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A Six Sigma approach for precision machining in milling

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Abstract

Controlling the process variations on the perimeter of a component to the targeted mean in milling is a huge challenge. Several factors such as spindle speed, feed rate, depth of cut, etc. affects this process variation. In this paper, spindle speed and feed rate are considered. Aluminum alloy 6061 widely used materials in aircraft, automobile and helicopter components is selected for this study. A full factorial design of experiment is carried out with five levels. Three different machining conditions: machining 2 mm thickness, machining 3 mm thickness and machining 4 mm thickness are considered. The objectives of the study are: (a) to determine the optimum cutting parameters to minimize the process variations found on the perimeter of the work piece;' (b) to determine which machining condition provides least process variations. To achieve this, 25 different combinations of experiments are conducted under each machining condition. Thus, a total of 75 experiments are carried out. Non-contact laser detection system is used to collect the real-time machining data. Two-way ANOVA is used to analyze the data. The results found that (a) both spindle speed and feed rate are significant over the process variations on the perimeter of a component; (b) feed rate is more significant on the outcome when compared to spindle speed; (c) process variations found on the perimeter of the component size 2 mm thickness are more when compared to a component size 4 mm thickness; and (d) mathematical models are derived for determination of optimum cutting parameters to achieve tighter process variations.

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Keywords: Machining, DOE, Process variation, Milling

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1. Introduction

Often "high quality" is referred as fewer defects, fewer failures, fewer errors, lesser process variations and so on. When parts are machined or manufactured to low quality means possible defect, failure or poor response time. Six Sigma is a systematic approach or methodology which aids to reduce these deficiencies so as to achieve a greater level of quality. By producing such "high quality" parts or products would lead to a longer product life usage, more product or service salable, lower total cost of a product, faster cycle time, lower warranty cost, and lesser scraps and reworks. When such framework is implemented correctly in a manufacturing processes of producing parts or components, a company could get a competitive advantage over its competition. However, Dhole et.al [1] argue that the current technology cannot produce perfect smooth surface finish whatever may be the manufacturing processes. Now, researchers are concentrating on minimizing the process variations found within a "high quality" parts or products. In other words, defining tight tolerances in manufacturing processes of a part or component. Fig. 1 (a) and (b) illustrates such process variations exists in an component being machined in milling; and that process variations representing in linear form respectively. Here, the objective is to minimize or eliminate this dimensional process variations (a_1, a_2, etc.), which is a huge challenge in the industry.

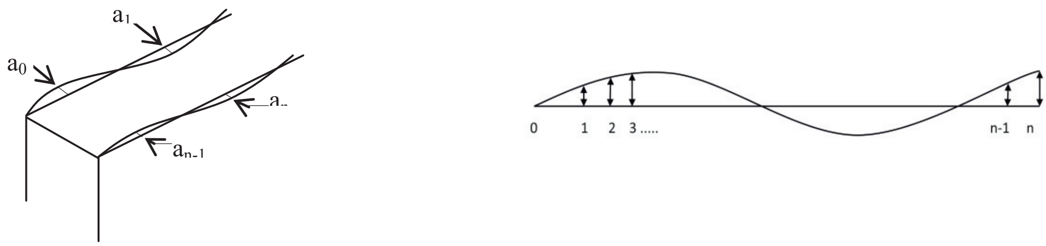

Fig. 1 (a) Process variations in a "high quality" part; (b) Process variations represented in linear form.

This paper demonstrates a model to minimize this dimensional process variations in milling using Six Sigma approach. For this, the mathematical model to achieve this precision machining and the selection of optimum cutting parameters are vital. The mathematical model is derived using the least square method and the selection of optimum cutting parameters in milling are derived using full factorial design of experiments.

2. Mathematical model

The process variations described in Fig. 2(b) is generalized from a straight line (i.e., first degree polynomial) to a k^{th} degree of polynomial and it could be represented as,

$$y = a_0 + a_1 x + \cdots + a_k x^k \quad (1)$$

and its residual is given by,

$$R^2 = \sum_{i=1}^{n} \left[y_i - n \left(a_0 + a_1 x_i + \ldots + a_k x_i^k \right) \right]^2 \quad (2)$$

Here, the objective is to minimize the R^2 =0 using least square method. This R^2 is solved using partial derivatives: