Optical Immersed Surface Inspection of Honed Cylinder Bores

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1 Introduction

In production of combustion engines honing is the finishing process for cylinder bores. Fluctuations in the honing process lead to deficient cylinder surface quality, which causes higher oil consumption of motors. To monitor the honing process of cylinder bores, different measuring methods, such as tactile roughness measurement, scanning electron microscopy (SEM) and image analysis [1], have been employed. However, the application of these methods requires clean cylinder bores, which are free of cooling lubricant and production residues. None of these methods is applicable for inline inspection due to the short production takt time (approx. 30 seconds) and harsh manufacturing conditions. In this paper an innovative approach for inline surface inspection of honed cylinder bores using optical sensors is presented.

2 Measuring System

When applying standard tactile surface measuring methods for cylinder bores a cleaning operation of cooling lubricant is necessary. This paper presents an innovative approach for the optical inline surface inspection. The setup of the optical measuring system is shown in Figure 1(a). Cylinder bores of the engine block and the probe are fully filled with the cooling lubricant. The cooling lubricant between the probe and the cylinder surface serves as immersion medium for the optical measurement, making the time-consuming cleaning operation unnecessary. By means of synchronization with the motion control unit the surface profile can be measured.

Due to the fine profile (R_a smaller than 0.5 µm) and the diameter (approx. 85 mm) of cylinder bores, the optical sensors should be: 1) precise enough; 2) small enough to enable a measurement within the cylinder bore. Two fiber based sensors, a chromatic-confocal sensor and a fiber-optic low-coherence interferometer, have been selected for measurements. The chromatic-confocal sensor utilizes chromatic aberration to spectrally encode the measured distance [2]. In our measuring system, the chromatic-confocal sensing probe has been designed, optimized and built by Precitec Optronik GmbH. The sensing principle of the fiber-optic low-coherence interferometer is based on low-coherence interferometry [3]. It has been developed at Fraunhofer Institute for Production Technology IPT and is now provided by fionec GmbH. The housing of both sensors is of the same shape to ensure the comparability in our measuring system.

As the measuring system will be integrated into a honing machine for inline surface inspection, a test bench is set up for performance tests of the optical sensors while simulating manufacturing conditions (Figure 1(b)). Different experiments with different influences and manufacturing conditions, e.g. the change of lubricant type and temperature, whirling of the lubricant, rough and fine surface, scanning speed etc., are performed for the evaluation of the sensors.

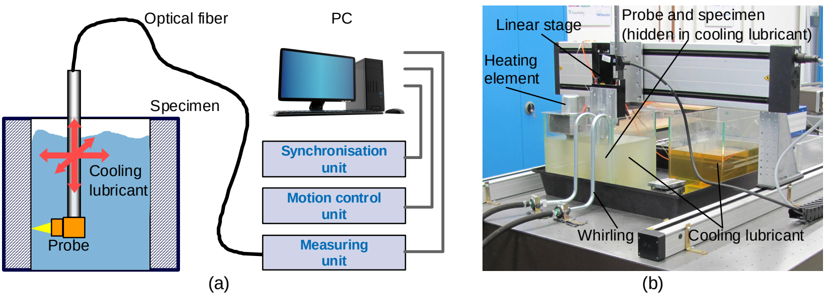

Figure 1: Optical measuring system (a) and test bench (b)

3 Measurement series and results

To evaluate the performance of both sensors, a series of tests are conducted on the test bench:

- Calibration with depth setting standard
- Tests on roughness standards
- Tests on honed cylinder surfaces

3.1 Calibration with depth setting standard

Both sensors are distance sensors. Therefore the sensors have to be calibrated before roughness measurements can be performed. Since the measuring process of both sensors is similar to a tactile stylus profiler, a depth-setting standard according to ISO 5436-1 type A 1 [4] is used for the calibration in cooling lubricant. The depth setting standard has two grooves. One has a depth of 20 µm while the other has a depth of 50 µm. The standard is calibrated with the white-light interferometer Veeco NT1100, which has been calibrated with a standard from Physikalisch-Technische Bundesanstalt (PTB).

For the immersed surface inspection, the refractive index of the cooling lubricant affects the optical path length of the measuring light beam. Since the refractive index can vary over temperatures, cleanness or type of cooling lubricant, a calibration with the depth setting standard is necessary for each measuring setup.

3.2 Tests on roughness standards

Although both sensors have been characterized for roughness measurements in dry conditions [5], different roughness standards with R_z values of 3.2 µm, 10 µm and 20 µm are measured in cooling lubricant. Different measuring frequencies and scanning speeds are tested in the test bench filled with honing oil or emulsion.

The results show that the fiber-optic interferometer is capable to measure roughness in honing oil and emulsion while the chromatic-confocal sensor can only be applied in honing oil. The maximal deviations from the calibrated value in honing oil for the measured R_z values of both sensors are within ±15% and for R_a values within ±6.6% in all measuring setups.

3.3 Tests on honed cylinder bore surfaces

Table 1: Experimental design of tests on cylinder bore surfaces

Factors	**Factor level 1 (-)**	**Factor level 2 (+)**
Lateral Resolution (A)	2 µm spacing	1.5 µm spacing
Measuring frequency (B)	Low (1 kHz)	High (2 kHz)
Whirling (C)	Off	On
Tilting (D)	Low (< 0.02°)	High (> 0.04°)
Temperature (E)	25 °C	21 °C

Since the optical measuring system will be integrated into a honing machine for inline surface inspection, the performances of the sensors have to be tested under manufacturing conditions. Different factors, which may influence the measurement results, e.g. temperature, whirling, lateral resolution, etc., are evaluated in the test bench according to a design of experiments test chart (Table 1).

A full factorial experiment of 1280 measurements is conducted for both sensors in honing oil and emulsion with 10 repeat measurements on each run. The results indicate that the optical measurements are mostly affected by temperature, which causes a change of refractive index of cooling lubricant, although the change of temperature is only 4 Kelvin between two factor levels. In comparison to results, which have been acquired with tactile stylus measurements, the expanded uncertainty for R_a (using a coverage factor of 2) is approximately 80 nm for both optical sensors.

4 Conclusion

In this paper an innovative approach for inline surface inspection, in which the cooling lubricant serves as immersion medium for the optical measurement, is presented. The 100% surface inspection of the honed cylinder bores is enabled, since the time-consuming cleaning operation is no longer necessary. The results of the testing series show that both sensors, the chromatic-confocal sensor and the fiber-optic low-coherence interferometer, are capable to measure roughness in honing oil. The fiber-optic low-coherence interferometer is also applicable in honing emulsion and generally shows slight advantage. Therefore it will be integrated into a honing machine for the 100% inline surface inspection.

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References:

[1] D. Geus, M. Stiebler, Industrial application of advanced measuring and evaluation methods for cylinder liners of engine blocks, Meas. Sci. Technol. 19 (2008) 064004.
[2] H. J. Tiziani, H.-M. Uhde, Three-dimensional image sensing by chromatic confocal microscopy, Appl. Opt. 33 (1994) 1838-1843.
[3] F. Depiereux, P. Lehmann, T. Pfeifer, R. Schmitt, Fiber-optical sensor with miniaturized probe head and nanometer accuracy based on spatially modulated low-coherence interferogram analysis, Appl. Opt. 46 (2007) 3425-3431.
[4] ISO 5436-1, Geometrical Product Specifications (GPS) – Surface texture: Profile method; Measurement standards – Part 1: Material measures (ISO 5436-1:2000).
[5] R. Schmitt, N. König, E. M. de Araújo, Surface profile analysis using a fiber-optic low-coherence interferometer, Proceeding of the SPIE 7389 (2009) 738914.