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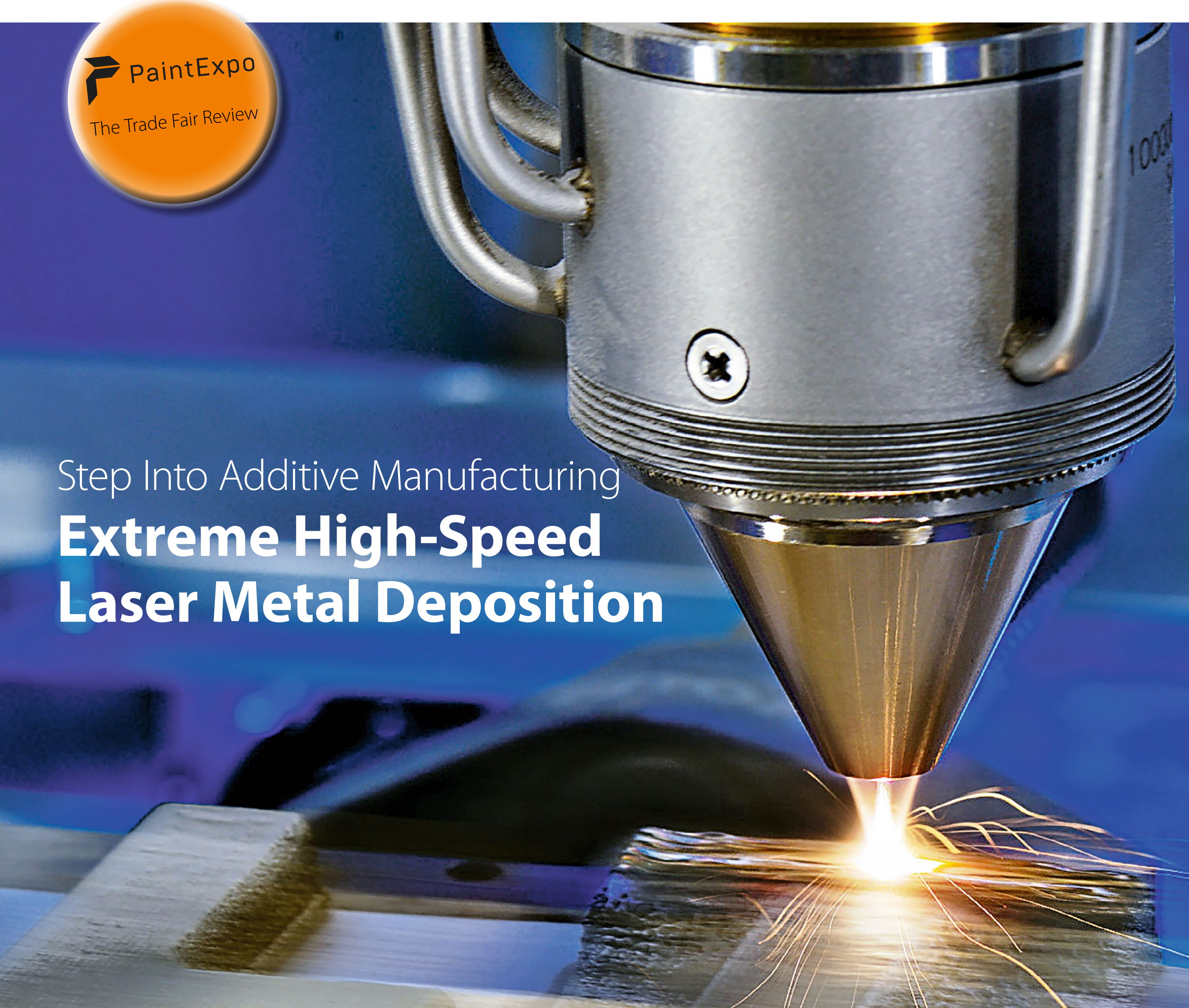

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Trace Components by Fingerprint Every Second

In order to improve production processes, it is important to identify the potential root cause of failures and to trace those. Production data that can be assigned to individual components are the key to this. Together with a research institute, an automotive supplier has equipped a pilot production line for diesel injectors with marker-free tracking technology.

Alexander Förste, Tobias Schmid-Schirling, Thomas Koerber

In mass production, components drop off the assembly line every second. This makes it necessary to be able to identify and trace an individual component very quickly. The state of the art in tracing are machine-readable markings, for example data matrix codes (DMC), which are applied to each individual component and clearly identify it. But such kind of marking is not always practicable.

Surface microstructures as fingerprints

The Track & Trace Fingerprint technology developed at Fraunhofer IPM makes it possible for the first time to trace components without marking: it uses the individual microstructure of component surfaces as a "fingerprint" for identification. This also makes the tracing of small components and semi-finished products economically feasible. Fraunhofer IPM and Bosch have now integrated the technology into a pilot production line for diesel injectors at the Bosch site in Bamberg, Germany.

Microstructures, colour textures – almost all technical surfaces are characterised by random features in a unique way. In the Track & Trace Fingerprint process, defined areas of the component surface are captured in high resolution with a camera system adapted to the respective application (*figure 2*). A unique code is then calculated from the image data with their specific structural patterns and their position in relation to each other. This fingerprint is stored in a database together with an individual ID specified by the user.

A component registered once in this way can be found again by taking another fingerprint and comparing it with all the fingerprints stored in the database. If the fingerprint matches, the searched component is identified and the corresponding ID is returned to the user. Additional information such as measurement or manufacturing data can now be assigned to the component.

Together with Bosch, Fraunhofer IPM has now been able to demonstrate that identification also works technically under real production conditions and is also economical. At the Bosch lead plant in Bamberg, the team integrated Track & Trace Fingerprint into an assembly line for Common Rail Injectors. So-called anchors are to be identified there. These small components (*figure 3*) are installed in every Common Rail Injector with a solenoid valve. The quality characteristics of the armature and its interaction with other injector components are decisive for the function and injection accuracy of the Common Rail Injectors. It is therefore profitable for the quality of the entire assembly to analyse data, trace it back to individual components and thus optimise the production process. The system in-

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Figure 1 > Component identification on the basis of the surface structure: The components are registered at the matching machine with the help of the Track & Trace Fingerprint reading system.

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Figure 2 > (left picture) Optics and illumination of the Track & Trace Fingerprint reading system are adapted to the application. The system uses standard components of industrial image processing.

Figure 3 > (right picture) CRI2 Solenoid Valve Injector with a round armature component in the middle. Track & Trace Fingerprint takes six fingerprints of the pole surface for identification.

stalled at Bosch consists of two Track & Trace Fingerprint systems: The registration system is attached to the armature matching machine (*figure 1*), records the fingerprint of the components and stores it in the database. A second reading system for recognition is integrated into the assembly line. It identifies the individual components in the assembly process.

Tracking of small components only possible without marking

The armature itself does not offer the possibility of applying a machine-readable marking at a position that remains accessible throughout production. The top pole surface of the component is a functional surface, so labelling there is out of the question. For the non-marking Track & Trace Fingerprint, it is exactly this easily accessible pole surface that lends itself as a fingerprint area. However, the polished, reflective surface is a challenge for the optical system. Another complicating factor is that the installation space and working distance are predetermined by the production equipment.

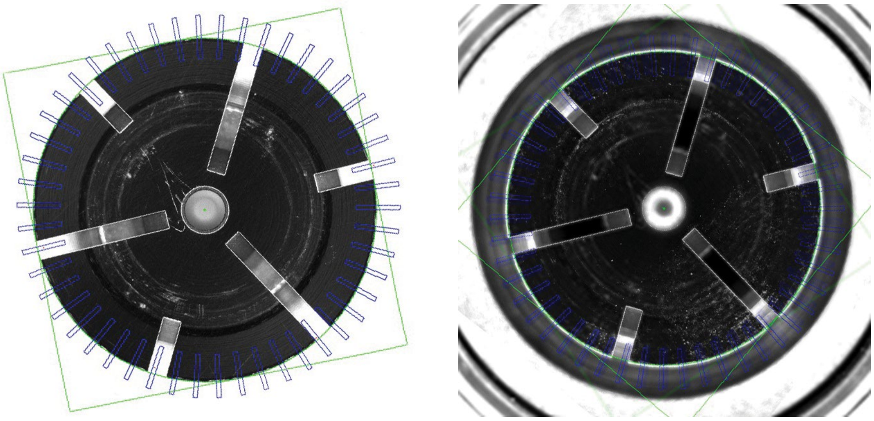
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Figure 4 > Image of the same component for fingerprint registration (left) and identification in the assembly line (right). In the high-resolution camera image, the microstructure and the multitude of matches of the reflective surface become visible. The blue and green markings indicate the result of image pre-processing for software positioning of the armature.

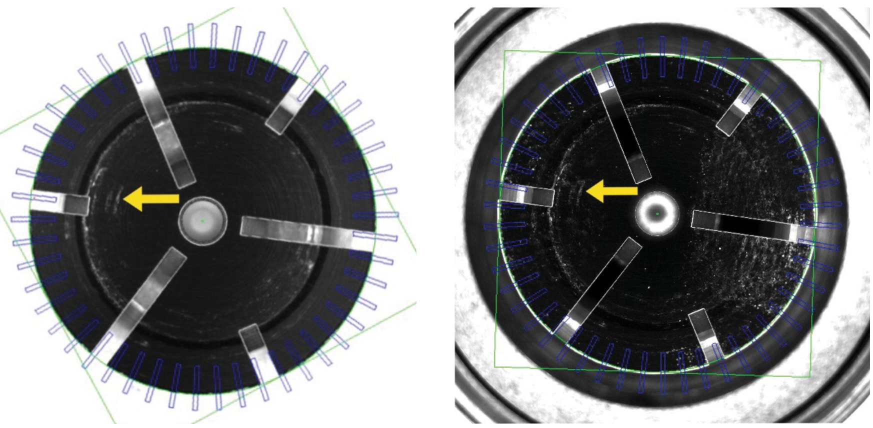
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Figure 5 > Image of the same component for fingerprint registration (left) and identification in the assembly line (right). In the left image section, some matching microstructures can be seen (yellow arrows). The right image section in each case shows strong differences. The component was nevertheless reliably identified.

The high production volume also places enormous demands on the technical availability and robustness of the system: the identification of a component must take no more than one second. In contrast to reading out a DMC, for example, two steps are necessary to determine the ID in the Track & Trace Fingerprint process: First, the image information is converted into the fingerprint, then this fingerprint is compared with all fingerprints available in the database to determine the corresponding ID.

Robustness, data processing and speed

In practice, a single armature must be distinguishable from hundreds of thousands of components in production until it is used in assembly. All these components are positioned at any angle in front of the camera and have up to six-fold symmetry on the top, i.e. six possible angles of rotation. Therefore, six fingerprints are generated and matched for each armature during recognition.

Another challenge for the Track & Trace Fingerprint system is the compensation of positioning inaccuracies of the components. Tolerances of ±1 mm in the horizontal direction and ±0.1 mm in the vertical direction are compensated for in the software by means of image processing immediately before the actual fingerprint algorithm is applied. The component is centred software-based via the outer geometry.

The slightly different light conditions during the image acquisition of the components at the matching machine and the later identification of the already installed components in the assembly line lead to differences in the imaging of the microstructure. In the case of the installed armature, there is more light from the side, which makes the structures on the polished surface more apparent. *Figure 4* shows the pre-processed images of one and the same armature, where the visible microstructures are almost identical. In *figure 5*, a large number of similarities, but also many differences, can be seen in the images. But this component was also reliably recognised with the Track & Trace Fingerprint system.

In addition to the ID, the system provides a statistical value that indicates the reliability of the identification. A threshold value has been defined for this characteristic value, which specifies from which characteristic value an identification is considered reliable. If the characteristic value is too low, the identification is considered unsafe or "not identified". No ID is returned by the system.

In the trial run, the Track & Trace Fingerprint software was initially parametrized for maximum recognition reliability and adapted to the production process. This includes that armatures that were identified on the assembly line no longer appear there in regular operation and are therefore moved from the active database to a backup database. Due to special processes, this rule is occasionally deviated from, so that the Track & Trace Fingerprint system then searches for these components in the backup database.

99.95 % of the components reliably identified

Before being used in series production, the system was tested on 30,000 armatures with regard to a variety of criteria such as identification rate and duration. Fingerprints of about 100,000 armatures were stored in the database. This large quantity results from the dwell time of armature between the two production stations equipped with reading systems. Weeks before the start of the test run, armatures were registered at the Track & Trace Fingerprint matching machine.

During the evaluation of the test run, three result categories were distinguished: "Reliable identification", "Non-identification" and "False identification". In order to avoid false identifications, the threshold value for the minimum necessary identification certainty was set very high. In return, a slight increase in non-identifications was accepted, since even correctly identified components are classified as non-identifications due to too low detection reliability. The results of the series test were convincing: 32,645 of the 32,661 tested armatures could be reliably identified. Among them were also components that were deliberately changed during validation, for example. Only 16 armatures could not be identified with sufficient reliability. The reasons for this typically lay in the image acquisition. No component was incorrectly identified. The identification rate resulted in 99.95 %. To check the identification, a DMC was applied to the bottom of the armature plate. Since this is no longer accessible after installation in the Injector Body, the control step was carried out manually on the second reading system. The system needed an average of 1.1 s to identify the components: 0.3 s for image acquisition and generation of the fingerprint, and an average of 0.8 s for fingerprint matching. This meant that identification was successful even with 100,000 component data sets in a production cycle. The pilot test has shown that with the Track & Trace Fingerprint technology, a 1:1 allocation of process data is also possible for mass-produced components. Since the process does not require any marking, it is particularly suitable for smaller components. The high speed and reliability of the technology make it possible to identify and avoid the causes of production errors, which ultimately contributes to lower scrap and reduced manufacturing costs. //

Authors

Dr. Alexander Förste
Project Manager Inline Vision Systems

Dr. Tobias Schmid-Schirling
Group Manager Inline Vision Systems
Fraunhofer Institute for Physical
Measurement Techniques IPM
Freiburg (Germany)
tobias.schmid-schirling@ipm.fraunhofer.de
www.ipm.fraunhofer.de/en

Thomas Koerber
Senior Manager Manufacturing Operations
Common Rail Injector
Robert Bosch GmbH
Bamberg Plant (Germany)
thomas.koerber@de.bosch.com
www.bosch.de