Evaluation of a Function Oriented Optical In-Process Measurement System for Cylinder Liners

100% Measurement of the honed surface

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Abstract:

Nowadays the honing process of cylinder liners for combustion engines is monitored by 2D tactile measurements of the honing structure. The problem of tactile measuring is the required offline measurement of the cylinder blocks, which results in increased handling efforts and costs. In this paper a method is introduced which overcomes this disadvantage by applying an inline optical measuring system for 100% in line measurement of the honed cylinder liner surfaces. Focus is the comparison of two optical sensors, working after the principle of chromatic aberration and a fiber based white-light interferometer.

Introduction

State of the art is the surface controlling of the cylinder liners in engine blocks for combustion engines by tactile 2D measurements. For this measuring operation, each surface has to be carefully cleaned up, to receive valuable results. Because of this high effort, it is not possible to measure every liner or block, but only a small sample can be controlled. If a failure (surface parameters not in the specification) occurs in the honing process, the numbers of blocks between two samples own this defect, which means high efforts on capacity and costs. To be able to react faster on process variations a system for 100% measurement is needed, which tests every cylinder liner and detects the failure soon after its appearance. It is not possible to use a 100% measurement system based on a tactile probing head in dependence of DIN EN ISO 3274:1998 [1] without any cleaning operation because of leftovers from the coolant and particles. Only with optical sensors it is possible to overcome this problem without a cleaning operation. For the whole measuring process a C-frame (fig. 1) measuring cell is planned, which consists of the frame, linear axles to position the probe head and the specimen, a feed unit for the probe head, a coolant system which "floods" the probe head with coolant and the needed controller for evaluating the surface parameter values and the communication between the measuring cell and the hone machine. This cell should be integrated into the manufacturing line direct behind the hone machine.
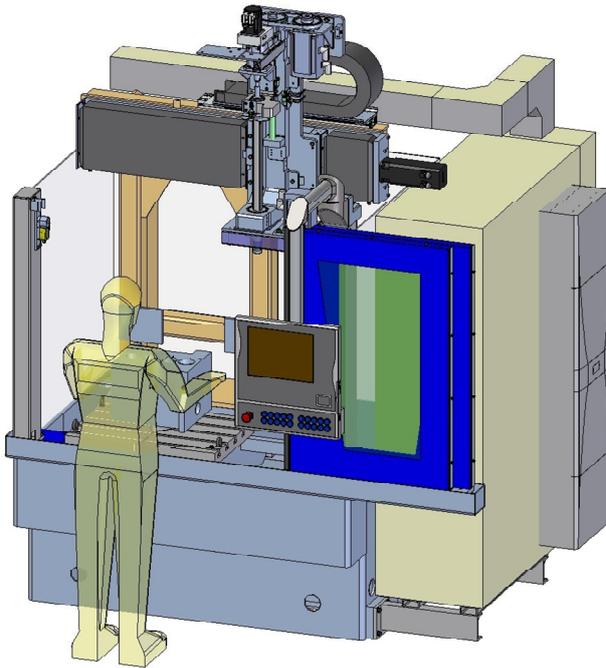
Fig. 1: C-frame measuring cell

Simulation of the influences

Because of the rough conditions during the measurement of the un-cleaned surfaces, the influences on the results have to be evaluated.

For simulating most of the influences during the measurement within the production line, a test rig (Fig.2) has been built. The rig consists of a basin in which the coolant (hone oil or hone emulsion) is filled. For handling the sensors, linear axles have been installed. To create turbulence in the coolant, an adjustable pump is part of the test rig as well as a heating unit and a temperature sensor for tempering the coolant, which simulates the environment conditions in the manufacturing hall. For the positioning of the specimen pitch, an adjustment screw is used, which controls an angle between probe head and the specimen. Controlling the probes, measuring and analyzing the affiliated values and for temperature monitoring, a software using LabVIEW has been developed.

For the tests, the specimen is placed into the filled reservoir in a way that the pitch and the sensor are completely covered with the used coolant to simulate the "flooded" probe head in C-frame measuring cell.
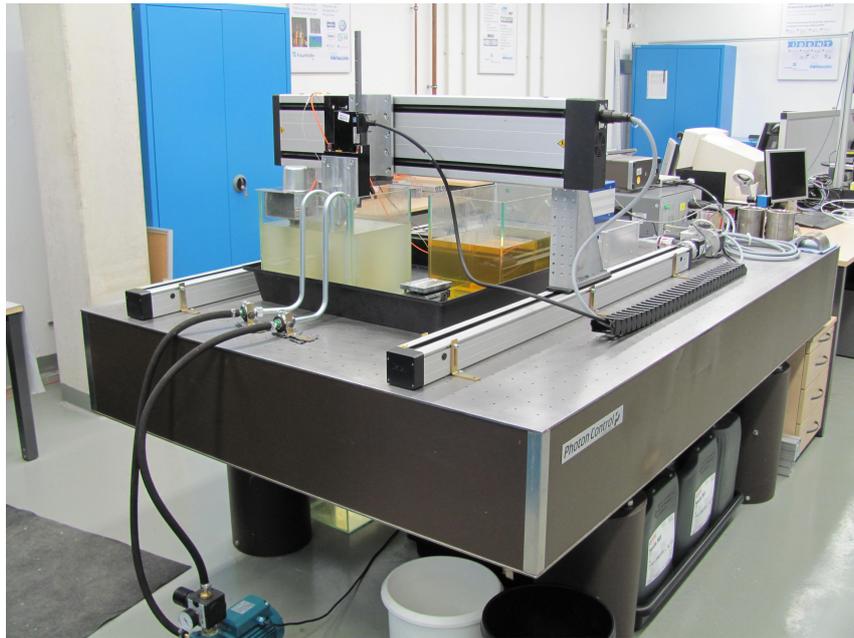
Fig. 2: Test rig for the evaluation of the two sensors

Evaluation using DoE

In order to reduce the required tests by using DoE (Design of Experiments), a full factorial design was developed. Within this design, the factors lateral resolution (A), measuring frequency (B), coolant whirling (C), specimen pitch (D) and coolant temperature (E) were considered. For each factor two factor levels have been defined (table 1). As results the evaluation of two parameters Ra and Rz are used.

Table 1: Factor level setup for the first series of experiments

factor	factor level	facor level
	1 ≙ -	2 ≙ +
lateral resolution (A)	1 µm	1,5 µm
measuring frequency (B)	1 kHz	2 kHz
coolant whirling (C)	on	off
specimen pitch (D)	< 0,02°	> 0,1°
coolant temperature (E)	21 °C	39 °C

The results' evaluation from the first test run is showing the dominance of temperature influence, see fig. 3. The reason for this behaviour is assumed to be the step at the factor

coolant temperature from 21°C to 39°C, which distorts the results of the test run in concerning the significance of the temperature.

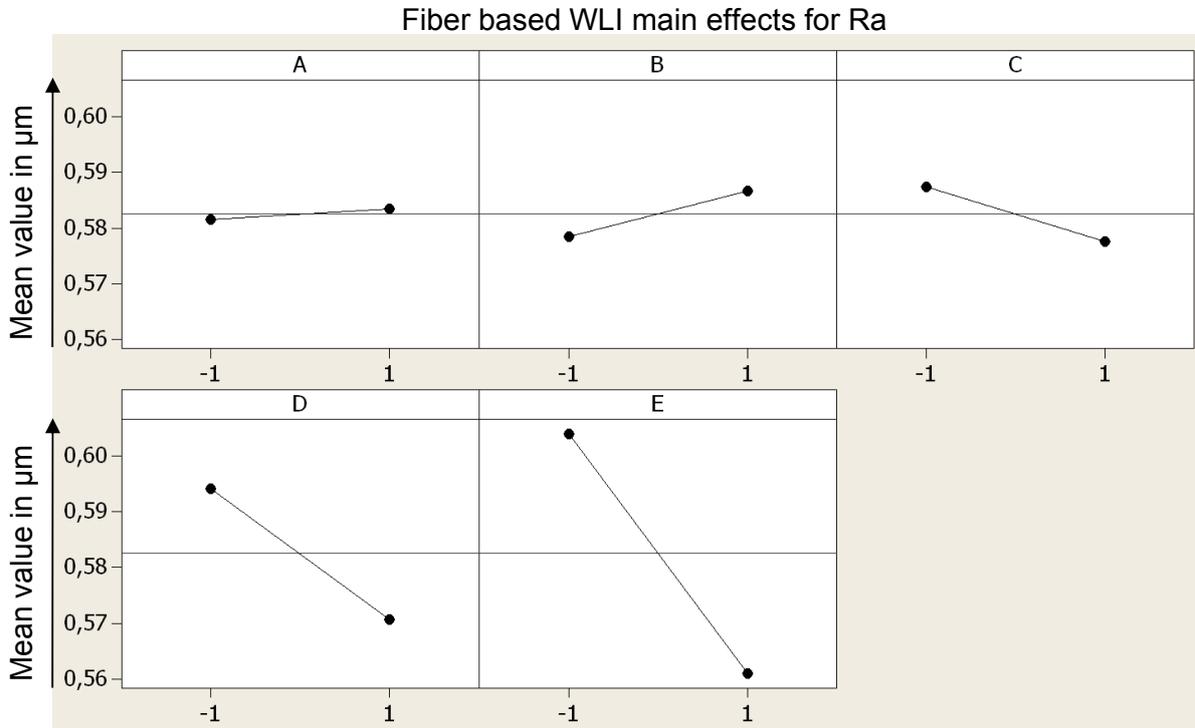Fiber based WLI main effects for Ra

Fig. 3: Main effects on fiber based white-light interferometer at the first test run

Because of the special behaviour of test run one, the factor level setup has been changed for the second test run – especially the coolant temperature's factor step (39°C reduced to 25°C), see table 2.

Table 2: Optimized factor level setup

factor	factor level	factor level
	1 ≙ +	2 ≙ -
lateral resolution (A)	1 µm	2 µm
measuring frequency (B)	2 kHz	1 kHz
coolant whirling (C)	An	Aus
specimen pitch (D)	> 0,04°	> 0,02°
coolant temperature (E)	21 °C	25 °C

In table 3 and 4 the significant effects from test run 1 and 2 are summarized. Each letter from "A" to "E" represents a factor, two letters e.g. "AB" represent a combination of factors which

have a significant influence on the measurement result. The summary is showing the temperature is involved in 60% of the significant effects in test run 1 and in test run 2 in 65%. The assumption of the temperature dominance in test run 1 is wrong. The influence of the temperature is less than assumed.

Table 3: Summary of the significant effects from test run 1

Test run 1						
test conditions	parameter	significant effects				
fiber based WLI	Ra	E	AB			
in hone oil	Rz	C	E	DE	D	
CWL	Ra	B	BE	C	AE	DE
in hone oil	Rz	E	DE	B	BE	

Table 4: Summary of the significant effects from test run 2

Test run 2						
test conditions	parameter	significant effects				
fiber based WLI	Ra	E				
in hone oil	Rz	CD	DE	A		
fiber based WLI	Ra	DE	E	CD	CE	BD
in emulsion	Rz	CD	E	DE	BD	
CWL	Ra	keine				
in hone oil	Rz	DE	E	CE	BE	

Measurement uncertainty evaluation

Corresponding to the DIN EN ISO 15530-3:2009 [2] a collection of data has been done with each sensor to evaluate the measurement uncertainty to quantify the quality of the measurement results quantified.

In order to create a reference value, ten parallel 12.5 mm long profiles with a distance from 0.5 mm have been scanned tactile. These measurements were repeated 20 times. The parameters Ra and Rz have been evaluated based on these measurements.

The basis for the measurements with the optical sensors was the full factorial design with the factor level setups shown in table 1 and table 2 in order to capture most of the influences.

During test run 1, the tests have been done only in hone oil. For test run 2 measurements also in emulsion have been done but the results from the CWL have been significant higher than the results from the other measurements. Because of this, they had not been used for the evaluation.

In table 5 the systematic deviation from the tactile measured reference values in percent is presented. The reference values are for Ra=0,53 µm and for Rz=5,81 µm. Table 5 is also showing that the values for the deviation are in test run 2 on 3 positions much better than in test run 1. The root cause for this behaviour is an optimized probe head fastener, which is much more stable.

Table 5: Systematic deviation from the reference value in percent

	Test run 1	Test run 2	Test run 1	Test run 2
	WLI	WLI	CWL	CWL
Ra in hone oil	10,2	10,6	12,5	-2,3
Ra in emulsion	n.a.	3,0	n.a.	
Rz in hone oil	9,0	-1,8	31,2	-8,3
Rz in emulsion	n.a.	-9,0	n.a.	

Regarding to the standard deviation from the tactile measuring ($u_{reference}$) and the standard deviation from the measurements with the optical sensors ($u_{measuring\ process}$), a first measurement uncertainty with k = 2 has been evaluated regarding to the following formula:

$$U = k * \sqrt{u_{Referenz}^2 + u_{Messprozess}^2}$$

The results from this first evaluation are shown in table 6. The data are given as percentage of the tactile measured value for Ra=0,53 µm and Rz=5,81µm. Because of the improved sensor fastener the values from test run 2 are much better than these from test run 1. Comparing the values from the fiber based white-light interferometer and the chromatic aberration probe, they are nearly the same in hone oil for both parameters. Here it is important to know, that the values from the measurements with the chromatic aberration probe in hone emulsion in test run 2 have not been evaluated because of the bad systematic deviation.

Table 6: Measurement uncertainty (k=2) in percent of the reference values

	Test run 1	Test run 2	Test run 1	Test run 2
	WLI	WLI	CWL	CWL
Ra in hone oil	25,9	15,7	26,3	15,5
Ra in emulsion	n.a.	15,7	n.a.	
Rz in hone oil	22,1	18,4	28,2	18,4
Rz in emulsion	n.a.	19,0	n.a.	

Further Research Work

The results which were gained on the test rig have to be confirmed on the C-frame measuring cell (fig. 1), planned for the 100% in-line surface measuring. Because of the better performance, the fiber based white-light interferometer is chosen for integration into the measuring cell. The next step is to link the measuring cell with the hone machine and create a feedback control with the data gained from the surface measurements, also as the implementing of function oriented evaluation of parameters comparable to DIN EN ISO 13565-2:1998 [3].

Acknowledgements

[1]   DIN EN ISO 3274 April 1998

Geometrische   Produktspezifikationen   (GPS)   -   Oberflächenbeschaffenheit: Tastschnittverfahren - Nenneigenschaften von Tastschnittgeräten

[2]   DIN EN ISO 15530-3 July 2009

Geometrische Produktspezifikation und -prüfung (GPS) - Verfahren zur Ermittlung der Messunsicherheit von Koordinatenmessgeräten (KMG) - Teil 3: Anwendung von kalibrierten Werkstücken oder Normalen

[3]   DIN EN ISO 13565-2 April 1998

Geometrische   Produktspezifikationen   (GPS)   -   Oberflächenbeschaffenheit: Tastschnittverfahren   -   Oberflächen   mit   plateauartigen   funktionsrelevanten Eigenschaften - Teil 2: Beschreibung der Höhe mittels linearer Darstellung der Materialanteilkurve