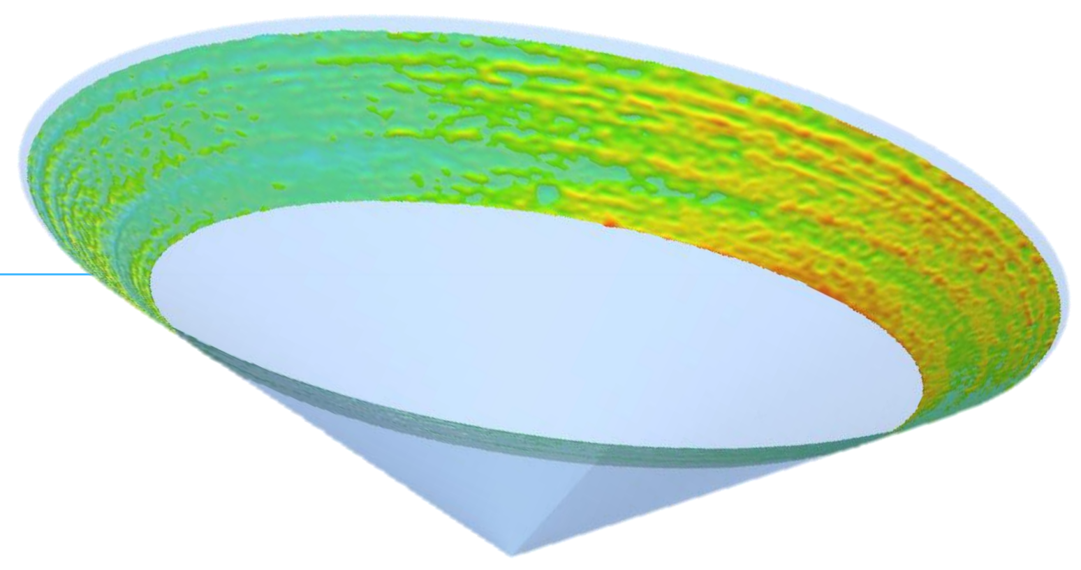
Automatic Valve Inspection of Fuel Injection Nozzles with a Focus-Variation Instrument



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Abstract

The leak-tightness of valves for fuel injection nozzles is a crucial requirement to reduce fuel consumption and emissions. Due to the small dimensions and small tolerances of such nozzles, as well as the fact that the measurement is performed through a hole, the check for leaks is a demanding challenge. Here we present an optical measurement device based on the Focus-Variation technology that measures the topography of the valves and automatically extracts significant parameters from this topography in order to judge the leak-tightness. In the following we present the 3D measurement device used for the inspection and describe the inspection methodology. Additionally we provide results that show that the classification of valves into good and defect parts is possible by using the determined parameters.

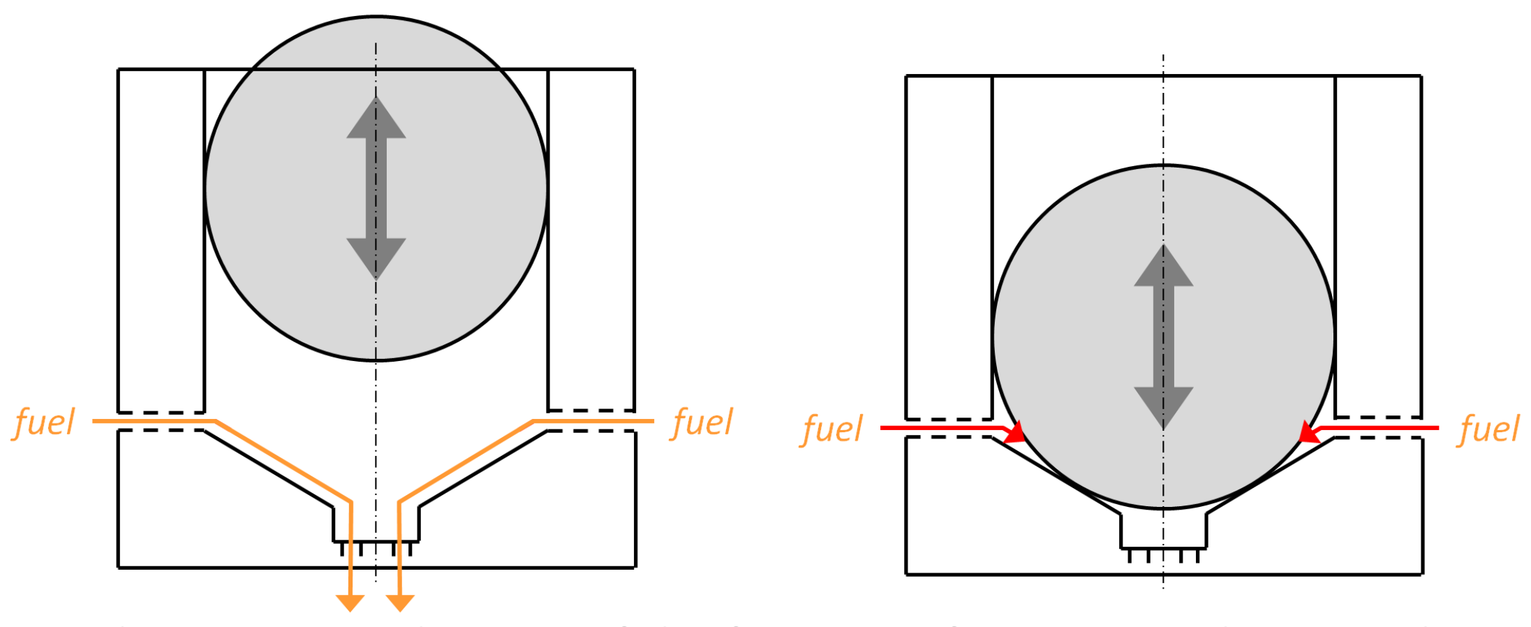
Automated Valve Inspection

General Measurement Task

The function of a valve is as follows. A sphere seals the valve so that no fuel is injected. Once the sphere is lifted fuel is injected through the nozzle. The crucial part is to ensure that the sealing between the sphere and the valve is tight so that no fuel can leak through.

In order to inspect whether the valve is tightly sealed a measurement software has been developed that **automatically** checks the quality of the valve.

First a 3D measurement of the valve is performed and afterwards a series of parameters are automatically extracted to characterize whether the valve is good or bad. Some of these parameters are calculated for the complete cone-like valve, some of them are calculated for the position where the sphere touches the valve.



Schematic visualization of the function of injection valves. On the left fuel is floating whereas on the right it is stopped by the sphere.

What can be measured?

Among the obtained parameters for the characterization of the valve are values for

- roughness (Sa, Sq,Sz, Spk, Svk, ...)
- flatness deviation to the cone (FLTt, ..)
- roundness (RONa, RONq, RONt)
- coaxiality and deviation to a sphere

Roughness

In addition also the surface roughness (Sa, Sq, Sz...) of the valve is inspected according to latest ISO standards on area-based measurements

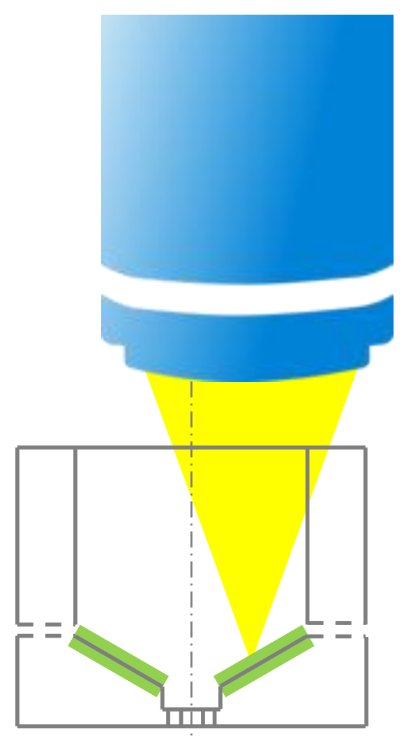
Flatness

The flatness is measured for the whole measured valve after the conical form has been automatically removed.

Roundness

For more information about the roundness measurement please see below.

Due to the geometry of a valve it is necessary that the measurement device offers a large working distance. (See the schematic graphic on the left.) The relevant measurement area which is the sealing face is marked in green is located rather at the bottom of the valve.



Measurement on the sealing face

Measurement Challenge

The critical aspect during the roundness calculation is the calculation of the position where the sphere contacts the valve since this position defines the cutting sphere.

Fitting method

The sphere position can either be determined by:

Figure a) fitting the sphere in a least squares sense into the contact points of the valve

Figure b) by letting the sphere fall down so that it touches the cone

Deformation handling

Two ways have been analyzed to handle surface irregularities:

Figure c) ignore outliers

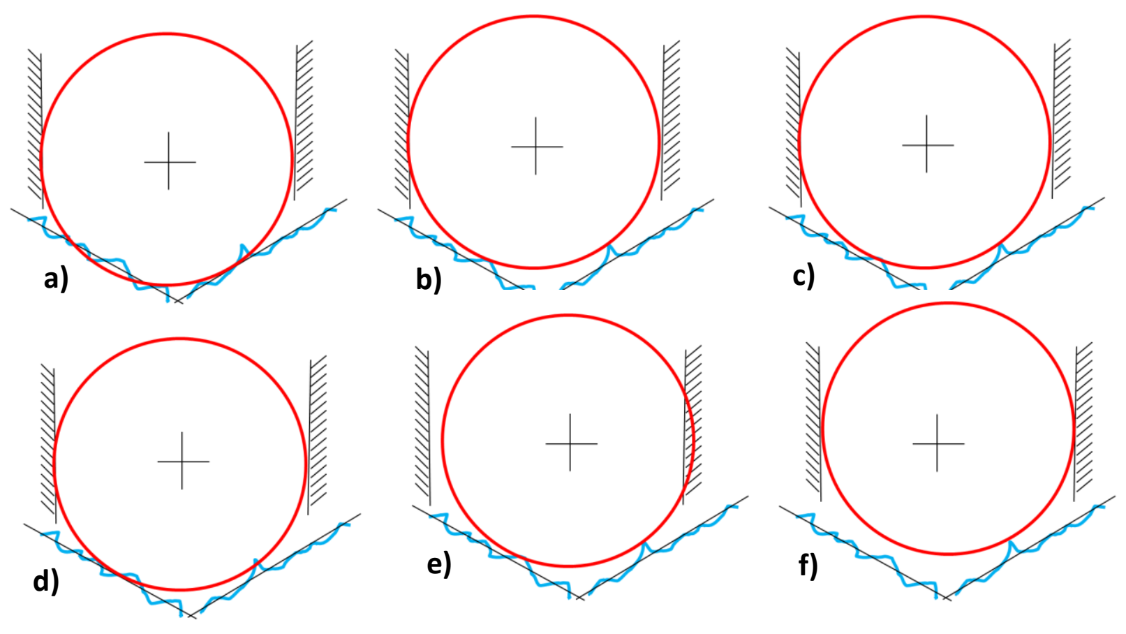
Figure d) automatically cut the highest peaks that would be removed automatically by the fall down of the sphere

Guidance of the sphere

Final considerations have been made with respect to the way how and if the sphere is guided by the cylinder

Figure e) The lowest position of the sphere is determined where the sphere may move in all three coordinates (x,y,z)

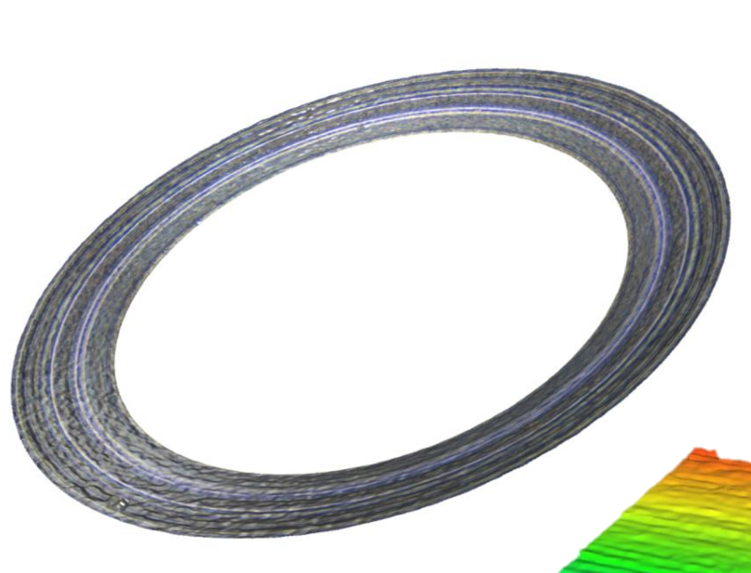
Figure f) Estimate the cylinder axis and search the sphere position where the sphere touches the valve and the (x,y) position lies on the axis of the estimated cylinder



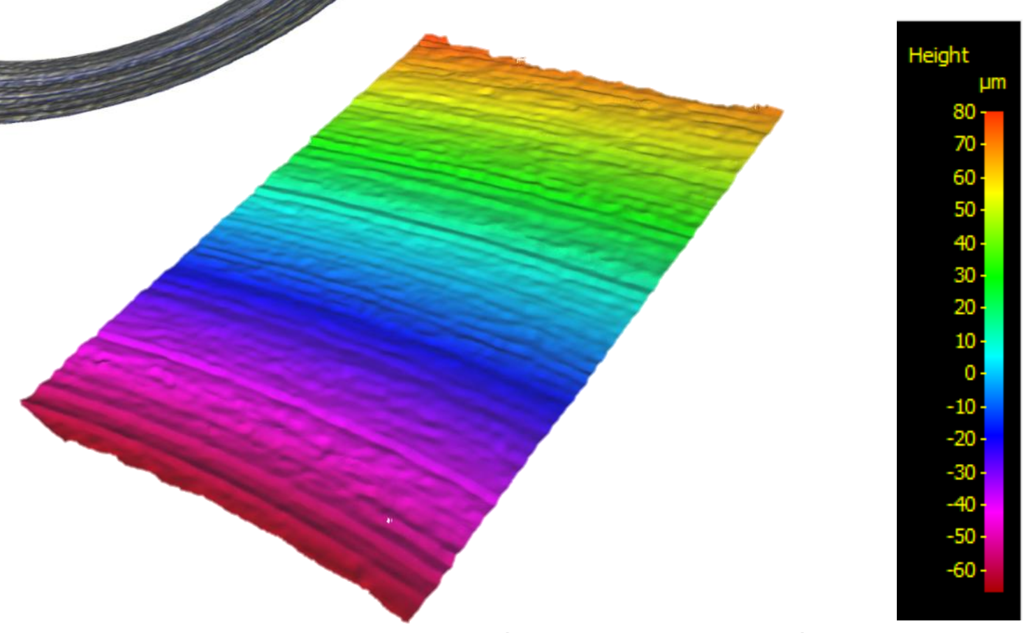
Results

3D-Datasets

Here you see two 3D measurements of valves from injection nozzles measured with the Focus-Variation technology. The upper graphic shows the measurement of the whole valve. The lower graphic shows a detailed measurement of one part displayed in pseudo colors representing the depth.



3D measurement of the conical surface of the valve



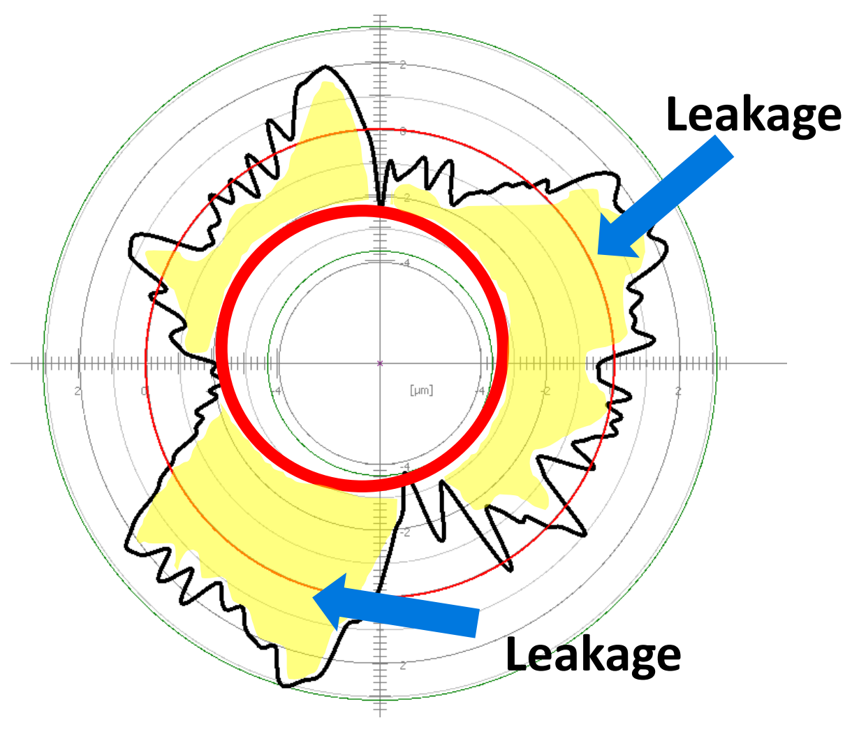
3D high resolution measurement of the sealing face – especially used for roughness measurements

Roundness Measurement

A diagram of the roundness profile is provided in the following figure. It shows the exaggerated deviations of the profile to a least-squares circle (outer red circle) fitted into the points.

The roundness is calculated according to the following procedure:

1. High resolution measurement of the valve using Focus-Variation
2. Determination of the position of a sphere falling into the valve (see top left visualization)
3. Automatic positioning of a cutting plane at the contact points of the sphere
4. Generation of the cutting profile
5. Waviness filtering of the cutting profile
6. Calculation of the parameters RONa, RONq, RONt.



Schematic diagram of the roundness profile, showing the exaggerated deviations of the profile to a least-squares circle (outer red circle) fitted into the points.

Differentiating Good From Defect Parts

In the following we checked whether the measured parameters can be used to classify valves into good and bad parts.

The parameters have been compared for good and defect parts as shown in Table 1. The calculated parameters allow a clear discrimination of the function of the part (good, bad) based on the extracted parameters. Good parts had Sq values in the range of 0.15µm to 0.2µm whereas bad parts had Sq values that were between a range of 0.32µm to 1.02µm. The RONq values showed a similar tendency with good parts having values up to 0.6µm and bad parts having values of about 1µm and more.

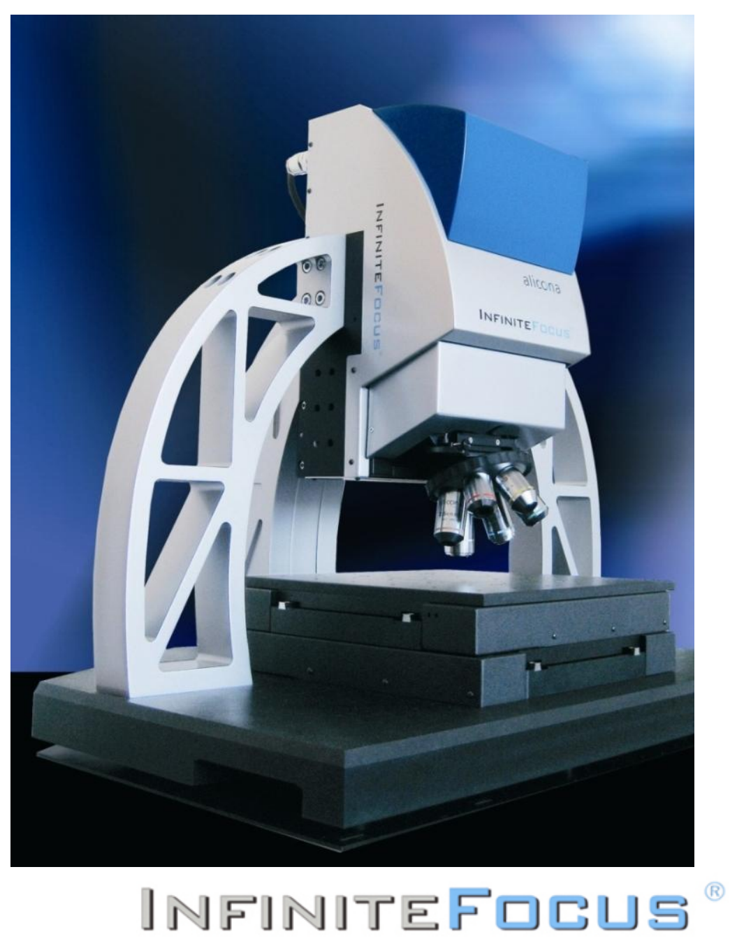
TABLE 1. Comparison of obtained parameters for good and bad parts. The bad parts have significantly higher Sq and RONq values.

Value 1	Sq [µm]	RONq [µm]
Good part 1	0.2	0.6
Good part 2	0.15	0.75
Good part 3	0.16	0.35
Bad part 1	0.32	1.14
Bad part 2	0.76	0.97
Bad part 3	1.02	1.7

Measurement Device

InfiniteFocus

InfiniteFocus is an optical 3D measurement device for quality assurance in the micro- and nano range. It provides all functionalities for dimensional measurements, surface analysis and characterization. Geometries with steep flanks, highly reflective properties and strong roughness are measured with a vertical resolution up to 10nm. The 3D measurements are performed directly on the optical image.

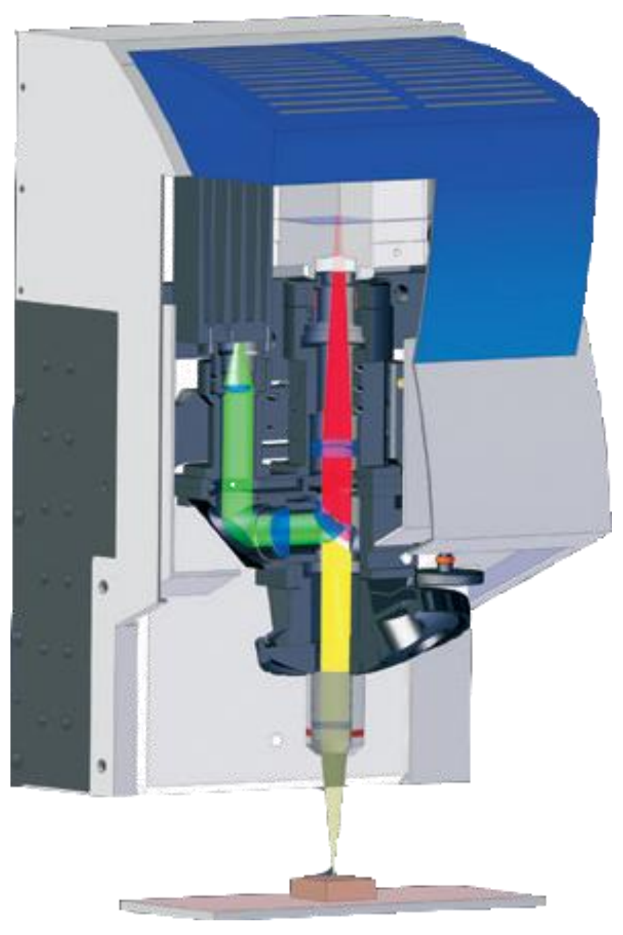


Technology

Focus-Variation

The operating principle of InfiniteFocus is Focus-Variation which combines the small depth of focus of an optical system with vertical scanning to provide topographical and color information from the variation of the focus.

The light is reflected by the specimen and projected onto a digital sensor in the precision optic. As the distance between specimen and objective is varied the change of sharpness is measured. Depending on the 3-dimensional structure of the specimen some areas are depicted sharp whereas others are not. The sharp data is then used to construct the 3D dataset. For every position on the object the sharp regions are measured. The variation of the sharpness values is used for the measurement of the 3D-position.



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