Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 58 (2017) 364 – 369

www.elsevier.com/locate/procedia

16th CIRP Conference on Modelling of Machining Operations

Surface generation modelling for micro end milling considering the minimum chip thickness and tool runout

Wanqun Chen[a,b], Dehong Huo[a,*], Xiangyu Teng[a], Yazhou Sun[b]

[a]School of Mechanical and Systems Engineering, Newcastle University, Newcastle upon Tyne, NE1 7RU, UK
[b]Center for Precision Engineering, Harbin Institute of Technology, Harbin, 150001, People's Republic of China

* Corresponding author. Tel.: 44 (0) 191 208 6230; fax: 44 (0) 191 208 6230. E-mail address: dehong.huo@newcastle.ac.uk

Abstract

Surface roughness is considered as one of the significant factors on the quality and functionality of micro components. Considering that in micro milling feed per tooth and uncut chip thickness are very small compared to those in conventional milling, it is necessary to study surface generation precisely in micro scale. This paper proposes a surface generation model for micro-end-milling process, where the effect of the minimum chip thickness (MCT) and tool runout are considered. The MCT values were determined through finite element simulations for AISI 1045 steel, and the magnitude of the tool runout in machining rotational speed was obtained by displacement measurement using capacitive sensors. Based on the proposed model, the influence of the tool runout, MCT as well as the tool geometric parameters on the surface generation was studied. Finally, simulation results were compared with experimental data and a good agreement was obtained.

Peer-review under responsibility of the scientific committee of The 16th CIRP Conference on Modelling of Machining Operations

Keywords: Micro milling; surface generation; modelling; tool runout; minimum chip thickness;

1 Introduction

Micro components are widely in demand in the fields such as electronics, telecommunications, medicine, bioengineering, and optics, which has encouraged the development of micro manufacturing processes [1-4]. Micro milling is recognised as one of the most versatile micro manufacturing processes [5], due to its high applicability for wide workpiece material, capability of producing 3D geometries with complex shape, excellent dimensional accuracy, high efficiency, low cost and environmental friendliness [6-9]. The size of micro features produced by micro milling are normally at the order of several tens to several hundreds of microns, which makes the subsequent finishing processes, e.g. grinding or polishing, expensive or even impossible. Producing high quality surface finishing directly from micro milling to meet certain stringent specification without subsequent processes has become a pressing task. Numerous research has been focused on the study of surface quality in micro milling in recent years. Oliaei and Karpat [10] investigated the influence of machining parameters on the surface roughness of stainless steel machining. Bissacco et al. [11] studied the size effects on surface generation by ball nose and flat end micro milling of hardened tool steel, and the effects of the increased ratio between cutting edge radius and chip thickness have been observed. Saklakoglu and Kasman [12] used regression analysis to develop a mathematical model and determine the effect of process parameters on the surface roughness and milling depth. Sun et at. [13] studied the influence of the feedrate on the surface roughness considering the minimum chip thickness. Vogler et al. [14] proposed a surface generation model to predict the surface roughness for the slot milling based on the minimum chip thickness concept. Li et al. [15] proposed a trajectory-based surface roughness model for micro end milling by considering the minimum chip thickness, micro tool geometry and process parameters. Based on this model, a surface roughness model with tool wear effect was developed by taking the material removal volume

Peer-review under responsibility of the scientific committee of The 16th CIRP Conference on Modelling of Machining Operations
doi:10.1016/j.procir.2017.03.237

and cutting velocity into account and was experimentally validated.

Previous research studied the influence of cutting tool geometry, machining parameters, tool wear and MCT on the surface generation in micro milling. However, spindle or tool runout has been ignored, even though tool runout presents an imperative impact on the surface generation due to the fact that in micro milling the magnitude of tool runout is comparable with the feed per tooth. In this paper, a surface generation model has been established taking account of both tool runout and MCT.

2 Micro cutting tool geometry and spindle runout test

The micro machining system used in this paper is a precision three axis meso-scale milling machine tool (Nanowave MTS5R) which is equipped with a precision high speed spindle with 6,000-80,000 rpm speed range. 0.5 mm diameter two flute tungsten carbide micro end mills were used in the simulation and experiments.

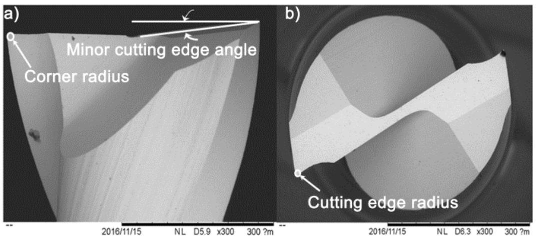

Fig. 1 SEM images of the micro cutter tool used in the simulation and experiment. a) side view; b) top view.

In order to obtain the geometry parameters, the micro end mills were examined by SEM prior to machining experiments. Fig.1 shows the side view and top view of the micro cutting tool. The geometrical parameters of the micro cutting tool are shown in Table 1.

Table 1 Parameters of the micro cutting tool

Parameter	Value
Cutting diameter, D	0.5 mm
Number of flutes, N	2
Cutting edge radius, r_e	3 µm
Minor cutting edge angle, k_r'	5°
Corner radius, r_ε	5µm

Tool runout can be considered as the total amount of inaccuracy of tool manufacturing errors and spindle/tool alignment errors. Different to conventional milling, the ratio of tool runout to tool diameter cannot be neglected in micro milling, thus it considered to be a significant factor during the machining process [16]. To obtain the tool runout in machining rotational speed, a runout test was carried out using a modular capacitive sensor system (capaNCDT 6200, Micro-epsilon) and a capacitive sensor (CS005, Micro-epsilon) with 1nm dynamic resolution and 50 µm measuring range is used. As shown in the schematic in Fig.2, the spindle runout in radial direction was measured on the cylindrical part of the tool.

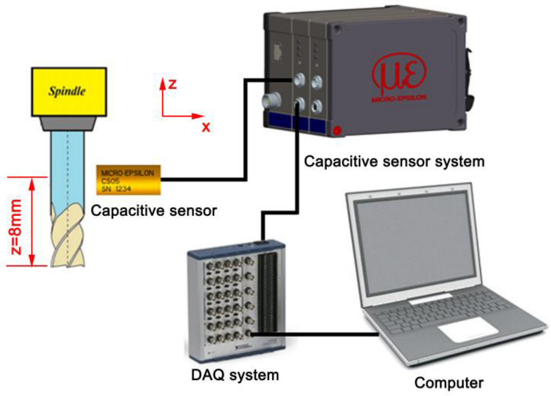

Fig.2 Schematic of the tool runout test

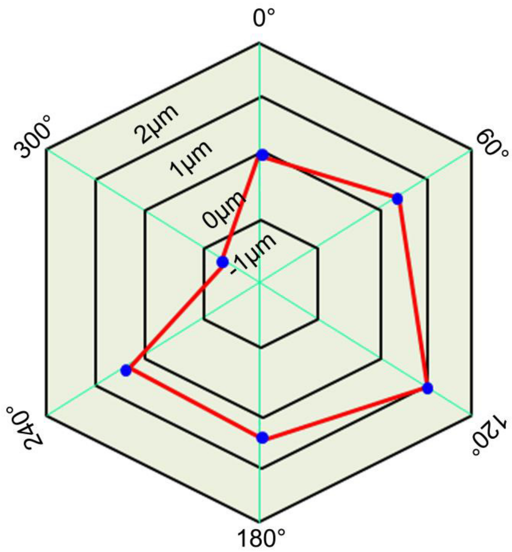

Fig.3 Measured tool run-out offset

Fig. 3 shows the run-out magnitudes and the related run-out angles in a given revolution (40,000 rpm) at z=8mm, which is measured from the tool tip as shown in Fig.2. The tool centre set as the coordinate origin of the tool coordinate system, and the position which parallel to Y axial is set as the 0°. Six angle positions are recorded per revolution at z=8 mm. It can be seen that the maximum measured offset distance and the corresponding location angle, are 1 µm and 120°, respectively.

3 Minimum chip thickness simulation

Due to the difficulties in measuring MCT experimentally, a finite element (FE) model was established using commercial package, ABAQUS/Explicit, to predict the minimum chip thickness. The parameters of the micro cutting tool used in the