# Design and Analysis of Flexible Machining Fixtures

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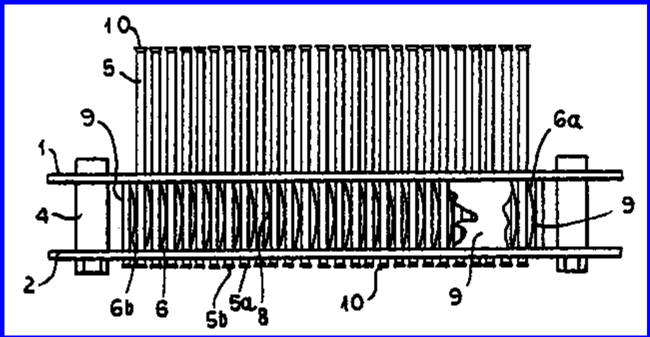
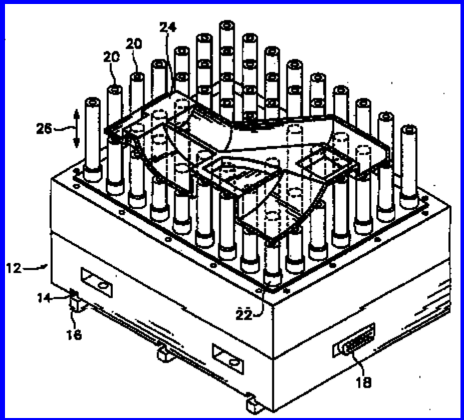
# Background

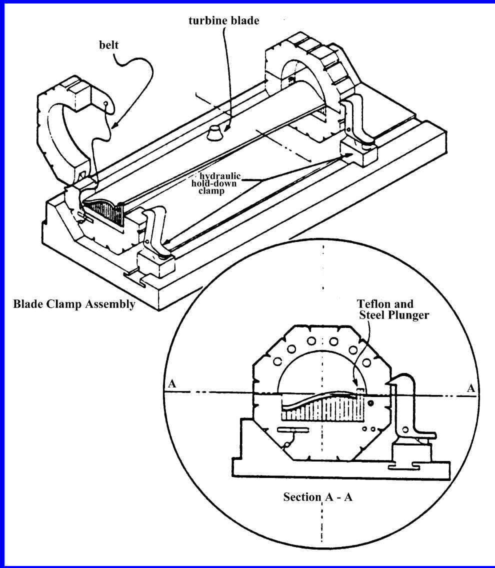
- A flexible fixture accommodates parts with different shapes and sizes.



(U.S. Patent 4,936,560)



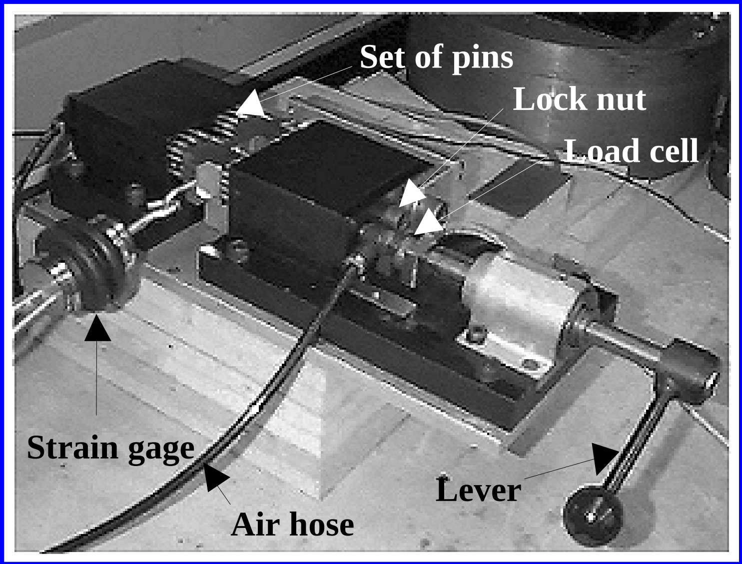
(U.S. Patent 5,722,646)

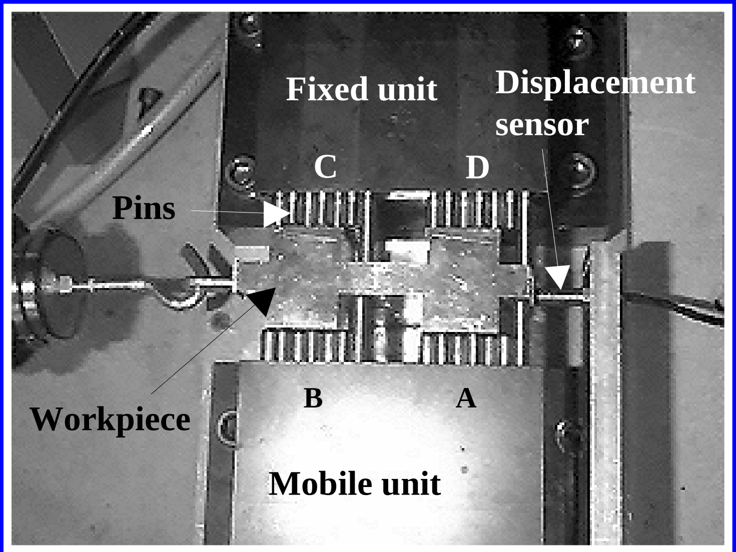



(Cutkosky et al., 1982)

# Motivation

- Flexible fixtures of the mechanical type, such as the bed-of-nails, have been proposed for machining.



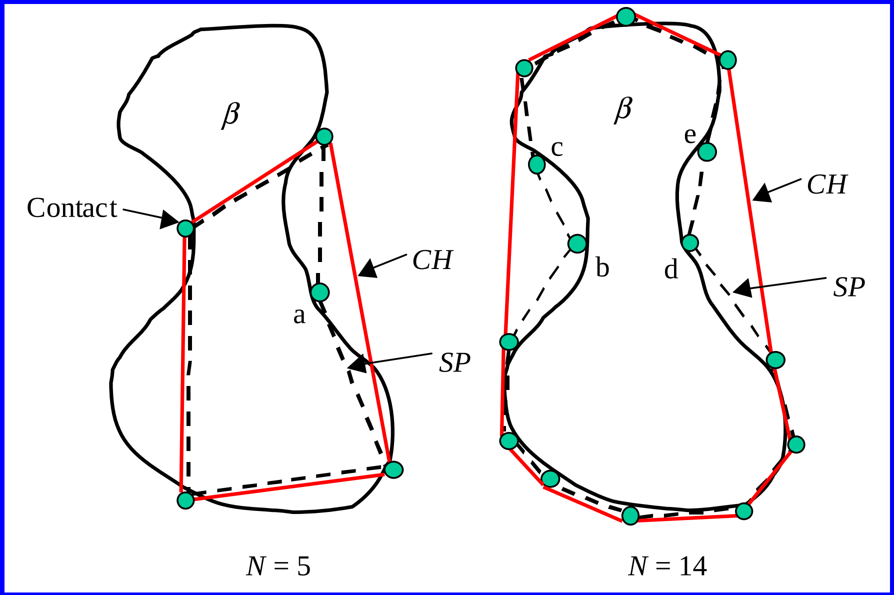

Matrix Pin-Array Type Machining Fixture (X-Clamp)

# Objectives

- Develop a design methodology and analysis tools for mechanical flexible machining fixtures, e.g. pin-array.
- Specific areas of interest:
  - Fixture-Workpiece ***conformability*** and its effect on static **stability**.
  - Tolerance-based **stiffness** optimization of flexible (and dedicated) fixtures.

# Fixture-Workpiece Conformability

- Development and experimental validation of global and local conformability metrics, $C_1$ and $C_2$




$$C_1^{2D} = \frac{1}{\text{Perimeter}(\beta) - \text{Perimeter}(SP)}$$

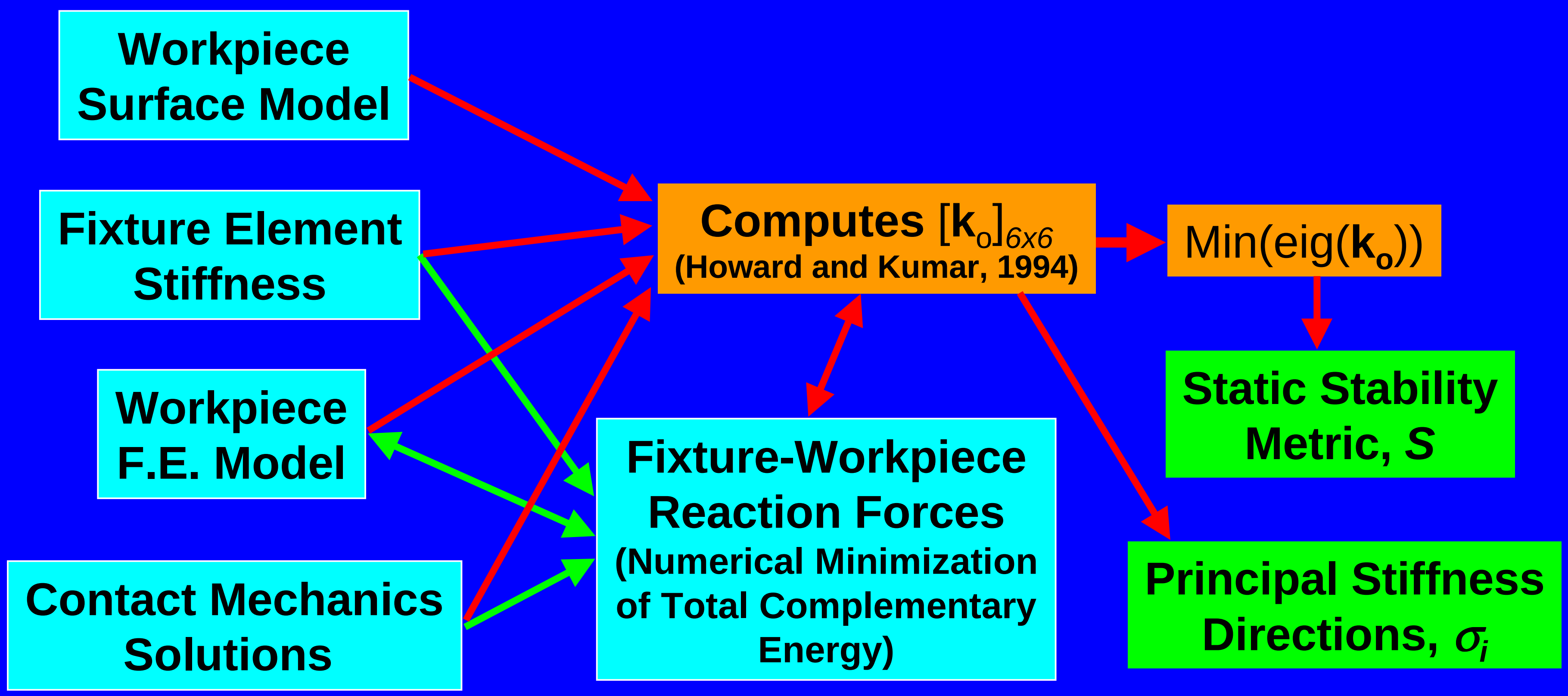
$$C_1^{3D} = \frac{1}{\text{Surface Area}(\beta) - \text{Surface Area}(SP)}$$

$$C_2 = \sum_i {}^i\Delta_n A_i \sum_j d_{ij} \quad (i = 1 \ldots N,\ j = 1 \ldots N)$$

$${}^i\Delta_n = {}^i\Delta_n^c + {}^i\Delta_n^w$$

# Fixture-Workpiece Stability

- Development and validation of a model to quantify the static stability of the fixture-workpiece system accounting for all compliance sources.



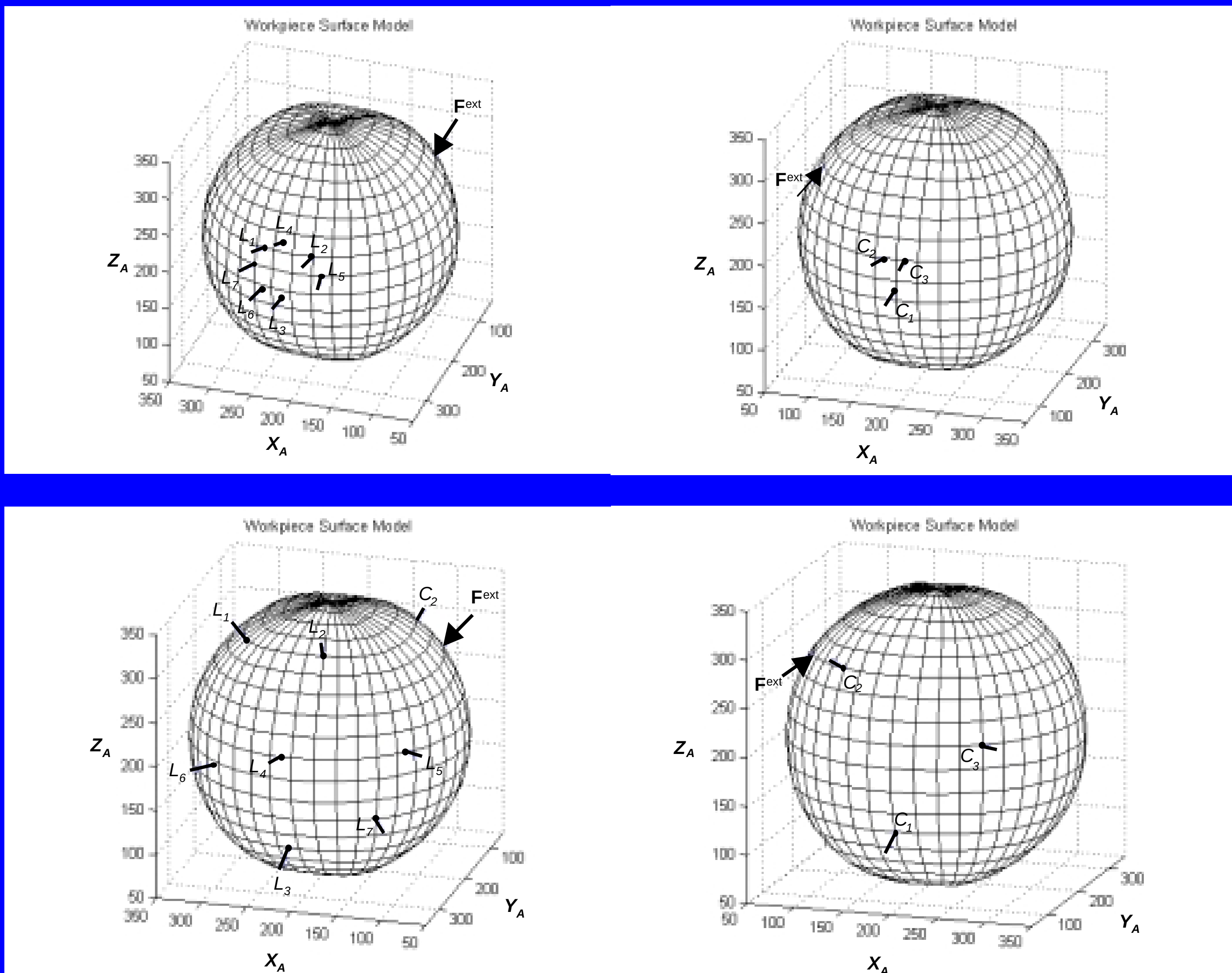
# Application of the Conformability-Stability Model

- Computer simulations to study the effect of conformability on static stability of fixture-workpiece system.

- The model can be used for the optimal reconfiguration of flexible fixtures:

  – To determine the optimal orientation of the workpiece in the flexible fixture that maximizes stability and achieves a part feature accessibility goal.

# Example #1. Computer Simulation.




## Scenario #1

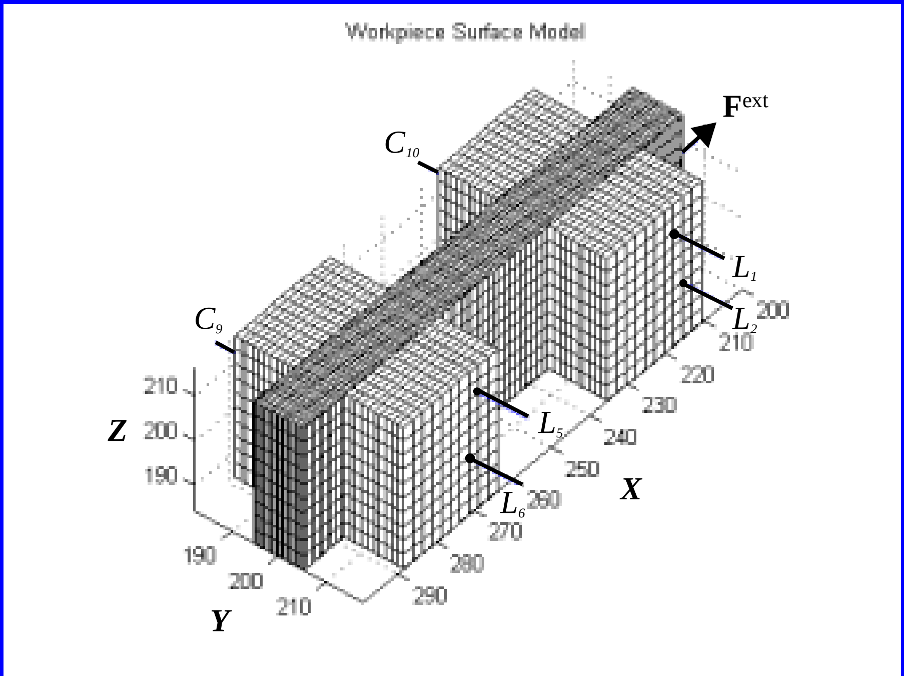
$S$ = 4510
$C_1$ = 4.3x10$^{-6}$ mm$^{-2}$
$C_2$ = 167.9 mm$^4$

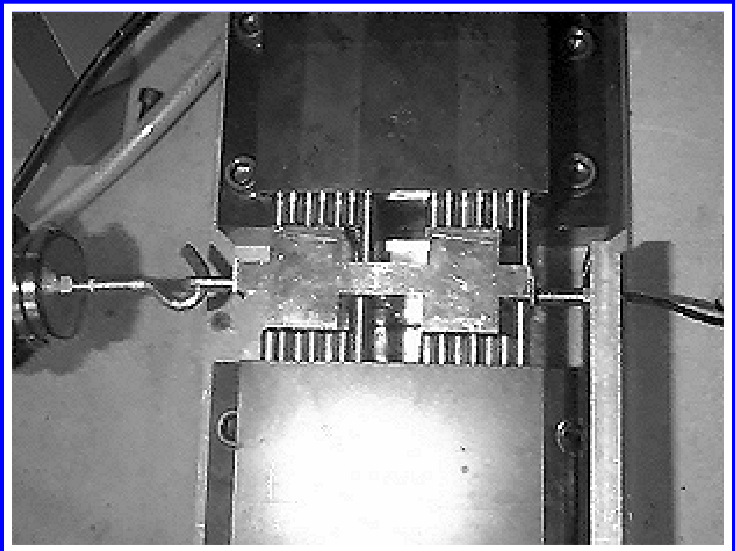
## Scenario #2

$S$ = 8240
$C_1$ = 8.9x10$^{-6}$ mm$^{-2}$
$C_2$ = 212.6 mm$^4$

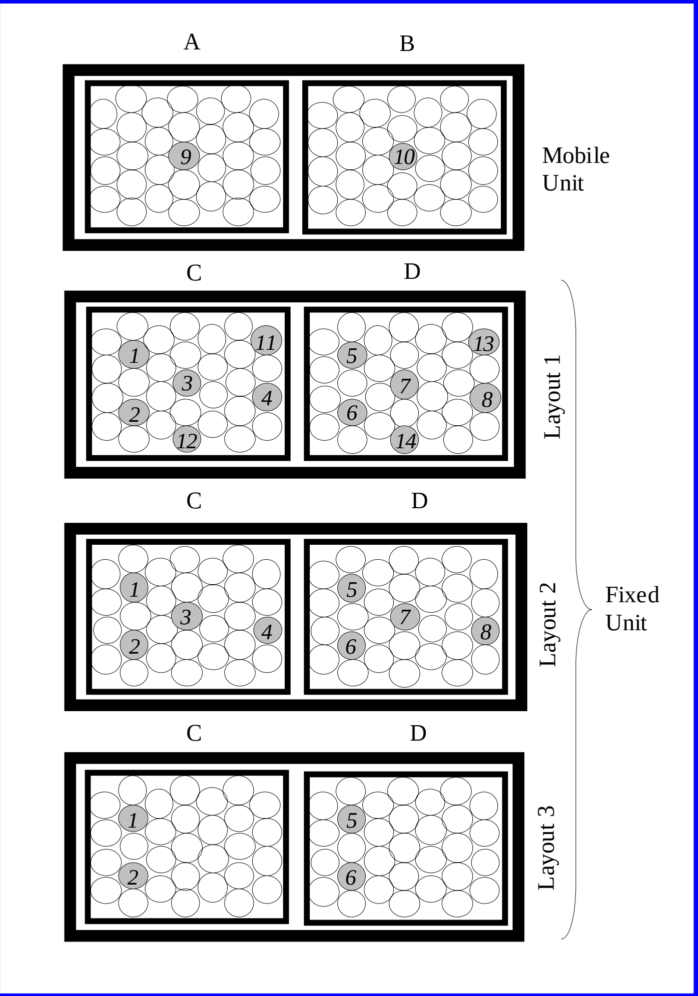
# Experimental Validation

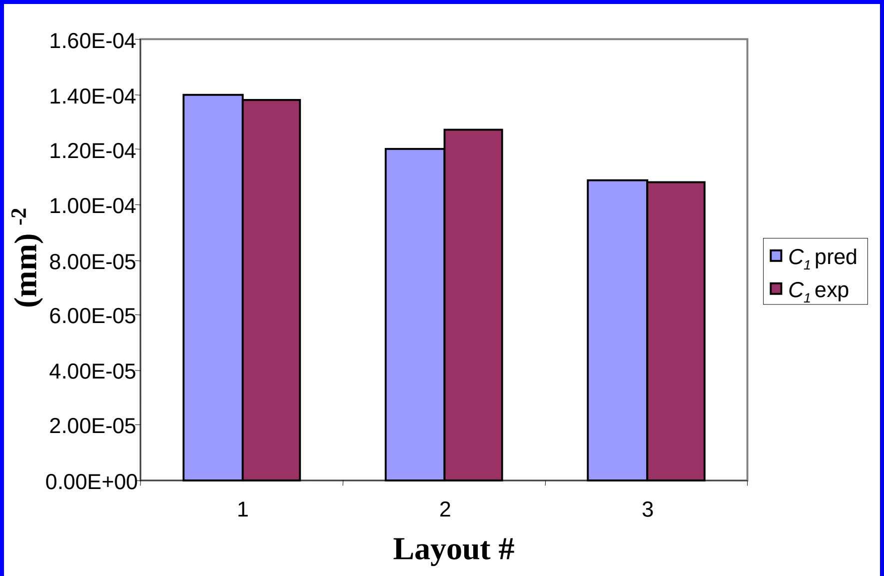
- This model showed good agreement with experimental data taken from the X-Clamp flexible fixture.

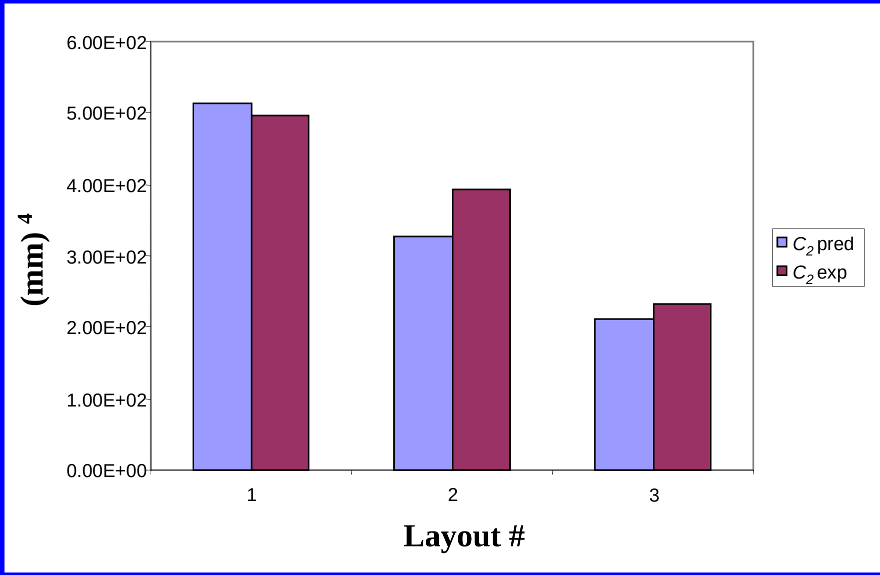


# Validation Results



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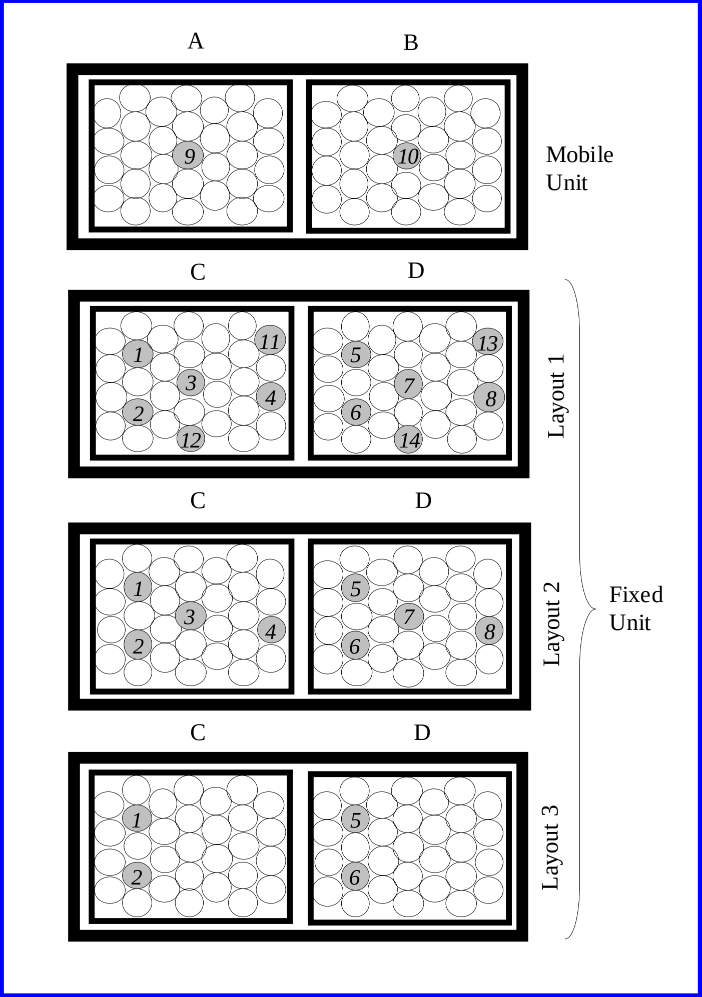
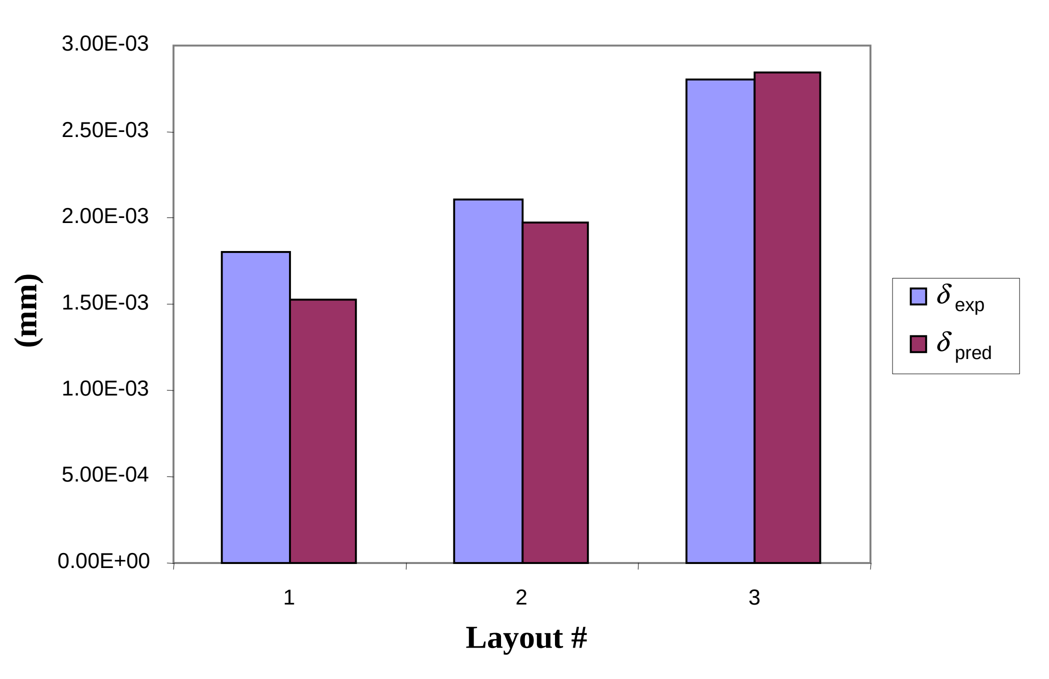
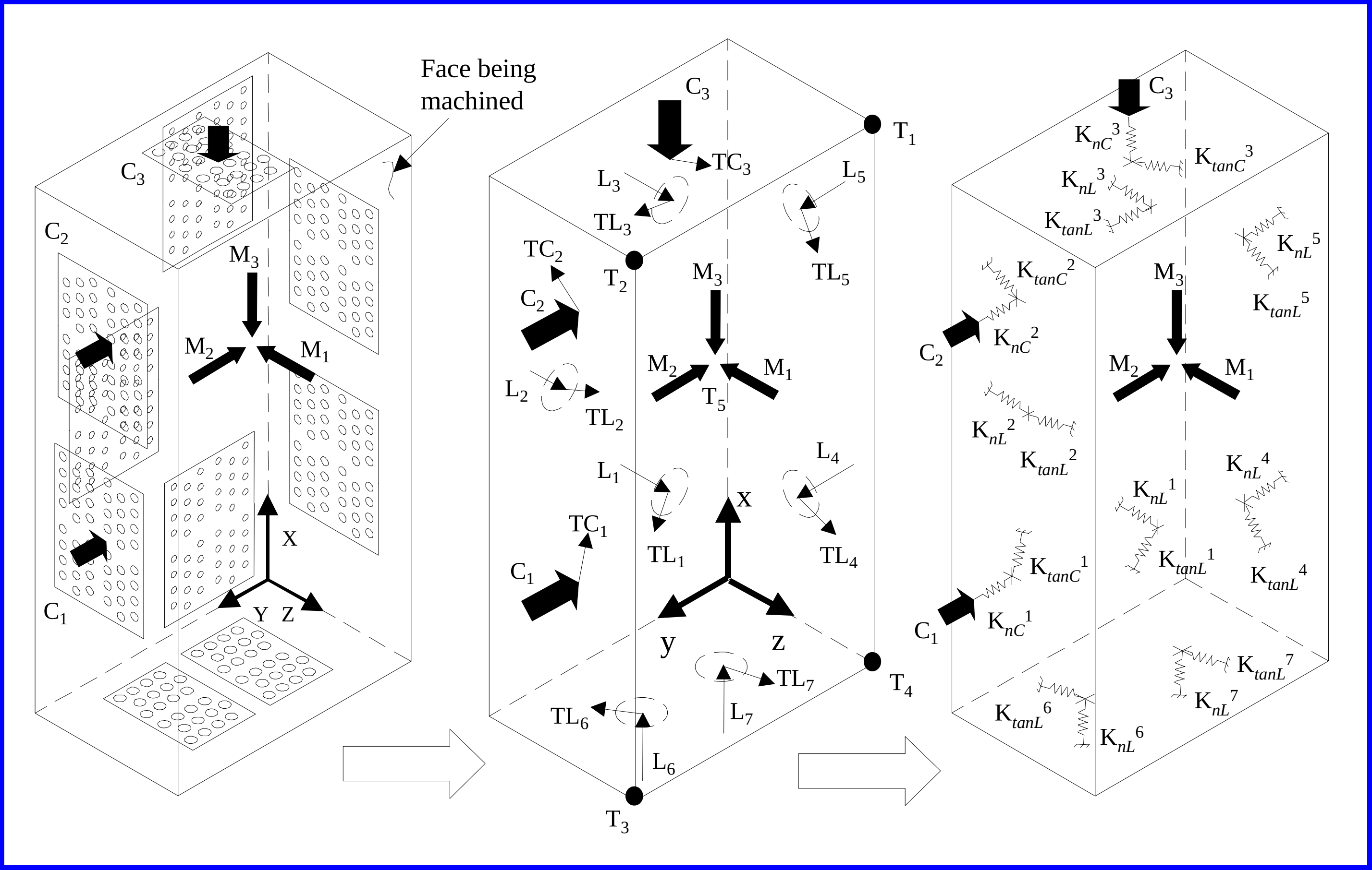


# Tolerance-Based Stiffness Optimization

- Determine fixture stiffness necessary to keep within tolerance the workpiece feature error due to fixture elastic deformation.



# Example #2. Optimal Design.

| Array Parameters | $EL_1$ | $EL_2$ | $EL_3$ | $EL_4$ | $EL_5$ |
|---|---|---|---|---|---|
| **Pitch, *P* (mm)** | 4.33 | 6.71 | 4.25 | 4.24 | 4.24 |
| **Pin Radius, *R* (mm)** | 1.03 | 0.71 | 0.96 | 0.97 | 0.97 |
| **Number of Columns, $N_{COL}$** | 25 | 17 | 26 | 26 | 26 |
| **Number of Rows, $N_R$** | 26 | 17 | 26 | 26 | 26 |
| **Axial Stiffness (N/mm)** | 1.20E+07 | 2.73E+06 | 1.09E+07 | 1.13E+07 | 1.12E+07 |
| **Bending Stiffness (N/mm)** | 1.31E+04 | 1.35E+03 | 1.02E+04 | 1.10E+04 | 1.08E+04 |
| | $EL_6$ | $EL_7$ | $C_1$ | $C_2$ | $C_3$ |
| **Pitch, *P* (mm)** | 4.24 | 4.56 | 6.61 | 6.61 | 4.00 |
| **Pin Radius, *R* (mm)** | 0.97 | 1.01 | 0.85 | 0.86 | 1.29 |
| **Number of Columns, $N_{COL}$** | 26 | 24 | 17 | 17 | 27 |
| **Number of Rows, $N_R$** | 26 | 25 | 17 | 17 | 28 |
| **Axial Stiffness (N/mm)** | 1.13E+07 | 1.07E+07 | 3.80E+06 | 3.83E+06 | 2.10E+07 |
| **Bending Stiffness (N/mm)** | 1.09E+04 | 1.11E+04 | 2.77E+03 | 2.82E+03 | 3.78E+04 |

# Future Work

- Experimental validation of the tolerance-based stiffness optimization algorithm.
- Synthesis of pin-array type flexible machining fixtures.