Cutting time in pocket machining for different tool-path approximation segments

G. Medina-Sánchez, E. Torres-Jimenez, R. Lopez-Garcia, R. Dorado-Vicente*

Department of Mechanical and Mining Engineering, Campus las Lagunillas, University of Jaén, Jaén 23071, Spain

Abstract

Despite of the importance of cutting time in pocket machining for manufacturing cost prediction and process planning, its estimation is usually neglected and conducted dividing the total tool path length by the programmed feed rate. Nevertheless, driving the tool with a constant feed rate is, in general, not possible. We study the cutting time dependency with the tool-path curvature, type of interpolation (linear G01 or circular G02) and the distance between interpolation points (segment length). The study, conducted in two different milling machines, shows how shorter segments increase the actual cutting time, which is lower for G01 than for G02. According to the experimental results, we define a piecewise equation that estimates the real cutting time respect to the segment length and type (G1 or G2).

Keywords: G-code; feed rate; experimental tests; cutting time.

1. Introduction

Cutting time is a main factor to obtain manufacturing costs. Accurate time estimation helps to optimize a manufacturing process [1]. Nevertheless, an accurate and general time estimation is a complex task due to its dependence on tool-path geometry, the interpolation used, the CNC machine as well as the process dynamic [2,3].

---

* Corresponding author. Tel.: +34 95-321-2439; fax: +34 95-321-2870.
  E-mail address: rdorado@ujaen.es

Theoretical time estimation, based on the programmed feed rate and the path length, is far from the real cutting time. The actual feed rate does not reach the programmed one; it changes through the whole cutting process. Complex tool-paths, with a huge number of interpolation segments, increase the frequency of tool acceleration-deceleration. This fact, joined to high programmed feed rates, produce a remarkable increment of the real cutting time respect to the theoretical one [4,5].

In order to obtain more accurate estimations, there are different strategies that have been developed during the last decades. Liu et al. [2] distinguish different solutions based on:

- Material removal rate. These methods compute the cutting time as a function of removed material rate, which varies along the tool-path.
- NC program and machine characteristics. Machine acceleration-deceleration capability and interpolation segment lengths are used to estimate cutting time. An interesting example of this category is explained by Coelho et al. [3], who define a parameter, machine response time (MRT), dependent on the machine characteristics, and it is able to predict the cutting time in each tool-path interpolation segment.
- Artificial intelligence techniques. Neural networks, fuzzy systems and other soft-computing tools to estimate the operation time.

Besides the previous solutions, it is noteworthy the development of heuristic procedures such as the technique proposed by Kim and Choi [6], and the research on the machining time dependence with the tool path geometry [7].

In general, it is difficult to reproduce heuristic procedures. On the other hand, according to Liu et al. [2], material removal and artificial intelligence methods are less accurate than those based on machine characteristics and ISO codes that, however, neglect the effect of the tool-path geometry.

In this work, we extend the method of Coelho et al. [3] to tool-paths with circular interpolation; so that the effect of the curvature can be take into account in the time estimation. Experimental tests are conducted in different CNC milling machines to estimate the actual feed rate along a line and several circumferences of different radii. For both the line path and the circular path, we assess different interpolation segment lengths and types (G01 and G02). Finally, we fit the experimental data by a degree-two polynomial to estimate the actual feed-rate as a function of the segment length. The sum of the feed rates by the segment lengths along the tool-path provides the actual cutting time.

The present paper is divided into 4 sections. Section 2 explains the methodology to determine the actual feed rate, the experiments design and the algorithm developed by the authors to estimate feed rate. Section 3 shows the experimental results and an example of time estimation for a tool-path composed of line and circular arcs. Finally, the main conclusions are summarized in Section 4.

2. Methodology

Experimental tests are designed in order to determine the value of the actual feed rate of several tool paths with different lengths between consecutive interpolation points (segment lengths). Experimental results are used to compare an estimation of the cutting time developed by the authors to the theoretical one.

2.1. Calculating actual feed rate

In order to estimate the real feed rate, we use the following procedure:

- Step 1. Write a set of NC programs, with different lengths between interpolation points (from 0.05 to 5 mm), to follow a reference path (we test straight lines and circles).
- Step 2. Run the NC programs at maximum feed rate.
- Step 3. Measure the total cutting time of each trajectory. The average real feed rate is calculated from the total length and the time measured.
- Step 4. Determine the actual feed rate f as a function of the approximating segment lengths s.