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Modeling the mechanics and dynamics of arbitrary edge drills

K. Ahmadi [a,*], A. Savilov [b]

[a] Manufacturing Automation Laboratory, Department of Mechanical Engineering, The University of British Columbia, Vancouver, B.C., Canada V6T 1Z4[1]
[b] High Productivity Machining Laboratory, Institute of Aeronautics, Mechanical Engineering and Transportation, Irkutsk State Technical University, Irkutsk, Russia

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A B S T R A C T

This paper presents a new approach for modelling the cutting forces and chatter stability limits in drills with arbitrary lip geometry. The oblique cutting geometry at each point on the drill lip is modelled using parametric curve equations. The cutting force and process damping coefficients at different parts of the drill lip are identified empirically; the cutting force coefficients are identified from non-symmetric drilling tests, and the process damping coefficients are identified from chatter-free orthogonal turning tests. The presented approach provides a practical method for modelling the cutting forces and vibration stability without needing the detailed geometry of drill lips. The accuracy of presented model in predicting lateral and torsional-axial chatter stability limits is verified by conducting drilling tests using drills with various edge geometries.

1. Introduction

Usually the long overhang of the drills in deep hole drilling, and the spiral design of the drill bits make them prone to vibration instability in lateral and torsional-axial directions. Unstable vibrations of drill bits result in multi-sided hole shapes, bad surface quality and/or damage to drills. Developing predictive models for determining stable drilling conditions is essential for avoiding costly trials, rework and post-drilling operations.

Vibration instability, known as regenerative chatter in machining processes, is caused by the feedback between the vibration waves generated in subsequent cuts [1]. Numerous studies have been presented in literature on modelling regenerative chatter in different machining operations [2]. Tobias and Fishwick [3] developed the basic regenerative chatter model in drilling; they formulated the chip regeneration and developed the stability lobe diagrams. Armarego [4]developed the basic geometrical models of drills, and Armarego and Wright [5] presented mechanical models to predict cutting forces and torque in drills with standard geometry. The effect of drill geometry on the accuracy and roundness of drilled holes was investigated experimentally by Galloway [6]. Emma et al. [7,8] conducted drilling experiments to study the initiation of lateral chatter at different cutting parameters and used the damping characteristics of impact dampers to suppress the chatter in lateral directions. The beam theory was used [9] to model the dynamics of micro-drills. As the drill bit penetrates into the drilled whole the boundary condition of the vibratory system changes due to the wall contact. This variation was also studied in [9] and the natural frequency of the drill was shown to reduce by moving the drill inside the hole. Alternatively, Tekinalp and Ulsoy [10] used Finite Element Analysis to model the drill bit dynamics in lateral direction under different cutting conditions. Torsional-axial vibrations of drills were modelled using a single degree of freedom system and stability lobes were developed by Bayly et al. [11]. They showed that in torsional-axial mode the pre-twisted drill bit unwinds under the cutting torque and results in chip regeneration. Arvajeh and Ismail in [12] and [13] studied the lateral and torsional-axial vibrations of drills and investigated the effect of coriolis and gyroscopic forces on vibration instability. Their study also showed that, depending on slenderness of the drill and cutting conditions, both lateral and torsional modes may become unstable; thus both of the modes should be considered simultaneously for accurate modelling of drilling vibrations. Roukema and Altintas [14] presented a time domain simulation of drilling by considering the exact kinematics of the process. They also presented a frequency domain analysis of chatter stability in both lateral and torsional-axial modes [15], however their model underestimated the stability border because the effect of process damping at low cutting speeds was neglected in modelling. Ahmadi and Altintas presented a unified model for predicting lateral and torsional-axial chatter by including the effect of process damping [16].

* Corresponding author.
E-mail addresses: kahmadi@mail.ubc.ca, keivan.ahmadi@gmail.com (K. Ahmadi).

[1] http://www.mal.mech.ubc.ca.

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Variety of drills with different geometries are used in hole making processes to achieve a higher tool life and tighter dimensional tolerances, yet majority of above mentioned studies concentrate on drills with conventional geometry and straight lips. Stephenson and Agapiou [17] divided the arbitrary geometry of drill lips into straight, axially curved, radially curved, or gap segments and developed a mechanics model for predicting the cutting forces and torque. Assuming that the profile and kinematics of the grinding wheel are known, Chandrasekharan et al. [18,19] modelled the arbitrary geometry of drill lips, flank surface and flute surface using parametric curve and surface equations, respectively. The oblique cutting geometry (normal rake and inclination angles) and chip area were computed based on the lip's and flute's parametric equations, and then were used to obtain the cutting forces and torque.

In this paper, geometry of the drill lip is modelled by fitting parametric curve equations on a limited number of points measured on the lips. The cutting lips are divided into finite number of cutting elements with oblique cutting geometry. Mechanistic cutting force model is used for computing the forces at each

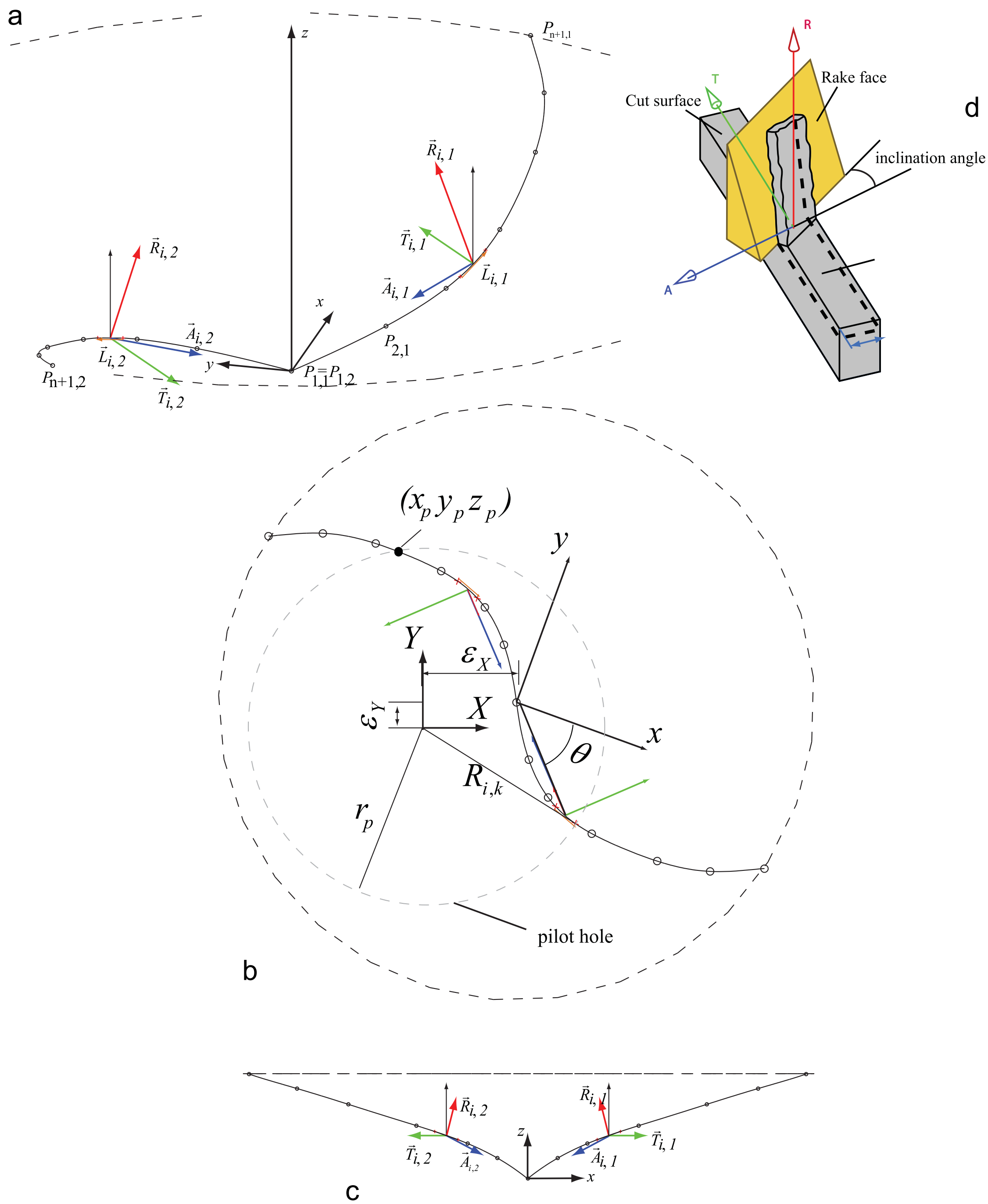

Fig. 1. Geometry of arbitrary drill: (a) 3D polynomial equation approximating the lips of Drill 2 with 15 mm diameter, tangential ($\vec{T}$), radial ($\vec{R}$) and axial $\vec{A}$ unit vectors; (b) top (xy plane) view of the lips of Drill 2 and (c) side (xz plane) view of the lips of Drill 2.