Static and Dynamic Analysis of Machining Fixtures

Bo Li , Graduate Research Assistant

Shreyes N. Melkote , Assistant Professor

The George W. Woodruff School of Mechanical Engineering

Georgia Institute of Technology

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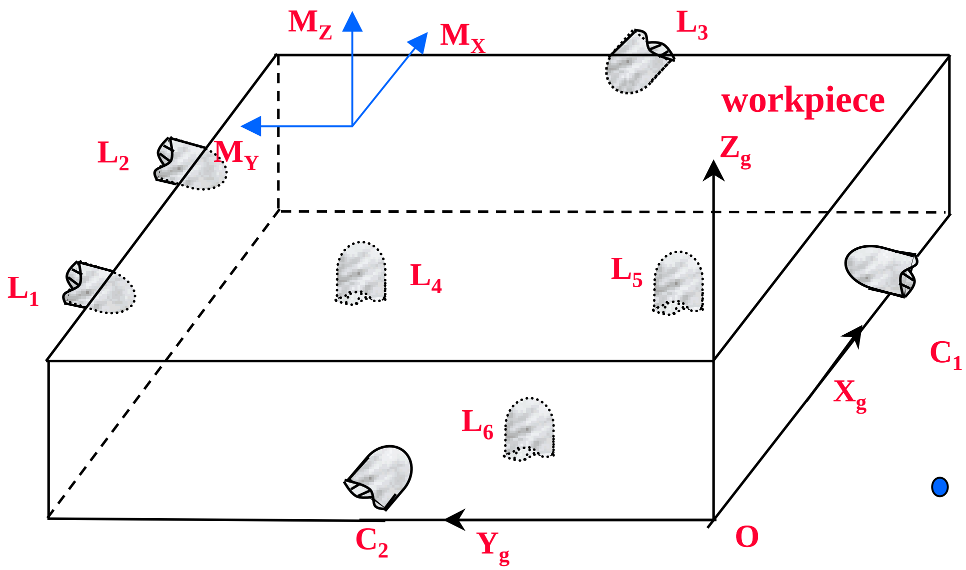
Introduction

- ***Fixtures are devices used to locate and hold a workpiece accurately during machining process.***

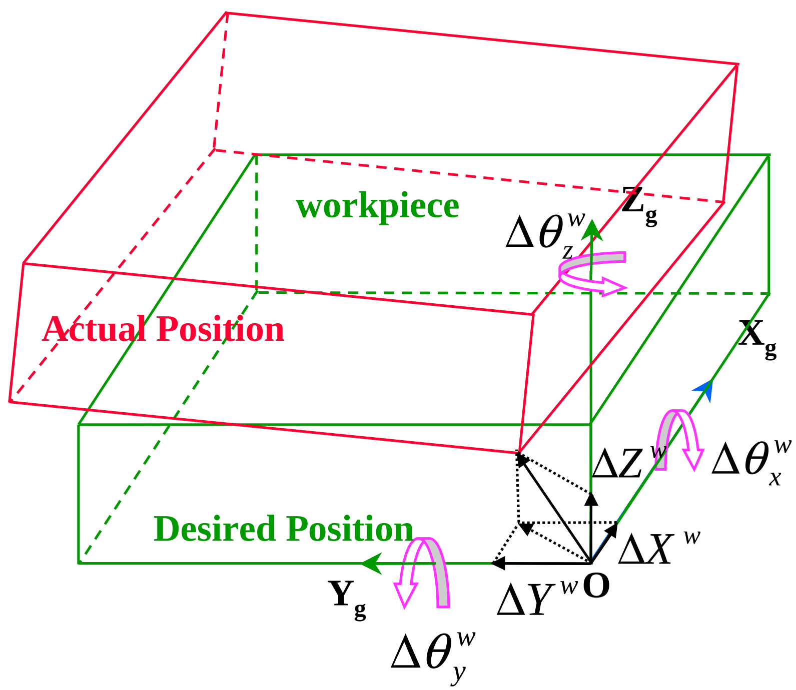


- *3-2-1 Fixturing Scheme*

L_1 - L_6	*Workpiece-fixture locator*
C_1 - C_2	*Workpiece-fixture clamp*
M_X-M_Y-M_Z	*Machining forces*
X_g-Y_g-Z_g	*Inertial coordinate system*

Introduction (cont.)

- ***Typically, the workpiece rotates and translates in machining fixture due to localized deformation at each workpiece-fixture contact. This impacts the part quality.***



- *Workpiece Translation and Rotation*

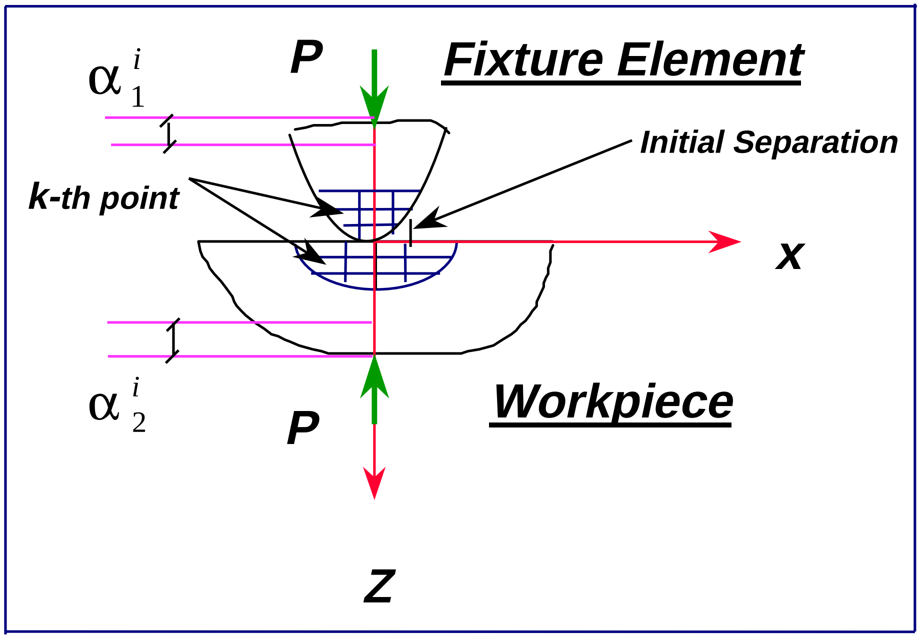
Overall Objective

- ***Predict contact forces in the normal and tangential directions due to clamping and machining loads;***
- ***Investigate the workpiece rigid body motion in the machining fixture and its impact on final part quality.***
- ***Predict the onset of undesired slip and loss of contact at workpiece-fixture interface during machining.***

Static Model

- ***Static indeterminacy in rigid body analysis can be resolved by including the workpiece-fixture contact compliance.***
- ***At each contact patch, normal force and tangential force are discretized into small components.***

- ***Undeformed Workpiece / Fixture Element Contact***



Static Model (cont.)

- ***The elastic deformation in the normal and tangential directions is a linear summation of the influence of all forces components acting on this patch.***

- ***The minimum total complementary energy principle is used to solve the contact problem.***

δ ***W=0*** → ***Min W***

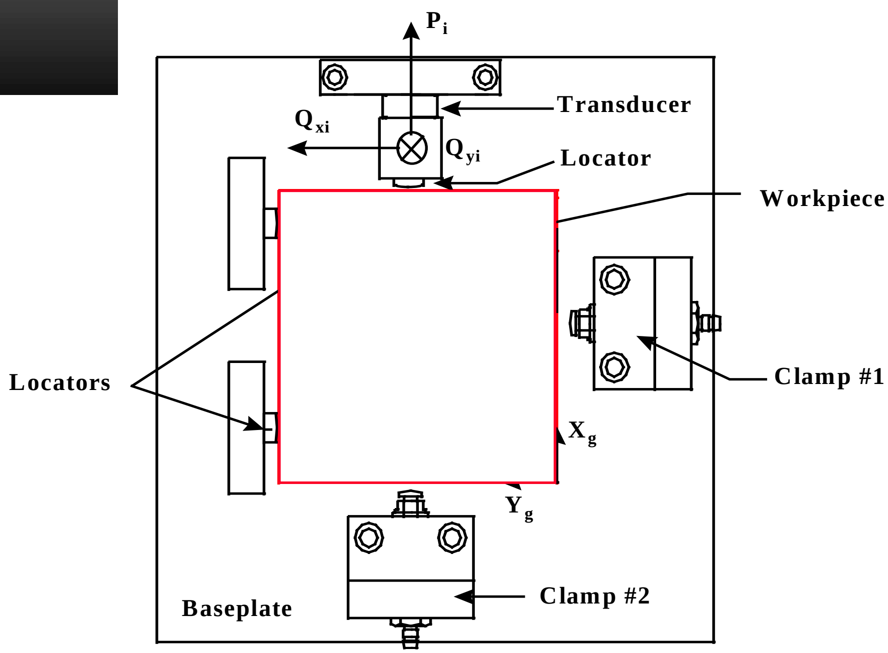
S.t. (1) Static equilibrium

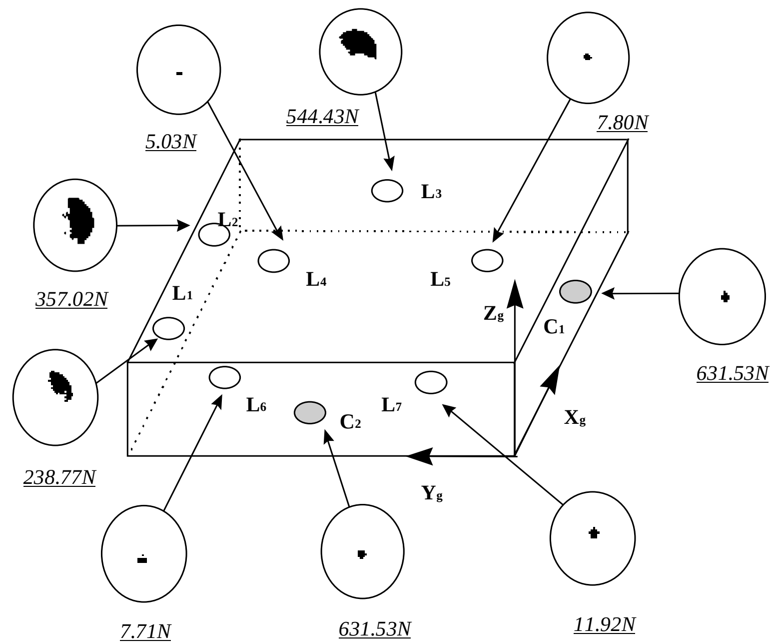
(2) Coulomb's friction law

(3) Non-negative normal force

Experiment Work

- Static model verification: Normal force at each fixture-workpiece contact is measured using a pressure sensitive film (Fuji prescale film).

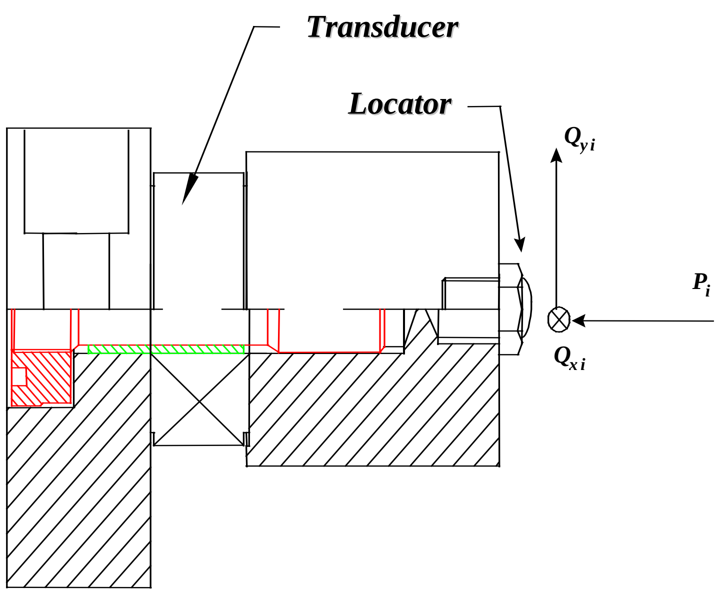




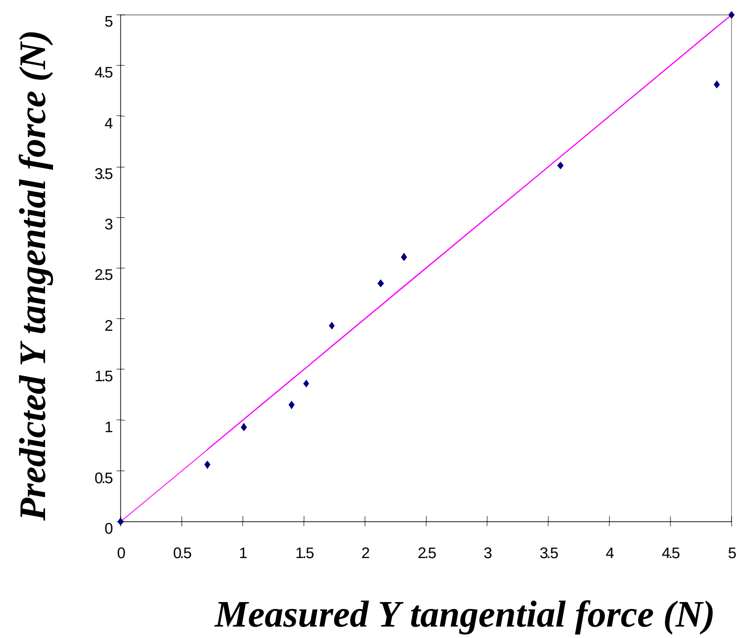
- Experimental setup (top view)
- Normal force and actual contact area map

Experiment Work (cont.)

- ***Static model verification: Locator L3 is instrumented with a three-axis piezoelectric force transducer to measure the tangential force.***



- ***Transducer (Kistler 9117A)***



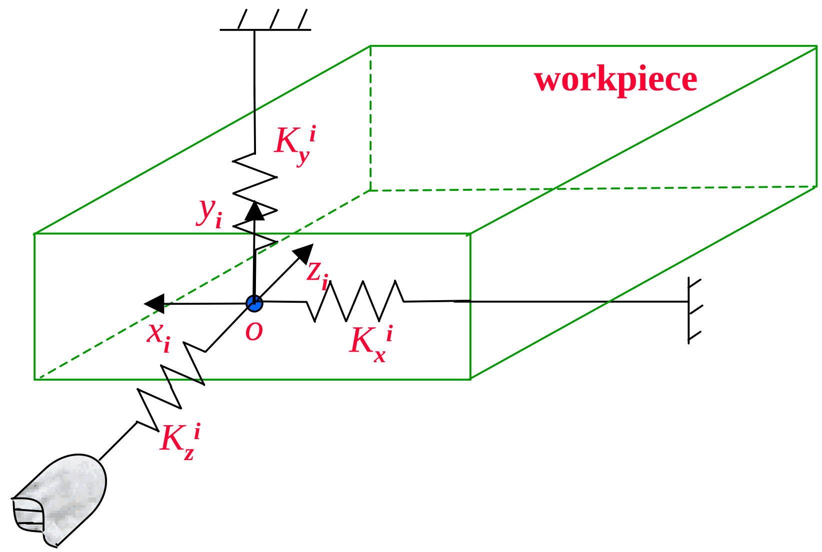
- ***Comparison of measured and predicted tangential forces***

Experiment Work (cont.)

- ***Normal force:*** ***The maximum relative error for the side locators ranges from 2% to 10% for three different sets of clamping forces. The absolute error for the bottom locators ranges from 0.12 N to 1.29 N.***
- ***Tangential force:*** ***The maximum absolute prediction errors are 5.93 N for X component and 0.57 N for Y component at locator L_3 .***
- ***It is apparent from the above comparisons that the model performs well under different clamping forces.***

Dynamic Model

- ***Lumped linear stiffness model.***
- ***Inertial effects are considered.***



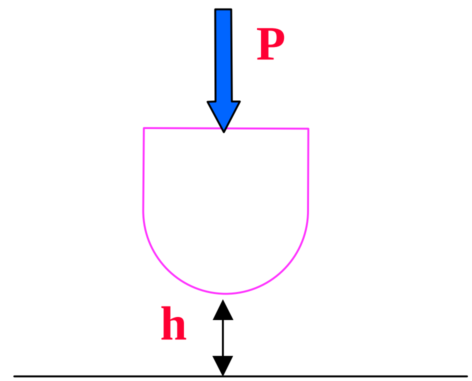
x_i-y_i-z_i *Local Coordinate at the i-th Contact*

Lumped stiffness is a function of: (1) workpiece-fixture material properties.
(2) workpiece-fixture contact geometry.
(3) clamping and machining loads.

Dynamic Model (cont.)

Workpiece rigid body motion q(t)

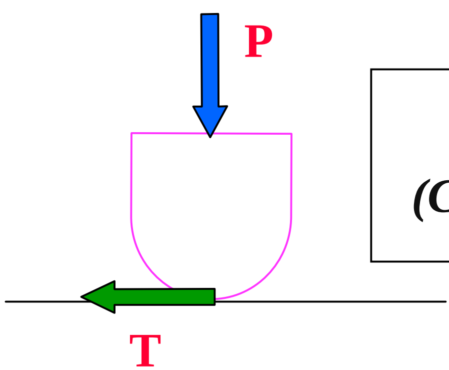
Newton-Euler equations of motion

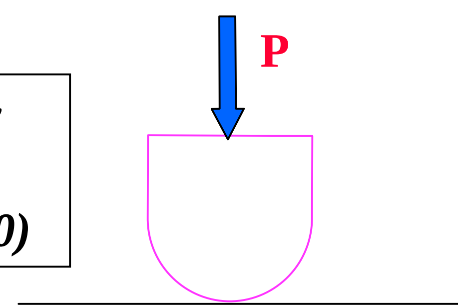


Machining forces M(t)

Stick/slip (Coulomb friction)

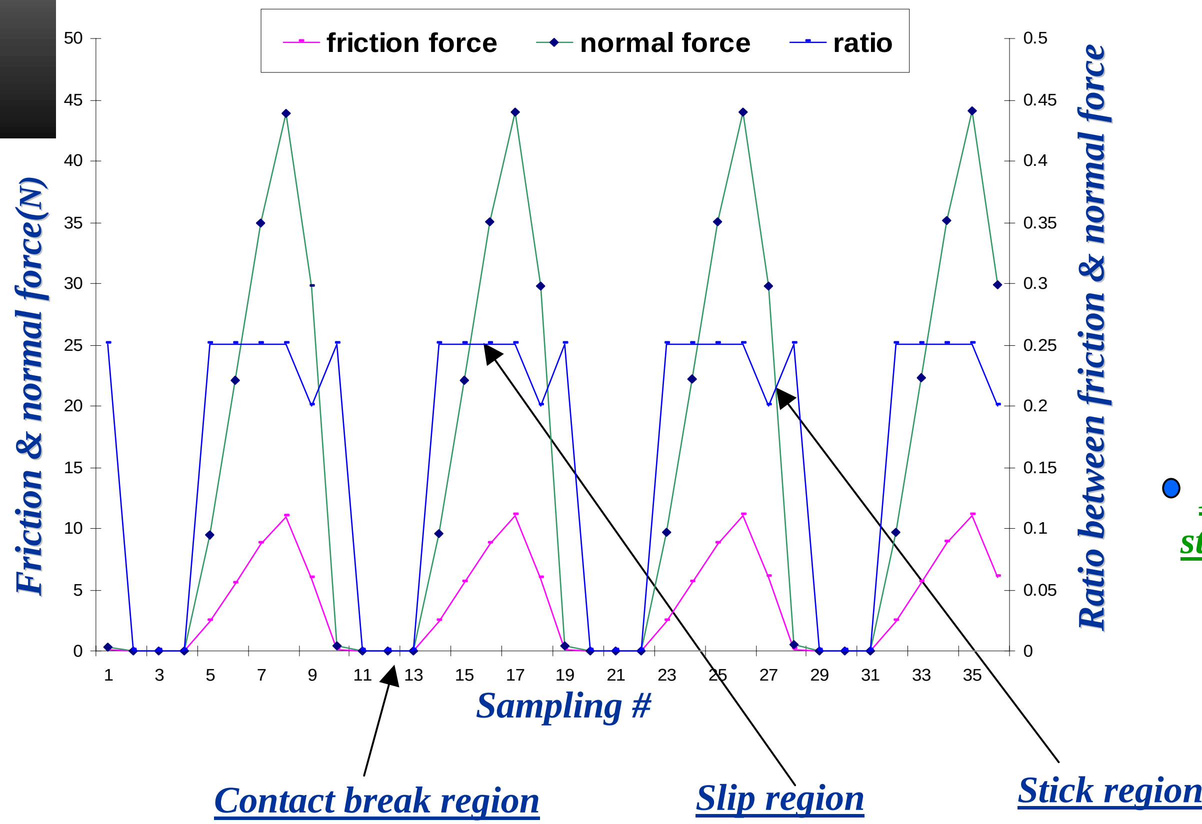
Complementary contact ($P \geq 0$, $h \geq 0$, $hP=0$)





Dynamic Model Simulation

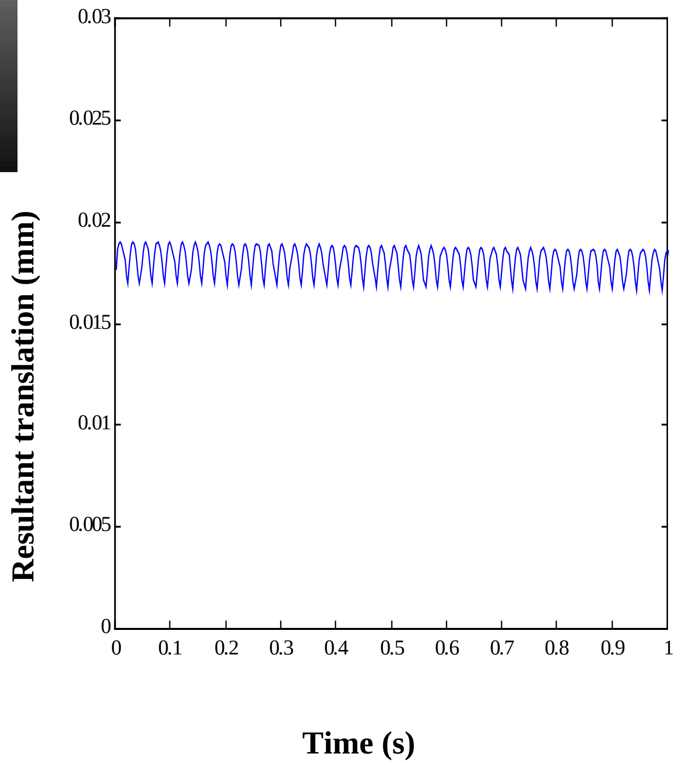
- **25.4mm wide slot machining condition:** ***(1) spindle speed = 660rpm; (2) axial depth of cut = 6.35mm, (3) feed rate = 7.6mm/sec. (4) clamping force c_1= 266.88N, c_2 = 889.60N.***

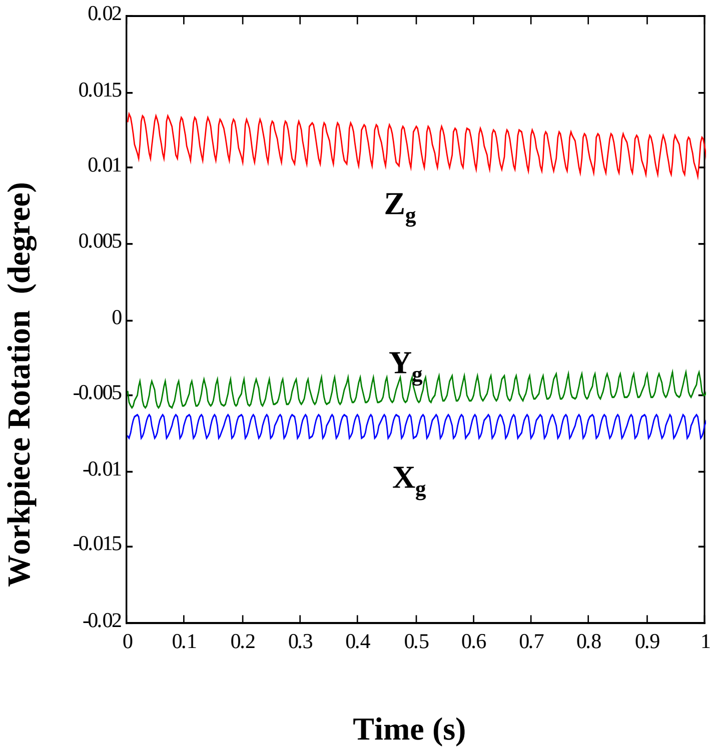


- *Intermittent contact and stick/slip transition at clamp C_1*

Dynamic Model Simulation (cont.)

- ***Workpiece rigid body resultant translation and rotation about x_g , y_g and z_g axis during machining:***





Conclusion

- ***The static model can accurately predict the magnitude of the inwardly directed normal forces, and the magnitude and direction of the tangential force at each contact patch.***
- ***Localized deformation at each contact and the workpiece rigid body motion due to the static loading can be determined.***
- ***The dynamic model can predict the workpiece rigid body motion in the fixture due to dynamic loading while explicitly accounting for contact/no contact and stick/slip conditions.***

Ongoing/Future Work

- *Incorporate the impact of frictional damping and other energy dissipation mechanisms into the model.*
- *Eliminate the workpiece-fixture system vibration due to the dynamic loading through proper friction damping.*
- *Develop an efficient fixture design strategy to yield the optimum fixture layout and corresponding optimum clamping force(s) based on dynamic model.*