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Optimizing the Cutting Parameters for Better Surface Quality in 2.5D Cutting Utilizing Titanium Coated Carbide Ball End Mill

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The 2.5D cutting operations are intended for creating NC programs for components with pockets, lugs, flat sections etc, for which, it is too time consuming to produce a 3D volume model of the component. A 2.5D machining processes can perform the cutting operation only in two of the three axes at a time, the movement of the cutter on the main planes before moves to the next depth produced a terrace-like approximation of the required shape. However, adopting the right cutting parameters could be an ideal solution to improve the product quality. This study focused on optimizing the cutting parameters for higher surface quality in 2.5D cutting utilizing titanium coated carbide ball end mill. These parameters include; machined surface inclined angle, axial depth of cut, spindle speed and feed rate. Taguchi optimization method is the most effective method to optimize the cutting parameters, in which the most significant response variables could be identified. The standard orthogonal array of L_9 (3^4) is used, while the signal to noise (S/N), target performance measurement (TPM) response analysis and analysis of variance (Pareto ANOVA) methods are carried out to determine which parameters are statistically significant. Finally, confirmation tests are carried out to investigate the optimization improvements.

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1. Introduction

Milling is a machining process where a surface is generated by continuous chip removal.[1] 2.5D cutting is one of the common milling operations especially in pocket and contouring milling operation. A 2.5D cutting possesses the capability to translate in all three axes but can perform the cutting operation only in two of the three axes at a time. The code for a 2.5D is significantly less than a 3D machining, while the 2.5D image is a simplified three-dimensional (x, y, z) surface representation that contains at most one depth (z) value for every point in the (x, y) plane. The 2.5D operations normally involve two types of processes, roughing and finishing process. During operation, the depth of cut remains constant and the cutter movement only interpolate two axes simultaneously which means that the cutter moves only on the main planes XY, YZ and ZX and then it moves to the next depth and repeated the same movement. A terrace-like approximation of the required shape is produced in a roughing process in order to remove the excess material. After the roughing has been done, a finishing process is used to transform the part to its final design shape with acceptable tolerance.[2] An extensive work has been done on 2.5D cutting operation such as a study in producing efficient cutter paths,[3] studying the cutter path patterns,[4] investigating cutter engagement functions in 2.5D milling operation,[5] cutting tool sizes for a 2.5D pocket etc. However, the demand for high quality focuses attention on the surface quality which is the surface condition of a workpiece after being modified by a manufacturing process.

The surface quality after machining processes correlates very closely with the cutting parameters and the tool geometries. These machining processes will only deteriorate the surface quality if the improper parameters are used, such as dull tools, too high feed speeds or depth of cut, improper cutting speeds, coolant or lubrication, or incorrect tool hardness. Hence, if the cutting conditions are not selected properly, the process may result in violations of machine limitations and part quality or reduced productivity. Therefore, it is important to understand the relationship between the cutting conditions and the surface quality of the machined part especially the surface roughness of

the machined surface, because of its effect on product appearance, function, and reliability.

Surface roughness is defined as a group of irregular waves in the surface, measured in micrometers (μm). The roughness data obtained by measurement can be manipulated to determine the roughness parameter. There are many different roughness parameters in use, but R_a is the most common. Surface roughness is mainly affected by different controlled cutting parameters that can be setup in advance, such as spindle speed, feed rate, and depth of cut. However, it is also affected by other uncontrolled variables such as the mechanical properties of the workpiece material, the type of the cutter, and the vibration produced during the process.[6,7] In metal machining, the small increase in R_a value was thought to be due to the increased unbalance of the tool at the higher cutting speed together with possibly higher cutting forces leading to vibrational effects.[8,9] Apparently, there will be an increase in surface roughness value with increasing cutting speed up to certain value, however, the surface roughness will decreases with the further increased cutting speed as the feed rate/tooth (mm/tooth) value will be decreased consequently with the increase of the cutting speed.[10] Low depth of cut will consistently provide a low surface roughness.[11-13] Meanwhile, increasing feed rate will increase the surface roughness of a material.[14] This is due to the increase in maximum chip thickness caused by the increase in feed rate and depth of cut. However, in 2.5D cutting, the effect of these parameters need to be investigated, especially the way of inclined machined surface angle affecting the cutting speed as shown in Fig. 1. Increasing the machined surface angle, θ, will cause the distance, r, to decrease. Furthermore, the decreasing r will decreases the cutting speed since the tool diameter is directly proportional to the cutting speed leading to different surface integrity characteristics.

Following the literature above, for optimizing the cutting parameters for lower surface roughness in 2.5D cutting, this study has been conducted by anticipating, spindle speed, feed rate, depth of cut and machined surface inclined angles as control variables. The main objective of this research work is to find the best combination of these parameters in milling of carbon steel workpieces utilizing titanium coated carbide ball end mill to get lower surface roughness. The conventional method to achieve that is to use the “trial and error approach. However, due to the large number of experiments, the “trial and error” approach is very time consuming. Hence, a reliable systematic approach for optimizing the machining parameters is thus required. Taguchi optimization method is an efficient, effective, reliable and simpler approach, in which the response parameters affecting surface roughness can be optimized. The steps in the Taguchi optimization method include: selecting the orthogonal array (OA) according to the numbers of controllable factors, running experiments based on that OA, analyzing data, identifying the optimum parameters, and conducting confirmation test with the optimal levels of all parameters.[15]

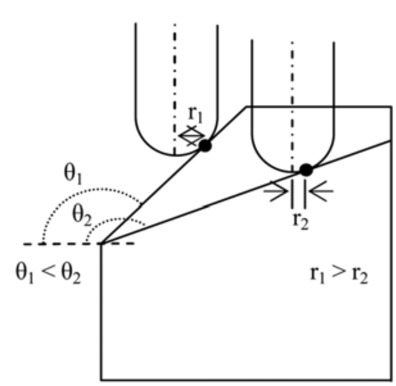

Fig. 1 Schematic of the tool position during machining

2. Design of Experiment

The most important thing of experiment design lies in the selection of control factors. All possible factors should be included, so that identification of non-significant variables could be done easily by Taguchi method, which is the best method to offer such facility. The control factors and experimental condition levels used are shown in Table 1. With the four control factors at three levels each, the Taguchi fractional factorial design used is the standardized orthogonal array $L_9(3^4)$. The levels of Factor A, and B, were chosen based on the result in preliminary experiment, while, both of the Factor C, and D levels are selected based on recommendations given by the tool manufacturer’s recommendation. The nine experiments with the details of combinations for each control factor (A-D) are shown in Table 2.

3. Experimental Setup and Procedure

After the orthogonal array has been selected, the second step in Taguchi optimization method is running the experiment based on that orthogonal array. The experimental setup used in this research is shown in Fig. 2. The machine used is a Five-axis CNC machining center (SPINNER U-620) built with Siemens controller. The tilting table integrated in the machine structure is useful for workpieces about 500 × 500 × 500 mm. The machine is designed for highest precision, best access to working area and top-value technical data as standard,

Table 1 Factors and levels used in experiments

Factors	Experimental Condition Levels (i)		
	1	2	3
A-Machined surface inclined angle (θ°)	100	110	120
B-Axial depth of cut (mm)	0.1	0.25	0.5
C-Spindle Speed (min^{-1})	3200	3700	4200
D-Feed Rate (mm min^{-1})	870	920	970

Table 2 L_9 (3^4) Orthogonal array

Experiment Level	Control factors and levels (i)			
	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1