Prediction of Multi-Flute Machining Forces in Transient Cuts

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Introduction and Motivation

- Most of Cutting Time is Spent on Transient Cutting
- Continuous Change Cutting Configuration and Cutting Force
- Variant Surface Texture and Accuracy of Workpiece
- Help to Optimize a Cutting Process and Improve Workpiece Quality
Cutting Force Model at Steady State

- Closed-Form Expression of Cutting Force in the Frequency and Time Domain
- Cutting Edge Function
- Cutting Condition-Speed, DOC and Feed Rate
- Material Properties
- Can Be Used for Any Cutting Configuration in Steady State Cutting
  - Helical End Milling
  - Face Milling
- Verified by A Variety of Tests
- Extended this Model to Transient Cutting
Down End Milling

**Time Domain**

- Cutting forces in angle domain - Cutting No. 31

**Frequency Domain**

- Cutting force in frequency domain - Cutting No. 31

**Specifications**

- Speed = 210 RPM
- Feed Rate = 5 ipm
- Axial DOC = 0.1 in
- Radial DOC = 0.05 in
Up Face Milling

**Time Domain**

- $F_x$ (lbf)
  - Angle (degree)
  - $F_x$ (lbf)
  - Angle (degree)
  - $F_z$ (lbf)
  - Angle (degree)

**Frequency Domain**

- $F_x$ (Hz)
  - Frequency (Hz)
  - $F_y$ (Hz)
  - Frequency (Hz)
  - $F_z$ (Hz)
  - Frequency (Hz)

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**Specifications**

- Speed = 420 RPM
- Feed Rate = 5 ipm
- Axial DOC = 0.05 in
- Radial DOC = 0.9 in
Basic Idea of Modeling Transient Cutting Force

- Considering a cutting in a very short cutting time, the change of cutting configuration may be negligible and cutting forces during this time can be computed by using the above steady state model.

- Discretizing a continuous transient cutting process into a series of steady state cutting processes with different cutting configurations, transient cutting forces can be constructed by using the model at steady state cutting condition.
Transient Cutting Configuration

\[ \vec{F} = G(y_2 (\Delta t \cdot m)) - G(y_1 (\Delta t \cdot m)) + G(y_4 (\Delta t \cdot m)) - G(y_3 (\Delta t \cdot m)) \]

Phase 1

\[ \vec{F} = G(y_2 (\Delta t \cdot m)) - G(y_1 (\Delta t \cdot m)) \]

Phase 2

\[ \vec{F} = G(y_4 (\Delta t \cdot m)) - G(y_3 (\Delta t \cdot m)) \]
Helical End Milling

- High Speed Steel End Mill
- Diameter of 7/16 Inch
- Helix Angle of 30 Degree
- Flute of 4
- Aluminum 6061
Example 1 (Up Engaging Cutting)

Speed = 420 RPM  
Axial DOC = 0.18 in  
Feed Rate = 6 ipm  
Radial DOC = 0.3 in
Example 2 (Down Disengaging Cutting)

Speed = 420  RPM
Axial DOC = 0.18 in
Feed Rate = 6 ipm
Radial DOC = 0.3 in
Example 3 (Down Engaging Cutting)

Speed = 210 RPM  
Axial DOC = 0.2 in  
Feed Rate = 4 ipm  
Radial DOC = 0.2 in
Conclusions

- General Cutting Force Model
- Explicit Expression
- Simple Computation Method
  - Discretization and Superposition
- Good Agreement Between Predicted and Measured Cutting Force
  - Waveform
  - Average Error 15%