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

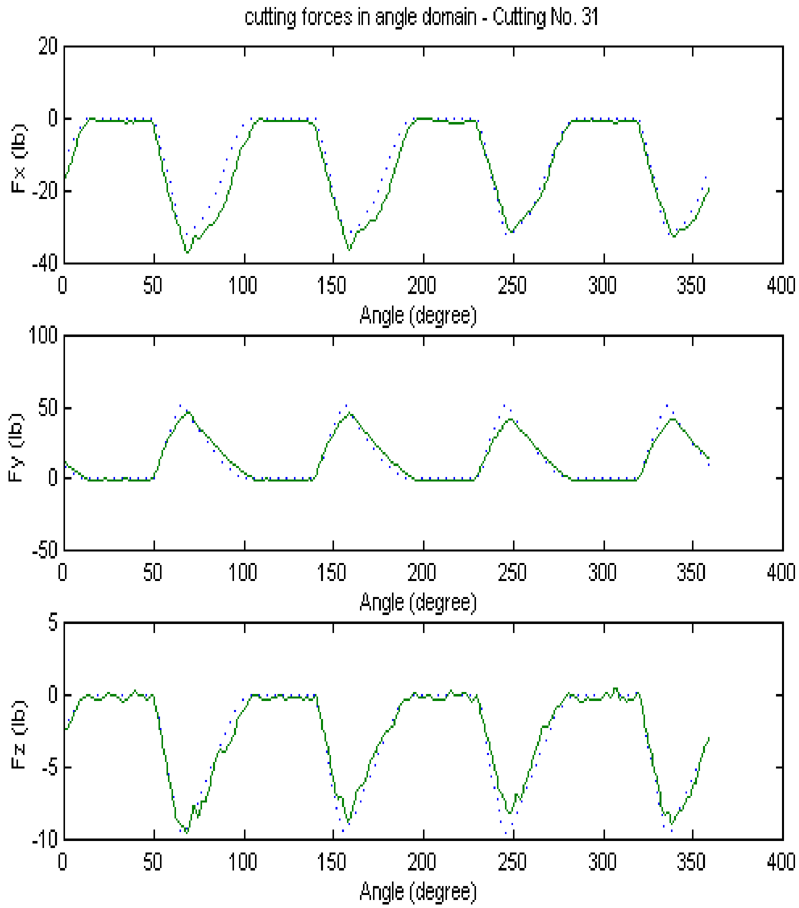
Cutting Force Model at Steady State

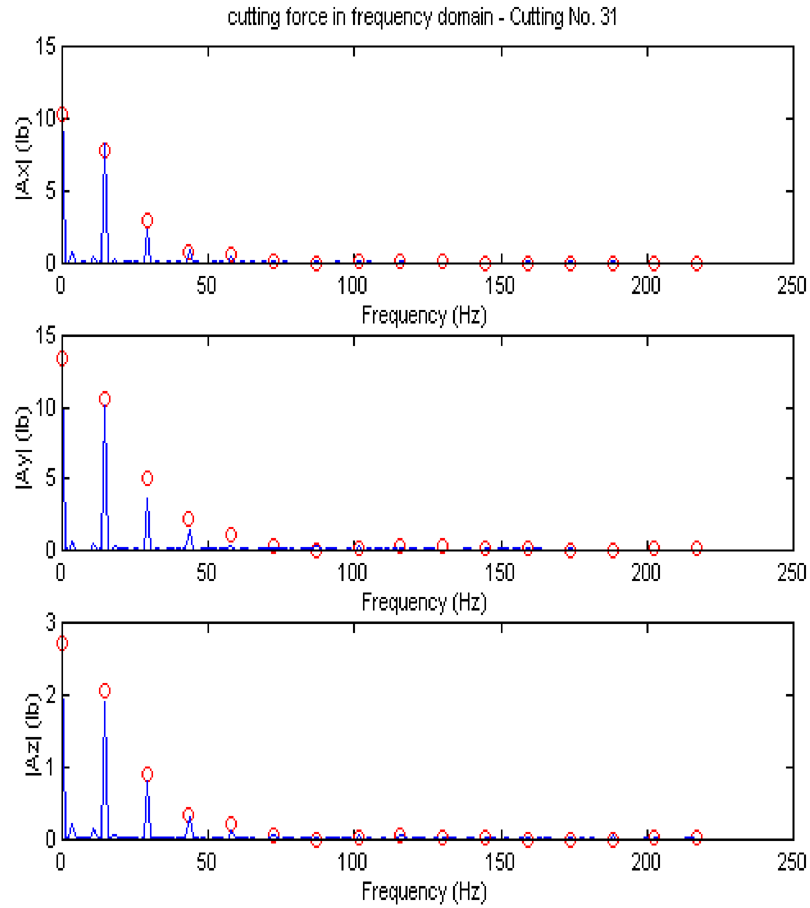
- Closed-Form Expression of Cutting Force in the Frequency and Time Domain
- Cutting Edge Function
- Cutting Condition-Speed, DOC and Feed Rate
- Material Properties
- Can Be Used for Any Cutting Configuration in Steady State Cutting
  - Helical End Milling
  - Face Milling
- Verified by A Variety of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

Down End Milling

Time Domain

Frequency Domain





Speed = 210 RPM

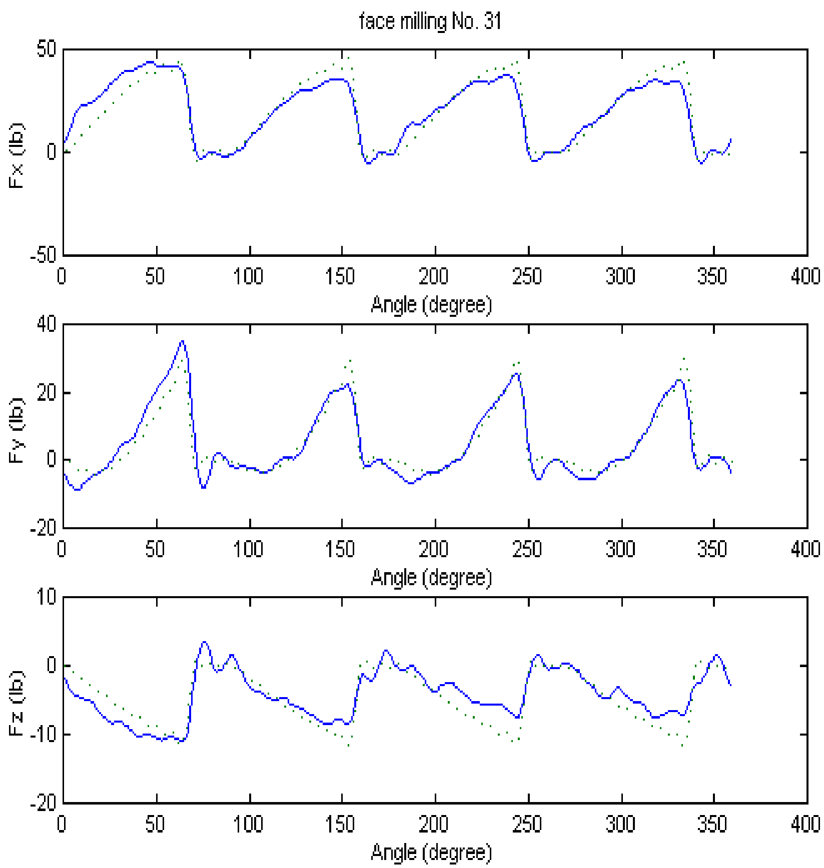
Axial DOC = 0.1 in

Feed Rate = 5 ipm

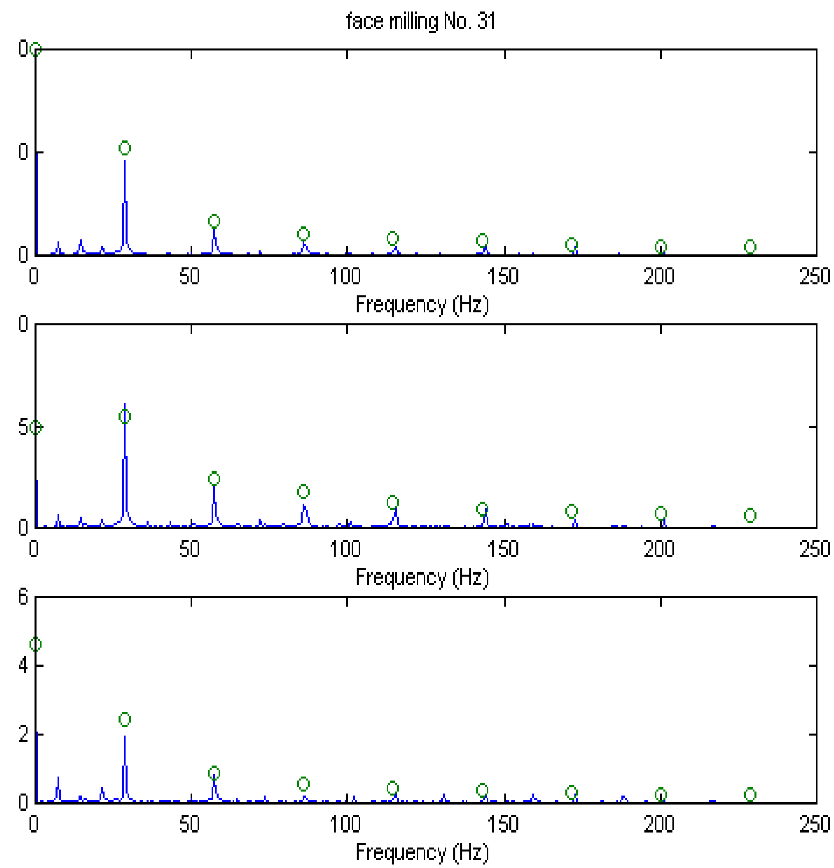
Radial DOC = 0.05 in

Up Face Milling

Time Domain



Frequency Domain



Speed = 420 RPM

Axial DOC = 0.05 in

Feed Rate = 5 ipm

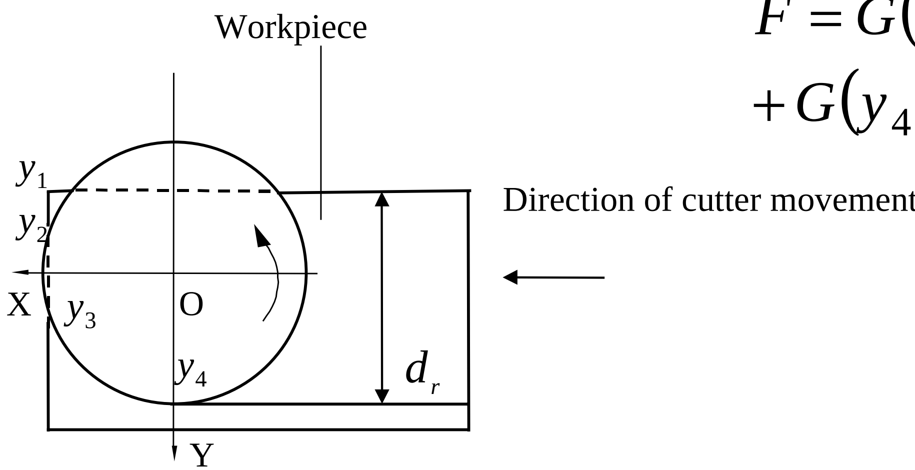
Radial DOC = 0.9 in

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.

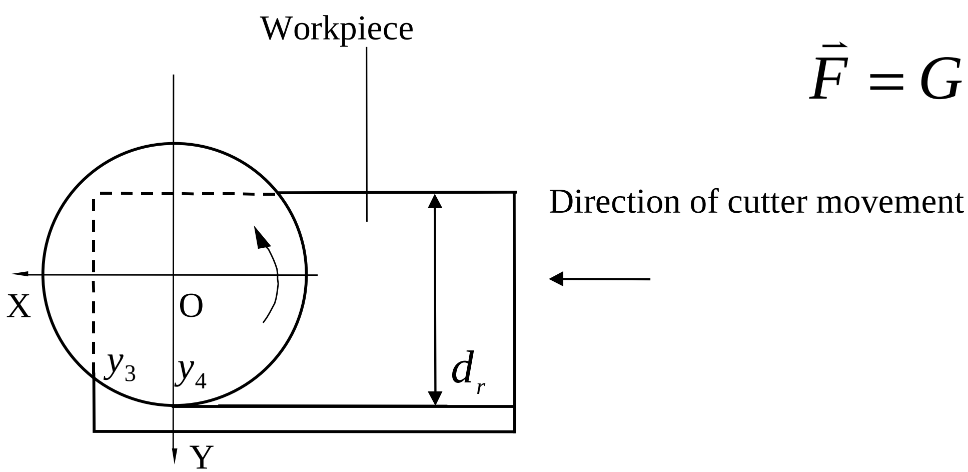
Transient Cutting Configuration

Phase 1



$$\vec{F} = G\left(y_2(\Delta t \cdot m)\right) - G\left(y_1(\Delta t \cdot m)\right) + G\left(y_4(\Delta t \cdot m)\right) - G\left(y_3(\Delta t \cdot m)\right)$$

Phase 2

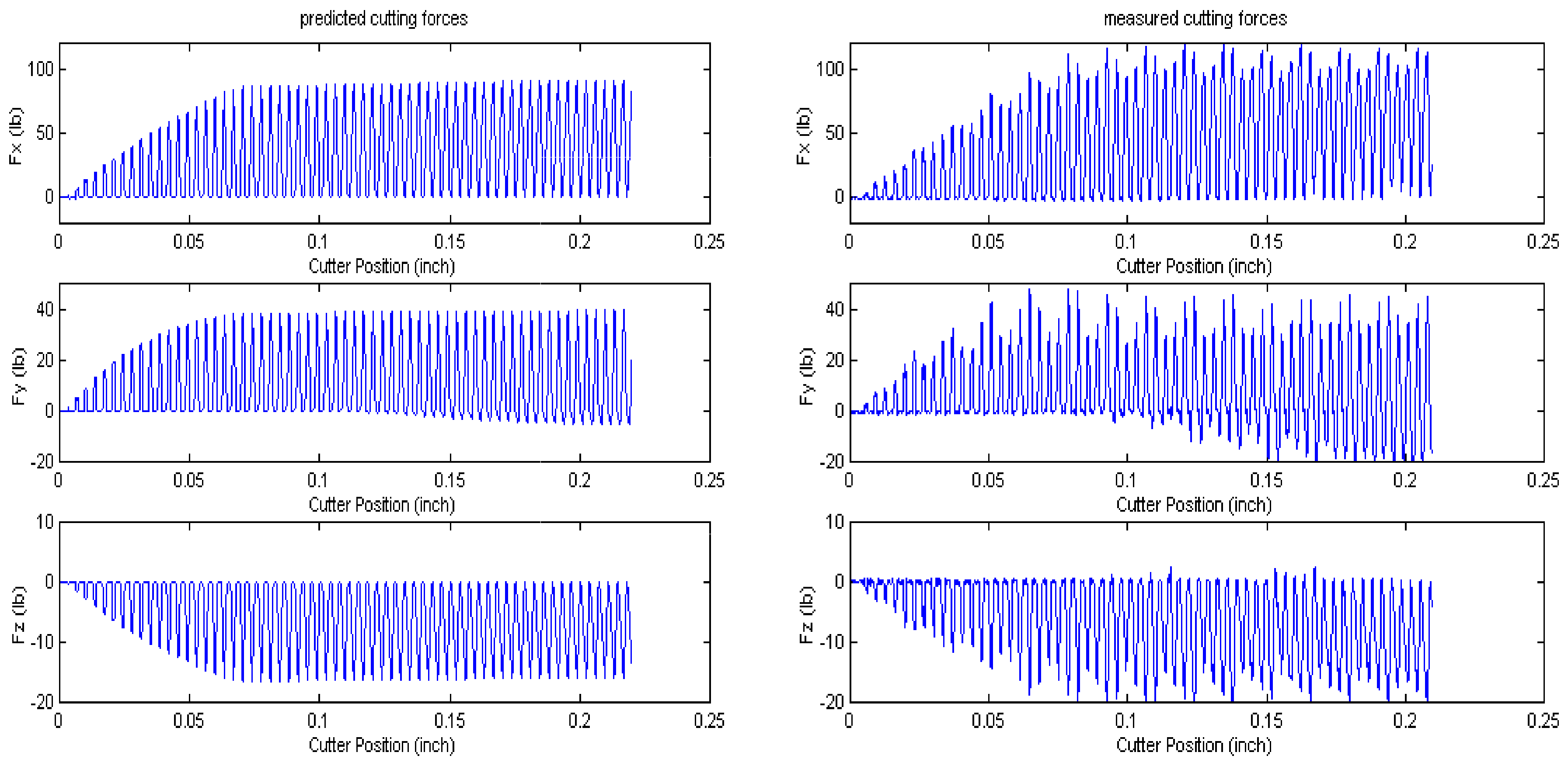


$$\vec{F} = G\left(y_4(\Delta t \cdot m)\right) - G\left(y_3(\Delta t \cdot m)\right)$$

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)



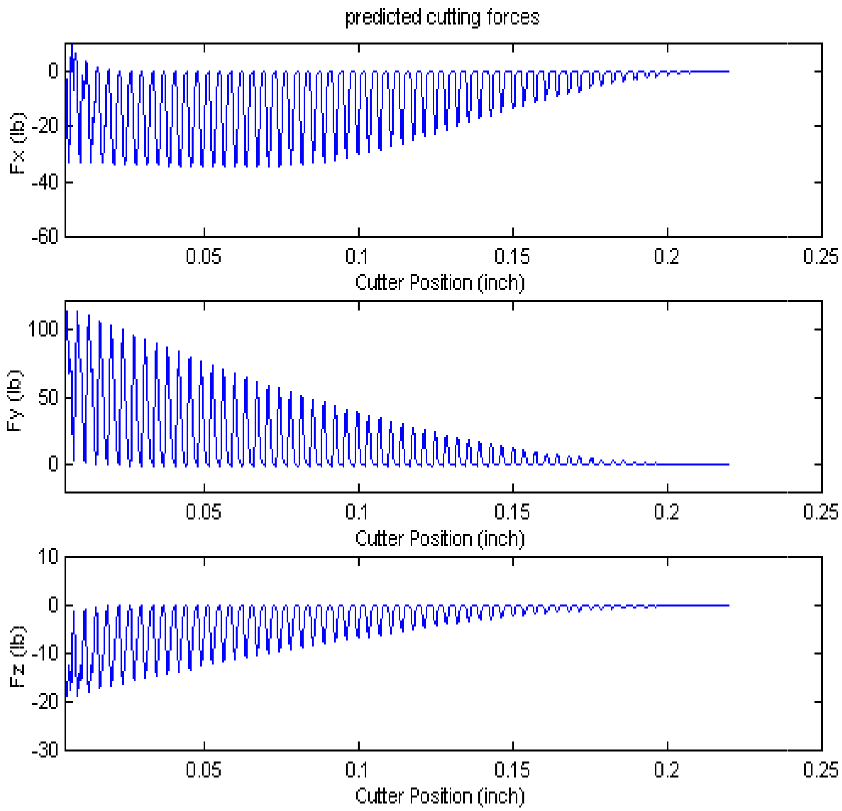
Speed = 420 RPM

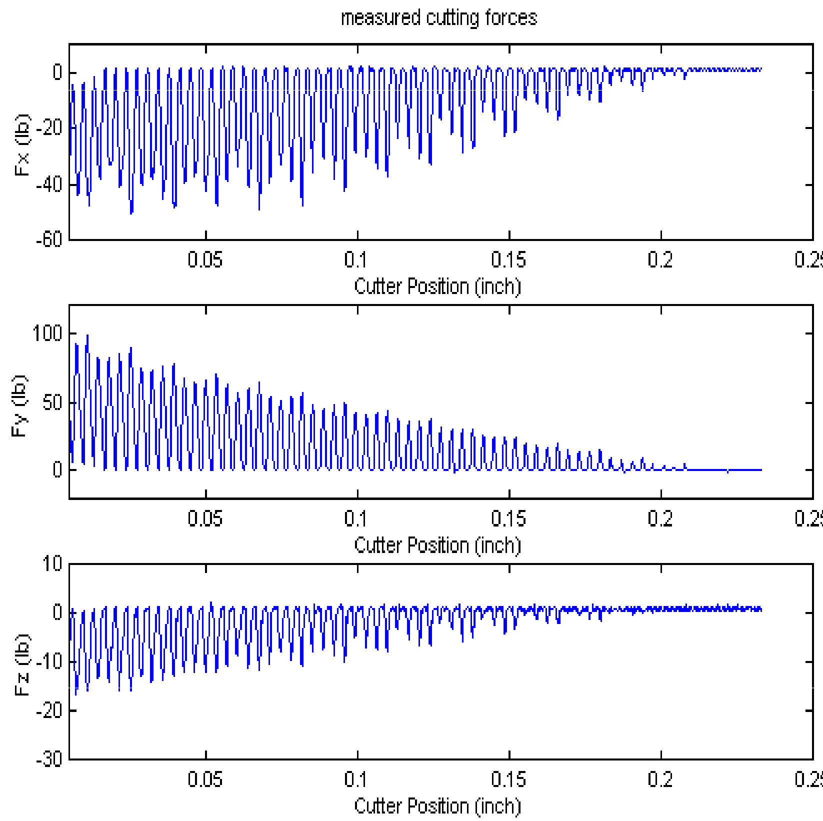
Axial DOC = 0.18 in

Feed Rate = 6 ipm

Radial DOC = 0.3 in

Example 2 (Down Disengaging Cutting)





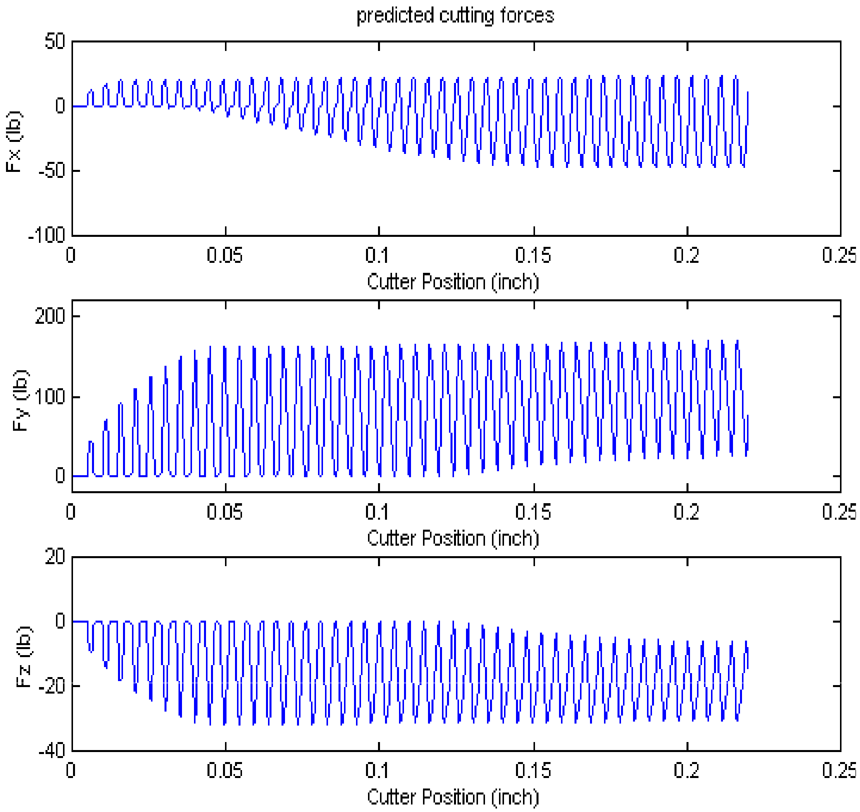
Speed = 420 RPM

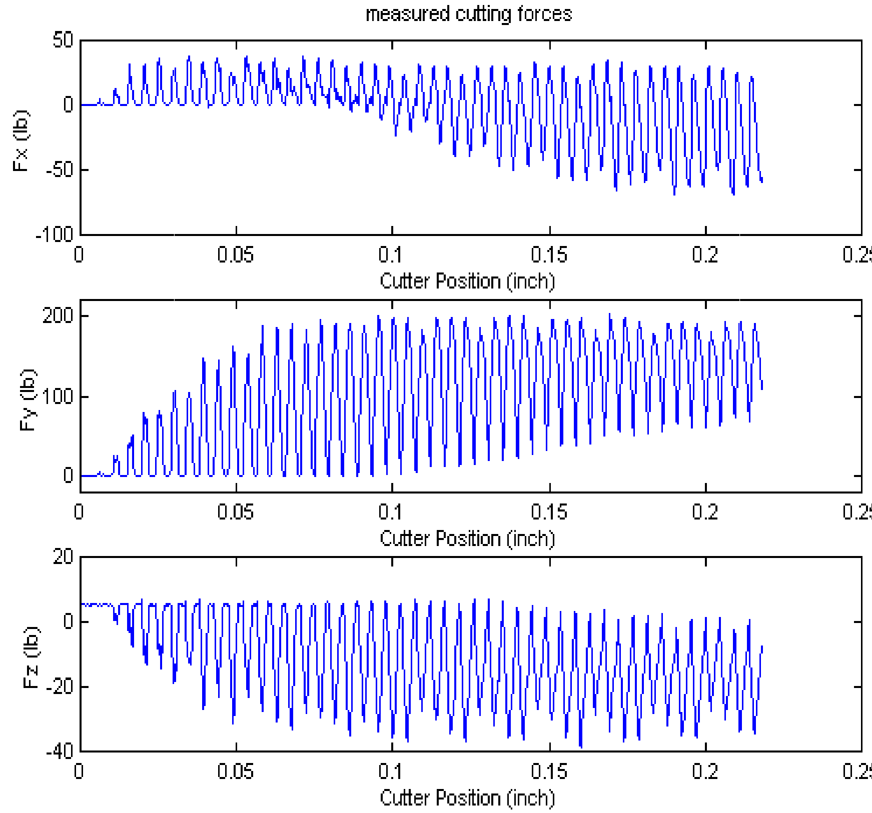
Axial DOC = 0.18 in

Feed Rate = 6 ipm

Radial DOC = 0.3in

Example 3 (Down Engaging Cutting)





Speed = 210 RPM   Feed Rate = 4 ipm

Axial DOC = 0.2 in   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%