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Titanium, Composites—and Buckypaper?

Society of Manufacturing Engineers

Metrology Technologies Elevating Aircraft Manufacturing

Photo courtesy SURVICE Engineering

To develop fully autonomous measurements alone a photogrammetry system is combined with a Nikon MV 330 laser radar, allowing autonomous operation of the radar.

Noncontact metrology increasingly used to reduce costs, assist in automation and speed up manufacturing and assembly times

Bruce Morey
Contributing Editor

Making airframes may be one of the most challenging manufacturing feats ever. Long a critical tool in the aerospace and defense industry, metrology equipment has grown in importance beyond simple things like setting tools and inspection.

Today, metrology technology is playing an increasingly sophisticated role in overall operations. Marrying metrology systems, such as laser trackers, to fixed automation and flexible robotic systems is becoming an acceptable solution leading to more cost-saving automation. Additionally, there's a move toward increasingly autonomous measurement in inspection, saving the need for teams of highly trained metrologists, who are in short supply anyway.

Ideally, these moves will also help speed throughput, which is particularly important as orders climb for commercial aircraft.

"I am starting to see the aerospace industry embrace automation the way automotive did decades ago," said Michael Kleemann chief engineer of Variation Reduction Solutions Inc. (VRSI; Plymouth, MI). VRSI started life in 1998 by serving up automation solutions to the automotive industry. Aerospace has its differences, though. Aside from size, lower production rates and increased complexity, there is a more pronounced need for flexible automation in aerospace. Robots need to drill different holes in different areas, insert different fasteners, unlike in automotive, which uses automation for limited repetitive tasks on an assembly line.

"Integrated measurement brings both flexibility and precision to automated processes," Kleemann said.

In fact, drilling holes and placing fasteners may be the 'killer app' for metrology-guided robotics. "Some estimate that 40% of the cost of an airframe assembly involves drilling and filling," Kleemann explained.

Given his experiences in both automotive and aerospace, Kleemann predicts this shift will have an impact on future aerospace design and development. "Today, automotive products are designed to be built by robots. In aerospace, that is just beginning to be the case," remarked Kleemann.

Want More Information?

For more information on how metrology is assisting automation, please see "Aerospace Automation Picks Up the Pace" on page 55.

Inspection Plus

"There are two basic areas where we deliver our metrology devices," says Paul Lightowler of Nikon (Brighton, MI). "One is in pure inspection, making sure the parts are correct. The other is in guiding assembly, using systems like our K-Series sensors to guide robots to drill holes and fill with fasteners."

Lightowler from Nikon has seen interest in robotics for aerospace for a few years now, generally as a replacement for fixed purpose-built automation. He believes aerospace manufacturers see them as being cheaper, more flexible, and quicker to deploy. While robotic replacements for monolith or gantry-type machines have been tried, they have met varying degrees of success, according to Lightowler. "One issue is accuracy," he said. Robots by themselves struggle to achieve aerospace tolerance accuracy, about 0.2 mm, even with calibration or error mapping.

Photo courtesy VRSI

A robotic drilling system (below), guided by a laser tracker, enabled replacing difficult manual drilling (above) in the inlet section of the F-35.

"What we are looking at is taking robots guided by metrology into smaller parts, replacing manual operations rather than trying to compete with the big, [purpose-built] machines," explains Lightowler. They are developing a lightweight drilling concept as part of a project for GKN Aerospace that allows the robot to drill (guided) holes, then swap the head out for a laser radar, such as the Nikon ModelMaker MMDx, and perform in-line inspection. The guided portion of the drilling used a Nikon K-Series sensor with Nikon's Adaptive Robot control (ARC) software on a Fanuc R1000iA 80Kg payload robot. "Inspection stations are quite often away from the manufacturing area and overloaded. In-process measurement offers benefits in time, quality, and logistics," Lightowler explained.

The motivation? "Our customers were losing work to companies taking advantage of low-wage areas of the world," Lightowler said. Feasibility studies showed a combined robotic operation could save a vast amount, allowing them to keep the work in the UK.

Beyond that, he notes that they are currently developing two projects that include not only guiding and inspecting, but performing adaptive machining as well. "Another task we are doing for an aircraft engine manufacturer is to scan parts that they know are going to vary, create a reverse engineering model if you will, and adaptively machine those parts based on that information," said Lightowler. This eliminates the need to try to develop machining programs from a nominal CAD model alone; the scan allows for precise, adaptive machining of parts from as-built.

Metrology and the Monoliths

Another task that can require highly skilled metrologists is the periodic recertification of assembly tooling. Like others, Electroimpact (Mukilteo, WA) uses metrology to compensate for machine tool motion, say during drilling and fastening operations. The company also delivers tooling fixtures used to mate aircraft sections together. These, too, can be a drain on resources skilled in metrology, albeit periodically. "When you build a jig initially, you measure it precisely before going into production," said Robert Flynn project manager of Electroimpact. "However, once in production, you cannot ignore its measurement and tolerances—issues occur." Minor mishaps, such as a bump with a heavy tool or a glance with a forklift, could cause a misalignment. With tolerances so tight, between 0.010 and 0.007" (0.254 and 0.178 mm), production crews may not notice. So, it is recertified periodically, anywhere from six months to two years, according to Flynn. "The downside is that re-certs can take tooling out of production for a few days to a few weeks, and it requires specialized technicians," said Flynn, two cost items airframe manufacturers need to reduce.

In response, the company created an automated system for tooling recertifications. They used a combination of existing technologies—laser trackers, low-cost targets, and metrology software—engineered into a simple-to-use system. While specific times for recertification measurements were set not to exceed a few hours, the real goal of the Automated Measurement System (AMS) was to enable nonspecialist operators of the assembly tool to perform the task.

A laser tracker requires a precisely planted target to reflect a laser beam, such as a prism or Spherically Mounted Retroreflectors (SMR). The AMS system used both permanently installed targets as well as temporary, replaceable targets. Placing temporary targets is time consuming and only used when higher accuracy is required. However, with the help of software and routines on the laser tracker itself, every-day operators are fully capable of placing these targets, said Ray Ryan, vice president of East Coast Metrology (Topsfield, MA), a partner in the project. Specialists are not needed. The project reported a test measuring a large commercial wing jig in less than eight hours—much less than the week or so, it took before.

While existing technology, like laser trackers, provides the needed speed and accuracy, "the sophistication of the metrology equipment that exists does not make it easy to modify," he explained. "You need to adjust the process to fit the equipment." For example, the traditional method of using a laser tracker was to place it at random on the factory floor, and then measure a series of points to locate the instrument in the aircraft coordinates—then use it for measurement or guided assembly. Automating the process requires putting instruments in an exact location, with special pre-determined floor mounts. "At that point, you can push a button and have the device start measuring points," he said, a simple example of how smart design leads to automation.

This is especially true for software as well. This means integrators writing graphical user interfaces, with all-important error trapping, on top of sophisticated metrology software. This turns software programs like Spatial Analyzer from New River Kinematics into tools for day-to-day operators, according to Ryan. "This is becoming a common process in airframe manufacturing," he said.

Evolving Technology

How does Ryan, with over 30 years of experience in industrial metrology, see the future of airframe assembly? "Today, the benchmark for metrology is the laser tracker," said Ryan. Workers put targets on either the mating tooling or the parts themselves, enabling part-to-part mating automation.

However, if you cannot use targets, or have too many features to check that makes targeting impractical, he recommends the next technology to investigate is Laser Radar (LIDAR). "It is not quite as accurate, but provides much more data," he said, and given that it is 2–3× more expensive in general compared to laser trackers, the application must require the unique broad area of the LIDAR. Indoor GPS (iGPS) from Nikon Metrology is another key enabling technology, used for locating other sensors or used directly in certain assembly operations. "For the future, I see the sensor—what-

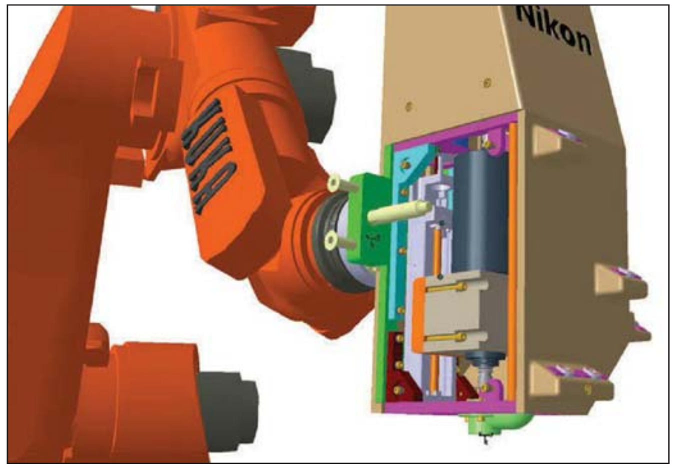

Image courtesy Nikon Metrology

A lightweight, small, drilling robot guided through metrology is an approach that Nikon metrology is pursuing as an optimum use of flexible, reconfigurable robots.

ever it might be—becoming more affordable, more reliable, cheaper, and faster," said Ryan.

Combinations of sensors are another approach some integrators are taking. In the search for fully autonomous measurement, SURVICE Engineering (Belcamp, MD) married a photogrammetry system to a Nikon MV 330 laser radar. "Under an Air Force research grant, we are enhancing the laser radar by integrating a metrology-grade photogrammetry system with computer-vision technology to create a fully-autonomous metrology system," explained Mark Butkiewicz from SURVICE. "The goal is to make it accessible to the nonspecialist in aircraft manufacturing." The MV330/350 laser radar measures to about 25 μm of accuracy (to 2 sigma) at 2 m and collects about 4000 points per second. "The laser radar is programmable to take automated measurements," said Butkiewicz. "However, it takes an expert to operate it and there is a certain amount of setup time every time you reposition the unit." To make it more autonomous, the computer vision kit

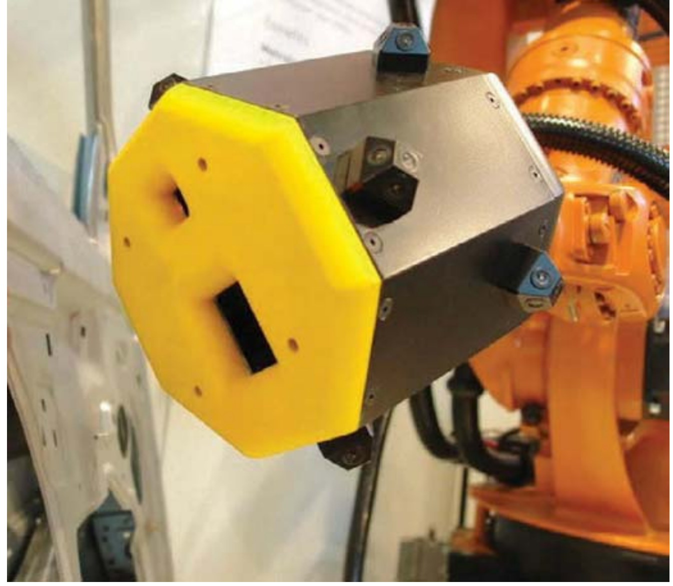

Photo courtesy Nikon Metrology

A Robotic MMDx scanner mounted to a robot replaces the hand-held version of the sensor.

consisting of a stereo digital camera is fitted to the Nikon laser radar. The vision system will examine each cost center, the areas where different parts or stages of the airframe are being assembled. "The vision system then automatically recognizes where it is and what it is looking at. It will then perform a pre-programmed script to measure what is needed for that operation," he said. "This will become a smart system." Somewhat like laser trackers, the digital photogrammetry portion of the system requires coded targets placed precisely in the scene.

They are moving on to the Phase II portion of an SBIR grant. The Phase I requirement called for a measuring accuracy of ± 0.002" (50 µm). "We expect to hit 0.001" [0.025 mm] and we measure Key Characteristics of features—surfaces, holes, or chamfers—within the limit of what the laser radar can provide," said Butkiewicz. "We provide out the characteristics of that hole within the global reference frame, not just a cloud of points that need to be analyzed and assessed."

White-Light Systems

Another wide-area scanning technology is so-called 'white-light metrology.' Noted for simplicity and accuracy, it is also being used in metrology-assisted manufacturing. Noted for capturing millions of points at a time, structured white-light systems project shadows of lines from a 2D lens onto a 3D surface. They then apply sophisticated mathematics to determine point clouds of measurements.

Lockheed Martin (Fort Worth, TX) is looking into using these systems to help in critical but mundane tasks. "Our primary goal is to investigate advanced noncontact measurement technologies which could replace current manual gages which are typically imprecise and slow. The ability to take repeatable measurements independent of an operator is critical in order to avoid the need for a fleet of trained metrologists to inspect the aircraft," said Chris Barrow of Lockheed Martin. He notes that even though individual inspection with a hand gage may take less than five seconds, with 45,000 fasteners on the outer surfaces of the F-35, that is a lot of inspection. It is easy for an operator to miss a problem, and the cost of rework is exponentially more expensive later on. "Structured light scanners offer the capability to capture larger areas of data in a single measurement as well as the flexibility to measure complicated parts and assemblies that would not be feasible otherwise," he said. He reports that Lockheed Martin is using the Cognitens WLS400M blue-light scanner from Hexagon in a system that verifies hinge location in F-35 doors and openings. They are using the data to determine the source of alignment defects. "Although the Cognitens system is currently being used manually, the feasibility of an automated door-inspection cell is being investigated," he said

Another such system is the Advanced Topometric Sensor (ATOS) provided by Gesellschaft für Optische Messtechnik (GOM). System integrator ShapeFidelity (Huntsville, AL) is using these systems to effect part-to-part mating through robotic guidance in a variety of applications. "We are using the ATOS-guided systems to replace hard tooling for placement," explained Rob Black, senior applications engineer for ShapeFidelity. They call their system Digital Tooling. "We have delivered dozens of these systems, in commercial and defense aircraft applications, including aircraft, spacecraft, and rocket applications," he said.

To illustrate the utility of the concept, he cites a NASA example using their Digital Tooling to mate the adapter fitting between the Orion space capsule and the Delta IV rocket for an upcoming test launch. The Orion diameter is 18' (5.5 m) while the Delta IV rocket is 16' (4.9 m), requiring an inverted cone to make the rocket usable. "We are using the ATOS system in lieu of hard tooling by scanning the parts in process, after each manufacturing step, and using that data to draw the toolpath definition for the robotic weld tools," he explained. "We saved them at least a million dollars by eliminating the need for hard tooling, not to mention that this was a test flight and only one part was needed." Another example is a Digital Tool system that mates the joint between the hydrogen and oxygen dome tanks on the Ares rocket's upper stage. He notes the print fit-up tolerance for that was 0.010" [0.25], requiring a measuring accuracy of about 0.005" (0.13 mm) over an 18' diameter. The ATOS scans the 18' diameter dome in about 45 minutes. "We have delivered Digital Tooling now in dozens of applications, from building one-of-a-kind to seeing it used to build hundreds of parts per month," stated Black. **ME**

Want More Information?

East Coast Metrology
Ph: 978-887-5781
Web site: http://www.eastcoast metrology.com/

Electroimpact
Ph: 425-348-8090
Web site: http://www.electro impact.com/

Lockheed Martin
Web site: https://www.f35.com/

Nikon Metrology
Ph: 519-884-1376
Web site: http://www.nikon metrology.com//

ShapeFidelity
Ph: 919-345-8893
Web site: http://shapefidelity.com/

SURVICE Engineering
Ph: 410-273-7722
Web site: http://www.survice.com/c

VRSI
Ph: 734-414-0035
Web site: http://vrs-inc.com/