Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, Volume 21, No. 1, ISSN 1726-9679
ISBN 978-3-901509-73-5, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria, EU, 2010
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Annals of DAAAM International

ADJUSTABLE TOOLHOLDER FOR TOOL RUNOUT ANALYSIS IN PERIPHERAL MILLING

DIEZ CIFUENTES, E[duardo]; PEREZ GARCIA, H[ilde]; GUZMAN VILLASENOR, M[ario] & VIZAN IDOIPE, A[ntonio]

Abstract: *Tool runout is an important phenomenon in machining process. Tool runout modifies cutting force pattern, deteriorates the quality of the machined surface and affects stability limits in peripheral milling. This paper proposes the use of an adjustable toolholder to emulate the effects of tool runout in peripheral milling. Measured and simulated cutting forces for different tool offset values are presented. The results presented show the usefulness of the proposed scheme to perform experimental milling tests varying tool runout.*
Key words: *milling, forces, runout, simulation*

1. INTRODUCTION

Peripheral milling is affected by several variables that make its modelling especially complex. Among these characteristics, radial tool runout has received special attention from researchers, starting with the work published by Kline and DeVor [Kline and DeVor, 1983], which focused on the effects of radial tool runout on cutting forces in end milling. Tool runout affects cutting geometry in end milling [Wang and Liang, 1996] making that each flute of the tool cuts uneven quantities of material. Important effects of tool runout in milling are the decrease of the milled surface quality and the increase of the radial and axial force variation [Wang and Zheng, 2003], which may lead to shorter tool life under uneven wear conditions for each cutting edge. In addition, a modification of the stability limits against chatter has been reported by Insperger *et al*. [Insperger *et al*. 2008] and Wan *et al*. [Wan *et al*. 2010]. Due to its complexity, it has been considered necessary the development of an experimental procedure oriented to the emulation of this cutting condition. In this work, an experimental procedure oriented to emulate tool runout is presented. This procedure is employed to validate a cutting force model for peripheral milling. Measured cutting forces and numerical simulations show the application of the proposed method to perform experimental testing and to analyze the effects of tool runout in peripheral milling in an efficient way.

2. TOOL RUNOUT IN PERIPHERAL MILLING

2.1 Tool runout modelling

Tool runout in milling may arise from many sources. According to Bao and Tansel [Bao and Tansel, 2000], tool runout mainly depends on spindle and toolholder characteristics. Nature of tool runout can be either static or dynamic. While static runout may come from tool-toolholder-spindle assembly errors or thermal deformation, dynamic tool runout may arise from other sources such as spindle and tool imbalance and non-uniform tool wear progression. Since tool runout is significantly affected by the eccentricity of tool-tool holder-spindle assembly, researchers relate tool runout to parallel eccentricity, using for the eccentricity definition two parameters, its magnitude and its angular position referring to a reference flute. When tool tilting is taken into account, other parameters should be considered such as the tilt angle, its angular position and the overhang length of the cutter.

In oblique cutting, each point along the flute has a different runout value. Thus, for simulation purposes, the tool was divided into a finite number of disks and a mechanistic approach in static milling regime was considered. The chip thickness for the j^{th} disk along the i^{th} flute of the tool can be calculated as follows:

(1)

Where m_i is a factor indicating that i^{th} flute is removing the material left by m^{th} previous flute, f_t is the feed rate per tooth, $\theta_{i,j}(\phi)$ is the cutting edge position angle along the flute, and ϕ is the tool rotation angle. $R_{i,j}(z)$ is the actual radius of the i^{th} flute at j^{th} disk and height z:

—— (2)

Where $R(z)$ is the flute radius at z, ρ is the tool offset magnitude, λ is the tool offset position angle, and $\psi_{i,j}(z)$ is the angle measured backwards starting from the tip of the i^{th} flute up to the portion of the cutting edge in the j^{th} disk, and N is the number of the flutes of the tool. More information on equations (1) and (2) can be found in references [Kline and DeVor, 1983; Wan and Zhang, 2009], as well as detailed information on mechanistic cutting force models. The cutting force coefficients were estimated in a previous work using a conventional collet chuck tool holder where tool runout was negligible.

2.2 Tool runout emulation

In this work, the authors propose the use of an adjustable toolholder, originally conceived as a boring head, to achieve the variation of the position of the tool in the toolholder. Figure 1 shows the experimental setup to vary tool offset. The tool offset can be modified by means of a scale screw. The movement of the tool in radial direction is accompanied by an error in tool position which is negligible, and a variation in tilting angle. This variation in tilt angle was found to be less than 0.5º.

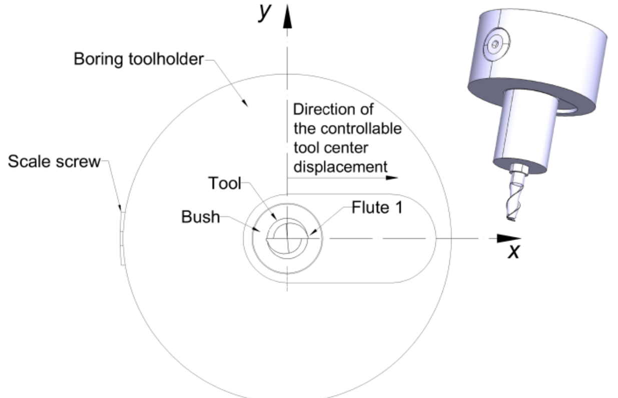

Fig. 1. Adjustable toolholder to vary tool offset magnitude.

In order to obtain the zero runout position, an initial adjustment was performed to ensure that both flutes cut the same amount of material. Figure 2 shows the procedure for the determination of the zero runout condition. From this point, it is possible to adjust the tool runout value within the desired range. The minimum allowable displacement, given by the proper goniometer of the toolholder, is 10 µm in diameter. In all cases the adjusted value of tool runout was measured with a dial indicator.

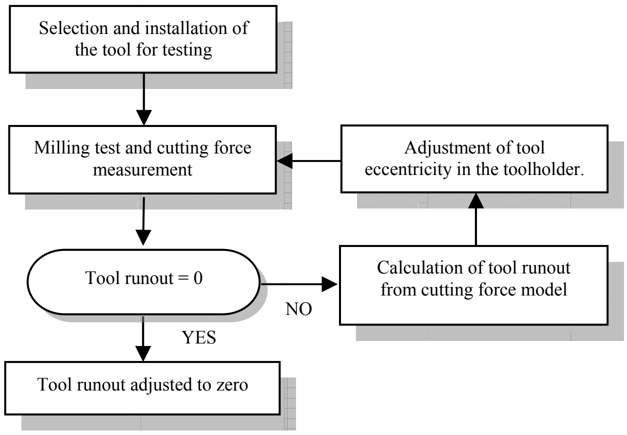

Fig. 2. Procedure to find the zero runout position.

3. EXPERIMENTAL VERIFICATION

In order to check the proposed procedure to emulate tool runout, several milling tests were conducted for a wide range of tool positions considering an extensive variety of cutting conditions and milling types, i.e. slotting, up and down milling, etc. Spindle speed and depth of cut were selected to avoid chatter. Special consideration was made regarding to spindle speed selection in order to prevent high vibrations of the assembly due to toolholder imbalance. In this way, a chatter free milling is assured.

Figure 3 shows the experimental and simulated cutting forces for different tool offset values. The cutting conditions are shown in table 1. The milling type analyzed is slotting. The position of the tool in the tool holder was varied from 0-30 µm (Figures 3a to 3d), where 0 µm correspond to a non-runout condition, as show the measured cutting forces in figure 3a. The tool offset position angle for all tests was set to zero by means of aligning the cutting edges with the direction of the controllable tool center displacement. Additional tests considering a tool offset position angle equal to 90º (not shown in this paper) were performed. In this case, a variation in tool offset magnitude does not have any appreciable influence in cutting forces.

Tool diameter	mm	8
Flute number	-	2
Helix angle	º	30
Spindle speed	rpm	1200
Feed per tooth	mm/flute	0.075
Axial depth of cut	mm	2
Workpiece Material	AL 7040	

Tab. 1. Cutting conditions

4. CONCLUSIONS

In this paper, a novel methodology to emulate tool runout in peripheral milling was developed. The main conclusions from this work are the following:

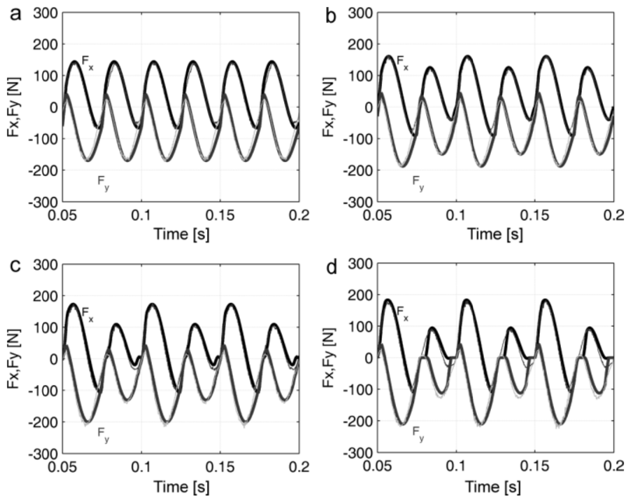

Fig. 3. Measured and simulated cutting forces for tool offset (a) 0 µm, (b) 10 µm, (c) 20 µm, and (d) 30 µm.

1. The use of an adjustable toolholder has been proposed to emulate tool runout in peripheral milling. The presented methodology allows us to test a cutting tool with different offset values under the same cutting conditions.
2. In relation to cutting force modeling, tool tilting was not considered in the calculation of the chip section. This issue might be considered as a limitation of this research. However, as measurements revealed, for the cutting conditions considered in this study, this factor did not represent an important source of error. In fact, it was shown that the errors associated to the setting of the runout magnitude were small in relation to the milling parameters considered in this investigation.
3. The cutting force model fit presented for three different runout conditions is good, as shown in figure 3. The small differences between measured and simulated cutting forces are due to the non-inclusion of tool tilt effect in the calculation of the chip section.

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