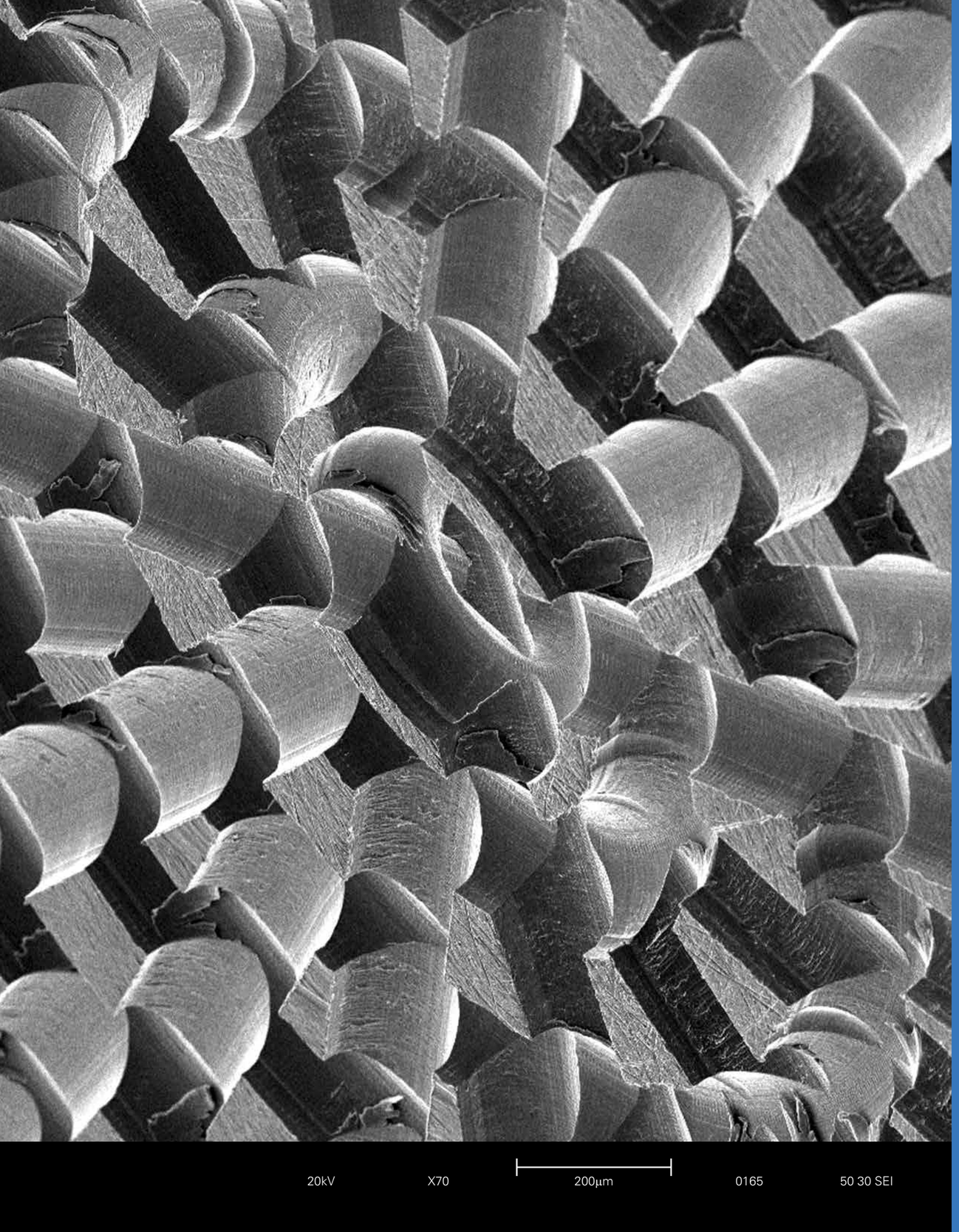
Micromachining Technologies

MAKINO
Promise of Performance



No opportunity too small.
No production goal too ambitious.

Makino provides ultra-precision micromachining technologies for the most challenging parts and features. At Makino, we're machining parts with micro scale features to micron level tolerances every day. As applications grow in complexity and shrink in size, Makino provides the milling and EDM solutions with the extreme accuracy necessary to machine these micro and miniature parts.

Makino Micromachining

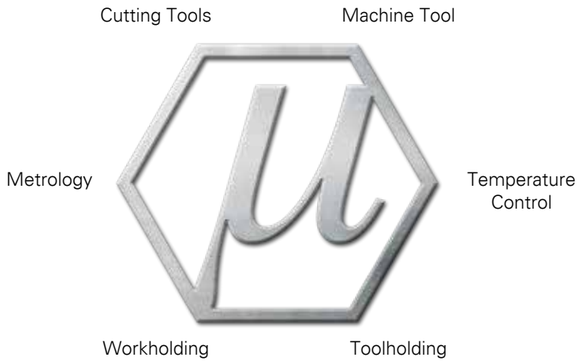
In response to demand for new innovations from our customers, Makino is committed to providing new ideas for micro scale manufacturing. It is our aim to foster innovation that will lead to engineering of new high value products that previously could not be made without our technology.

This guide will provide a reference to better understand Makino's micro machining technologies, and introduce key components that must be considered to work in concert with the machine tool. Without this supporting investment, it will not be possible to consistently reach the full potential of this high level machining technology.

The Key Ingredients

Although Makino cannot present a business model and operating structure to guarantee complete success, we can help you identify the physical elements that are required to create a proper foundation from which your micromachining business can grow and succeed.

It is critical to have a basic understanding of these individual items, what they provide, and how they interact and affect other elements. A lack of upfront planning and investment will ultimately result in machining performance and part quality that will likely not meet your expectations on a consistent basis.



Machine Tool. Motion device that is essentially the physical interface between the part design and the final physical part. If it is assumed that the electronic part model is free of error, then this is the point where all geometric error is entered into the final part.

Temperature Control. Thermal environment surrounding the machine tool, and associated supporting devices. For machining accuracy, and repeatability of 2µm or less, it is recommended that the temperature variation of your machining environment not exceed ±1°C.*

Tool Holding. Precision tooling device for holding and locating the cutting tool. Ideally, this device should provide locating repeatability of less than 1µm when clamped in the spindle interface device.

Work Holding. Tooling device for holding the work piece. Ideally this device should provide kinematic locating accuracy, repeatability and alignment of 1µm or less when clamped in the table interface device, or transferred to another like interface receiver on another machine or set-up location.

Metrology. The methodology of inspecting the machining result in reference to a qualified standard. Gauge R&R standards typically require the inspection device to provide accuracy and repeatability not exceeding 10% of the total feature tolerance.

Cutting Tools. The physical interface between the machine tool and work piece material. This tool is responsible for work piece material removal. This tool can represent a rotating or stationary cutting tool, drill, tap, EDM electrode, or wire EDM electrode.

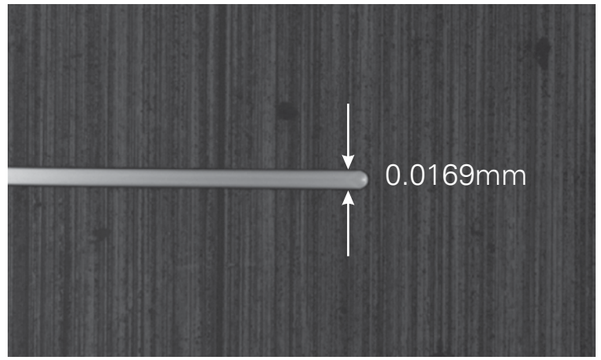
*If this is not possible, a Thermal Chamber option is available from Makino to provide a temperature control environment immediately surrounding the machine tool.

Ultra Precision Wire EDM

The UPN-01 ultra precision wire EDM platform is the pinnacle of Makino's 30+ years of research and development, as directed by the customer's most challenging demands. This machine is regarded as the highest accuracy wire EDM machine in the world.

This machine was developed specifically to provide "reference" level accuracy, for master gauges and ultra precision tooling that otherwise could not be produced.

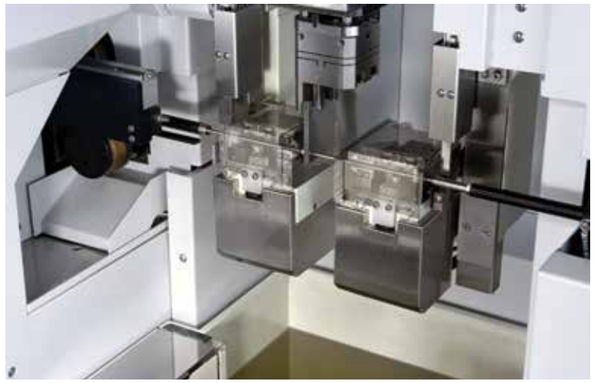
- By implementing the very latest technologies in axis slideway and motion control systems, this ultra precision wire EDM platform provides the highest level of wire EDM machining precision available in the world, providing guaranteed positioning accuracy of ±500nm (0.5 microns), with 500nm repeatability and achievable machining shape accuracy of ±500nm.
- Provides capability of utilizing 15 micron diameter wire
- Self-contained machine thermal chamber ensures consistent temperature environment for machine
- Can successfully auto thread 20 micron diameter wire through 30 micron diameter start hole
- Roundness of machined hole is 600nm in XY plane, and when tapering, UV plane roundness of hole is within 200nm

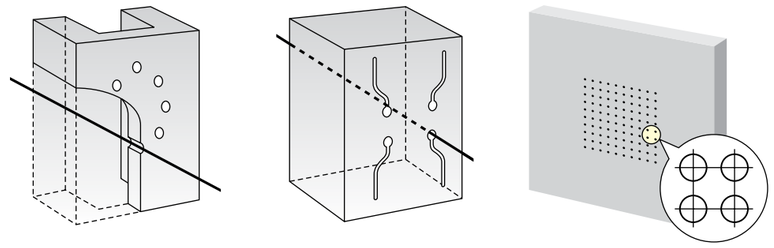


Why Horizontal

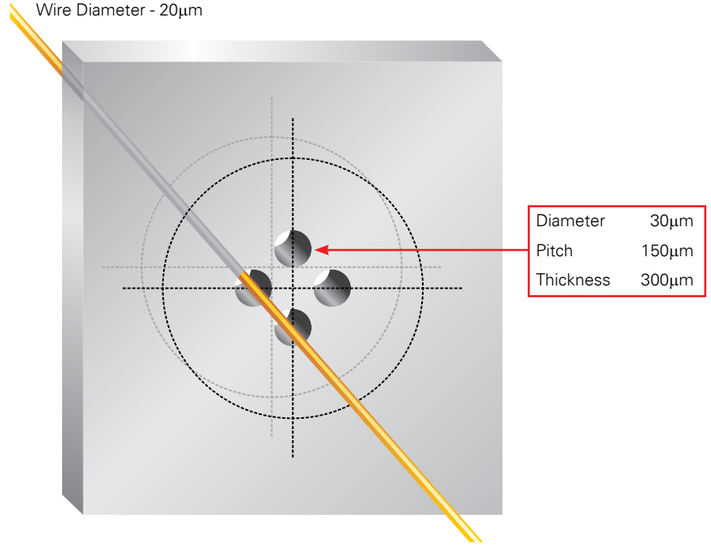
1. Superior automatic wire threading performance

The innovative wire threading system on the UPN-01 and UPJ-2 machines, provide automatic threading performance in situations that are not possible to thread the wire manually. This technology permits completely unmanned threading operations where the start hole diameter is as small as 30microns, with pitch distances between holes of 150microns. Since the wire is fed through the start hole by using an air vacuum system, there is very little chance of a failed threading operation.





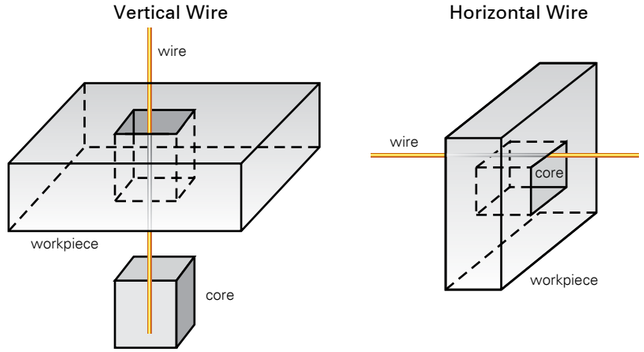
These start hole configurations most commonly create failure for conventional wire threading systems. These scenarios are easily managed by the UPN-01 and UPJ-2 wire feeding systems. This unique ability provides the assurance of a fully completed job cycle during unmanned operations.



2. Safe removal of slug, during unmanned operation

During slug removal, the slug falls freely to the bottom of the tank, safely away from the upper and lower heads, which are positioned to the left and right hand sides of the work piece. During the same operation on a vertical wire EDM, small slugs occasionally enter the lower head, thus interrupting machine operation.

Completely Unattended Operation



Core falls naturally.

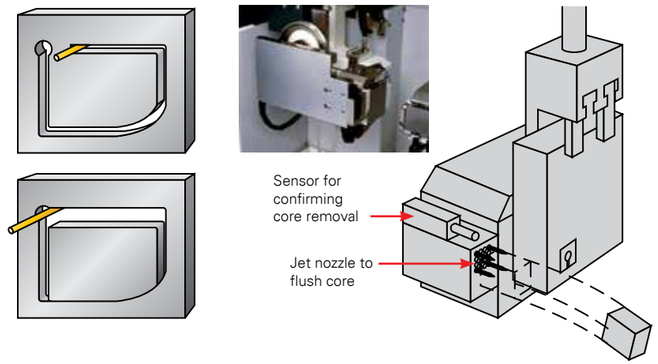
Core remains in workpiece.

3. Slug management / unmanned cut-off operation with fine diameter wire

During the slug cutoff routine, the slug naturally falls downward, away from the wire. When this operation is performed on a conventional vertical wire EDM, small slugs commonly contact the wire during cut-off , thus breaking the wire, and interrupting automatic machine operation. This situation is especially common while using wire diameters of 70 microns and smaller.

Core Remover Option

Core remains in workpiece.



Other Ultra Precision Wire EDM Platforms

UPJ-2

- Horizontal wire feed
- Submicron accuracy
- 20µm minimum wire diameter
- Auto feed ∅30µm start hole
- Dielectric oil

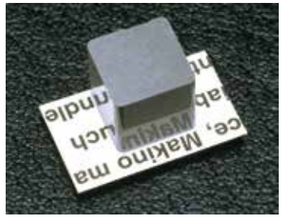
UPV-series

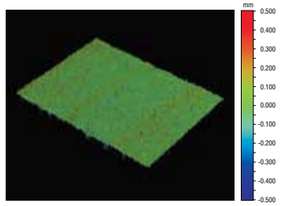
- Vertical wire feed
- 1µm accuracy
- 50µm minimum wire diameter
- 100mm cut thickness
- Dielectric oil

- Tungsten cabide
- 0.2µm Rz surface finish

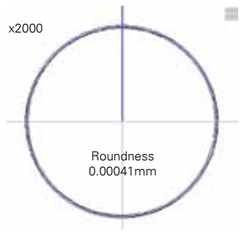
Benefits of Using an Ultra Precision Machine Platform

- High predictability of machining result
- High repeatability of machining result after process adjustment is made
- Improves ability to reach high level surface finish, as multiple pass processing is needed. Nanometer levels of positioning repeatability facilitate “mirror finish” surface finish results
- Gauge level feature accuracy is achieved with standard machining processes





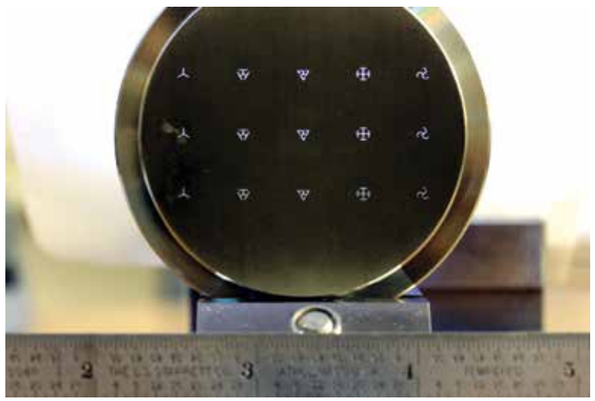
WYKO NT8100
(VEECO)
Minimum Resolution: 0.1nm



- 0.16µmRy surface finish
- 10mm thick
- Tungsten carbide

- ∅70µm machined hole
- 400mm roundness shape error

Part Samples



Spinerret Die

- ∅60µm start holes
- ∅30µm wire used
- 70µm width of finished feature
- Work piece thickness: 7mm
- Machine Used: UPJ-2

Key Machine Technologies

- Automatic wire threading
- Utilization of 30µmØ diameter wire
- Ultra precision positioning accuracy of machine tool

Benefits

- Reliable, predictable machining results
- Reduced cost of tool / part production
- Unmatched precision of completed tools

PCD Cutting Insert

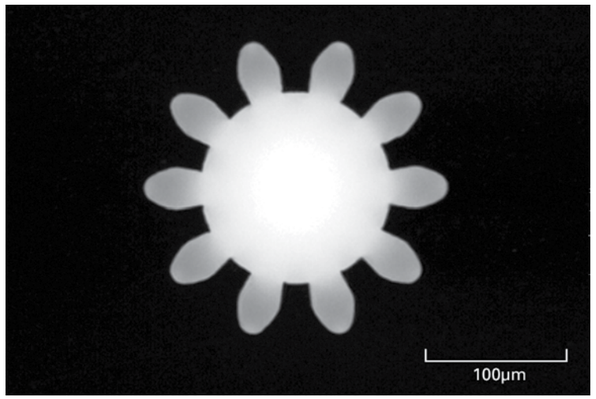
- ∅70µm wire used
- PCD Thickness: 1.5mm
- Substrate Thickness: WC / 3.0mm
- Number of Passes: 4
- Surface Finish: 0.7µmRz
- Machining Time: 23 minutes
- Machine Used: UPV-3

Key Machine Technologies

- Dielectric oil
- Anti-electrolysis generator

Benefits

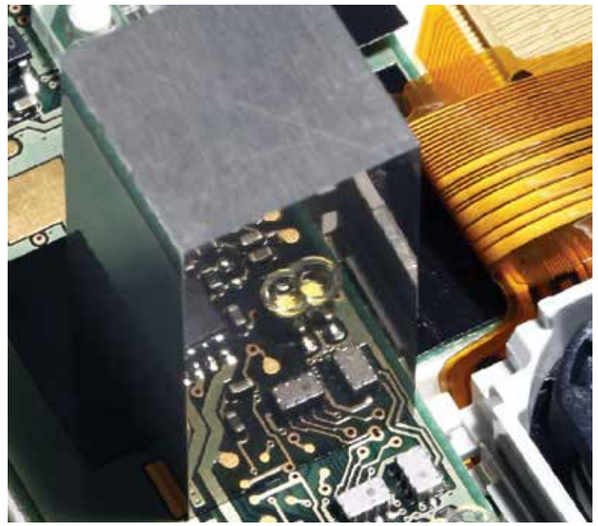
- Enhanced surface finish
- Elimination of electrolysis
- Improved tool life



Mitutoyo ULTRA QV350－PRO

Micro Module Gear

- ∅15µm wire used
- Module: 0.018mm
  - *Module = Length of pitch circle diameter per tooth*
- Outer Gear Diameter: 0.216mm
- Number of Teeth: 10
- Work piece thickness: 0.200mm
- Material: Tungsten carbide
- Machining Time: 76 minutes
- Machine Used: UPN-01



Fine Blanking Punch

- ∅150µm wire used
- Punch Thickness: 15mm
- Surface Finish: 0.2µmRz
- Material: Tungsten Carbide
- Machine Used: UPV-5

Key Machine Technologies

- Dielectric oil
- Anti-electrolysis
- Fine finishing generator

Benefits

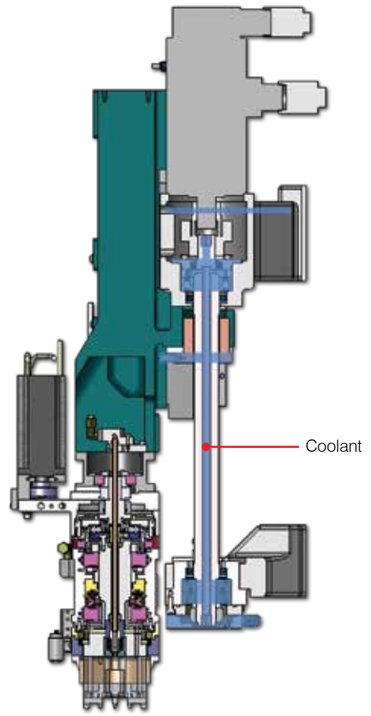
- Achieve 2x better surface finish vs water dielectric
- Eliminate electrolysis
- Eliminate manual polishing
- Improved tool life, geometric integrity of tooling

Ultra Precision Sinker EDM

- This immensely flexible CNC sinker platform is regarded as the most accurate sinker EDM in the world, relative to its travel envelope and wide scope of flexibility
- Provides positioning accuracy of 1 micron across the entire XY axes stroke, and axis squareness of 1 micron
- Using a uniquely designed, intercooled Z axis, the EDAC1 effectively provides Z axis depth control within 1 micron even during long hours of high-speed Z axis jumping
- Using rotary scale feedback, the Mi C-axis of the EDAC1 provides indexing accuracy of 2 arc seconds, facilitating ultra precision indexing during unmanned operation
- The EDFH1, based upon the mechanical platform of the EDAC1, provides a fully automated system for producing high precision, micro-sized holes

The intercooled spindle incorporates the circulation temperature controlled oil to thermally stabilize the moving components of the Z axis ram

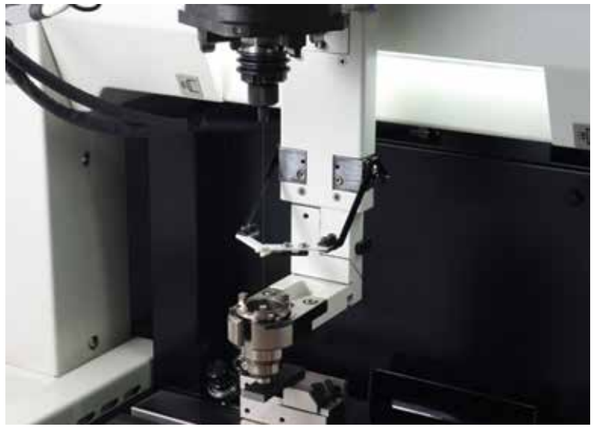
- Long duration, Z axis jump motion, without change in electrode position
- Consistent surface blend of Z level tool surfaces to sub micron levels



CNC Sinking + Fine Hole EDM

Intelligent design, incredible flexibility / provides the following capabilities in a single machine

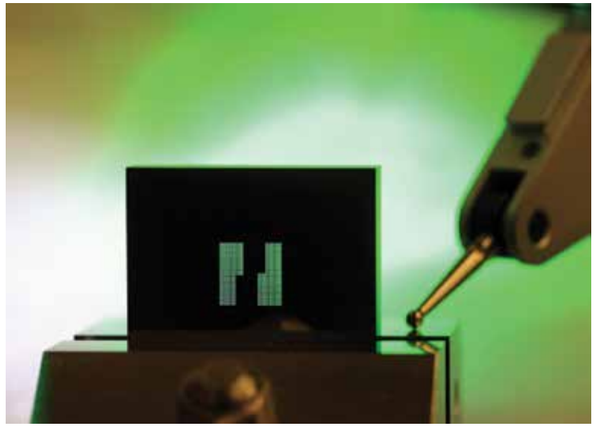
- Precision CNC die sinking / with automatic global orbiting in any axis direction
- Spindle rotation (2000rpm) + indexing
- Maximum electrode weight of 5kg
- Maximum work piece weight of 50kg
- Best achievable surface finish of 0.2umRy
- Fine diameter electrode spin-dressing / minimum dressed diameter of 0.006mm
- Guided electrode machining / smallest diameter of 0.015mm
- Through spindle flushing with 10mPa flushing pressure
- Automatic electrode changing of pipe electrodes and guide with diameter as small as 0.080mm.



Fine Hole Machining Approaches

Guided Electrode

- Incorporates electrode guide, and generally uses rotating electrode
- Can utilize pipe eletrode with through electrode flushing up to 1560psi
- Ideal for precision start holes
- Ideal for large quantity of repeating holes, where longer electrode length is desired for automatiion purposes
- Must use stock diameter electrode material/stock die guide size
- Aspect ratio of hole can be as high as 75:1 from each side of the work piece
- Smallest hole: ∅25µm



Fine Hole Machining Approaches

Extrusion Die insert: Tungsten Carbide

- ∅0.100mm holes through 0.5mm thickness (x780)

Key EDFH1 Machine Technologies

- Through spindle flushing (1500psi)
- Guided, rotating electrode
- Tungsten carbide machining circuit

Machining Technique:

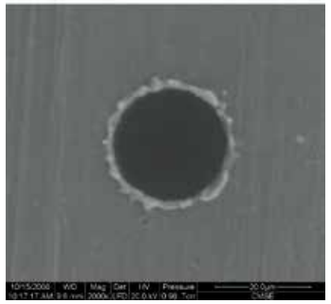
- Guided pipe electrode

Fine Hole Machining Approaches

Dressed Electrode

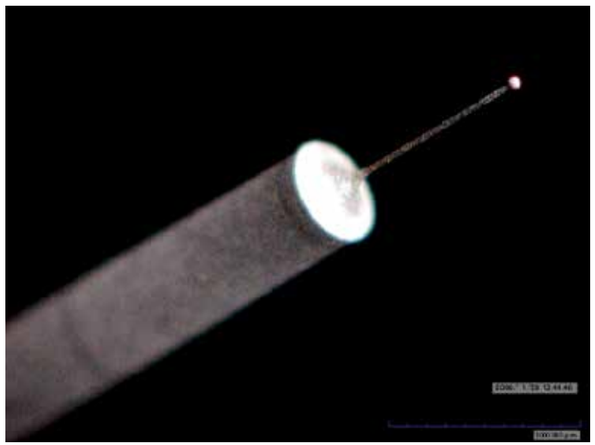
- Incorporates spindle mounted electrode - no guide
- Provides for custom dressed electrode diameter, shape as desired
- Ideal for high-precision finished hole, or precision location of hole
- Can utilize dressing electrode mounted to table, or wire dressing option
- Aspect ratio of hole generally less than 15:1 from each side of the work piece
- Smallest hole: ∅10µm

Dressed electrode: ∅14µm



Machined hole: ∅20µm through 0.150mm thickness

Part Samples



Micro Probe

- 0.030mm shank x 1.00mm long / 0.050mm sphere
- Material: Tungsten carbide

Key Machine Technologies

- Precision rotating spindle (2000 rpm)
- Ultra fine spark generator (SPG circuit)
- Tungsten carbide machining circuit
- Sub-micron positioning accuracy/repeatability
- Machining technique: Spin dressing + side machining

Plastic Mold/Mobile Phone

- Cavity Material: Stavax
- Electrode Material: Oxygen-free copper
- 1µmRz(0.12Ra).

Key Machine Technologies

- Ultra fine spark generator (SPG circuit)
- Mirror finishing circuitry
- Highly rigid machine structure facilitates larger workpiece and electrode sizes
- 30 amp power supply provides aggressive roughing performance for larger electrodes

Part Samples

Micro Rotary Tool

- ∅0.4mm x 300mm
- Material: Stainless steel
- Electrode Material: Oxygen-free copper

Key Machine Technologies

- Ultra fine spark generator (SPG circuit)
- Horizontal machining and orbiting
- Sub-micron orbiting increment for ultra precise size control

Connector Mold Insert

- Material: Stavax

Key Part Feature

- 5µm inside corner radii

Key Machine Technologies

- Ultra fine spark generator (SPG circuit)
- High accuracy Mi C-axis (2 arc second positioning accuracy)
- Sub-micron positioing accuracy/repeatability
- Z-axis core cooled spindle

Market Place Demand

It is no secret that all consumers consistently expect innovative, higher quality products, at the same price point or lower than a previously used product. These high expectations place more performance and cost pressures on the tooling providers than ever before.

Makino is helping to meet these demands by providing machine tool products that reduce the dependence upon high cost labor and subsequent finishing operations. Our end goal is to help you present a higher quality product to your customer, in a shorter period of time, at a lower price point.

These high precision, high performance machine platforms incorporate a wealth of accumulated technologies to run faster, machine hardened materials, and provide finished tool surfaces that do not require subsequent finishing operations.

High Value Target Market Segments

- LED mold surfaces
- Finished mold components, cavities for micro mold tooling
- Ultra precision stamping die components
- Gauges
- Micro drilling
- Micro thread finishing
- Fuel cell tooling
- Solar power generation
- Fresnel optics
- Electrode machining
- Hard tooling/direct machining
- Mold/part for semiconductor manufacturing
- Ultra precision single piece components
- Research & development

Control and Craftsmanship

To establish final mechanical alignment, our ultra precision machines are assembled in individually controlled rooms, that match the environment of the customer's installation site.

*Linear accuracy is easily electronically compensated according to temperature after installation, but the squaring alignment of the moving axes must be established and held at constant temperature.

Meticulous preparation, assembly, and alignment of the machine tool components provides a foundation for long lasting mechanical precision.

Hand scraping of guideway surface.

Precision ground and lapped guideway surfaces.

Machine Loop Stiffness = Cutting Tool Stability

Simply stated, work piece surface finish is a direct result of the travelling motion of the cutting tool edge as it interfaces with the work piece material. The ability of the machine tool to consistently repeat this motion, will dictate the minimum achievable surface finish.

The inherent stiffness and mass of the machine tool and spindle interface to the cutting tool, will ultimately dictate the tool's ability to efficiently machine hard material.

The Makino Spindle

In addition to exceptional quality machine tool construction and loop stiffness, Makino's patented spindle technology delivers:

- Precise control of the cutting tool edge
- Sub micron tool run-out and spindle vibration, characteristics that are critical in optimizing tool life and high quality surface finish
- Predictable, efficient and consistent performance for micro drilling application
- Unusually wide range of machining capability (400 - 45,000 rpm operating speed on same spindle)
  - Rough machining
  - Rigid tapping / thread milling
  - Core cooling to provide continuous full rpm operation for finishing processes
  - At full rpm, peak to peak vibration level is below 1µm

Sub-micron Positioning of the Tool Tip

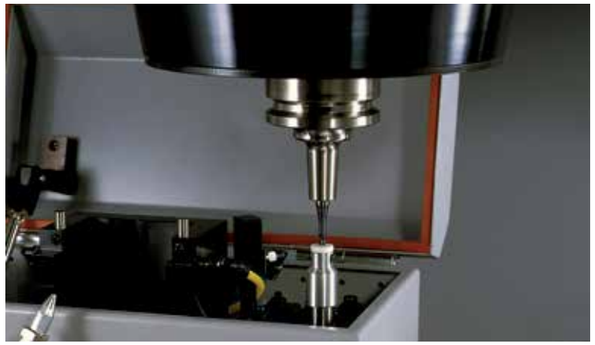
Makino's unique **Hybrid Tool Length Measurement (HTLM)** technology provides simple, delicate and highly accurate tool length measurement of tools with diameters as small as 10µm. Facilitates effective utilization of micro end mills and micro drills providing submicron control of tool tip location and control of tool blend accuracy to less than 1µm.

Key Features:

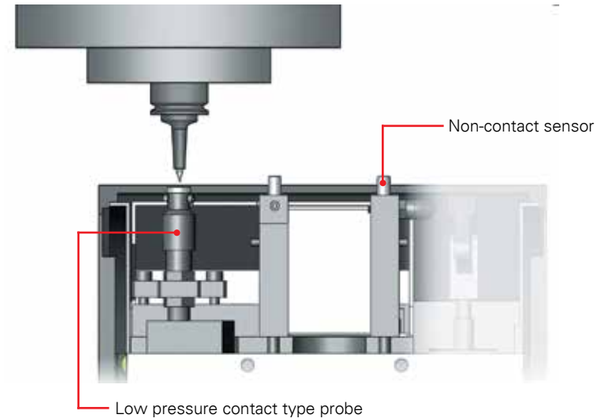
- Provides tool length measurements to 1µm accuracy and repeatability for tools as small as ∅10µm
- Automatically compensates for slight spindle displacement changes for varying spindle speeds

Benefits:

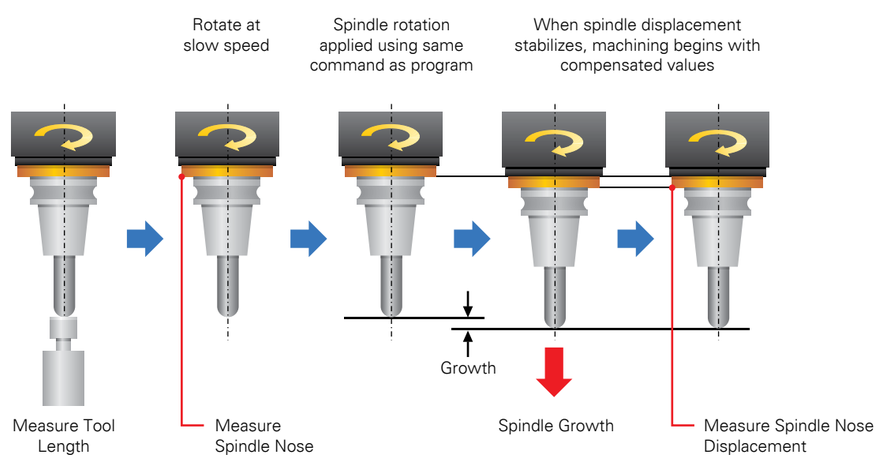
- Automated, reliable, safe pickup of micro tools
- Tool length measurement accuracy and repeatability is 5-6x better than conventional laser. This issue is especially critical for smaller diameter tools
- Consistent control of tool blending, regardless of spindle speed



What Is Hybrid Tool Length Measuring Device?

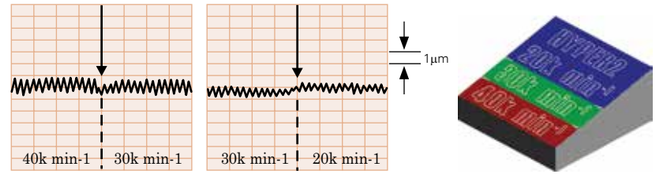


How Does the HTLM/Measuring Process Work?



HTLM Tool Blend Example

Material:	NAK80
Tool:	R1 ball end mill
Size:	10 x 10mm
Slope of machined face:	15°
Surface step difference:	<1µm



Optic Surface Sample - 0.012mmRa Finish

Machining Approach

- Hale machining / non rotating cutter
- Using monocrystal diamond
- 2000mm / min feed rate
- Sub-micron positioning accuracy/repeatability
- Material: A7075
- Step over: 0.200mm
- Step down: 0.002mm

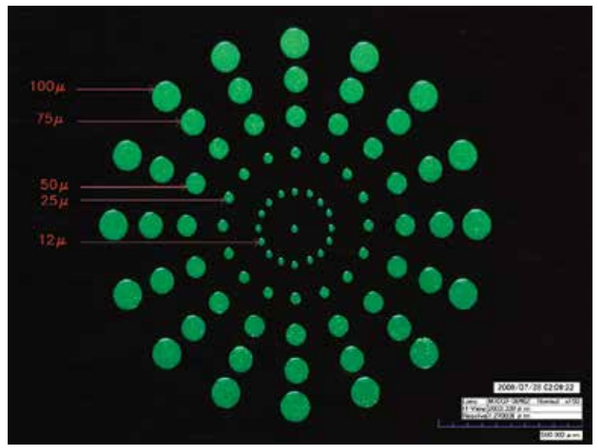
Features:

- Machine platform: iQ300 Vertical Machining Center
- Thermally controlled, stable mechanical platform
- 10nm minimum increment of axis movement

Benefits:

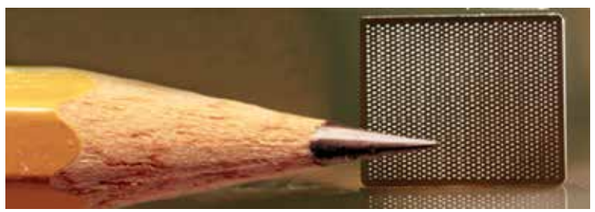
- Submicron control of feature shape, form accuracy possible
- Near optic-quality surface can achieved directly from machine

Mechanical Micro Drilling



- Aperture: 75µm thick brass
- Holes ranging from ∅12µm (0.0005") to ∅100µm (0.004")
- Mechanical drilling of holes ranging in diameter
- From (12µm to 100µm) facilitated by machine stiffness, low spindle vibration and run-out as well as using the ATLM device for tool tip registration.

Filter Insert



- Hole diameter: ∅100µm
- Material thickness: 500µm / 5:1 aspect ratio
- Number of holes: 1229 / 1 drill used
- Material: 6061 Al / water soluble coolant
- Machine used: V22

Key Tecnologies:

- SGI.4 / Precise, efficient control of drilling peck cycle
- HTLM Tool length measurement
- Low vibration, low run out spindle

Benefits:

- Efficient, predictable, high speed micro drilling
- Simple, effective measurement of drill tip to within 1µm accuracy

Restrictor Plate

- Hole diameter: ∅50µm
- Material thickness: 500µm / 10:1 aspect ratio
- Number of holes: 61 / 1 drill used
- Material: 303 Stainless Steel / water soluble coolant
- Machine used: V22

Key Tecnologies:

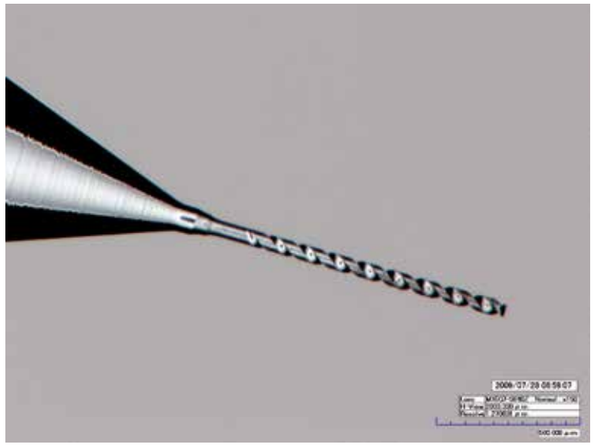
- SGI.4 / Precise, efficient control of drilling peck cycle
- HTLM Tool length measurement
- Low vibration, low run out spindle

Benefits:

- Efficient, predictable, high speed micro drilling
- Simple, effective measurement of drill tip to within 1µm accuracy

Keys to Successful Micro Drilling

- High quality micro drill geometry / no run out from shank to flute to tip
- High precision tooling assembly / no run out from spindle interface to tool holder to collet to drill shank
- High precision, highly controlled spindle / dynamic characteristics of spindle should not add run out or vibration to the tip of the drill
- Effective control of moving elements of the machine tool during machining cycle / it is important to have optimized movement of machine axes, yet no deviation in position can be tolerated as the fragile tool will be damaged



- High quality twist drill
- ∅50µm x 900µm length of flute

Keys to Successful Micro Milling

- High quality flute and cutting edge tool geometry
- High precision tooling assembly / no run out from spindle interface to tool holder to collet to drill shank
- High precision, highly controlled spindle / dynamic characteristics of spindle should not add run out or vibration to the tip of the drill
- Effective control of moving elements of the machine tool during machining cycle / it is important to have optimized movement of machine axes, yet no deviation in position can be tolerated as the fragile tool will be damaged
- Full understanding, and correct management of chip load on tool
- Implementation of correct entry and exit (lead in, lead out tool strategy. This subject goes hand in hand with the “chip load” statement above
- Zero run out tooling / regardless of shrink style or collet style holders
- Get to know the basics of the material structure of your work piece. This information will provide insight to the most effective ways to machine the material. E.g. What is the best tool geometry, feed rate, coolant type, abrasive or non abrasive machining, etc.
- Work holding: It is imperative to employ effective work holding strategies, as this provides the foundation of your entire process. Considerations:
  - Does my strategy permit simple and accurate movement of the part, on-off-on the machine during machining. In process inspection, or from one machine to another
  - Does your strategy provide access to multiple sides of the part?
  - Does your strategy place an external clamping force on the part that cannot be tolerated by your final part?

Workholding Solutions

Work holding solutions can be as varied as the part geometry, so it is important to be flexible and creative. Since cutting forces during micro machining are not commonly high, consider the following ideas that are effective solutions:

- Thin material: Can generally be mounted to a flat surface and held from the back side using various types of adhesive**:
  - Tape
  - Epoxy
  - Super Glue

  **Make sure you plan your exit strategy first (how will you remove your finished part, what solvents are safe to use, etc.)

- Parts with complex outer geometry that need to be externally clamped.
  - Create a machined nest that conforms to the perimeter of the part. A collapsing jaw designed into this nest will work nicely as a custom formed clamping vice. A cleverly planned stop pin will also provide a positive stop so as not to crush the work piece during clamping.
  - Consider “potting” the part inside of a nest using machine-able, and dissolvable epoxy. This solution will permit you to machine the part from many different directions, while still having a firm hold on the part. After certain operations are completed, more epoxy can be added to that surface so as to maintain effective hold. After all machining operations are complete, the epoxy can be removed with appropriate solvents or release procedures.

Do not confine your micro work holding solutions to your experience on macro sized parts.

High Quality Tooling/Milling

It is imperative that high quality cutting tools, micro drills and tool holders are employed to provide optimum spindle performance, tool life and surface finish. This is not a place where cost short cuts should be considered, as this is one of the most critical points that affect tool life, surface finish, cut accuracy and longevity of the spindle.

The following is a recommended list of companies that we recognize as consistent suppliers of high quality tooling, and tool holders.

Cutting Tools / Micro Drills:

- Union Tools
- NS Tool
- OSG
- Hitachi
- Contour Fine Tool / diamond tooling
- Polkhom / Voha
- Titex
- Guhring

Tool Holders:

- MST
- Nikken
- Yukiwa
- Big Kaiser

High Quality Tooling, Supplies for EDM

Fine Hole EDM Electrodes:

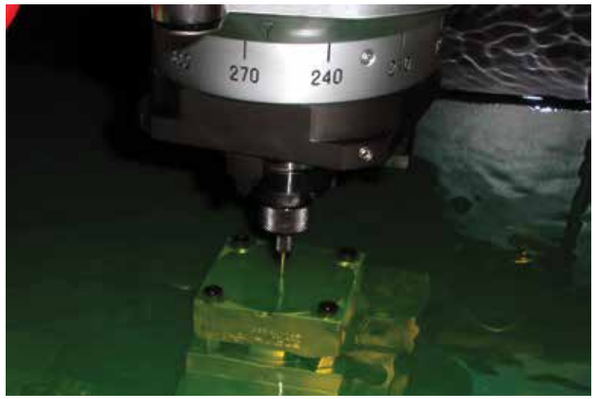
- Sumitomo Electric
- Balzer / Germany

Fine Diameter EDM Wire:

- Sumitomo Electric (∅15µm to ∅50µm)

Dielectric Oil:

- Iona Plus
- Commonwealth Oil



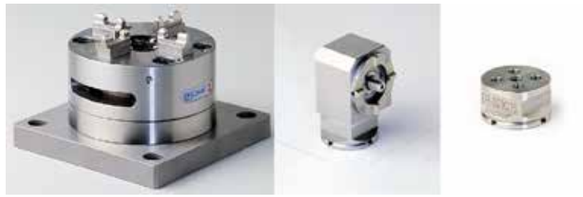
Integrated Tooling

It is recognized that the most time consuming, and high risk portion of the parts manufacturing process occurs during the initial set-up and qualification of the work piece element. In order to eliminate the duplication of this effort during the part manufacturing process, an integrated tooling system should be implemented. Several commercial solutions are available that provide the following benefits:

- Kinematic locating surfaces that provide locating repeatability of <2µm. During daily use, it has been found that these systems actually provide less than 1µm repeatability in most applications
- Standardized chucking devices provide transferrable location and mounting across separate machine platforms
- During process development, it is common to require removal of the part from the machine to perform offline inspection. Integrated tooling provides simple on-off-on chucking without concern of re-locating the work piece or electrode pallet.
- Once a work offset is established and saved for your machine, it is possible to simply re-register this work location via nc program when the job is re-introduced to the machine tool.
- If you are preparing materials for an outside customer, integrated tooling allows you to literally "transfer" part and pallet locations from your facility to your customer.
- Following manufacturers guidelines, these systems can be implemented in the following manufacturing processes:
  - Grinding
  - Turning
  - Milling
  - Stamping
  - Molding
  - Wire EDM
  - Sinker EDM
  - Laser

Integrated Tooling Examples

Erowa (Compact Combi)



Machining Chuck | Right Angle Adaptor | Part Pallet/Holder

Hirschmann

System 3R (Macro Nano)

Machining Chuck | Machining Chuck and Work Pallet

Machine Environment Control

Temperature stability is critical in controlling micron level machining and inspection processes. Variation of thermal stability, creates variation in process results.

Reference:

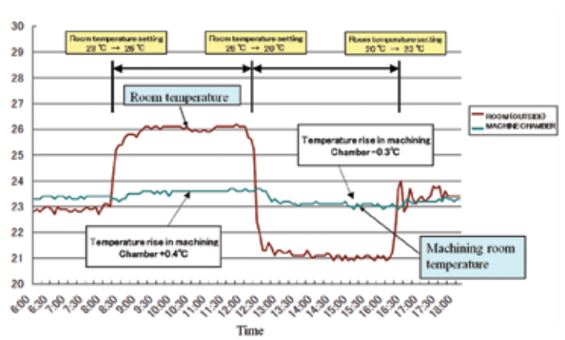
The thermal expansion coefficient of steel is 7.6 (10^{-6} in/in°F)

Machine Thermal Chamber

In the case where the complete machining room cannot be thermally controlled, an optional thermal chamber can be selected for the machine tool. This chamber isolates the machine tool from temperature fluctuations that may occur in the machining room, thus minimizing change in overall machining accuracy.

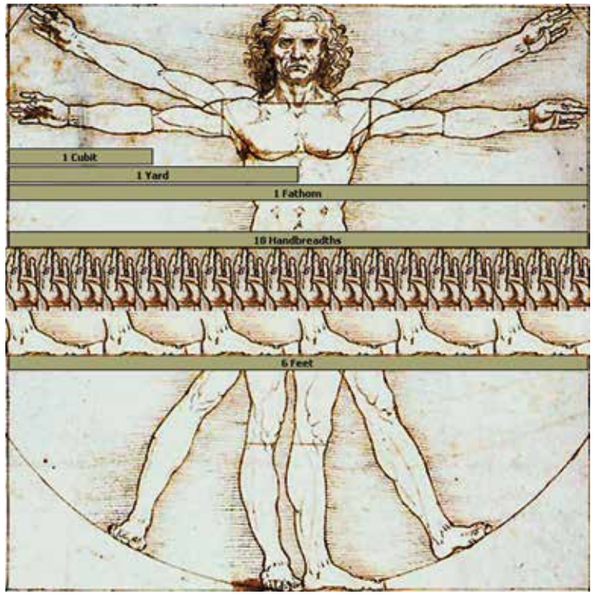
UPV-3 (without thermal chamber)

UPV-3 / (with thermal chamber)



Thermal Chamber Test Results:
Total room temperature fluctuation of room = 5.0°C / Machining chamber thermal fluctuation = 0.6°C

me-trol-o-gy: The science of weights and measures, or measurement



Metrology for Micromachining

Identifying the perfect inspection device for validating your micromachining requirement will be challenging. Due to the specific design intent of these highly specialized devices, it is important to realize that you will not be able to find that singular “perfect” inspection tool that satisfies all of your needs.

The following pages will provide illustration of commonly used metrology devices to help make you aware of these choices and the benefits that they may present to you.

These systems are provided for reference and example. You may find systems that provide superior performance and value specific to your application and budget.

3D Optical Microscope

Hirox KH7700

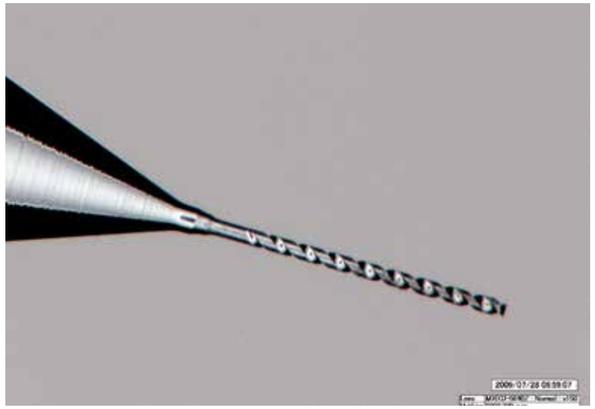


Image of ∅50µm micro drill

3D Optical microscope systems are extremely useful in providing high quality, high resolution 3D images of parts or features that must be magnified for effective viewing and interpretation.

Image of ∅120µm cross holes

Strengths:

- Qualitative analysis / medium range focal depth, magnification range from 50x - 7000x
- Quantitative measurements / to within 2 microns, dependent upon magnification level and calibration
- High magnification movie recording, provides rotational imaging of part or features, as well as capturing of actuating features/parts, to illustrate movement and interaction.
- High depth of field (presents 3D image where most of the image field is “in-focus”
- 3D synthesis of “pocketed” features, cross sectional viewing of blind features

Limitations:

- Measuring capability is limited by pixel resolution (generally not advised for inspection accuracies less than 3 microns).

Multi-Sensor Vision System

Vision systems provide excellent measurement capability where feature profiles can be highlighted with surface and/or back light illumination. Additional capabilities of laser and contact probe measurements provide excellent utility for surface depth measurements as well as feature sizes in the XY plane. Submicron measurement accuracy can be realized in many cases, while depth accuracy of 1 micron can be achieved using a "through-the-lens laser. Size and pitch accuracy will be part and feature dependent, and will vary based upon the X,Y stage accuracy of the measuring device.

Strengths:

- Through hole or through feature measurements, where back lighting contrast can be applied
- Blind feature measurement, where top surface contrast can be detected
- Depth measurement in Z axis direction
- Feature measurement in XY plane / using contact probe or optical vision system
- Pitch accuracy measurement (center to center location measurement of multiple features on the same work piece) / Accuracy of this measurement is solely reliant upon precision of XY stage

Limitations of Use:

- User selectable variables such as lighting, magnification and focal height may effect measurement accuracy
- Stage travel of XYZ will limit overall part size

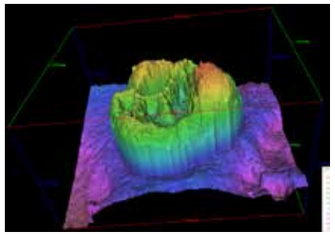
Alicona Infinite Focus

In the micromachining environment, it becomes increasingly difficult to apply traditional tactile measurement techniques to quantify features of form and surface topography. The unique capabilities of Infinite Focus provides a simple, yet powerful interface to quickly acquire and analyze highly dense surface data points, with sub micron resolution and measurement certainty. This technology enables the user the ability to understand and make efficient judgments related to micro scale surface features.

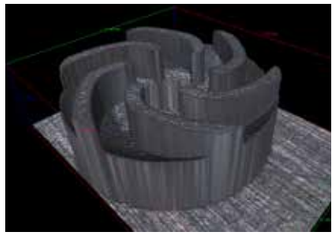
Alicona / IFM G4 Micro Coordinate Measurement System
(Images courtesy of Alicona)

Infinite Focus technology combines the ability to characterize surface roughness and form measurement using the same instrument:

- Non contact, high resolution, 3D metrology technology
- Rotary scanning of cutting tools provides the ability to fully analyze cutting tool flute geometry, diameters, relief angles and cutting edge tip radii
- Provides the ability to acquire surface data on vertical flanks up to 87 degrees
- Highly dense data sets from scans, allow for precise quantitative comparison to native model, as well as reverse engineering into tool path
- Field Imaging for larger surfaces / automatic stitching using true color alignment of data sets
- Vertical measurement resolution as fine as 10nm (dependent on objective)



Tooth Surface



Micro Turbine

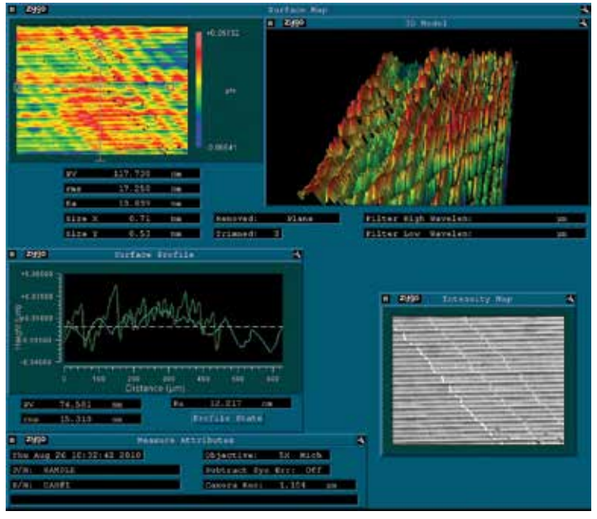
Optical Interferometric Profilers

Strengths:

- High resolution measurement of surface roughness, surface topography (below 1nm or better)
- Non contact sensing / no harm to surface being measured
- 1nm measurement repeatability

Limitations of Use:

- Sensitive to the angle of the measured surface relative to the focal plane
- XY field of measurement is limited by objective lens and focal depth
- Relatively “shallow” measurement height in Z direction



Arithmetical mean roughness (Ra)

A section of standard length is sampled from the mean line on the roughness chart. The mean line is laid on a Cartesian coordinate system wherein the mean line runs in the direction of the x-axis and magnification is the y-axis.The value obtained with the formula on the right is expressed in micrometer (μm) when y=f (x).

$$Ra = \frac{1}{\ell}\int_0^{\ell} |f(x)|\,dx$$

Maximum peak (Ry)

A section of standard length is sampled from the mean line on the roughness chart. The distance between the peaks and valleys of the sampled line is measured in the y direction. The value is expressed in micrometer (μm) .

Note : To obtain Ry, sample only the standard length. The part, where peaks and valleys are wide enough to be interpreted as scratches, should be avoided.

$$Ry = Rp + Rv$$

Ten-point mean roughness (Rz)

A section of standard length is sampled from the mean line on the roughness chart. The distance between the peaks and valleys of the sampled line is measured in the y direction.
Then, the average peak is obtained among 5 tallest peaks (Yp) , as is the average valley between 5 lowest valleys (Yv) .
The sum of these two values is expressed in micrometer (μm) .

$$Rz = \frac{|Yp_1 + Yp_2 + Yp_3 + Yp_4 + Yp_5| + |Yv_1 + Yv_2 + Yv_3 + Yv_4 + Yv_5|}{5}$$

Yp1, Yp2, Yp3, Yp4, Yp5 : Tallest 5 peaks within sample

Yv1, Yv2, Yv3, Yv4, Yv5 : Lowest 5 peaks within sample

Coordinate Measuring Machine (CMM)

Utilizes contact probe to identify and measure work piece surface in XYZ plane.

Strengths:

- Provides 3 dimensional information for part or feature position.
- Vision based (non contact) measurements can be performed with optional equipment
- Large travel envelope / facilitates larger part and feature span measurements

Limitations of Use:

- Relatively high probing force / can produce artificial error due to part deflection
- Probe diameter will limit access to and measurement of micro features

Stylus Profilometry

Utilizes low force, contact probe to scan work piece surface.

Strengths:

- Large scanning distance (up to 120mm) / X axis direction
- Large topographical sampling range (up to 4mm) / Z axis direction
- Surface finish and topography measurement data are provided
- Measurement “spot size” can be as small as 200nm (dependent upon material, probe size and probe force)
- Cost effective solution vs. optical interferometric solutions / (application dependent)
- High resolution in Z axis plane

Limitations of Use:

- Typical measurement is along single axis line. If additional data is required, probe would need to be re-positioned and a new scan would need
- Contact probe can potential “scratch” material surface during measurement process

MAKINO
Promise of Performance

Glossary

Makino micromachining
The process by which a part feature having dimension of 1mm x 1mm or smaller is produced by a removal machining technology that is relevant to the Makino machine tool products such as Wire EDM, Ram EDM, vertical and horizontal machining centers.

Precision machining
The machining process by which a machined feature can be produced to a specified size within a tolerance of 1 micron, and located to a of 1 micron, and then can be replicated to within a tolerance of 1 micron.

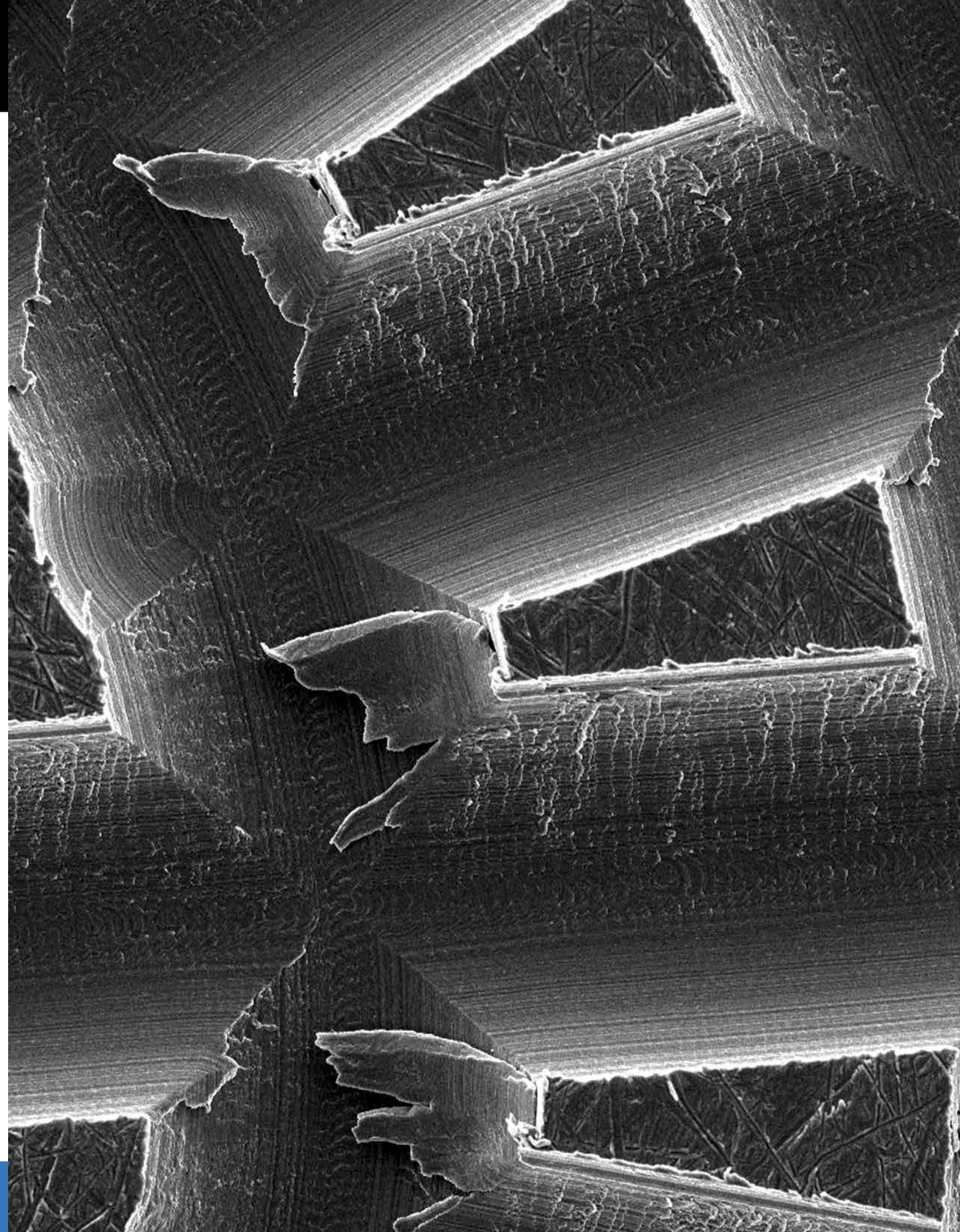
Ultra precision machining
The machining process by which a machined feature can be produced to a specific size and located to an accuracy of less than 1 micron. The replication of this process shall produce the feature to a specific size and location where the deviation shall be less than 1 micron.

Air bearing slide way
Where the machine tool slide way surface is lubricated by pressurized and conditioned air

Thermal chamber
Where the machine tool enclosure is insulated and provides a self conditioned environment to maintain a constant air temperature in the work zone of the machine tool and work piece

Repeatability
The variation in results when performing the same task repeatedly

Accuracy
The clustering of data about a known target. It is the difference between a physical quantity's average measurements and that of a known standard, accepted 'truth,' vs. 'benchmark.' Envision a target with many arrows circling the bullseye, however, none of them are near each other



www.makino.com