Generation and Evaluation of Meso-scale Machine Tool Designs for Micro-machining Applications

Research Assistants/Staff: *H. Chen*

Faculty: *J. Ni*

Objectives

- Integrated design and simulation software environment for meso-scale machine tool applications with expert-system based machine tool design optimization, systematic candidate design generation, and performance evaluation.

State-of-the-Art

•Lack of systematic methodology to generate and evaluate meso-scale machine tools (mMTs).

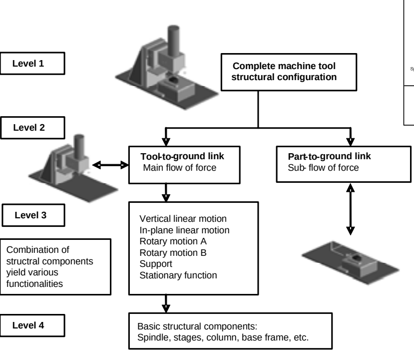
Approaches

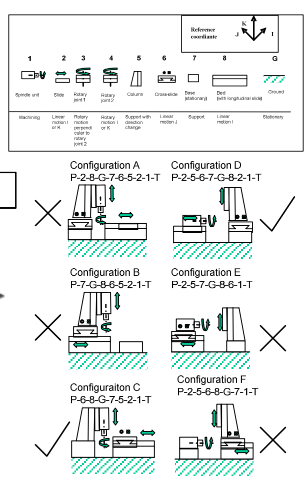
mMT design and evaluation framework

- **Machine tool design**
  - **Conceptual design** — Generation of feasible structural configurations
  - **Conceptual design** — Configuration reduction with functional requirements and expert design rules
  - **Detail candidate design** — Substitution of structural representation with parameterized components
- **Machine tool evaluation**
  - **Performance modules**
    - Kinematics error
    - Thermal behavior
    - Micro-milling force model
    - Machining dynamics
  - Evaluation of candidate design

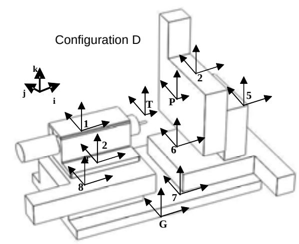
Accomplishments

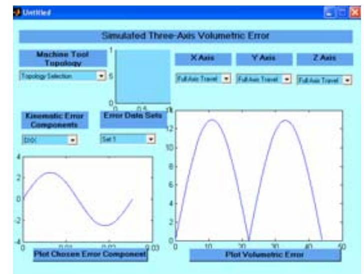
•Systematic generation of machine tool configurations with extended graph theory



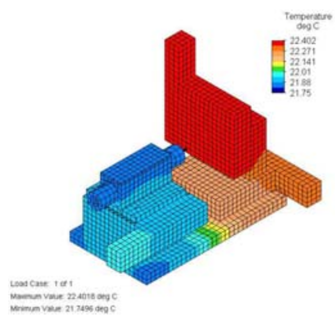


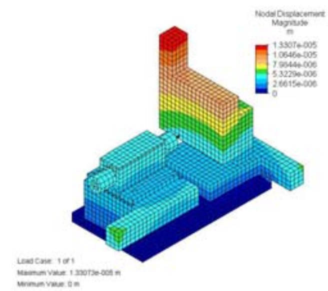
•Automated kinematic error model formulation



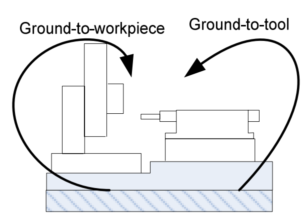


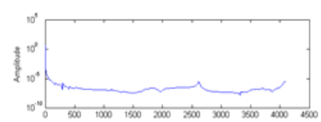
•Thermal error analysis with FEM simulations

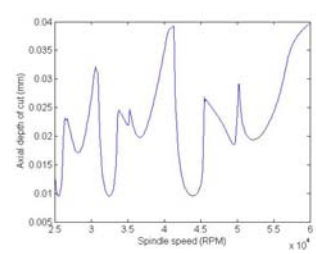




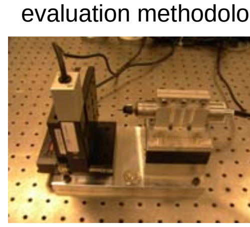
•Machining dynamics evaluation with micro-milling force model and receptance coupling methodology

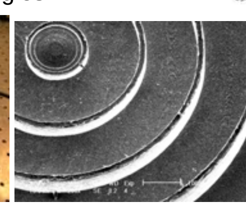


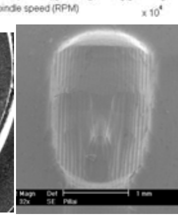




•New mMT platform built with developed design and evaluation methodologies







Sponsors

•NSF

For more information, contact Prof. J. Ni; Phone: 734-936-2918; Email: junni@umich.edu

Development of Meso-Scale Machine Tool (mMT) System

Research Assistants/Staff:
S. Lee, H. Chen, C. Kim

Faculty:
J. Ni

Objectives

To develop the foundation of a technology, rooted in conventional material removal principles, for the production of micro/meso-scale (100 - 10,000 mm) components by methods whose efficiency approaches to that of mass production

Approaches

• Create a "miniaturized" machine tool system referred to as a meso-scale Machine Tool (mMT) utilized in a massively parallel fashion
• Develop chip formation mechanisms and cutting mechanics model of micro-scale milling process
• Develop methodologies to characterize dynamic and static behaviors of mMT
• Develop a multi-axis miniaturized positioning system for mMT with the aid of a novel piezoelectric stick-and-clamping actuation technology

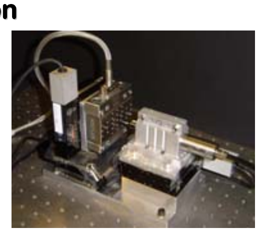
Impact

• Combination of advantages of relative accuracy achieved with a conventional material removal process and efficiency of MEMS-based technologies
• Production of fully 3D micro/meso-scale features without the limitation of materials
• Enhanced precision and accuracy via equipment downsizing
• Reduced machine costs, floor space requirement, energy, labor and operation costs

Accomplishments

❖ mMT testbed implementation

• Overall size: 210x114x153 mm
• Working volume: 25x25x25 mm
• Rotating system:
Air spindle (ω_{max}=120,000 rpm)
• Positioning system:
3-axis DC motor linear stages



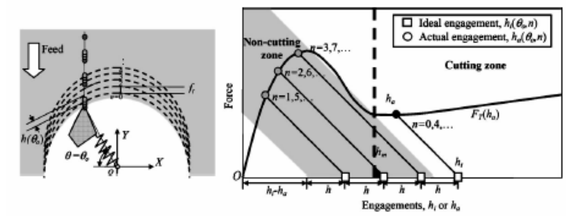
❖ Machining performances

Micro wall and circular channel
Tool: 127um flat endmill
Workpiece: Brass
Wall thickness: 20 um

Human face
Tool: 300um ball endmill
Workpiece: Aluminum
Size 3.5x1.8x1.1 mm

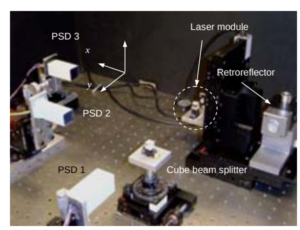
❖ Mechanics of micro-scale milling process

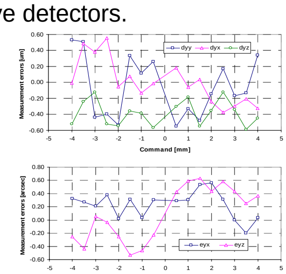
• The minimum chip thickness and intermittent chip formation in the micro-scale milling process were observed, and the cutting force model was established via combined molecular dynamics and slip-line analysis.



❖ Static accuracy characterization: 6-DOF geometric error measurement for mMT

• A novel optical 6-DOF geometric error measurement system was developed by using a laser module, a beam splitter, and position sensitive detectors.

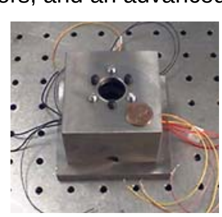


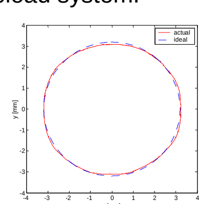


• A series of experiments to obtain full pose of the laser module were conducted and their results were compared with those from laser interferometer. Measurement accuracy was better than ±0.6 um for translational components and ±0.6 arcsec for rotational components respectively with calibration.

❖ Multi-axis stage based on piezoelectric stick-and-clamping actuation technology

• The piezoelectric stick-and-clamping actuation technology enables 2-DOF motion in a single plane by using 2-mode shearing piezoelectric actuators, expanding piezoelectric actuators, and an advanced preload system.





Sponsors

National Science Foundation (NSF)

For more information, contact Prof. J. Ni; Phone: 734-936-2918; Email: junni@umich.edu