Micro Scale Machine Technologies

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NIST Research at the Micro-Scale

Objective

Research and development of metrology methods and standards for improving the accuracy and resolution of Micro Scale machine technologies.

Motivation

Micro Scale machine technologies are enabling technologies for manufacturing devices for the nano, medical, telecommunications, and defense industries.

Focus on ability to accurately produce parts fitting in a work volume of 25 mm by 25 mm by 25 mm with part features approaching one micron in size.

Current Research at NIST

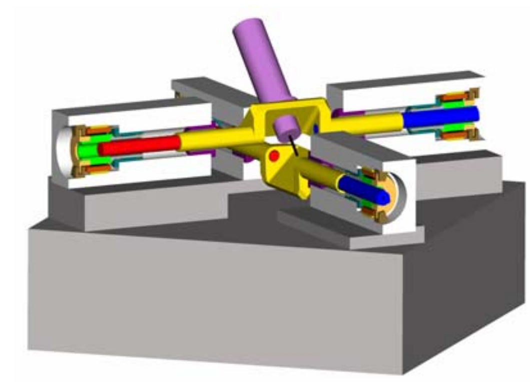
Project's research has four focus areas:

- Research and develop new micro machines based on new designs and technologies
- Develop new metrology tools and devices to improve micro machine accuracy and resolution
- Develop new metrology methods to characterize micro machines
- Develop new micro machining processes (i.e. micro fluidic devices)

Three machines are under development for use in this research project

Research on New Machine Designs: MesoMill

- **A five-axis milling machine with a novel kinematic configuration designed for the machining parts:micron to 25 mm cubed**
- **A five-axis machine allows for five sides of a part to be machined in one setup, thus minimizing errors introduced by part re-fixturing.**
- **A three-axis version of the MesoMill has been built and is under test at NIST. Machine configured for rotary milling applications.**



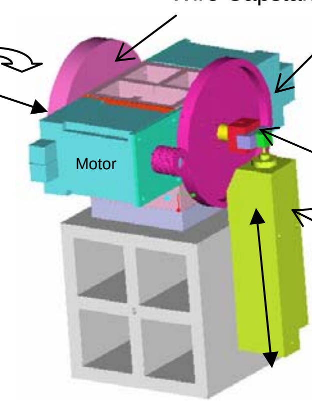
Courtesy of A.Slocum of MIT

Utilizes ball screw-spline actuators to provide linear/rotary axis motion in order to build

small low-cost machine structures

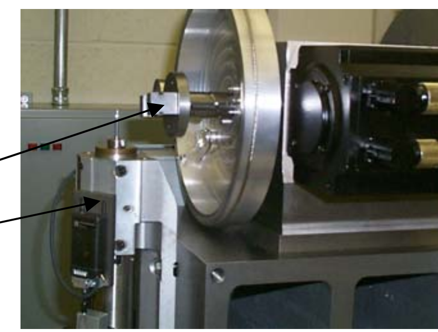
Utilize linear/rotary spindle standard in circuit board drilling industry

Wire Capstan Drives



Part & Vise

ESI Spindle

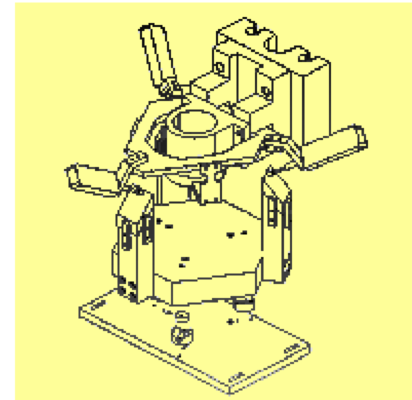


Three-Axis Design Concept

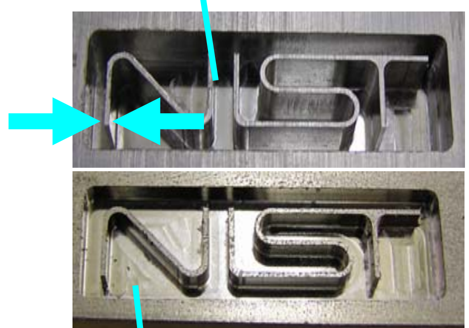
In Collaboration with Prof. Alexander Slocumr, MIT

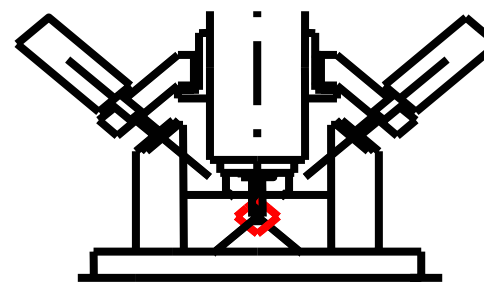
Research on Metrology Frames for Improving Machine Accuracy

- Concept – separation of metrology loop from the load bearing structure to improve machine accuracy
- Result – accuracy of the machine would only be affected by the accuracy of the metrology system (insensitive to machine thermal and structural deformations)



Metrology frame components made from invar for thermal stability, utilize kinematics mounts and flexures to prevent structural deformations.





Utilizes three high-precision displacement sensors as positioning feedback – three measurement axes intersect at the tool tip to obey Abbe principals.

Work volume: micron to 25 mm cubed with High speed spindle (10,000 to 40,000 rpm)

Research on Machines utilizing New Metrology Devices

•A high-speed three axis micro machine is under development.
•The machine will utilizes a two axis stage which incorporates a two dimensional grid encoder with 0.01 um resolution for the X and Y axes (Heidenhain PP281 encoder).
•The two axis stage is actuated by voice coil linear motors with 66 mm of travel.

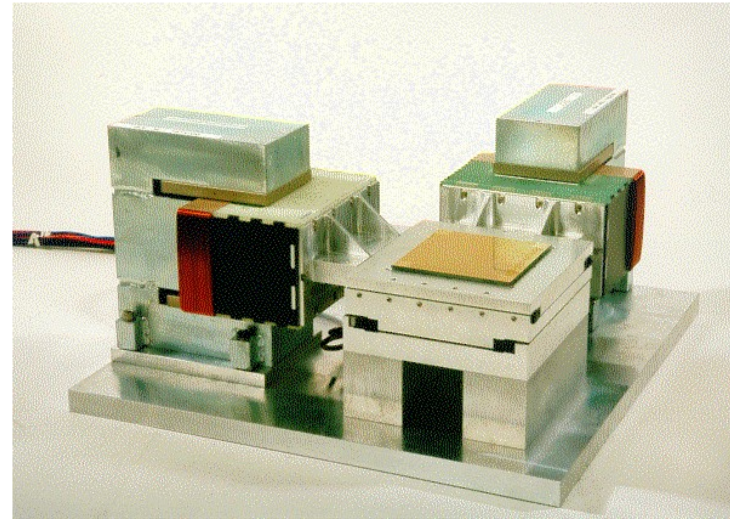
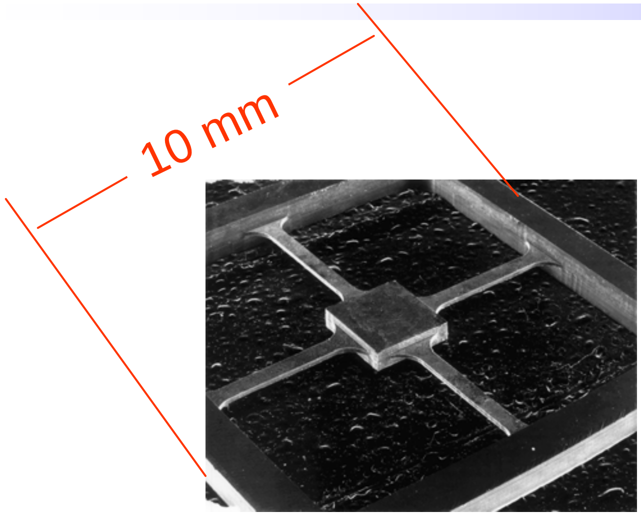


Photo Courtesy of Heidenhain Corp

In collaboration with Heidenhain Corp.

•A high speed spindle (10,000 to 40,000 rpm) will be incorporated with a vertical travel (Z axis) stage to complete the Cartesian machine.
•A granite base with bridge structure is being designed. The bridge structure will support the spindle and vertical travel stage.
•The machine work volume is designed to be 50 mm cubed.

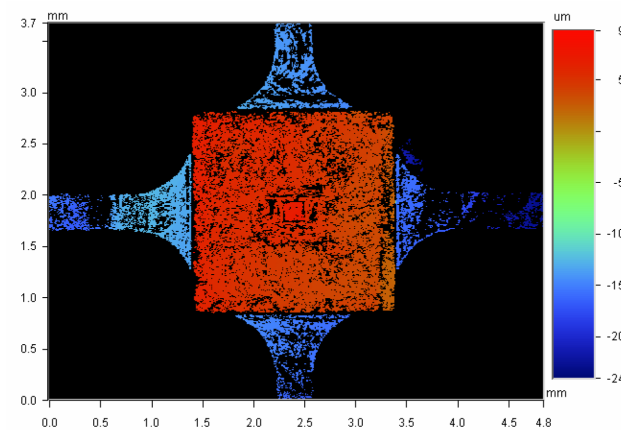
Scientific Barriers

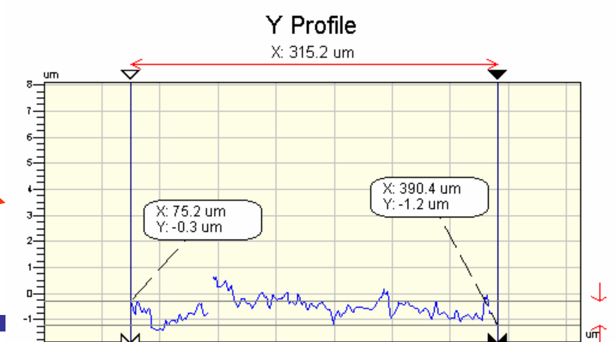


Magnification 13.7x

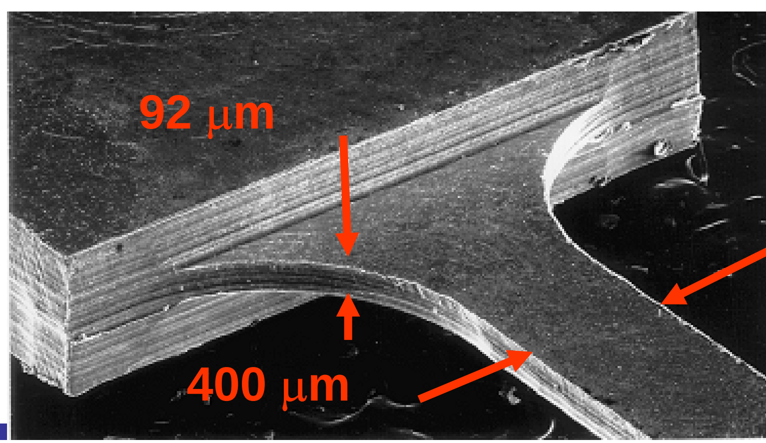
The metrology tools for measuring small parts are a significant barrier

White Light Interferometer





Machined Flexure for a Micro-scale Force Transducer



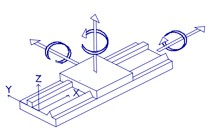
Magnification 68x

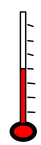
Technological Barriers

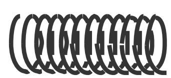
Machine Tool Performance Characterization of Conventional Machines

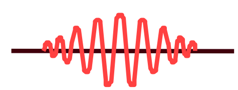
Models, parameters, tests, and standards to specify and evaluate machine tool performance.

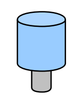
- Machine comparison, specification and acceptance
- Machine improvement (error compensation)
- Machine performance monitoring
- Machine capability analysis

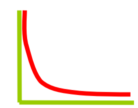

Geometric Errors


Thermal Errors

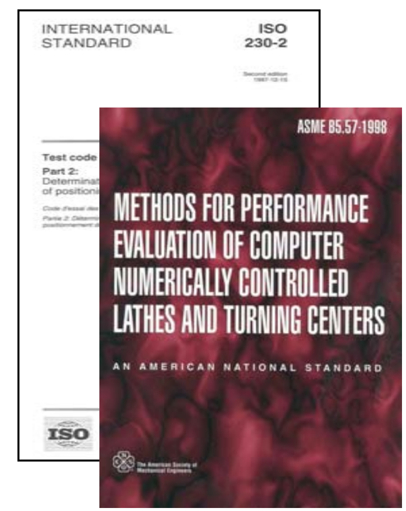

Stiffness & Hysteresis


Machine Dynamics

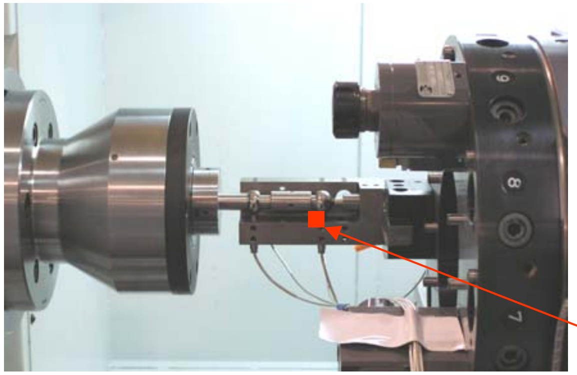

Axis of Rotation


Contouring

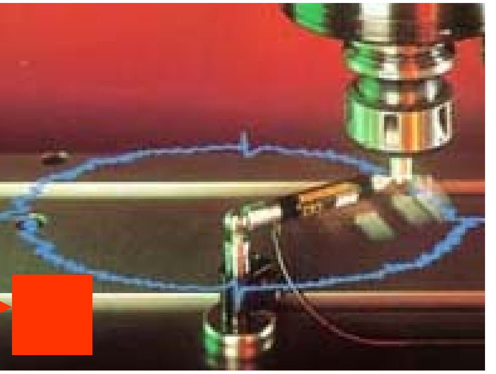
These methods and standards do not scale down completely



Technological Barriers



Artifact for Measuring Axis of Rotation



Telescoping Ballbar for Measuring Circularity Errors

Current Metrology Devices do not fit small machine tool work volumes

Laser Optics for Measuring Angular Errors

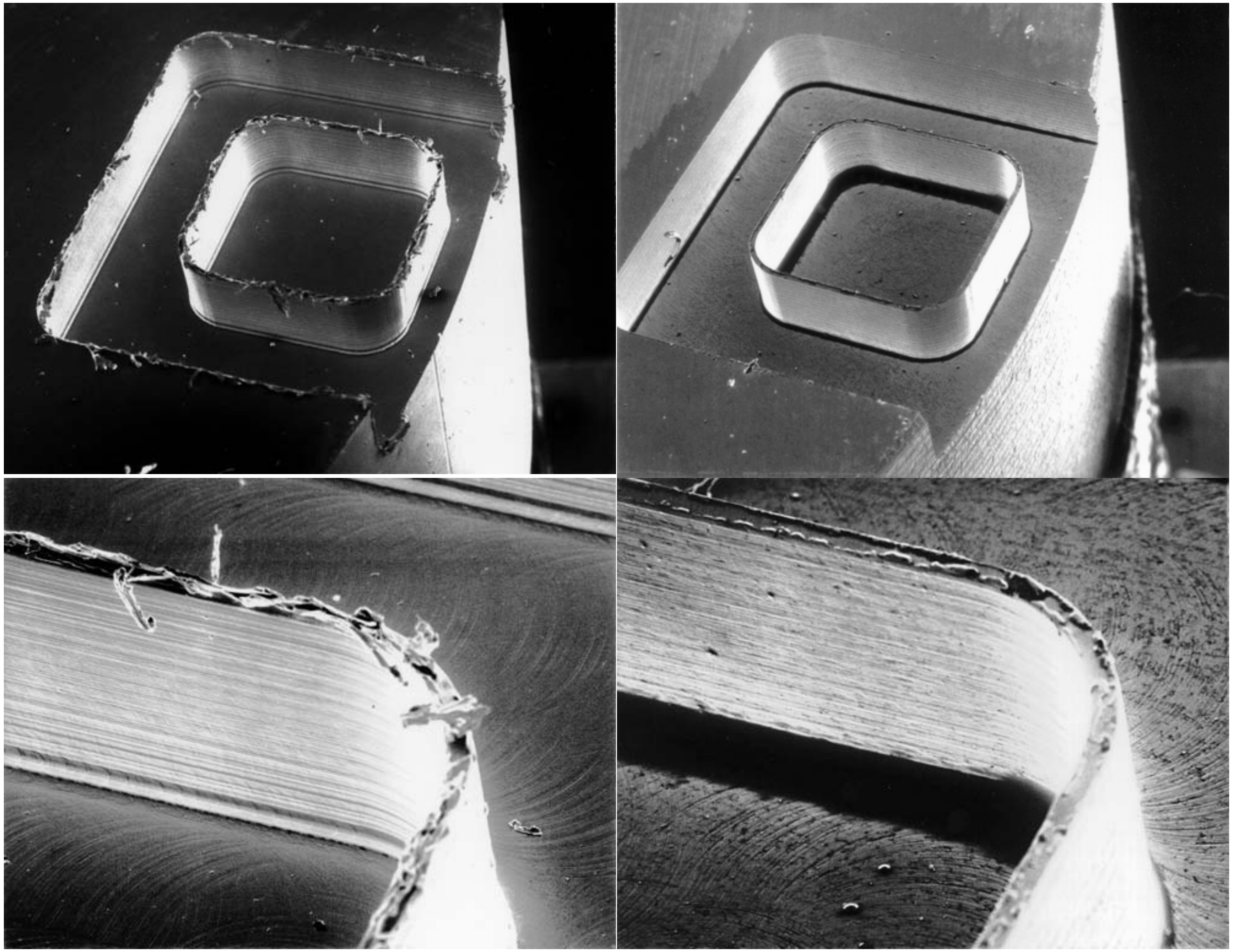
Grid Plate for Measuring Contour Errors

Micro Milling Capabilities

Machining Principle	Mechanical ablation (defined cutting edge)	**Removal Rate / Machining Time**	Medium...low/ Hours..days
Tool Type	end-mills	**Minimum Structure Details**	>5 µm (sub-µm for SPD milling)
Tool Material	Carbide, HSS, Diamond	**Maximum Aspect Ratio**	Typ. 10
Min. Tool Size	<50 µm ... 125 µm	**Accuracy**	1...3 µm (sub-µm for SPD milling)
Workpiece material	Ductile materials: polymers, copper, aluminum, graphite, green ceramics, steels	**Surface Finish (Ra)**	<0.1 µm

SPD: single point diamond

Micromilled Features at NIST



Pocket size: 2.5 mm
Wall Height: 0.5 mm
Wall thickness 100 um

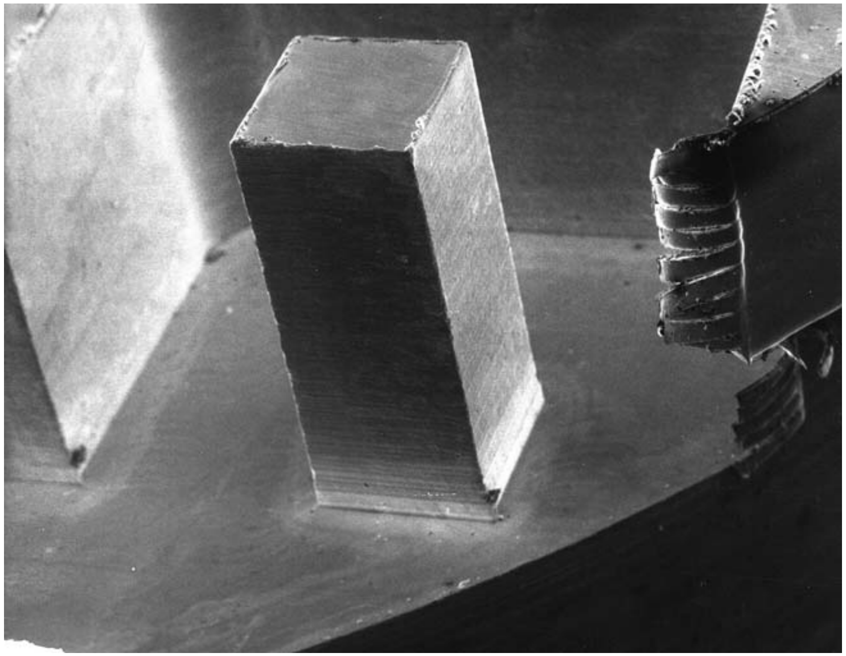
Magnification: 20x

Magnification: 100x

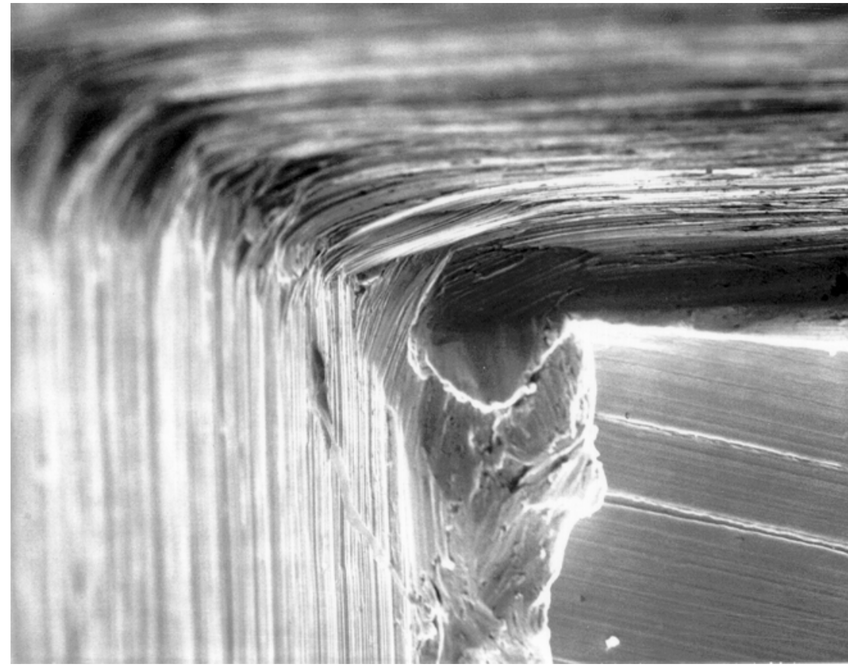
Material: 304 Stainless Steel

Material: Cast Iron

Micromilled Features at NIST

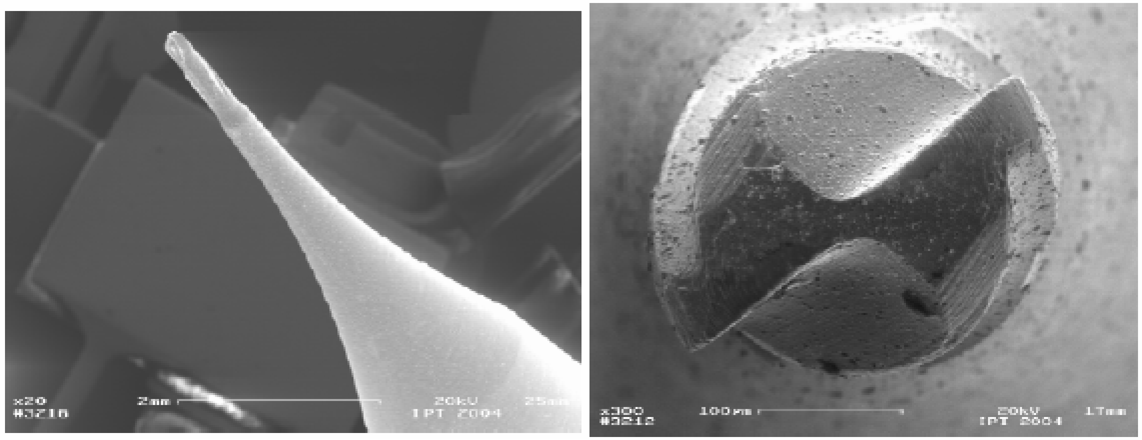


Feature size 0.5 mm by 2.5 mm depth
Material: Copper
Cutter: 1.57 mm: four flute endmill
Magnification: 25x

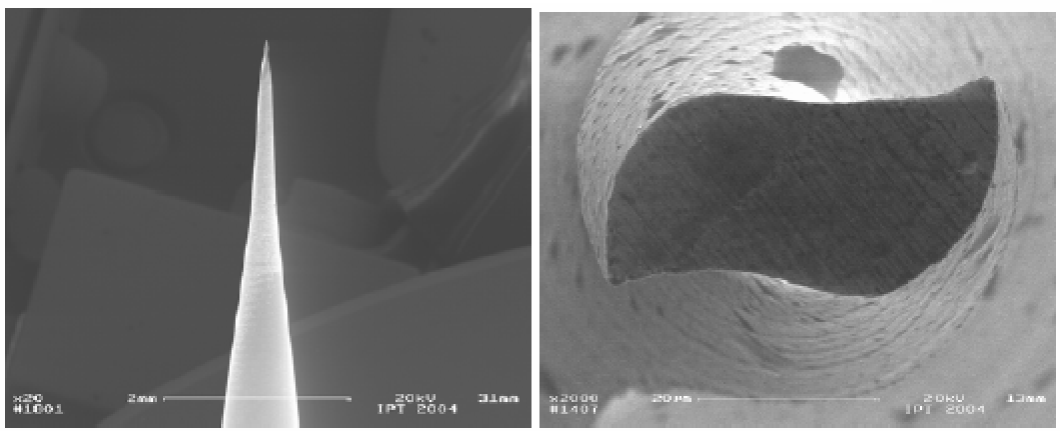


Edge of square post, 660x

Micro Endmill Tooling Examples



Micro endmill 50 um diameter

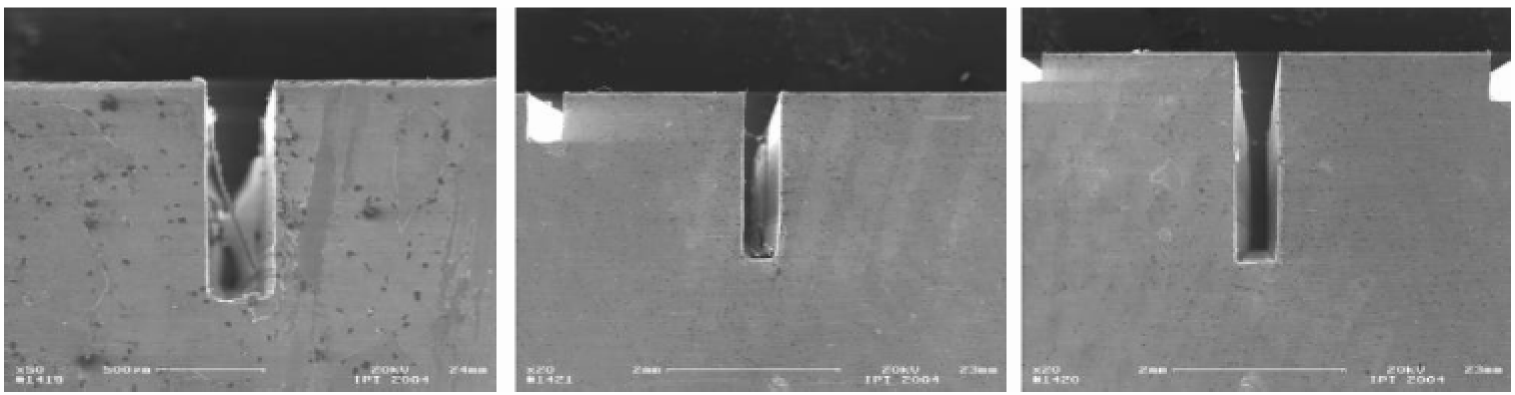


Micro endmill 50 um diameter

Results from the Fraunhofer Institute of Production Technology, Aachen Germany

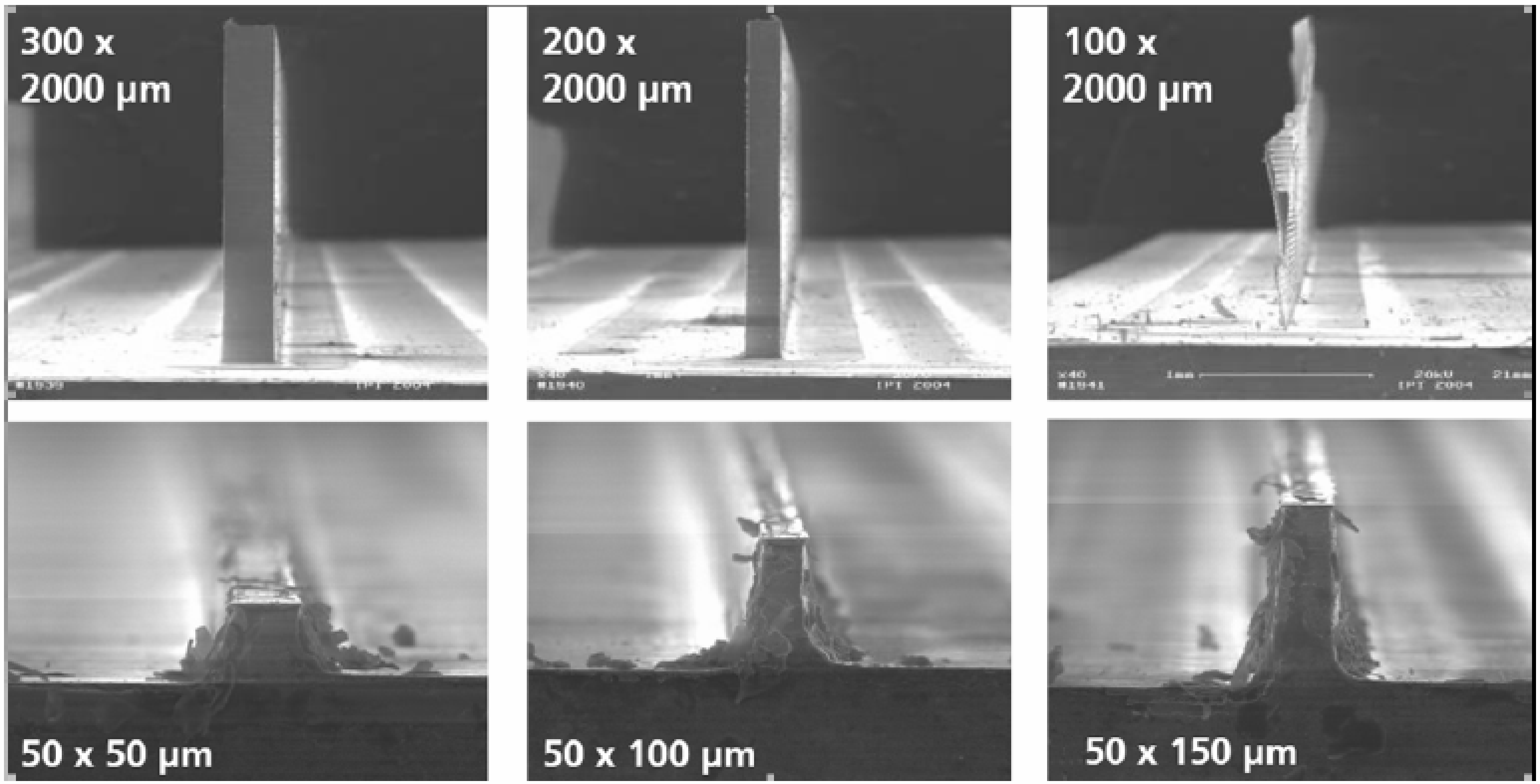
Slots micromilled in tool steel (55 Rc)

300µm Tool Magafor 9500-H ⇒ depth of slot = 1000 µm (40mm long)	400µm Tool Magafor 9509-H ⇒ depth of slot = 2000 µm (40mm long)	500µm Tool Magafor 9509-H ⇒ depth of slot = 2500 µm (40mm long)



Results from the Fraunhofer Institute of Production Technology, Aachen Germany

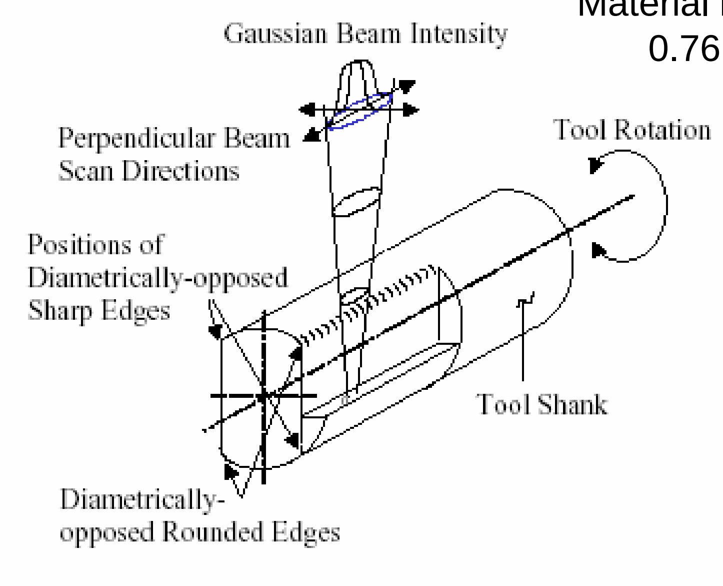
Rectangular features micromilled in tool steel (55 Rc)

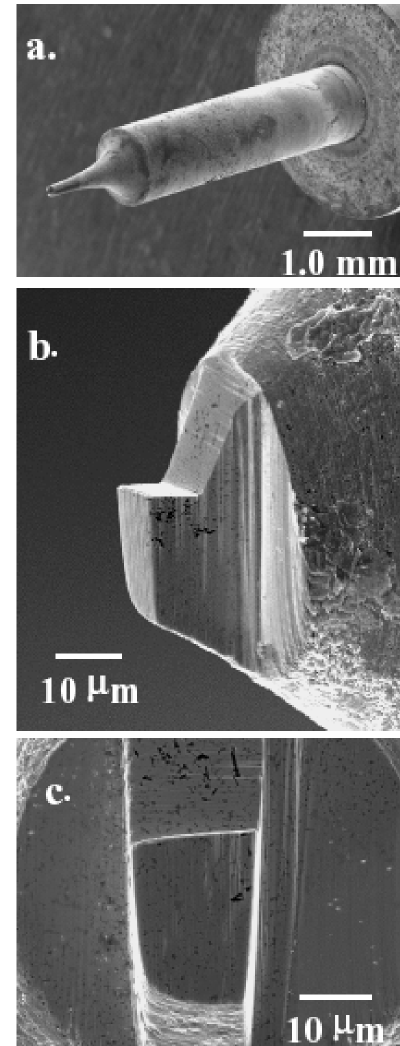


Results from the Fraunhofer Institute of Production Technology, Aachen Germany

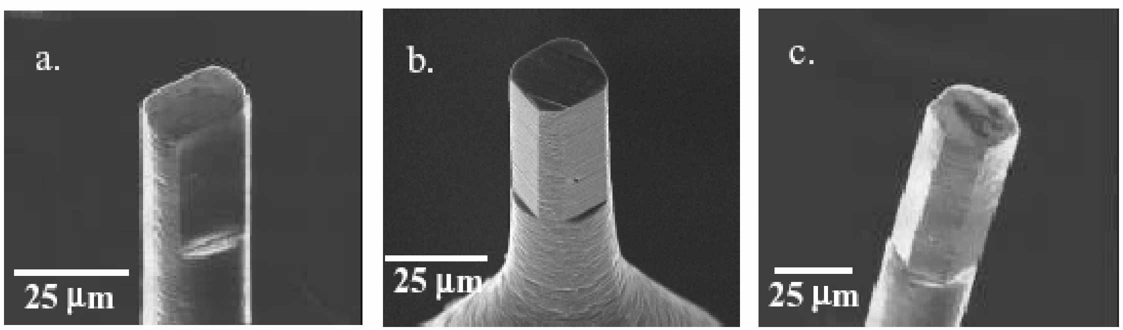
Focused Ion Beam Machining

Material removal rate:
0.76 μm³/sec





FIB machined
micro turning tool,
18 μm micro grooving/
threading tool



FIB machined micro endmills

Source: SNL

Focused Ion Beam Machining

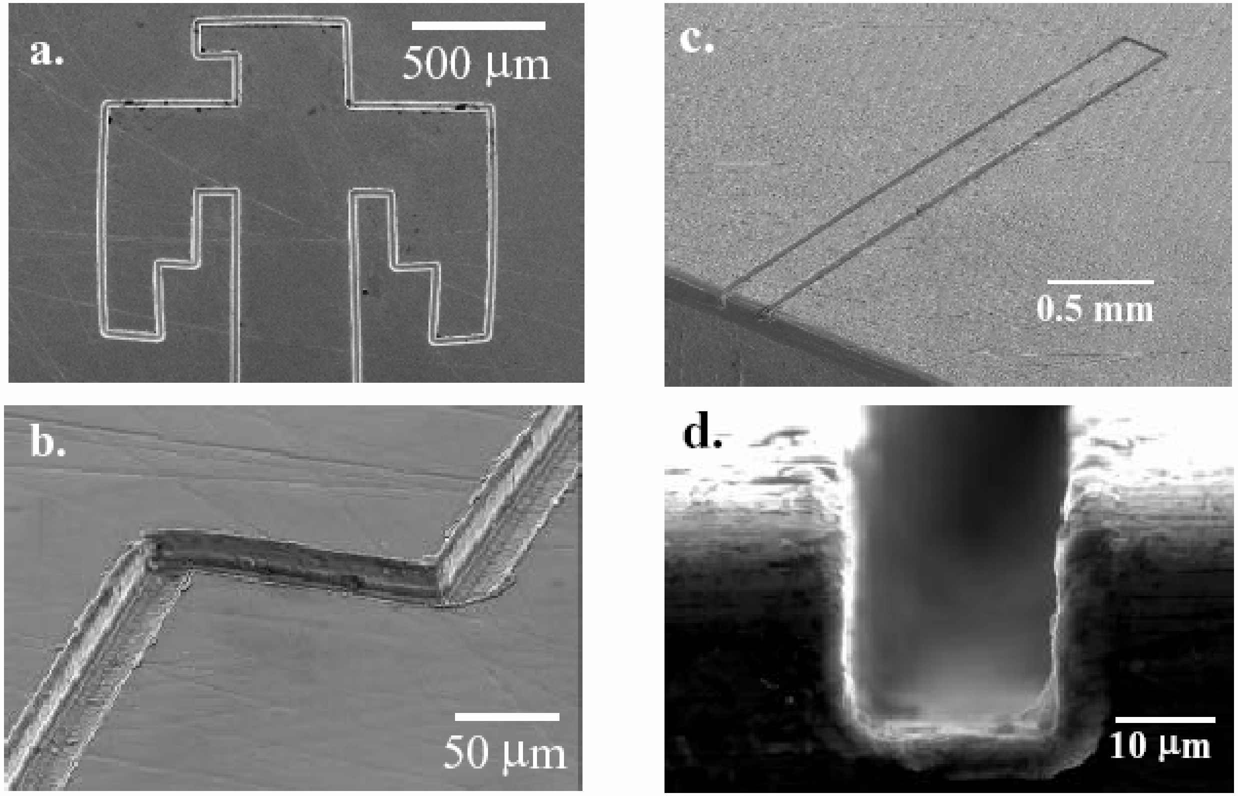


Figure 2.6. Micromilled metal workpieces including brass (a. and b.) and 6061 Al alloy (c. and d.)

Feedrate: 2-3 mm/minute, DOC ≥0.5 µm, tool dia. ≈25 µm

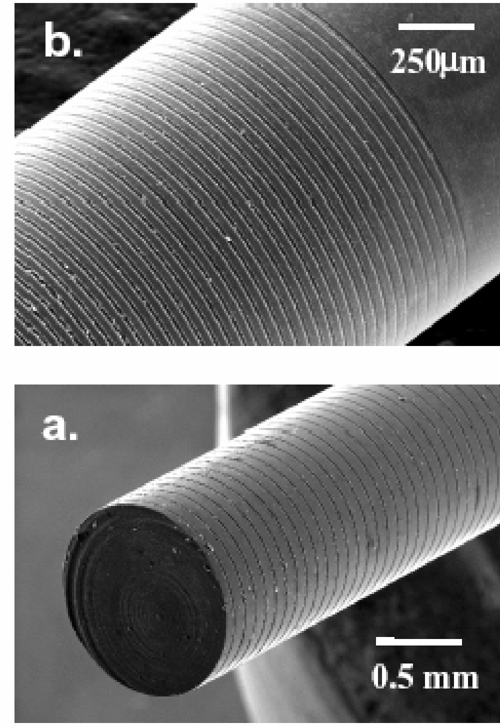


Figure 2.9. Cylindrical workpieces machined with lathe microtool. Helical grooves are fabricated into (a.) Al 6061 and (b.) PMMA.

13.2 µm by 4 µm deep grooves

Source: SNL

Micro fluidic device Application

Potential benefits of micromilling

- Micromilling can be used to produce stamping dies or directly produce micro channels
- Rapid manufacture of prototype devices
- Enable use of solvent and heat resistant materials (i.e. stainless steel, tool steel)
- 3D geometry creation
  - shaped walls
  - in channel features for fluid mixing
  - create transitions between channel elevations

Micro fluidic device Application

Potential limitations of micromilling

- Constraints imposed by limits of tool geometry
- Limits of material grain sizes
- Tooling wear and breakage
- Limits in surface finish
- Burr elimination
- Must have effective encapsulation techniques

Summary

- Micro manufacturing techniques present many challenges, but also many rewards.
- As parts scale down, a part’s accuracy requirement scales up.
- New metrology methods to characterize micro parts and machines are a key element in making small parts accurately.
- Micro machining technologies are enablers for many different industries, such as Medical Devices Manufacturing and Nanomanufacturing.