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A New Uncut Chip Thickness Model for Tilted Helical End Mills through Direct Correspondence with Local Oblique Cutting Geometry

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Abstract

Machining optimization algorithms in end-milling with helical cutters require an efficient and accurate model of the uncut chip thickness (*UCT*) at every location along the cutting flutes. Past work has either ignored the effects of tool tilt and orientation or treated them with simple assumptions about their coupling with tool shape. The current paper treats the problem with considerably greater generality using an arc-length parameterization of the axis-symmetric tool profile. Each discrete tool move was considered a 3-axis motion. Ignoring tool run-out, *UCT* was calculated in the direction of direct correspondence to local oblique cutting geometry, *i.e.*, perpendicular to the local cutting edge and cutting velocity. The flute curves were intersected with the engagement contour corresponding to the instantaneous tool-work contact and the *UCT* inspected within. For a candidate taper ball end mill, the *UCT* results of the new model were compared with the standard Martellotti model. The new model agrees closely with the Martellotti model in the flank region and predicts a more realistic variation in the ball region.

Keywords: milling, uncut chip thickness, helical, endmill

1 Introduction

Machining optimization has increasingly become an important tool for manufacturing engineers to reduce cycle time, control capital and overhead costs and drive higher product quality. Performed within a virtual machining simulation environment (*VMSE*), predominantly for end milling, feed-rates are scheduled to remove redundancy of slow motions in lighter portions and increasing safety against cutter breakage in heavier portions of cuts in a toolpath. Machining optimization is best done at the toolpath design stage so that the optimized toolpath can be run on any machine chosen to make the part. Therefore, considerations such as tool run-out, chatter stability etc. are of secondary importance. At this stage, tool designs can also be revised based on physical and geometrical quantities calculated

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from models of the machining process working within the *VMSE*. Later on, the same physical models can aid in machine selection or fixture design.

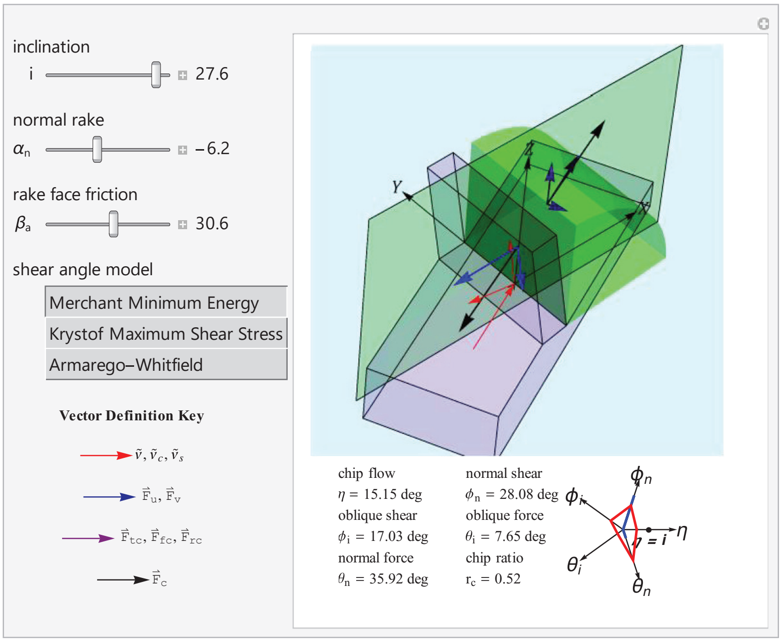

Figure 1: Wolfram Demonstration (Kountanya, 2014) on oblique cutting

The primary geometrical parameter governing the physical modeling of forces, moments, power etc. in end milling is the local uncut chip thickness (*UCT*). The maximum *UCT* deduced from the local *UCT* everywhere on all the flutes in a given move is indicative of whether the tool may chip and is related to part quality factors such as surface finish. Therefore, it is customary in machining optimization to set two limits; maximum force, power etc. and maximum *UCT*. Therefore, both the objectives necessitate a very accurate model for the local *UCT*.

Oblique cutting, a fundamental building block, needs to be carefully considered to model *UCT* and forces in helical end mills. Understanding the thin shear plane model in oblique cutting is possible through the interactive application in Kountanya (2014), a snapshot of which is shown in Figure 1. Knowing the local *UCT* and using mechanistic force models the differential force components along the normal and shear directions can be computed, which summed up, deliver the global force components and moments.

Oblique cutting geometry has been employed for helical end mills mainly by using distance along the axis of the cutter as the independent variable, for example, in Engin and Altintas (2001a) (2001b). This is equivalent to dividing the total tool into pieces of equal thickness along the tool axis. Then, the traditional Martellotti (1941) approximation of a circular tooth trajectory is used to calculate the *UCT*. While this approach is appealing and simple, sharp gradients in the cutter profile are not adequately resolved. For example, in flank milling applications with a taper ball end mill, the cutter engagement is predominantly in a zone with a constant shallow gradient. However, while cutting in the spherical ball portion of the cutter as in mold-milling applications, the gradient is essentially unbounded while approaching the tool tip.

The paper by Lazoglu (2003) presents data of an actual cutting edge profile collected with a CMM. Here, the tooth engagement was controlled through a switching function. This method, though simple in logic, may not allow arbitrary resolution of geometrical and physical quantities. The paper by Wu *et. al.* (2014) also takes the approach of uniform axial discretization. Liang and Yao (2011) note that