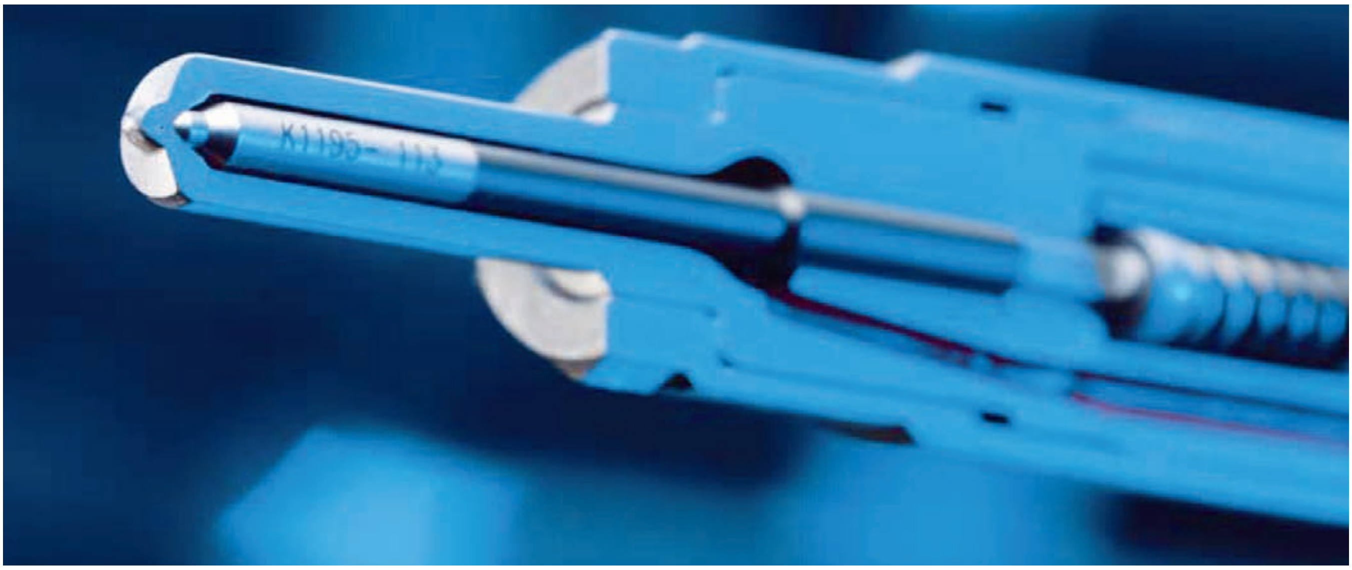

MEASUREMENT TECHNOLOGY FOR FUEL INJECTORS

Multisensor Systems for Micro-Features

For over ten years Continental AG has used machines from Werth Messtechnik GmbH in Giessen to measure fuel injectors all over the world. The image processing sensors used at first were soon joined by the patented Werth Fiber Probe and later by computed tomography. This allows high-precision measurement of dimensions, shapes, and roughness, and guarantees traceability of measurement results.

The geometry of fuel injectors for diesel and gasoline engines is crucial to engine power output and fuel consumption optimization. The nozzle holes of diesel fuel injectors in particular have inspection features that place high demands on measurement technology. Diameters as small as 90 µm with tolerances in the single-digit micron range must be measured at depths of up to one millimeter, with measurement deviations of fractions of microns.

Due to the small diameter of the nozzle hole, conventional tactile sensors cannot be used to measure fuel injectors. The first technical solutions therefore used non-contact image processing sensors. The necessary transmitted light illumination from the interior of the injector is obtained by inserting an optical fiber into the body of the injector. But precisely determining the diameter is possible only at the outlet of the hole. The edge radius at the inlet of the hole influences the measurement results, making precise traceability impossible. The shape of the nozzle hole (diameter progression) cannot be captured using this method.

Today image processing is used mainly to find the nozzle holes, check them for debris, and position them via the rotary axis for measurement using the fiber probe.

Complete Measurement with Fiber Probe

For the tactile measurement of micro-features, the tactile-optical WFP (Werth Fiber Probe) was developed in cooperation between Werth Messtechnik, Giessen, and the German National Metrology Institute (Physikalisch-Technische Bundesanstalt – PTB) in Braunschweig. With this micro-probe the deflection of the probe tip is directly optically measured (Figure 1), eliminating the transmission of the signal by the probe shaft. This allows the use of a thinner shaft with an extremely small probe tip (currently down to 20 µm diameter in series production).

This design is well suited to the nozzle measurement task. According to the manufacturer, the functional principle of the Werth Fiber Probe makes it one of the most precise sensors currently available for coordinate measuring machines. The elasticity of the probe shaft makes the system robust enough for shop floor use (Figure 2). The former Hydraulik-Ring AG (now part of Continental AG), together with Werth Messtechnik, was able to use the fiber probe for the first time in 1998 to completely determine the 3D geometry of the nozzle holes in a tactile process traceable to national and international standards.

The injectors were positioned relative to the sensor using a rotary/tilt axis in order to adapt to the elevation angle and circumferential location of the nozzle holes. This alignment required that the axial lo-

Fotos: Continental Automotive/Werth Messtechnik cation of each nozzle hole be determined. By using the fiber probe in combination with image processing in a multisensor coordinate measuring machine, this can be done optically very quickly and precisely.

The same optics that are used to determine the position of the fiber probe are preferably used for this task as well, so that the alignment is particularly exact. In this case the fiber module is automatically placed in a parking station. The fuel injector is then rotated and a brightness autofocus uses the maximum image brightness to identify the vertical orientation of the nozzle hole. The image processing sensor thereby automatically follows the position of the nozzle hole outlet. The alignment is particularly critical, as collisions between the probe shaft and the walls of the nozzle hole can occur when measuring deep inside the hole. The alignment is therefore performed separately for each surface line to be measured.

With a single-sphere probe, shadows can occur when the probe sphere is deep inside the nozzle hole (Figure 1, left). At first this influence was compensated for by precise calibration to reference holes, thus ensuring traceability.

The advanced development of the dual-sphere probe in 2006 made the use of reference holes redundant. The deflection of the fiber probe is now determined by capturing a second sphere that remains above the nozzle hole (Figure 1, right). This eliminates the influence of shadows. The contact procedures and optical imaging of the image processing sensor are decoupled, and the measurement is traceable, just like conventional probe systems. Additional developments such as the scanning fiber probe with integrated piezo-oscillator (patent pending) to prevent the stick-slip effect are adapting this technology to increasingly stringent requirements.

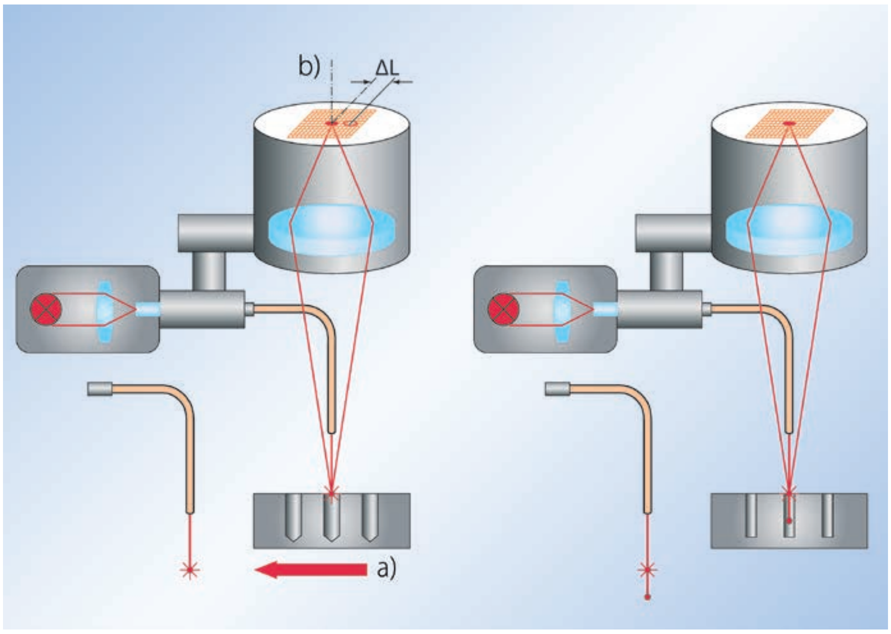

Figure 1. Functional principle of the fiber probe: Single-sphere probe (left): movement of the measured object (a) causes contact and deflection ΔL from the sensor origin in the image plane of the camera (b). Dual-sphere probe (right): even when contact is made at a great depth, the sphere is not in the shadow of the object.

A special WinWerth application with graphic user interface was introduced to provide simple, user-friendly operation even when injector dimensions vary greatly. The injector geometry data are taken from a database that is also used to control production. The operator just has to select the injector model and the alignment and measurement take place automatically. A number of additional functions are available. For example, correction data can be added, the nozzle holes, interior lighting, and sensors can be checked, and measured contours can be shown in a 3D graphic. The standardized parameter program guarantees the highest reproducibility and comparability of measurement results across different machines and locations around the world.

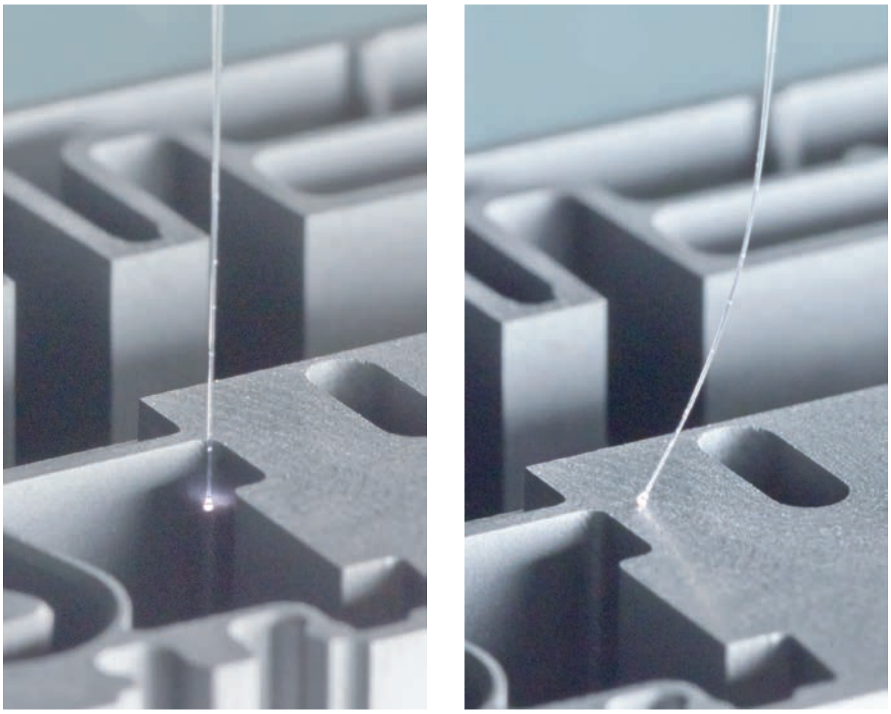

Figure 2. Even if there is an error in positioning, the probe will not be destroyed: left: contact procedure; right: positioning error.

Roughness Measurements on Fuel Injectors

In additional to capturing dimensions, roughness evaluation was implemented in 2004 using the fiber probe. Sufficiently small probe spheres are not possible without the tactile-optical principle. In joint experiments in 2011, the partners proved

Figure 3. Gasoline fuel injector mounted on a rotary/tilt axis on the multisensor coordinate measuring machine

the capability of an optical and therefore non-contact roughness measurement in nozzle holes for manufacturing inspection at Continental.

In comparative measurements with the highly precise WIP (Werth Interferometer Probe) distance sensor, the mean roughness Ra was within the calibration uncertainty U of the standard. This sensor, which is also inserted in the hole using a very thin indexing probe head, uses the elapsed time difference between two light beams (measurement and reference beams) in order to determine the position of the surface point.

Measuring Fuel Injectors for Gasoline Engines

The Werth Fiber Probe has been used to measure fuel injectors for gasoline engines since 2003. This method was first introduced at Continental in the plant in Pisa (Figure 3). Measurements were also controlled with the user software for fuel injectors. The short length of the nozzle hole presented a special challenge. Measurement process capability is ensured by the high measurement precision of the fiber probe (probing deviation as low as 0.15 µm) in conjunction with a high-precision Werth VideoCheck HA coordinate measuring machine.

Injector Measurement Using X-Ray Computed Tomography

In a research project (from 2006 to 2009) the participants demonstrated the principle capability of coordinate measuring technology with computed tomography (CT) for measuring fuel injectors. The advantage of tomography is particularly rapid and complete measurement with a high measurement point density.

After additional development work at Werth, the TomoScope 200 was qualified in 2013 for accurately measuring nozzle hole diameters with tolerances as low as 4 µm. Very low systematic measurement deviations in the low micron range are reduced down to the submicron range using the Werth Autocorrection process. Traceability is ensured by a one-time comparative measurement of a master injector that is calibrated using the fiber probe.

The deviations determined in this comparison are used to correct the CT series production inspections. The coordinate measuring machine with X-ray tomography is also operated from the uniform WinWerth user software platform using production data.□

Translated by Werth Messtechnik GmbH

▶ Continental Automotive GmbH
Dr. rer. nat. Andreas Lenk
T ++49 (0) 511 938-0
info.automotive@continental-corporation.com
www.conti-online.com

▶ Werth Messtechnik GmbH
Dr.-Ing. Ingomar Schmidt
T ++49 (0) 641 7938-0
mail@werth.de
www.werth.de

QZ-Archiv
www.qz-online.de/1077117

Masthead Publisher: Carl Hanser Verlag GmbH & Co. KG, Kolbergerstr. 22, 81679 München