2.71
Standard Deviation (μm)	0.59	0.58
C_{pk}	0.80	2.37
Cycle Time (seconds)	45	37

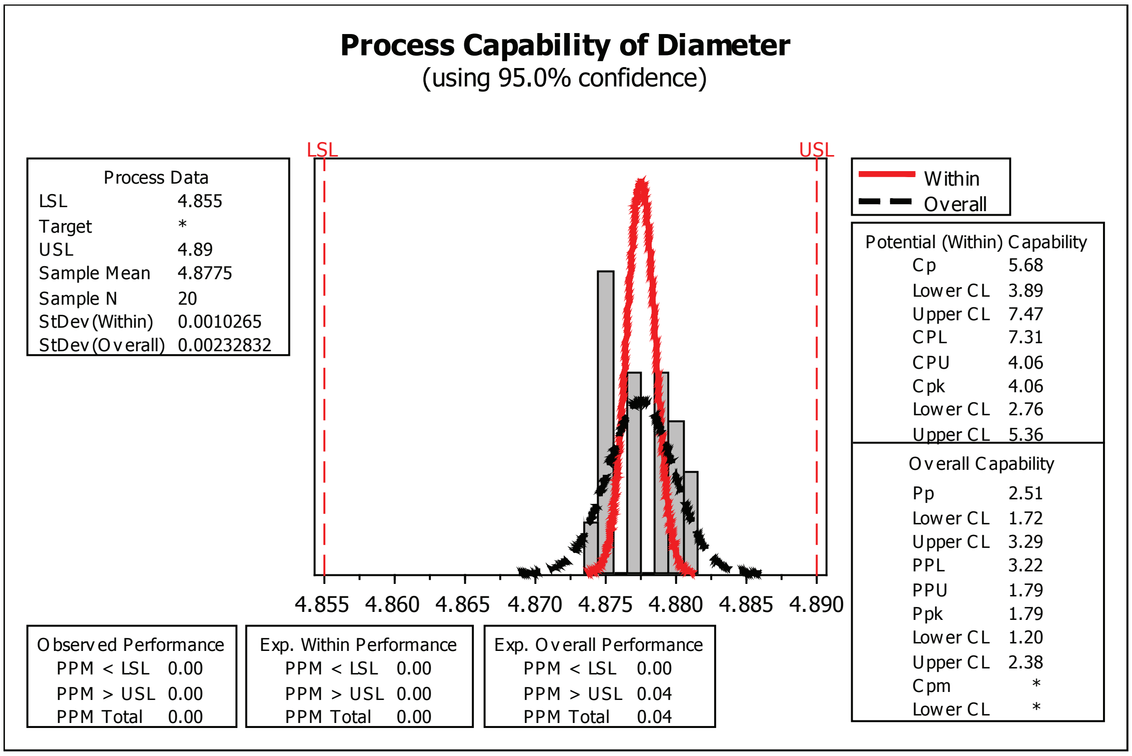

Figure 6 Process capability of diameter

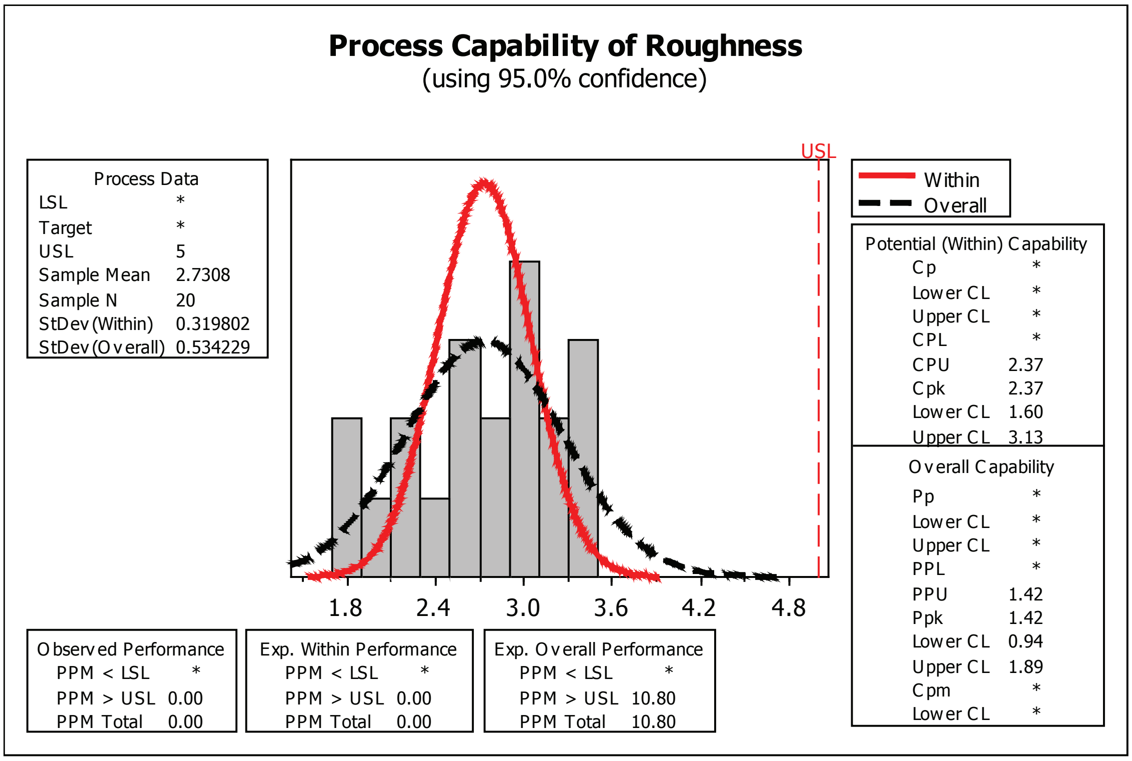

Figure 7 Process capability of surface roughness

Conclusions

The aim of this research is to find appropriate parameters for Rod Push production process, which affects the diameter, surface roughness and cycle time. Central composite design was used in this research.

The appropriate parameters from response optimiser were spindle speed of rough-cutting (A) = 1.11, feed rate of rough-cutting (B) = 0.60, depth of cut of rough-cutting (C) = 1.84, spindle speed of finish-cutting (D) = -0.49, and feed rate of finish-cutting (E) = -0.46. The diameter was 4.8725 mm, the surface roughness of 2.44 micrometers and cycle time of 42.36 seconds, the composite desirability of 0.97. After converted to the actual values were ξ_A, ξ_B, ξ_C, ξ_D, and ξ_E equal to 4,583 rpm, 0.72 mm/minute, 1.25 mm, 3,379 rpm, and 0.11 mm/minute respectively.

After the improvement, the results indicated that the diameter and the surface roughness were closer to the target value at confidence level of 95% and the C_{pk} of both response variables increase. Moreover, cycle time is reduced.

Suggestions

The influence of the factors to cutting tool wear has not been investigated in this research. So, further study could perform to improve the process.

Acknowledgments

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