

# Simulation of Oblique Cutting in High Speed Turning Processes

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## ABSTRACT

A Finite Element Model is developed for Oblique cutting process in high speed turning of H-13 tool steel. The material model used for workpiece is elastic-thermoplastic including the strain rate sensitivity effect. In order to predict the tool performance, tool is considered as non-rigid and direct stresses are determined around the tool tip. Lagrangian approach is utilized along with adaptive meshing to minimize element distortion around the tool tip. The model predicts cutting forces in 3-directions at different inclination angles. The results are compared with experimental data and found to be in good agreement. The model is also able to predict stress and temperature contours in the workpiece and the cutting tool which help in predicting workpiece surface integrity and performance of the cutting tool.

## KEYWORDS

Finite Element (FE) Model, H-13, High Speed Turning, Oblique Cutting

## 1 INTRODUCTION

Finite element methods are being widely used to model and optimize the machining processes for the last three decades. Most of the work however is limited to orthogonal cutting which needs a two-dimensional model and plane strain formulation. However majority of the real world applications require an oblique cutting operation with a non-straight cutting edge. Usually cutting takes place on more than one cutting edge and the chip flow cannot be simulated under a two-dimensional scheme. In order to optimize machining processes three-dimensional models are indispensable that are capable to simulate three-dimensional chip flow using more than one cutting edge.

Both analytical and numerical methods have been used in the literature to model oblique cutting processes. An analytical model was developed by Moufki et al. (Moufki, Devillez, Dudzinski, & Molinari, 2004) based on steady state cutting and continuous chip phenomenon. The chip formation was realized by the shearing at a thin deformation zone called primary shear zone. The deformation at the tool-chip interface was not considered in the model. However the predicted cutting forces are found to be in good agreement with the experimental results for different kind of chip morphologies. Molinari and Moufki (Molinari & Moufki, 2005; Moufki & Molinari, 2005) developed a modified version of the Moufki's model (Moufki, et al., 2004) in which the round nose cutting edge is decomposed into a set of cutting edge elements. These local cutting edges produced elementary chips and the global chip flow has been defined using interaction between adjacent chip elements. The model was able to predict cutting forces, chip flow direction, contact between tool and workpiece and temperature distribution along the rake face. These models (Molinari & Moufki, 2005; Moufki, et al., 2004; Moufki & Molinari, 2005) assume a rigid, visco-plastic workpiece material, hence unable to predict residual stresses distributions. A three dimensional FEM model was developed by Fang and Zeng (Fang & Zeng, 2005) based on coupled thermo-elastic-plastic material flow. The model utilized a

rigid tool and hence unable to simulate stresses inside the cutting tool. Cutting forces were measured at different inclination angles of the tool. The model was however, not validated experimentally. Zou et al. (Zou, Yellowley, & Seethaler, 2009) made a new oblique cutting model by using an upper bound approach. They introduced two new variables based on process kinematics that replaces chip flow angle and coefficient of friction in the traditional scheme. The chip flow angles predicted from the new model were found to be comparable with the experimental results.

In numerical modeling methods, both finite difference methods (FDM) and finite element methods (FEM) have been used to model oblique cutting processes. An FDM model to predict temperature fields in oblique cutting was developed by Lazoglu and Islam (Lazoglu & Islam, 2012). The proposed a new method based on elliptical structural grid generation and the computational expense was found to be much less as compared to the conventional FE models. The temperature predictions were found to be in good agreement with the experimental data using the proposed finite difference method. Li and shih (Li & Shih, 2006) developed a 3D finite element model (FEM) using AdvantEdge® to simulate oblique turning of titanium. The model can predict cutting forces, temperature at the tool-chip interface and chip thickness and the effect of various process parameters and cutting geometries can be investigated. In addition to continuous chip formation, serrated chips were also modeled. All the results are found to be in close agreement with the experimental observations. In addition to traditional Lagrangian scheme, Arbitrary Lagrangian Eulerian (ALE) method was also employed by researchers to model oblique cutting processes. An ALE model for oblique cutting of AISI 4340 with cemented carbide tools was developed by Llanos et al. (Llanos, Villar, Urresti, & Arrazola, 2009). Chip flow angles and cutting forces were predicted with different cutting parameters and tool geometries. Overall a good correlation was found with the experimental findings.

This study aims to model oblique cutting process in high speed turning operations for H-13 tool steel. Unlike ALE models which are computationally expensive, the developed model uses a Lagrangian approach with element deletion technique. The model is able to predict initial chip formation, chip growth and steady state chip formation and does not need any prior assumption regarding the chip flow. The accuracy of the model is verified by comparing cutting, feed and radial forces with the experimental data. In addition tool performance and surface integrity of the workpiece is analyzed using stress and temperature distribution in the workpiece and the cutting tool.

## 2 EXPERIMENTAL SETUP

Experiments were conducted on hardened AISI H-13 tool steel tubes (49 HRC) using PCBN triangular tool inserts having an edge chamfer of 0.1mm x 25°. The properties and composition of the workpiece and tool materials are listed in Table 1.

Cutting speed, feed rate, inclination angle are taken as input variable for the Taguchi's orthogonal L9 array as shown in Table 2. A constant depth of cut of 0.5 mm and rake angle of  $-7^\circ$  is employed for all experimental runs. Cutting, feed and thrust forces were measured, using a Kistler model 9257B force dynamometer.

The 5017B dual-mode charge amplifier was used to process the force signals from the dynamometer. A data acquisition system consisting of a data acquisition card and software (Dynaware) was utilized to get the force signals and generate the sampled data for the analysis.

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