INSPECTION FOR THE SMART FACTORY

PART III: FUTURE OF MANUFACTURING & INSPECTION

AUTODESK. FARO

OVERVIEW

Metrology is of fundamental importance to future factories because so much factory efficiency relies on accurate data. A process or product cannot be improved unless it can be measured accurately.

Metrology, the science and processes of measurement, captures data about both tooling and components to allow new manufacturing processes – such as additive manufacturing and robot-operated machining – to be tested and perfected. It can help process high volumes of data to make better decisions about "standard" but gradually improving manufacturing processes, like milling and turning.

The role of metrology in accelerating smart factories is underestimated, with much of the "Industry 4.0" dialogue focused on robots and automation. Measurement increases productivity while reducing waste and cost in manufacturing through improved control of production processes and more effective verification of components and final products.

Consider "Industry 4.0" as a catchall to describe disruption in how things are being made, to improve speed, accuracy, flexibility and customization.

Design engineers used to design, make, measure, discover errors then remake something. New "generative engineering" models allow a designer to describe what they want to make and the programme tells him/her the best way to revise the design, for manufacturability and cost. Simulation and better digital twins allows a manufacturing engineer to design and test the productivity of a new line or machine in the digital world before a dollar is spent on a prototype or new machine. This is making the physical prototype redundant.

In metrology, the big disruption is in-process measurement. Engineers want to measure and validate parts during manufacture – the cutting, welding, boring, moulding, and polishing – so they are fully validated at end-of-process with no final inspection stage required on a heavy, expensive coordinate measuring machine (CMM). Some industries and components still and will continue to require the batch testing of parts on a final CMM to be fully accredited for that application. But experts believe this will change as in-process, real-time metrology technology improves and validates more parts in production.

Another disruptive force is to move metrology out of manufacture altogether, and back into design engineering. Could robust measurement in CAD, combined with the best manufacturing technology, eventually bring an end to the need for in line or end-of-line inspection? Engineers and computer scientists are working on this today. "As long as everything is traceable, there could and should be another way to do it [metrology] than have a semi-redundant check at the end just in order to be 100% positive that a part is correct, which can then result in scrap," says Chuck Pfeffer, Director of Product Management at FARO Technologies.

This white paper by Autodesk and FARO investigates the role of metrology in manufacturing and the Future of Manufacturing and Inspection, covering scanning, data acquisition, sector applications and how different countries are developing metrology best practice.

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TRENDS IN SMART FACTORY METROLOGY

For decades, inspection has occurred at the end of the manufacture of a part, and then again in final assembly. Smart factories, those moving towards the cyber-physical state of "Industry 4.0" production, aim to integrate measurement in the process itself and away from the lab.

The main drivers for this are speed and the avoidance of scrap – despite the best CAD data, machines and tooling, parts can fail validation and are rejected. In the aerospace, nuclear and tool and die industries, for example, this is unacceptably expensive.

"If you think of Industry 3.0 as the fixed CMM lab, and Industry 3.8 – what we have today – as getting an articulated scan arm onto the factory floor, to a level that bypasses lab CMM, then Industry 4.0 is fully integrated in-process metrology," says FARO's Chuck Pfeffer.

A major trend in future factory technology is the rise of non-contact, scanning measurement systems.Non-contact scanning technology is divided into several types. These include:

Laser line scanning – uses a laser line at a fixed length from a camera, then uses triangulation to determine how far away the laser is from the source to measure a component.

Structured light – uses an LED projector, normally blue or white light, to project a pattern onto the surface of the component. The deflection in the patterns is then recorded by one or more cameras, which defines the geometry of the component surface.

Optical/image technology – this covers products that use camera sensors to make non-contact measurements. The technology allows for improved accuracy and flexibility – one recent introduction was a camera based assembly verification system that uses an iPad camera to align assemblies to CAD in real time, which enables inspectors to overlay CAD with real parts on the iPad screen to streamline their quality assurance processes.

X-ray and CT tomography – like a CT or MRI scan of a human, the tomography takes many images derived from the density of the material to build up a layer-by-layer picture of the part. Favoured for some AM components, it is suitable for difficult to access geometries but is slow.

Non-contact scanning offers speed and flexibility that a touch probe cannot match for specific tolerances above 30 microns. Laser line scanning and structured light have become more accurate and reliable for manufacturers. Today there are certain cases in certain applications where there is no longer a need to sentence (or pass quality for a customer) with a CMM contact system, especially with structured light scanning technology, where there is no need for a "first article inspection". Aerospace companies, for example, are today sentencing parts for flight using structured light scanning only.

TRENDS IN SMART FACTORY METROLOGY II

Smart metrology assists manufacturing process control

Subtractive and additive

New metrology technology is also part of the trend for real-time process control in machining operations.

Whereas setting machine tool feeds and speed values used to be fixed by the operator, intelligent machine tools can now analyse and feed data back to a machining CNC front end, about the tool cutting resistance and therefore the density and hardness of the material. The machine can make a corrective action, which can extend tool life, or optimise the cutting performance by suggesting a different tool, saving the company money in better tool selection and prolonged tool life.

In additive manufacture (AM), measurement can see distortions and feedback to the AM machine. "You can then tweak some of the parameters for the AM process to iron those out, such as deposition rate, the strength of the energy source to apply, more support structures or changing tool inserts," says Autodesk's Chris Steadman, Metrology Product Specialist Team Manager. "It's about both reducing time and improving the accuracy through real-time feedback."

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Sharing information in the supply chain

Software linking companies to reduce scrappage

Collaboration and sharing information is increasingly at the heart of smart industry. New software now allows customers to share their measurement reports. Where there is an area of uncertainty they can share results with the customer or tier one partner, who can decide on a part that may need rework or be accepted as is.

"The supplier could be scrapping parts unnecessarily, or the part can be at the edge of the tolerance, where the customer can check and may decide to let that one through," says Stedman at Autodesk.

Many of these very high value parts can be linked to the overall efficiency of the aircraft or asset too. So the end customer, such as the airline customer, can also be consulted on validation, if a critical and expensive part is "good" but the operational efficiency might be affected.

SMART METROLOGY FACTORY APPLICATIONS

More companies are today under pressure to manufacture a greater variety of products – either driven by competition or to offer mass customization – so future factories must respond or 'flex' quickly to changing demands.

Aerospace company Meggitt plc, for example, makes some components in volumes of several thousand-off, while others are one-off components for aircraft discontinued in the 1970s. Meggitt is not alone in this regard.

To service this flexibility, modern factory metrology provides a big range of tools and techniques, including:

- **CAD based inspection**
- **Dimensional analysis**
- **Non-contact inspection**
- **First article inspection**
- **Automated in-line inspection.**

Within this set, the primary smart factory technology is scanning, with laser scanning favoured by more companies than optical systems to date.

Manufacturers using smart metrology within their facilities have a range of flexible applications, with improved accuracy:

CAD inspection
Portable CMMs from FARO simplify the implementation of geometric dimensioning and tolerancing and provide efficient, easy-to-use solutions for CAD-based 3D inspections and nominal comparisons.

Dimensional analysis
Machined parts and assemblies come in a diverse range of shapes and sizes. Flexible and accurate 3D metrology tools for part inspection and dimensional analysis are required to verify their accuracy and quality.

Non-contact inspection
Complex and free-form surfaces can be captured as a dense and detailed 3D point cloud, allowing users to perform non-contact, 3D inspections with ease.

First Article Inspection ensures detailed verification of a produced part or assembly compared with the original design before full production begins.

Automated in-line inspection
Increase productivity and reduce costs by automating 3D measurement workflows. Move the inspection process from the quality lab to the shop floor.

SMART METROLOGY FACTORY APPLICATIONS NEW STANDARDS

The global measurement industry is working hard to identify, define and find consensus for new international measurement standards for new manufacturing technologies.

"International measurement standards are critical for manufacturing to truly achieve its goal of Industry 4.0," says Chuck Pfeffer at FARO Technologies.

"These standards are utilized as a defacto 'Rosetta Stone' between large OEMs and their suppliers, which in turn normalizes all data sets and allows for data analytics to make smarter production decisions, benefitting the global manufacturing industry with better efficiency and productivity."

ISO 10360 is the suite of standards for CMM measurement. An important standard for smart metrology that was passed in October 2016 is ISO 10360-12:2016 that specifies acceptance tests for verifying the performance of an articulated arm CMM by measuring calibrated test lengths as stated by the manufacturer.

It also specifies the re-verification tests that enable the user to periodically re-verify the performance of the articulated arm CMM.

Experts think factory non-contact metrology standards are likely to be developed by large OEMs within sectors, dictating their own best practice to their supply chain, rather than a universal set of standards across all sectors and businesses. However several international metrology and standards bodies are working to accredit these at the highest level so suppliers can manufacture acceptable to the widest pool of customers.

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AUTOMOTIVE

Forms of scanning metrology have been used for several years in the automotive industry, where it is used to measure various components including body-in-white inspection. It is increasingly being used in assembly, for example measuring in "gap and flush" and seal measurements.

"Laser beam scanners are now being used in automotive – we always knew aerospace was an application, but they're in automotive now because OEMs want to scan the entire vehicle instead of many components for speed," says Pete Edmonds, Vice President Global Factory Metrology at FARO.

The challenge in the 1990s and 2000s when scanning was being introduced was that often production engineers believed "if you're not touching it, it doesn't count" which has needed a cultural adjustment. This is happening, says Liam Bradley-Smith, Senior Research Engineer, Metrology at the Manufacturing Technology Centre (MTC) in Coventry, UK. "Today we see scanning is being adopted in new areas where there is a high demand for rapid cycle time and the quality of data is high enough with certain systems."

Automotive companies that are known to use non-contact scanning include BMW, Mercedes – specifically on the Sprinter van – and Red Bull Racing. BMW uses structured light technology for measuring body parts. Jaguar Land Rover in the UK is investigating better factory metrology with a Powertrain Metrology Centre of Excellent. Jeremy Stern is a precision engineer and Senior Manager Powertrain Quality Services at Jaguar Land Rover. He takes a new approach to metrology.

"We should be driving measurement out of manufacturing and back into the design of products," Stern says. "You take your measurements at the point you design and develop them so you better understand how these components and systems perform so you don't need costly and arguably ridiculous levels of process control and all the measurement that goes with it.

If we are saying measuring in manufacturing is our arbiter of success, and with that measurement comes uncertainty and different sample sizes, we are chancing our luck. It should be better than this," says Stern, who admits this is easy to say but very difficult to do.

Jaguar Land Rover has started a Design for Metrology project that incorporates requirements of metrology into engineering and design.

Across industry, Stern believes there is very little metrology-related information in an engineering drawing. "We need to incorporate this knowledge in to the drawing so there is a single correct way to design, and use that knowledge to characterize the product." For example, parts should be measured before they go on test and when they return so engineers understand how these dimensions relate to the functional performance of the products. A manufacturer can then decide if the measurements need to be "controlled" or if it's not necessary.

Stern and a team of university researchers have formed a group to investigate this approach. They are working to develop a data analytics framework to connect information – the development test data, the engineering measurement, the manufacturing process data, the field data – so that it can be used to give greater insight into product performance across the whole product life cycle.

"There is now a heavier reliance on better quality CAD data. What's becoming popular now is embedding more information into the CAD model to augment the metrology."

AEROSPACE

How parts are being sentenced, or validated, in aerospace is changing and CAD is playing a big role.

A typical standard procedure used to be to take a 2D drawing, an operator reads that values, and extracts the information in a 2D, non-digital format. What is commonplace today is a colour or "heat" map, providing physical properties on a 3D model that shows if the part's data is positive or negative versus the CAD model. This provides much more information about the variation or shape of the surface compared to the old 2D information. "There is now a heavier reliance on better quality CAD data," says Liam Bradley-Smith, at the MTC, UK. "What's becoming popular now is embedding more information into the CAD model to augment the metrology."

Rolls-Royce and other prime contractors face a challenge in standardizing how their suppliers inspect. These companies want to remove ambiguity in a drawing and put the data into a prescriptive model that allows for no interpretation. There can be great variance in the way suppliers use a CMM, in how many points that should be use, the angles and speed to select, the CMM supplier and age. Rolls-Royce has published that it spends £12 million per year just validating the CMM programmes, not creating them but merely ensuring that its supply chain implements the programme correctly.

The global metrology community is working on standards and methods to eliminate this variance.

Drone inspections

One application of new technology is drone inspection of aircraft. Companies that include Airbus and airlines KLM and Easyjet are using drones to scan aircraft for damage, pre-flight or maintenance inspection. The accuracy is not at the micron or sub-micron level, but it can provide useful data. "Ground-based and aerial drones have been considered by some customers for scanning in construction and we can dynamically scan on a rail to improve stability, but currently its not high accuracy scanning," says Pfeffer at FARO.

FUTURE DEVELOPMENTS

Metrology practitioners say the Industry 4.0 evolution is completely reliant on effective metrology. "No drive to Industry 4.0 can happen without data and that is driven from metrology," says Pfeffer at FARO.

Smart metrology devices are starting to pull in new features like augmented reality (AR). "We have solutions that use AR to provide additional sets of information to see things differently and add more meaning," says Pfeffer. "Each of our solutions is about providing data that is actionable that allows you to drive the change towards connected factories as an approach." Having released Visual Inspect and Visual Inspect for AR in 2016, Faro having the reach and exposure for that and will move that forward, increase the use of this AR in the assembly verification process. Allows for thorough and comprehensive checks of assemblies in real-time with an iPad.

A big field is improving metrology for additive. "One of the problems with measuring AM is that the form of each part varies, so you never get exactly the same part twice," says Autodesk's Chris Stedman. If you want to do final machining you need to know what the true form of the part is. We use technology called **adaptive software fixturing** to optimize the part set-up and ensure we can create the final part before any machining takes place." This is a feature of Autodesk PowerInspect.

In January, Autodesk will open its new **Advanced Manufacturing Facility** in Birmingham. Completely refurbished and enlarged, the facility has 5-axis machining centres, hybrid machines and advanced metrology solutions to better integrate metrology with additive and subtractive manufacturing. There are several High Value Manufacturing Catapult centres in Britain doing mid-TRL (technology readiness level) work in advanced metrology and a Future Metrology Hub, headquartered at University of Huddersfield, launched in September.

The PBT in Germany is engaged in many pan-European advanced metrology activities, including research in simulated metrology. The National Physical Laboratory in the UK, NIST and the Coordinate Metrology Society in the US, as well as PBT, are seeking to establish new standards for non-contact metrology and more reliable methods for measuring AM parts.

"No drive to Industry 4.0 can happen without data and that is driven from metrology."

Useful Links

Challenges and trends in manufacturing technology, PTB-reviewed article
https://www.j-sens-sens-syst.net/5/325/2016/

UK Measurement Strategy
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/605605/uk-measurement-strategy-supporting-information.pdf

Simulation software for virtual measurements in dimensional metrology
http://arxiv.org/abs/1707.01091

Optical metrology SimOptDevice
http://dx.doi.org/10.1364/OE.24.003393

European research project EMPR IND62 – "Traceable in-process dimensional measurement"
https://www.ptb.de/emrp/ind62-project.html

Coordinate Metrology Society – Certification
https://www.cmsc.org/about-cms

ISO standard for Acceptance and reverification tests for articulated arm coordinate measuring systems
https://www.iso.org/standard/63931.html

European Portable Metrology conference
http://www.epmc.events/

Drone inspection at Airbus
https://www.youtube.com/watch?v=KpoCf9ev0VM

FARO factory metrology products
http://factory-metrology.faro.com/en/

Autodesk PowerInspect
https://www.autodesk.com/products/powerinspect/overview

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