# *Past Accomplishments and New Project Opportunities*


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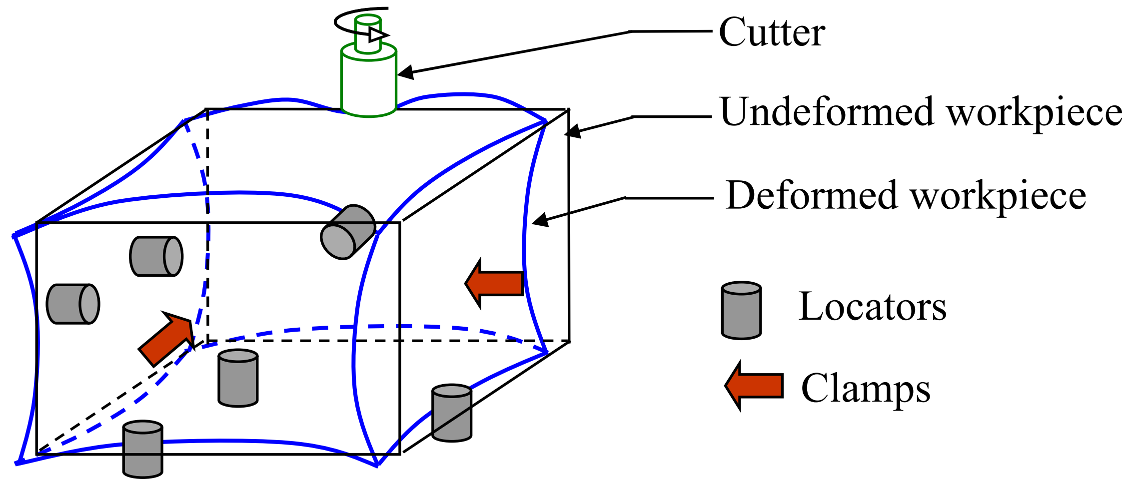
# *Fixturing: Modeling & Analysis*

## *(Sponsors: Ford, GM, NSF, Caterpillar)*

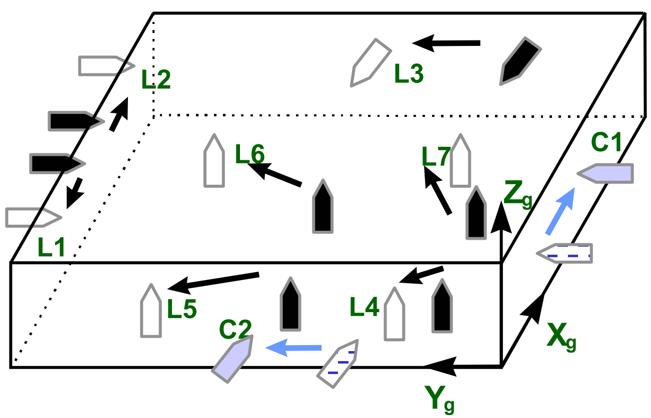
***Objectives:***

***Develop and verify models for:***

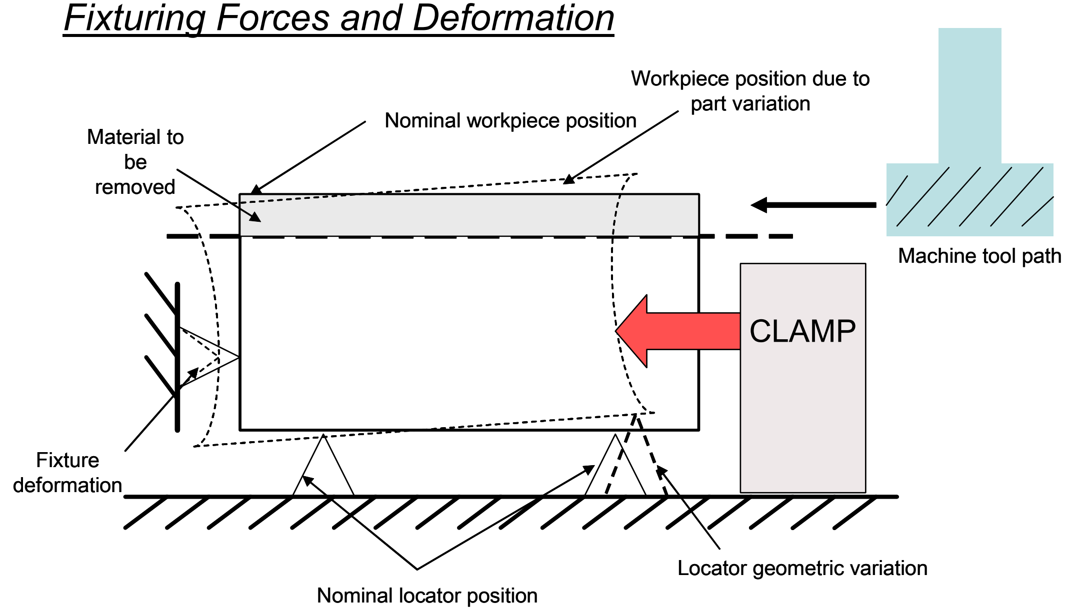
- ***prediction of fixture-workpiece contact forces/deformations***
- ***synthesis of fixture layout and clamping forces***
- ***prediction of part location errors***




*Fixturing Forces and Deformation*

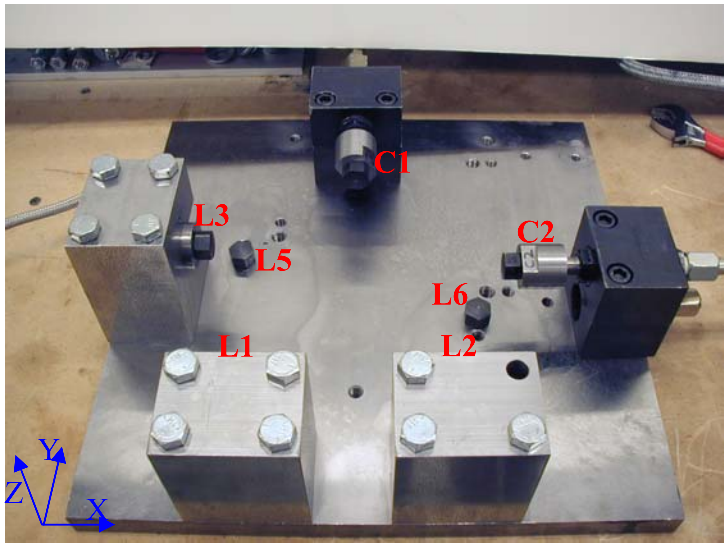


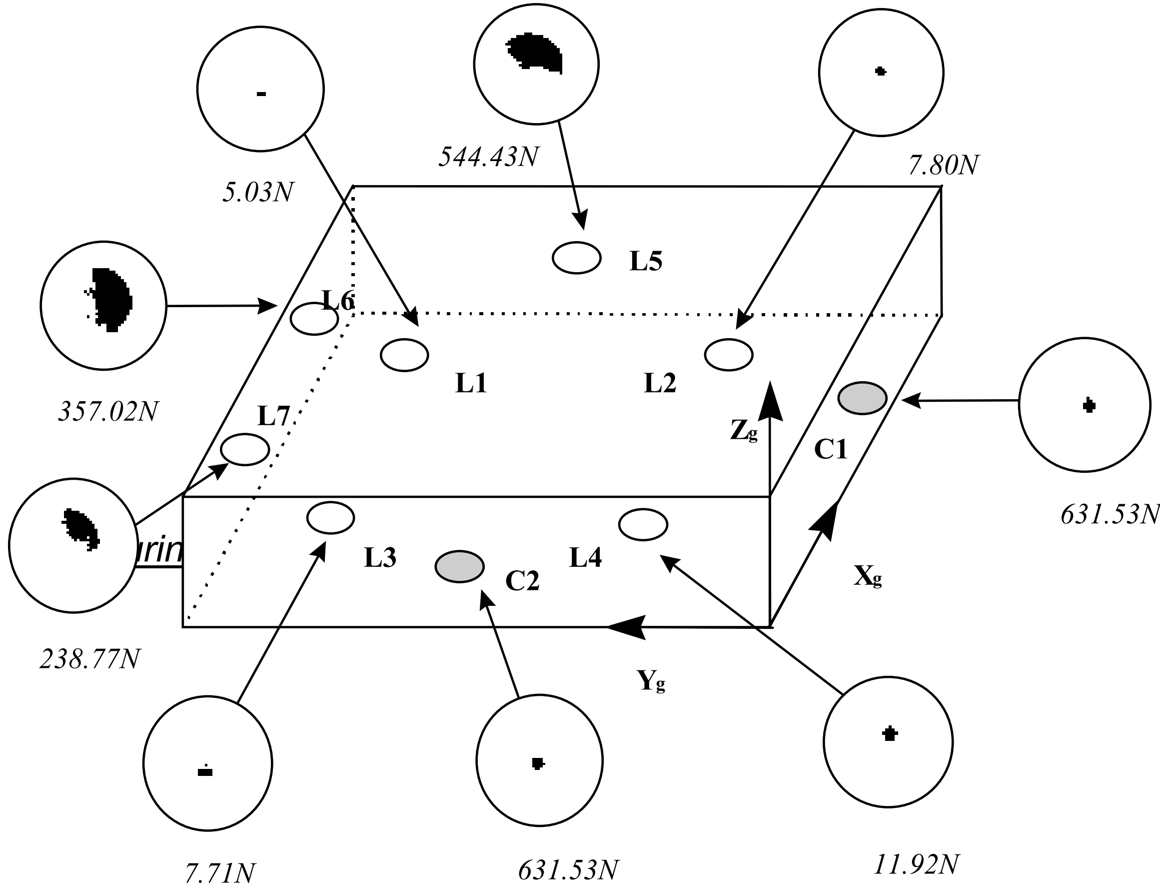

*Fixture Layout/Clamping Force Synthesis*




*Part Location Error Sources*

# Modeling & Analysis Results

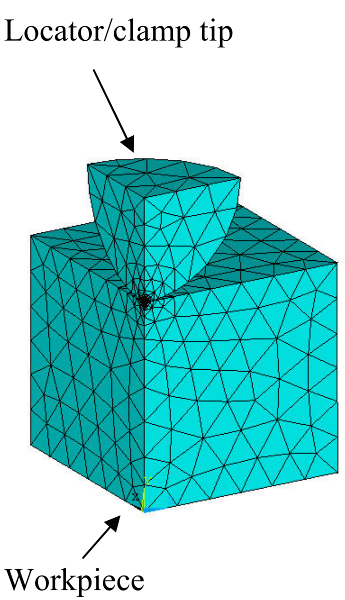


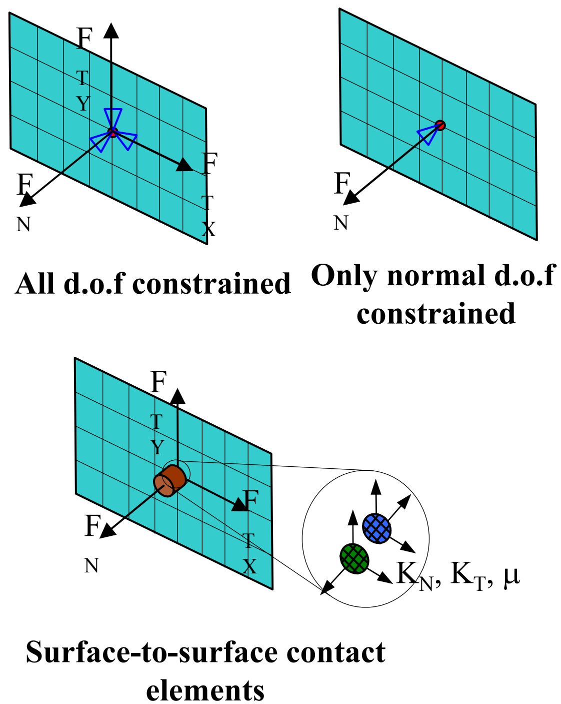



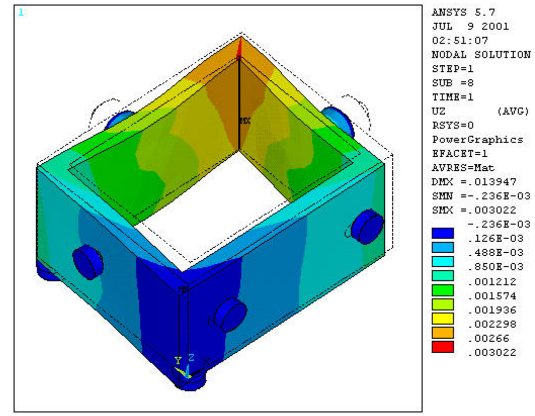

**Major Deliverables (Ford, GM, Caterpillar):**

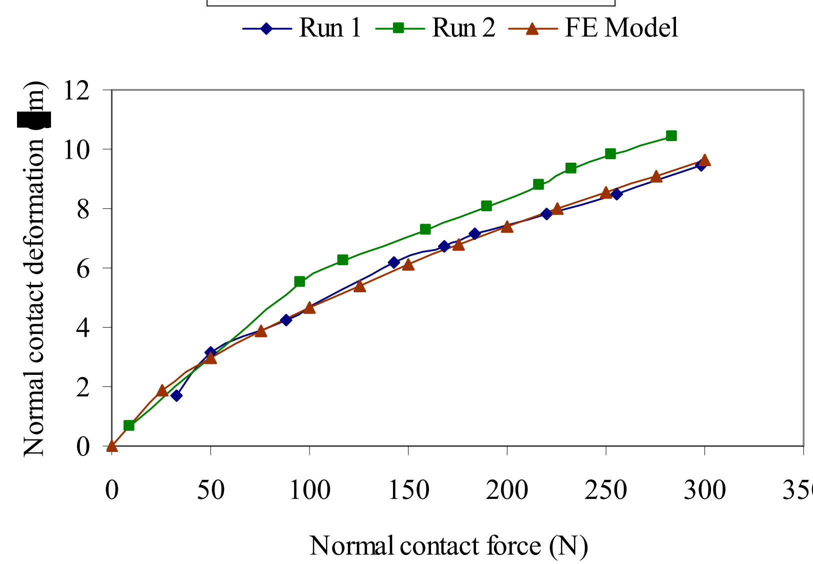
- *Matlab® codes for analysis of fixture-workpiece contact forces/deformations and optimization of clamping force*
- *Code implemented by sponsor (Ford AMTD, Livonia Plant)*

# *Modeling & Analysis Results*




***<u>Major Deliverables (Caterpillar):</u>***

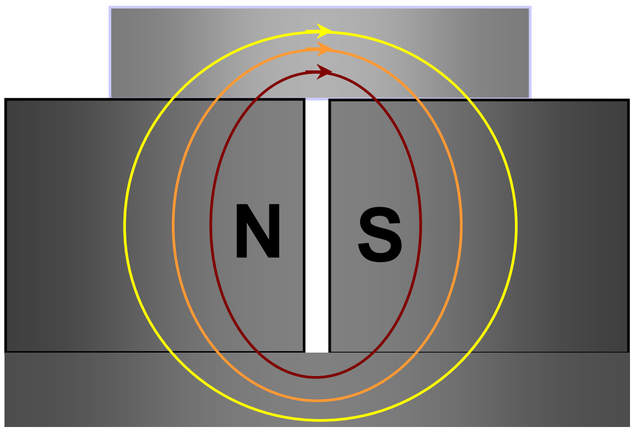
- *"Best practice" rules for fixture-workpiece contact modeling using the FEM.*
- *ABAQUS® modules for spherical/planar contact fixture-workpiece contact modeling*

# Flexible Fixturing

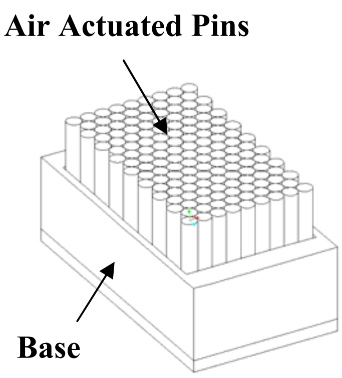
## (Sponsors: Timken, Lamb Technicon, NIST/ATP)

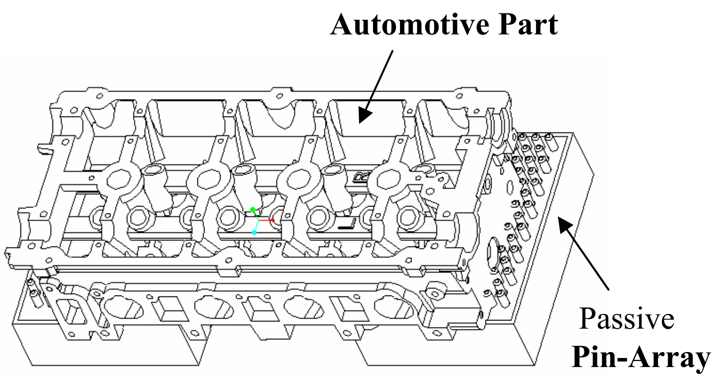
**Objectives:**

- ***Analysis of holding forces in electromagnetic chucks***
- ***Design and analysis of pin-array flexible fixture for machining***
- ***Develop tolerance-based fixture stiffness optimization method***



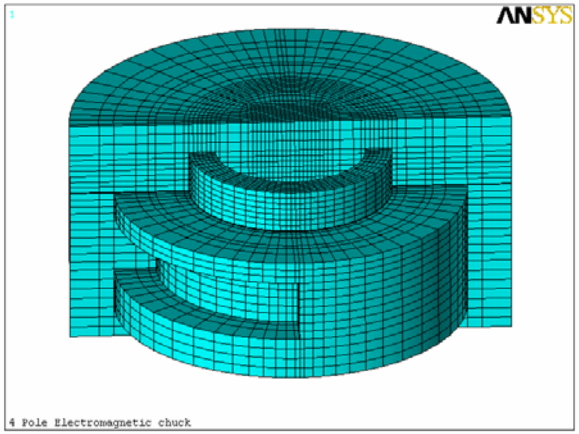

Magnetic Chuck

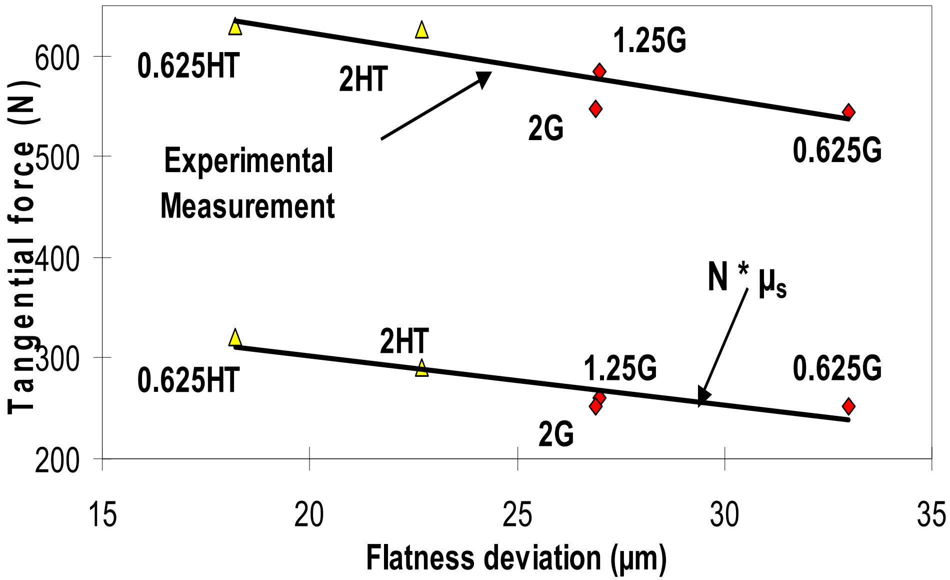



Pin-Array Flexible Fixtures

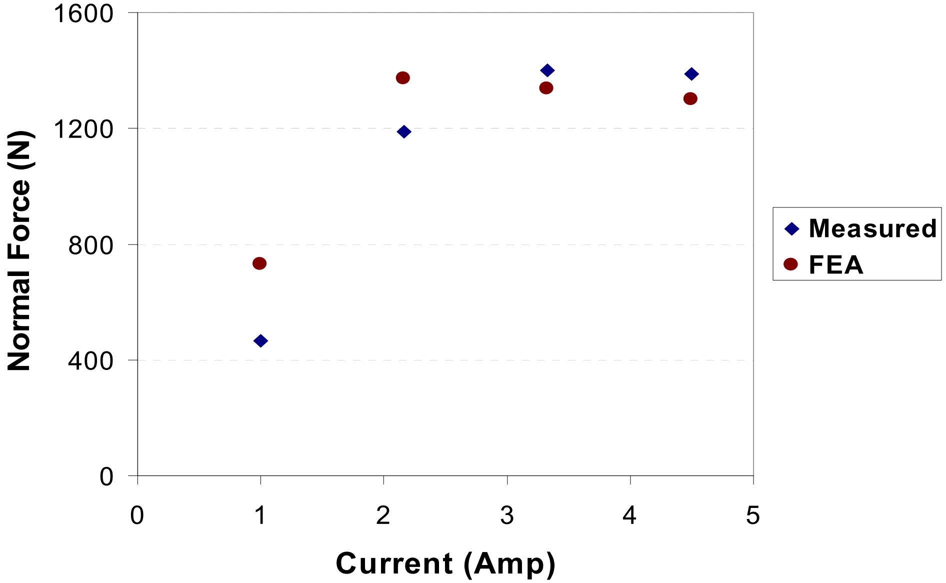
# Flexible Fixturing Results



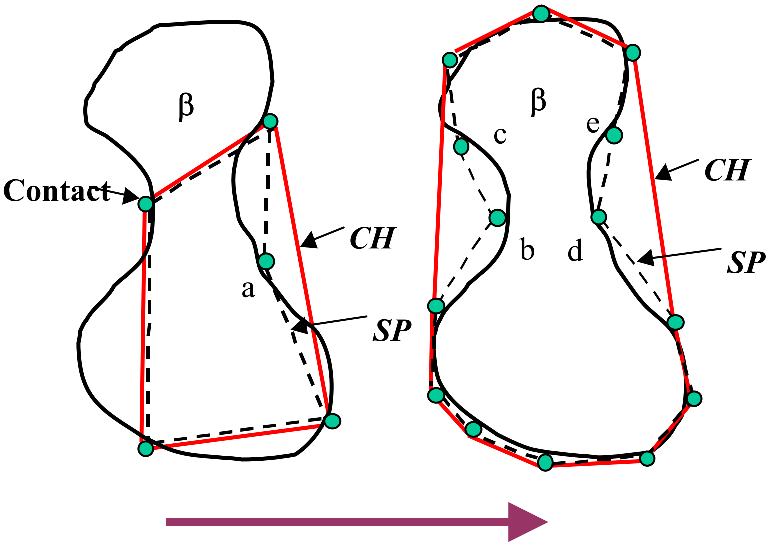




**Major Deliverables (Timken):**

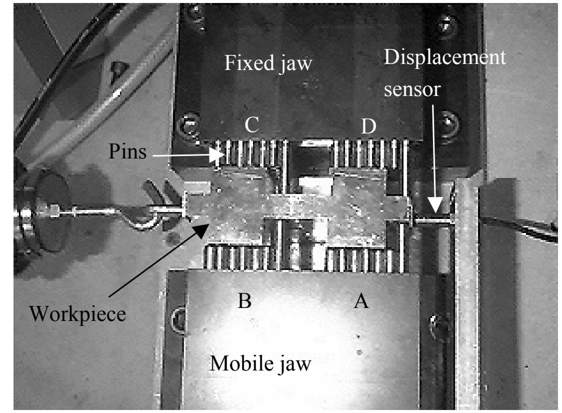
- *Holding force measurements on e-mag chuck*
- *Matlab code for estimation of normal holding force in chuck*



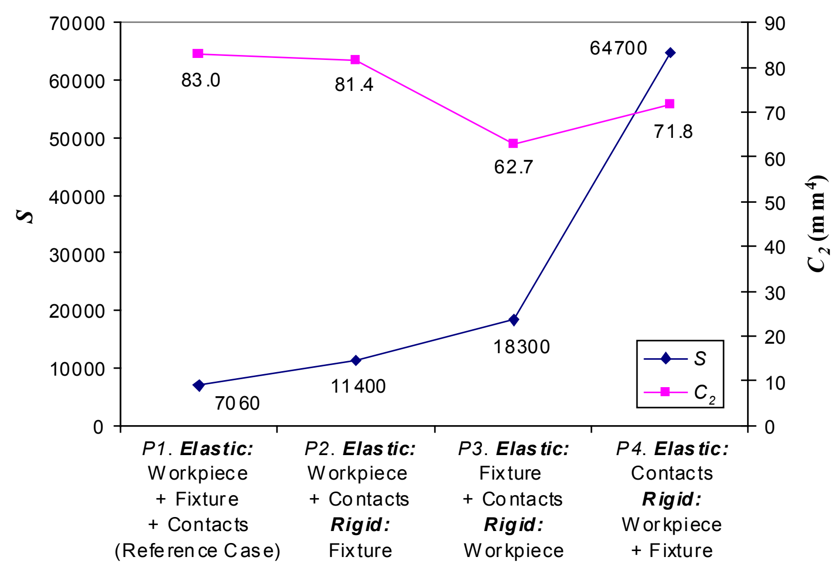
# *Flexible Fixturing Results*




**INCREASING CONFORMANCE**




**Active Pin-Array Vise**
**Holding a Complex Part**




## ***Major Deliverables (Lamb):***

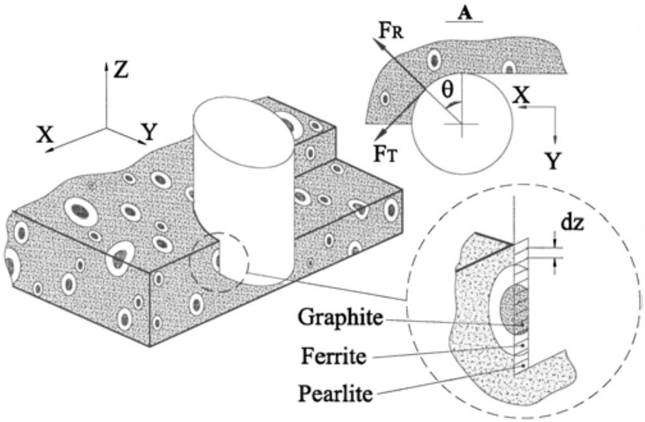
- *Matlab code for optimizing pin geometry and stiffness*
- *Elements of pin-array fixture design*
- *U.S. and World-wide patents pending*

# *New Research Projects:*

- *Micro/Nano-Cutting Process Science*
- *Interrupted Hard Turning*
- *Analysis of White Layers in Hard Turning*

# Macro Cutting vs Micro/Nano Cutting

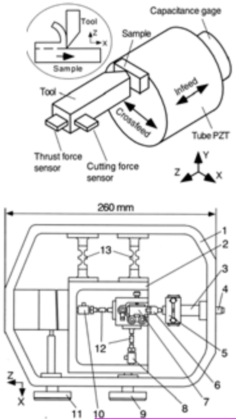
**TOOLS?** **PROCESS?**

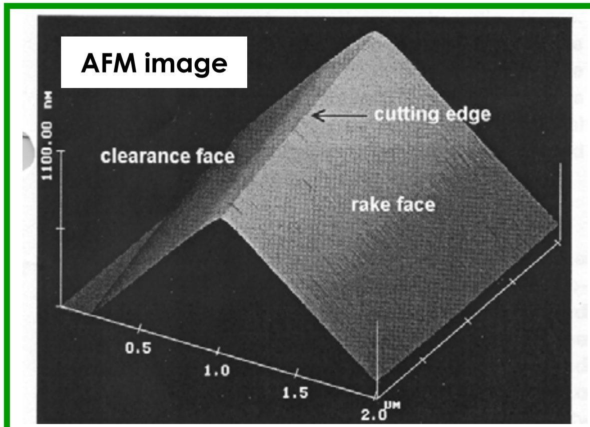



## Effect of Microstructure

Source: Vogler et al, *J. Manuf. Sci. Engg. Trans. ASME* Vol. 125, May 2003

## Special machine tools




Source: Brinksmeier et al., *Industrial Diomond Review*, 2/96

## Effect of edge geometry

**UPC-R**

A tool edge contour of 0.05 µm (50nm/0.000002") is achieved over a wide working angle of 90°.

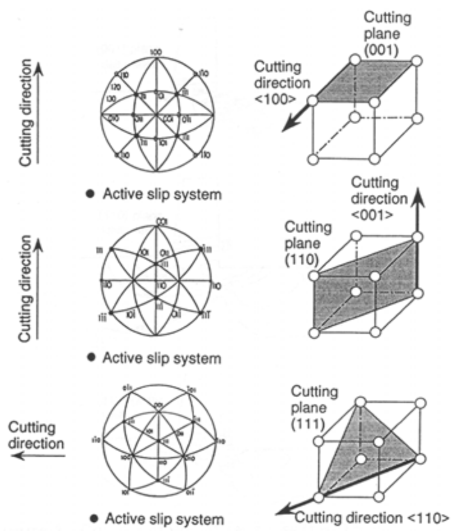

## Special cutting tools

$$F_c = \frac{H}{3\sqrt{3}}\frac{A_c}{\sin\phi}\cos\phi + \frac{H}{3}A_c + F_{c_{elastic}}$$

$$= \frac{HA_c}{3}\left(\frac{\cot\phi}{\sqrt{3}}+1\right) + \mu_f\sigma_f A_f$$

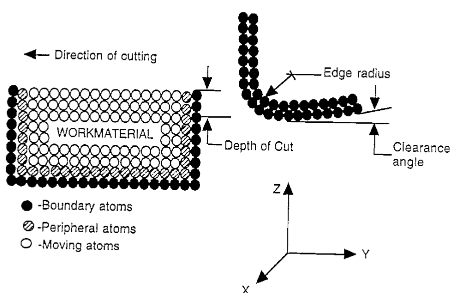
$$= \frac{HA_c}{3}\left(\frac{\cot\phi}{\sqrt{3}}+1\right) + \mu_f A_f\left(4.1H\sqrt{\frac{H}{E}}\right)$$

## Unique Force modeling



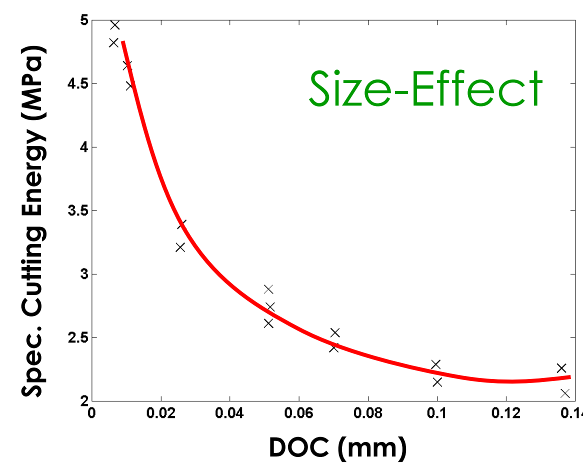

## Effect of Crystal Planes

Source: Liang et al, *Prec. Engg.* Vol. 16, No. 2, April 1994




Source: Komanduri et al, *Wear, Vol. 219* 1998

## MD Simulations




Source: Kopalinsky and Oxley, 3rd Conf Mech. Prop. High Rates of Strain 1984

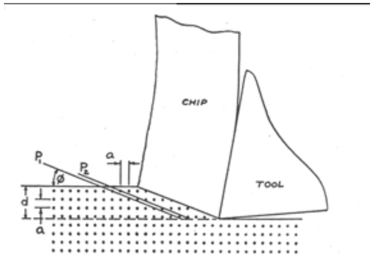



Fig. 4. Specimen with uniform array of weak spots.

**Shaw: Inhomogeneity**

**Can help understand forces and impact on surface and sub-surface**

**Determines how much energy is needed to cut**

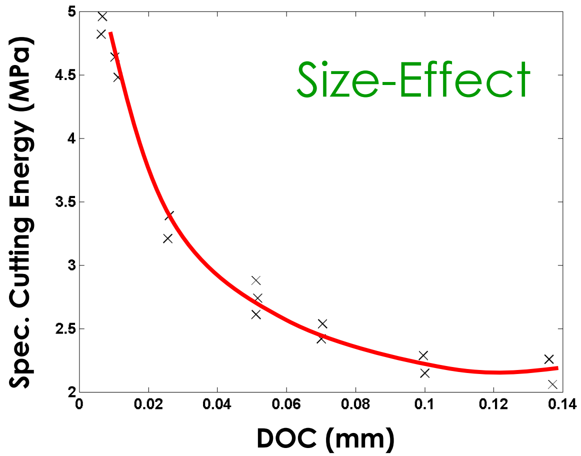
**Why study size-effect?**

**Oxley: Strain-rate effect**

Approach:
Incorporate length scale into macro cutting models

Past

**Strain gradient effect**




Source: Kopalinsky and Oxley, 3rd Conf Mech. Prop. High Rates of Strain 1984

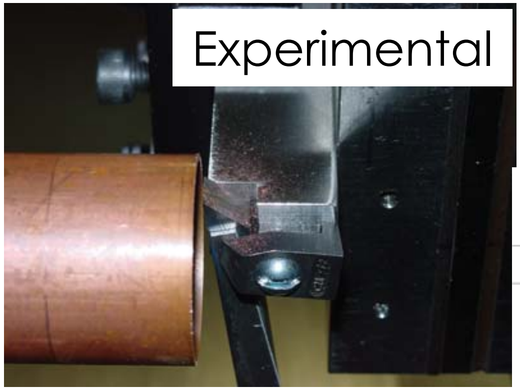
**Edge radius Effect**

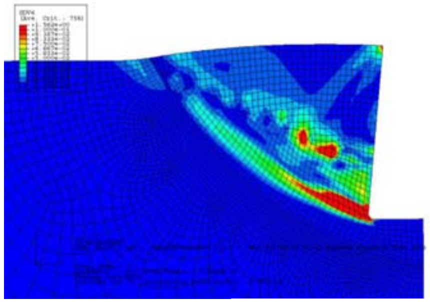
Past

Future

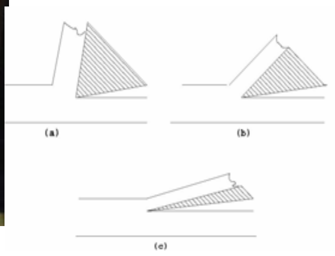
Future

Approach:
- $F = F_{inc} + F_{dec} + F_{const}$
- Perform orthogonal cuts and observe forces
- Relate force components to atomic bond energies, fracture strain energy, etc.



**FEA modeling with Strain gradient**



# *Interrupted Hard Turning*

**Goal:**

- To analyze hard turning process for parts with interruptions

**Motivation:**

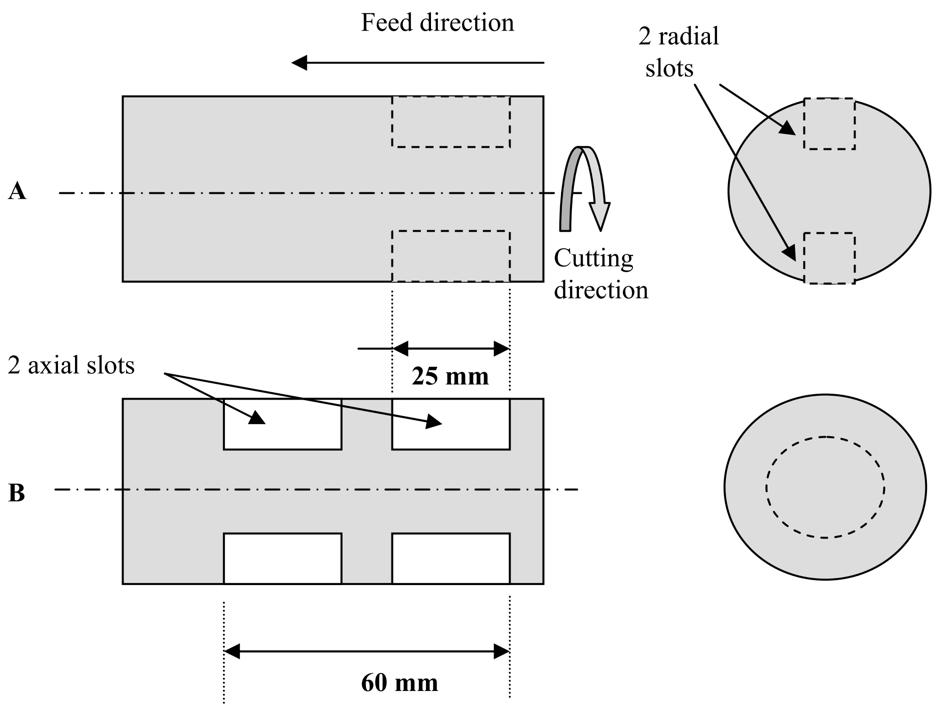
- Lack of scientific data on interrupted hard turning process
- Interruptions may be *deterministic* (part geom. variations) or *stochastic* (material inhomogeneities)

**Approach:**

- Experimental: forces, tool wear, surface texture/integrity
- Evaluate high-purity (binderless) cBN tools

**Expected Results:**

- Process data for interrupted hard turning
- Bounds on forces, tool wear, surface finish due to interruptions



# *Analysis of White Layers in Hard Machining*

**Goals:**

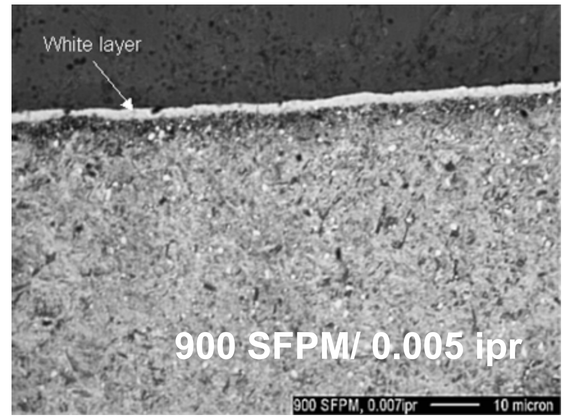
- To experimentally identify white layer formation mechanisms in hard machining
- To explain white layer formation in machining quantitatively in terms of the underlying mechanisms

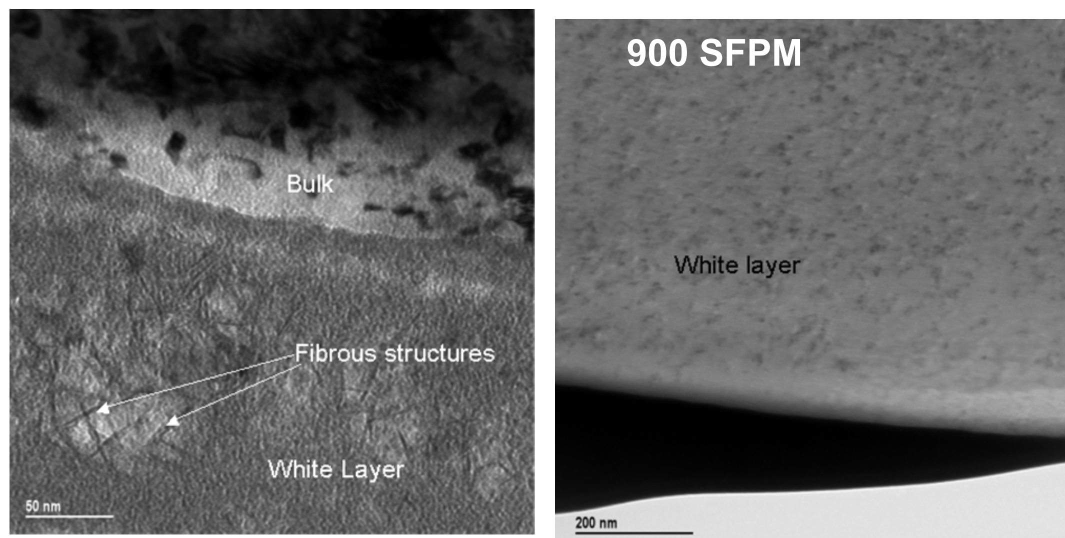
**Motivation:**

- Lack of complete understanding of white layer formation mechanisms (mechanical vs. thermal effects)

**Approach:**

- Using recently developed SEM techniques
- Numerical modeling




*Bright-Field TEM Images*