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## Good metrology balances tolerance budgets

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Maintaining a strict tolerance budget can be especially challenging for micropart manufacturers because with smaller features to machine, tolerances are tighter. A tolerance of 0.001" on length for a 12"-long part is fairly stringent, but 0.001" on a 0.1"-long part probably wouldn't be acceptable.

Accumulated error results from many factors, such as inaccuracies in the machine spindle, tool and toolholder, fixture and machine motion system—all of the components of a machining system. Factors such as thermal stability and machine repeatability can also increase measurement uncertainty and eat into allowable tolerances.

Machine tool builders and metrology equipment manufacturers help by making their mechanical alignments truer, their bases more rigid, thermal control more stable, and motion control and positioning more exact.

For example, Makino Inc., Mason, Ohio, a milling machine and EDM builder, attempts to ensure exact mechanical alignment by assembling certain machines in environmentally controlled rooms. For machining accuracy and repeatability of 2µm or less, Makino recommends that the temperature of a machining environment not exceed ±1° C.

Operating a high-accuracy machine tool when making microparts is one part of the solution to keeping tolerance budgets balanced. Another is using metrology tools that can verify that machining tolerances have been met.

At a Sept. 10, 2013, micromachining conference at its Auburn Hills, Mich., technology center, Makino not only displayed new equipment for micromachining, it also provided information on metrology equipment the company uses to keep its own manufacturing processes in check.

John Bradford, Makino's micromachining R&D team leader, said the company's metrology equipment "gives us the ability to quickly understand, at a highly magnified level, the many details of cutting processes. The metrology equipment gives us insights into tool wear, chip load, chip formation and burr formation."

One of the machines on display at the conference was the company's UPN-01 EDM, which Bradford said offers a positioning accuracy of ±0.5µm, 0.5µm repeatability and shape accuracy of ±0.5µm. The machine was developed specifically to provide "reference" level accuracy for master gages and ultraprecision tooling that otherwise could not be produced, according to the company.

To test the UPN-01's capabilities, a sample part was EDMed prior to the 1-day event. The part was used in a measurement demonstration utilizing a multisensor coordinate measuring machine from Werth Inc. that quantified submicron levels of accuracy and repeatability with respect to



A sinker EDM from Makino machines a part. Image courtesy L. Adams.

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SIZED PART  
HANDLING HAVE  
YOU PUZZLED ?

EASILY HANDLE  
PARTS AS  
SMALL AS  
100 MICRONS



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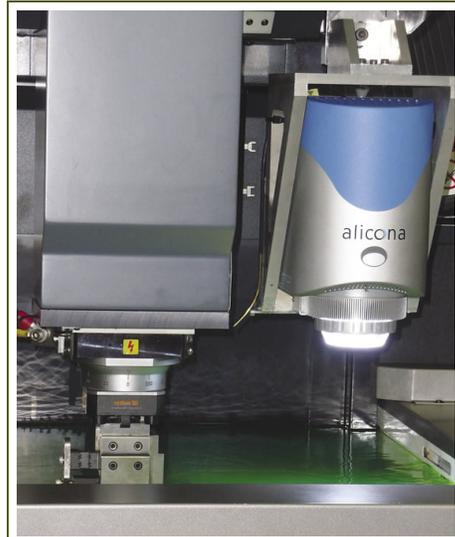
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hole size, roundness and location.

Jeff Bibee, vice president of sales and marketing for Werth, Old Saybrook, Conn., said he measured 20 $\mu$ m-dia. holes in the part with the CMM and verified the accuracy of the holes. Bibee added that microhole-making is becoming more common and is challenging for metrology equipment manufacturers because the rule of thumb is that equipment used to measure a part must be 10 times more accurate than the machine making the part.



An Alicona white light inspection device is attached to a Makino EDM to perform on-machine inspection. Image courtesy L. Adams.

"If you're trying to measure hole-to-hole location within a tolerance of  $\pm 2\mu$ m, and the measuring machine is only capable of repeating within  $2\mu$ m, you wouldn't know what you were measuring," Bibee said. "You couldn't tell whether it was in-tolerance or out-of-tolerance because your measurement uncertainty exceeds your tolerance band."

The Werth machine is just one of several metrology devices in use at Makino. Others include the InfiniteFocus 3-D optical measurement system from Alicona Corp., the Smartscope Flash device from Optical Gaging Products and the NewView optical surface profiler from Zygo Corp.

The NewView is a white-light interferometer that can take measurements below 1nm and capture data points in increments as fine as 0.1nm. One task Makino uses it for is to measure step heights as small as 100nm

in machined parts to illustrate and verify that the company's iQ300 machining center can discretely machine features to a prescribed depth and consistency, Bradford said.

In a video demonstrating the step-height test, Bradford examines a part with steps cut into the part in increments as small as 100nm deep and as large as  $3\mu$ m deep. "The white-light interferometry allows us to see, at the top of the part where we started the highest point in our cut, that the first step increment on either side of the part is 100nm, the next step below that is 250nm, then 500nm, then  $1\mu$ m,  $2\mu$ m and, finally,  $3\mu$ m," Bradford said. The NewView device validated that Makino's iQ300 machine was able to consistently machine the step dimensions to within an error level of less than 30nm, according to Bradford.

For both surface and form measurement, Makino uses the InfiniteFocus 3-D measurement system to quantify processes at the submicron and nanometer level, Bradford said. For instance, he used the device to measure a part with  $70\mu$ m-wide fins, a  $70\mu$ m-deep slot and inside corner radii of about  $5\mu$ m. "The system helped us view the part three-dimensionally," Bradford said. "It gave us visual information on corner definition and surface characteristics on the sidewall and the floor of the slot."

The InfiniteFocus combines the ability to characterize surface roughness and form measurement using the same instrument, said Brad Etter, U.S. sales manager for Alicona, Bartlett, Ill. It can acquire surface data on vertical flanks of up to  $87^\circ$  and can rotary-scan cutting tools and analyze their flute geometry, diameters, relief angles and cutting edge tip radii.

The InfiniteFocus name refers to its focus-variation capabilities. It uses objective lenses with various magnifications, including 5 $\times$ , 10 $\times$ , 20 $\times$ , 50 $\times$  and 100 $\times$ , all with different resolution ranges, to scan individual data points and capture information on several variables for each point, including X-, Y- and Z-axis positioning.

"Because we are quantifying several variables, when we put these individual fields of view together we can stitch them together more effectively into what we call an image field," Etter said.

Alicona technology also played a part in a demonstration of in-situ measurement presented during the event by Mark Raleigh, founder and CEO of EDM Department Inc., also based in Bartlett.

Raleigh demonstrated his company's version of closed-loop manufacturing by connecting an Alicona IF-SensorR25 optical 3-D measurement



The UPN-01 horizontal wire EDM from Makino features automatic wire threading of 0.050mm-dia. wire. Image courtesy Makino.

system to a sinker EDM from Makino. The sensor inspected electrodes at the event, but can inspect parts on the machine itself to avoid having to move them to another machine for verification. Parts are optically inspected for form, position and surface finish in-situ, which Raleigh said will reduce cycle time, increase accuracy and eliminate clamping errors.  $\mu$

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