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# A Fundamental Investigation of Modulated Tool Path Turning Mechanics

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**Abstract**

This paper describes an experimental machining platform that provides metrology during tube turning (orthogonal cutting) for force, global temperature, feed motion, tool wear, and chip formation during continuous feed and modulated tool path, or MTP, turning. MTP is a technique which produces discontinuous chips by superimposing tool oscillations in the tool feed direction on the nominal feed rate to repeatedly interrupt the cutting process. AISI 1026 cold-drawn steel machining experiments are performed and data is presented for: 1) feed motion and modeling; 2) force measurement and modeling; 3) temperature measurement; and 4) chip formation for constant and MTP tool paths. Shear-localized chip formation that begins and ends during a single MTP chip is demonstrated.


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*Keywords:* *Machining; modulated tool path; cutting force; temperature; chip formation*

## 1. Introduction

Unlike milling where the tool constantly engages and disengages the workpiece, conventional turning, boring, and threading operations typically exhibit continuous cutting. Once the cutting edge is engaged with the workpiece, it remains in contact at a specified feed rate until the cut concludes. This tends to produce a continuous chip that can wrap and collect near the cutting edge when machining ductile materials; see Fig. 1. The local buildup of this

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continuous chip can result in one or more of several undesirable outcomes: workpiece scratching, tool damage, machinist injury, and increased cycle time to clear the chip from the tool/workpiece.

Chip management strategies include the use of specialized rake face geometries (i.e., chip breakers) and high pressure coolant directed at the rake face-chip interface to intentionally fracture the otherwise continuous chip. The performance of these strategies depends on the chip thickness, chip radius of curvature, and workpiece material [1], as well as the coolant pressure, direction, and location when high pressure coolant is applied. An alternative approach to these techniques is modulated tool path (MTP) turning, where individual chips are formed by repeatedly interrupting the continuous chip formation via the superposition of tool oscillations on the nominal tool feed motion. In this case, successful chip separation is based on the tool oscillation frequency relative to the spindle speed and the oscillation amplitude relative to the global feed per revolution.

Prior MTP efforts have demonstrated its effectiveness for controlling broken chip length in both turning [2-5] and threading [6]. In this paper, an experimental platform is described that provides metrology during tube turning (which approximates orthogonal cutting conditions) for cutting force, global temperature, feed motion, tool wear, and chip formation during MTP turning. Example data is presented with a focus on: 1) feed motion and modeling; 2) force measurement and modeling; and 3) chip formation for MTP tool paths.

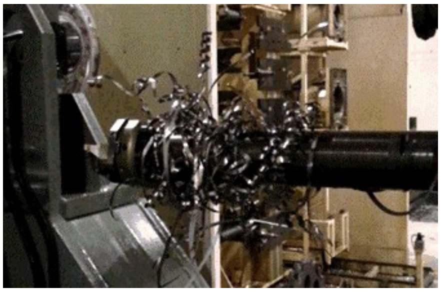

Fig. 1. Chip buildup observed in a boring operation.

**Nomenclature**

| | |
|---|---|
| MTP | modulated tool path |
| OPR | tool oscillation frequency relative to the spindle speed |
| RAF | oscillation amplitude relative to the global feed per revolution |
| $f$ | tool oscillation frequency (Hz) |
| $\Omega$ | spindle speed (rpm) |
| $A$ | tool oscillation amplitude |
| $f_r$ | global feed per revolution |
| $z$ | feed motion including the nominal feed and sinusoidal MTP oscillation |
| $F_c$ | force in the cutting direction |
| $F_t$ | force in the thrust direction |
| $b$ | chip width |
| $h$ | chip thickness |
| $k_c$ | force coefficient in the cutting direction |
| $k_t$ | force coefficient in the thrust direction |

## 2. MTP Description

As noted, MTP is a turning technique which produces discontinuous chips by superimposing oscillations in the tool feed direction to repeatedly interrupt the cutting process [5]. An exaggerated depiction of an MTP turning