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Epicycloidal versus trochoidal milling- Comparison of cutting force, tool tip vibration, and machining cycle time

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Abstract

Among several strategies for high performance cutting, trochoidal milling is an efficient one for roughing process and reduces the cycle times significantly. For maximization of the efficiency and reducing the machining cycle time in the trochoidal milling, a novel tool path strategy, so-called, epicycloidal milling is developed. In this paper, mathematical model of the epicycloidal milling is presented. For the two mentioned strategies, comparison between cutting forces, tool tip vibrations, and machining cycle times are performed by four levels of machining experiments. To calculate the tool tip vibration, modal parameters of machine tool are achieved by system identification and then dynamic models of the machine spindle has been developed. It is observed that epicycloidal milling can improve machining cycle time, while the measured forces and calculated vibrations increased slightly.

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Keywords: Machining cycle time; Cutting force; Machining vibration; Trochoidal tool path; Epicycliodal tool path

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1. Introduction

The objective of high performance cutting is to increase the material removal rate and to lower cycle time, considering the machining process constrains such as machine tool dynamics, spindle power, machining qualities and the cutting tool failures [1]. In this context, some strategies have been used with some success, described as follows [2] and [3]:

- Optimizing of cutting parameters,
- Selection of optimum tool path,

Discussing the first above mentioned strategy, it is possible to increase machining parameters such as depth of cut, feed rate, and cutting speed, etc. to reach the goal. However, increase of the parameters is limited to some extends due to high cutting heat generation and the abrasive cutting materials as well as the constrains on tooling and the machine tool dynamics [4] and [5].

The second mentioned approach to enhance the roughing process performance is selection of optimum tool path. Among the new strategies, trochoidal milling is an efficient strategy for hard cutting [6]. trochoidal tool path strategy (in CAM softwares [2]) consists of circular motion and linear translation. Roughing by a trochoidal milling reduces the cycle time significantly. In comparison to the conventional slot milling, trochoidal slot milling reduces the number of axial passes, because the tool cuts using the entire cutting flute length [7].

Up to date, some researches have been performed in the field of modeling of trochoidal milling [2], [4], and [7] have already focused on analytical modeling of trochoidal tool path as well as prediction method for tool loads and wears. Here in this work, a novel tool path strategy, called epicycloidal milling is developed and its performance (cutting forces, tool tip vibration and cycle time) are compared with CAM software

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generating trochoid path as well as real trochoid curvature. The experimental tests are performed on the 5 axes milling machine tool and the force values are measured by table dynamometer. The tool tip vibration is calculated, after achieving the machine modal parameters through system identification and inputting the measured forces values to the developed system dynamic model.

2. Mathematical modeling of epicycloidal tool path

Figure 1 depicts a geometric model of trochoidal tool path. Mathematical models of trochoidal curvature path has already been developed by M.Rauch et al. [2].

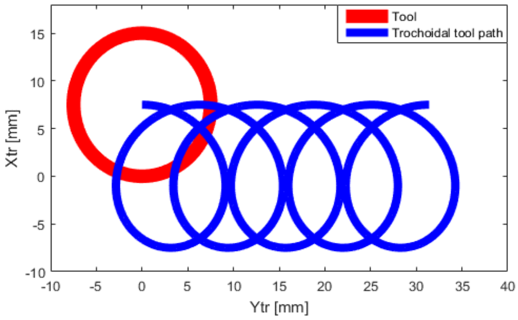

Figure 1. Model for trochoidal tool path

According to Figure 2, this work will focus on developing parametric equations of the novel tool path namely epicycloidal. According to the figure, the path which is developed for the center of the tool is divided into two arcs described as follows:

- Main arc is a trochoid curvature and determines the amount of step over (in green color),
- Side arcs that are trochoid curvatures (in blue color),

Defining the epicycliodal model for slot milling, the tool center positions in X and Y axes are:

$$X_{epi}=S_o\frac{\phi}{2\pi}+nB\sin\phi+nB\sin(m\phi) \tag{1}$$

$$Y_{epi}=nB\cos\phi+nB\cos(m\phi) \tag{2}$$

$$B=\frac{S_w-T_d}{2} \tag{3}$$

Where, X_{epi} and Y_{epi} are the positions of tool center in X and Y coordinate system, respectively. The S_o is step over, Φ is epicycloid path angle with the Y axis, S_w is slot width, and T_d is the tool diameter. n infers radial engagement ratio (rational number and smaller or equal to one) of side and main arcs. As an example, allocating $n=1/2$, the engagement ratio between the main and side arcs will be equal. m expresses the number of the side arcs.

As a result, using epicycloidal tool path (in comparison with trochoidal tool path), the step over value can be selected several times bigger. This makes the total curve length of epicycloidal tool path shorter than trochoidal path.

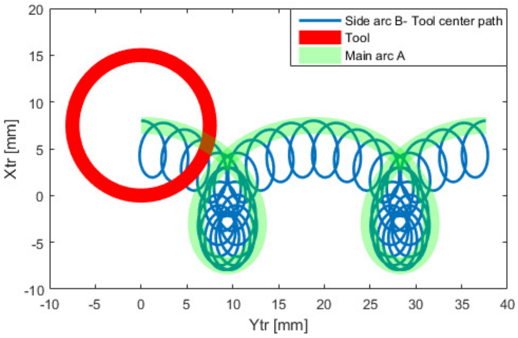

Figure 2.Model of epicycloidal tool path

3. Experimental system identification and machining tests, results and discussions

3.1. Experimental system identification process and modal parameters

In order to determine the modal parameters and developing the dynamic model for the spindle structure displacement, system identification is performed. In this scenario, an impulsive force was applied on the tool tip with an instrumented hammer. Then the accelerometers response (acceleration) is converted to the displacement (Figure 3).

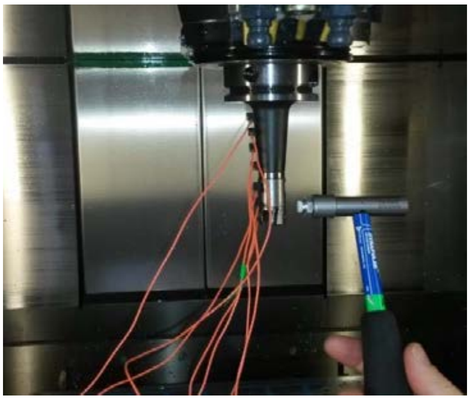

Figure 3. Experimental measurement of tool tip vibration by system identification

After experimental test, modal parameters are calculated by peak-picking technique [8]. In this case, the parameters are obtained from experimentally measured Frequency Response Function (FRF). Table 1 shows the identified modal parameters in Y axis.

Table 1. Identified modal parameters in Y axis

Modes	Freq. (Hz)	c_y (N-s/m)	k_y (N/m)	m_y (Kg)
1	2055	4.04e1	1.43e7	0,08568772

The modal parameters are used to create a simulated FRF. The compatibility of simulated FRF are validated by experimentally measured FRF. Figure 4 shows real and