Global and local mapping of motor blocks liners roughness for the analysis of honing performance

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Abstract. The manufacturing and finishing (honing) of cylinder liners for the automotive industry is a constant challenge in order to reduce friction losses and oil consumption. A better knowledge of surfaces generated during plateau honing is then required for optimization of the process. Despite a well-known and controlled honing process, variations in surface roughness appear at both global (due to honing tool wear) and local (TDC, middle stroke, BDC) scales and need to be mapped and analysed. The following paper proposes to map the global and local variations in roughness by using a confocal 3D measuring equipment able to measure and scan any area of a cylinder liner. Six motor blocks (five liners each) are evaluated with twenty topography measurements per liner. In total, six hundred 3D measurements of size 1x1 mm are performed and roughness parameters are computed. The results show that some parameters do correlate with the honing tool wear specific to each cylinder. Experimental models could be built. Furthermore surface roughness varies significantly over the axial length of the liners due to waviness deviations combined with a lack of flexibility of the honing tool in axial direction.

1. Introduction

The specifications of components in the automotive industry are strongly ruled by customer and legislation demands. Indeed, engineers are aiming for the production of engines with lower fuel consumption while keeping low emissions [1]. The cylinder liner is one of the engine components with real potential for lowering friction: a recent study by Holmberg et. Al. [2] showed that the piston assembly is responsible for 45% of the engine friction losses in passenger cars. One of the solution for reducing friction is to improve and control the surface roughness of the liners [3,4].

The plateau honing super finishing process is commonly used to obtain surfaces with good functionalities for the ring/liner contact. Nowadays surface quality control of the honing shows a lack of information (2D measurement of a non-functional area of the cylinder) to predict the functionality of the liners produced. Furthermore, despite a well-known and controlled honing process, spreading of surface roughness cannot be avoided and topography variations do exist at global scales (due to honing tool wear) and local scales (TDC, middle stroke, BDC). The existing variations need to be mapped and analysed for a better knowledge of the surfaces produced. By a better understanding of the process generating surfaces, optimizations leading to lower friction are possible.

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The following paper proposes to map the global and local variations in cylinder liner roughness by using a confocal 3D measurement equipment able to measure and scan any area of a cylinder liner from passenger cars.

2. Materials and methods

2.1. Motor blocks

Six standard motor blocks from the same production line were picked up with two days interval. The blocks are from the Volvo T5 [5], 2.5 litres petrol engine (254 hp) with 5 cylinders (see figure 1). The interval for picking up blocks provides a complete scan of the entire honing tools life which gives also a relevant overview of the surface roughness spreading.

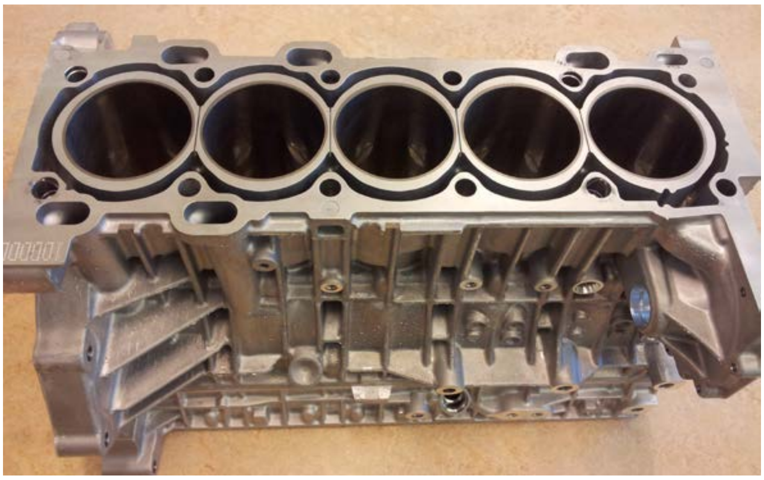

Figure 1. Motor block with 5 cylinders.

The blocks are labelled and the honing tools wear is recorded for each cylinder from each motor (see table 1). In this case, the honing tool wear is defined as the opening diameter of the tool to compensate wear of the honing stones.

Table 1. Honing tool wear (normalized) for each cylinder and block (cell in gray corresponds to a change of tool).

	Cylinder 1 (tool wear)	Cylinder 2 (tool wear)	Cylinder 3 (tool wear)	Cylinder 4 (tool wear)	Cylinder 5 (tool wear)
Motor block 1	63%	49%	0%	18%	74%
Motor block 2	73%	55%	8%	33%	84%
Motor block 3	80%	59%	14%	44%	92%
Motor block 4	82%	62%	16%	48%	95%
Motor block 5	86%	66%	21%	54%	100%
Motor block 6	99%	79%	34%	74%	1%

2.2. Measuring equipment
For this study, an optical 3D surface measuring system is used (see figure 2): the µsurf cylinder [6] is based on the confocal principle and allows automated cylinder liner inspections by positioning the optical objective according to depth (axial direction of the liner) and angle (circumferential direction of the liner). The methodology for acquiring 3D measurements (area: 1 by 1 mm, lateral resolution: 0.95µm, vertical resolution < 10nm) is presented in the section 3.1.

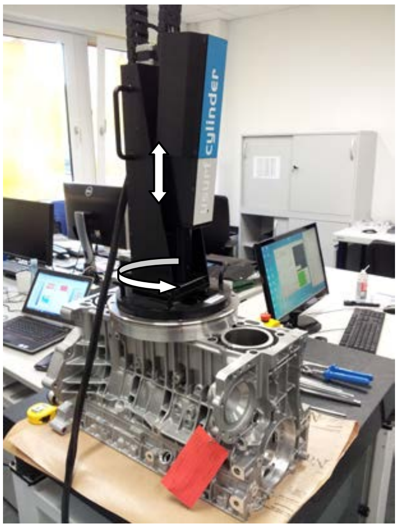

Figure 2. Confocal 3D measuring equipment installed on a Volvo engine block. System fully automated for scanning a cylinder liner in axial and circumferential direction.

2.3. Complementary measuring techniques
In order to complete the study, additional measurements were performed with a Phase Shift Technology MicroXam interferometer [7] and a mechanical stylus Surfascan 3CS [8]. The measuring area is approximately 600µm*800µm (1.089µm by 1.287µm lateral resolution and 0.1nm vertical resolution) for the interferometer. The profiles measured (see figure 4) with the stylus have a length of 98 mm (1µm lateral resolution and 6nm vertical resolution) allowing measuring at once much of the cylinder length (150mm).

The 3D measurements by interferometry are performed on replicas of the cylinder liner surfaces (see figure 3). A good agreement between replicas and original honed surfaces has been previously shown [9].

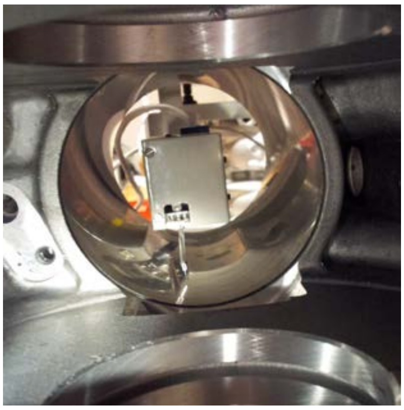

Figure 3. Mechanical stylus measuring over the length of a cylinder liner.

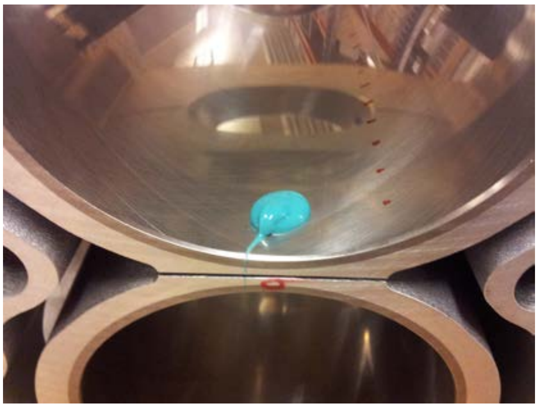

Figure 4. Replication of liner surfaces for different depth in order to measure with the interferometer.

3. Results and analysis

The six motor blocks presented in section 2.1 are measured using the measuring equipment presented in section 2.2. Each cylinder from each block is measured according to a methodology presented below in section 3.1. Additional measurements according to section 2.3 are performed to confirm trends observed.

3.1. Measuring methodology

Each cylinder from each block is measured according to the following measuring pattern:

- 4 angular positions in the circumferential direction of the liner are chosen as shown by the figure 5 (0°, 90°, 180°, 270°)
- 5 depth positions in the axial direction of the liner are chosen as shown by the figure 6 (10mm, 40mm, 50mm, 60mm, 70mm). More measurements are performed in the middle of the liner since it is a crucial area in terms of functionality. Furthermore, as mentioned before, for each depth 4 angular positions are measured. It is decided to perform the 4 measurements in a zigzag pattern along the reference depth to randomize the results as proposed by Rosén and Garnier [10].

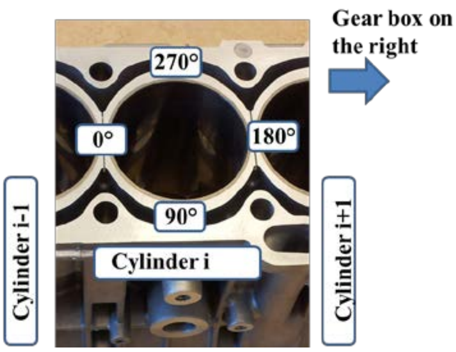

Figure 5. Labelling of cylinders and angles.

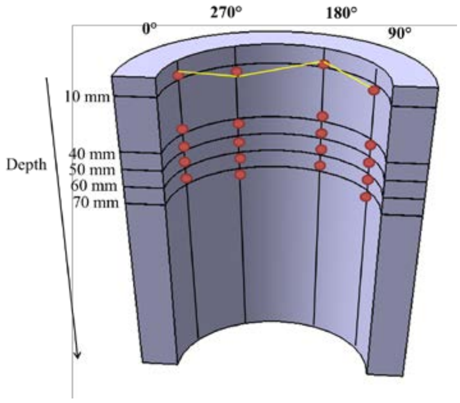

Figure 6. Unfolded cylinder and position of measuring points in a zigzag pattern along each depth position line.

3.2. Characterization

Once the surfaces acquired, the following pre-processing is performed by using MountainsMap® Premium 6.2 [11]: a polynomial filter of order 2 removes the form. Afterward, data with low light intensity are removed and a robust Gaussian filter (250 µm cut-off) is used to isolate the roughness.

A wide range of surface parameters is computed from the pre-processed surface (see figure 7) and includes the main families: amplitude, spatial, hybrid, functional, feature parameters.

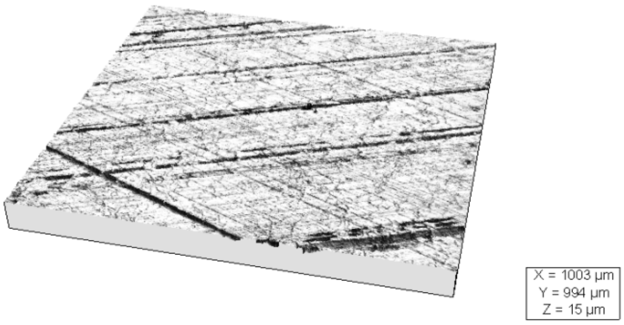

Figure 7. Example of a cylinder liner surface obtained after the pre-processing. The 3D surface is combined with the intensity layer for a more realistic visualization.

3.3. Correlations of surface roughness with honing tool wear (global variations)

Only the most interesting parameters are discussed in the following sections. A total of 600 measurements are processed (6 blocks, five cylinders, twenty positions) giving statistically significant results. The error bars in the following graphics represent the standard deviation to the mean. All results are presented as percentages of the mean value. The figure 8 presents the summit curvature parameter Ssc as a function of honing tool wear (6 motors picked up with different honing tool wear stages) for the different cylinders.

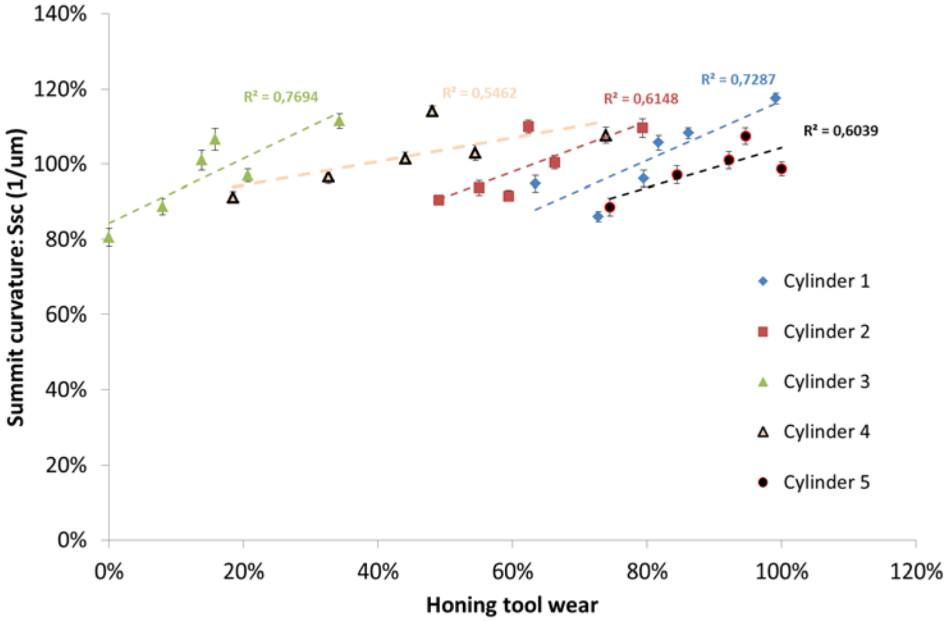

Figure 8. The summit curvature parameter Ssc is increasing with the honing tool wear specific to each cylinder.

No clear dependence can be observed between all the measurements and the honing tool wear. However, if the results are analysed separately, cylinder by cylinder, it is possible to see that Ssc increases with the honing tool wear specific to each cylinder (see trend lines on figure 8). A good correlation does exist between Ssc (as well as Spk and Sk) and the tool wear for a given cylinder (see figure 9) meaning that models could even be built for each cylinder. The possible reasons for finding good correlations only if each cylinder is analysed separately are the following: i) the proposed definition of the honing tool wear (opening diameter of the tool) is not accurate enough and not an absolute value ii) the honing process for each cylinder is complex and is depending on a wide amount of variables (lubrication, forms, heating) making it difficult to find a general model for every cylinder.

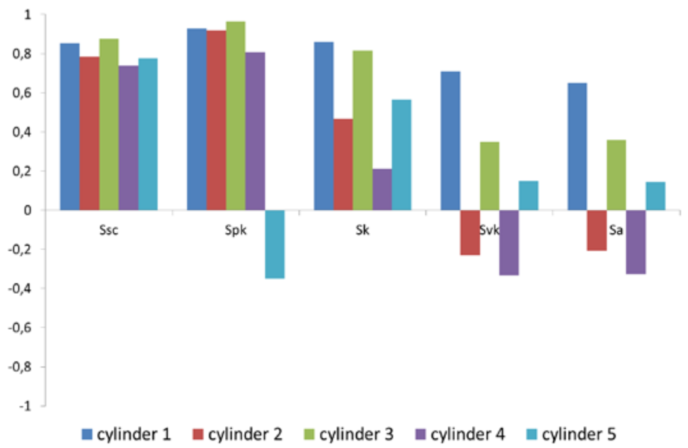

Figure 9. Correlation between different roughness parameters and the honing tool wear specific to each cylinder: Ssc, Spk and Sk increases with the honing tool wear whereas Svk and Sa have no clear dependence with the tool wear.

Globally, it is possible to analyse the results in the following way: as the honing tool wears down: i) the plateau and peaks are rougher (Sk, Spk) ii) asperities gets sharper (Ssc) iii) valleys are not significantly influenced (Svk).

3.4. Surface roughness variations over the liners (local variations)
More local evaluations of the honing process are also performed. The figure 10 presents the variations of the Sk parameter at different depths inside the liners. Similar behaviours are observed for Spk, Svk and Ssc.

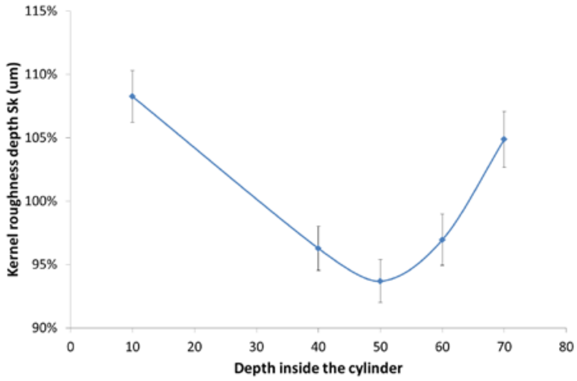

Figure 10. Trend of the roughness depending on depth observed with the confocal system

The same trend is confirmed by the analysis of 60 additional interferometer measurements along the axial direction (see figure 11). The complementary measurements also provide information deeper inside the liner. According to the figure presented below, the roughness varies along the axial direction of the liners due to the existing waviness (valleys of the waviness are less honed compared to the waviness hills). On the waviness hills, the honing tool is probably more in contact with the surfaces which results in a lower roughness. A lack of flexibility of the honing tool in the axial direction seems to be the reason. Techniques presented by Schmid [12] to compensate form deviations are based on similar assumptions. No influence of angular position is observed in the results since the tool is more flexible in circumferential direction.

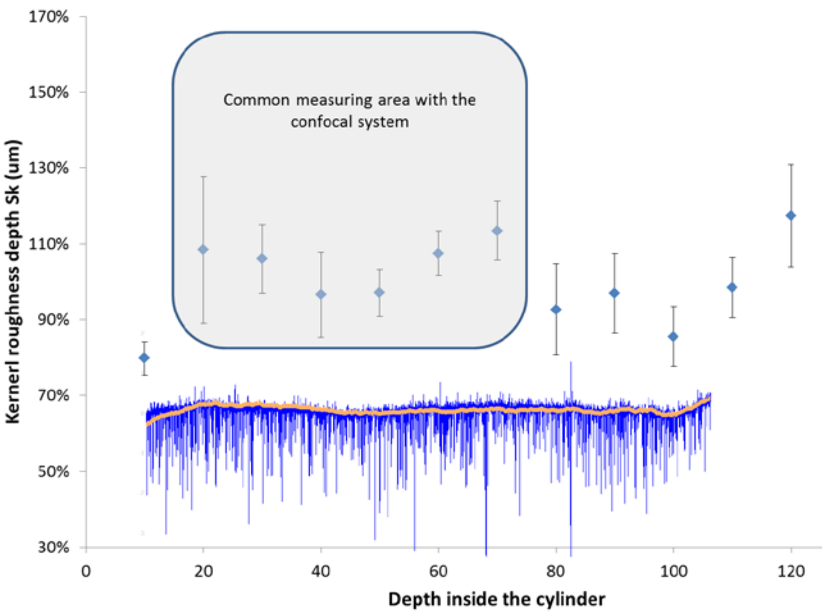

Figure 11. Confirmed trend observed by the interferometer for the cylinder 4 of motor 5. The measured stylus profile is superimposed to show that the Sk roughness values are depending on the waviness profile.

4. Conclusion

In order to improve the performance of the ring liner system, a better knowledge of surfaces generated during plateau honing of the cylinder liners is required. The paper proposed to use a 3D confocal measuring system with automated positioning in order to measure 600 surfaces from motor blocks picked up from production at different honing tool wear stages. The following conclusions were found:

- The most interesting parameters to link manufacturing and characterization are Spk, Sk and Ssc.
- As the honing tool wears down:
  - The plateau and peaks are rougher (Sk, Spk)
  - Asperities gets sharper (Ssc)
  - Valleys are not significantly influenced (Svk)
- Surface roughness varies significantly over the axial length of the liners but not around the circumferential direction
- The variations observed are due to waviness deviations combined with a lack of flexibility of the honing tool in axial direction. In other words, the honing stones cannot conform to the waviness in order to produce a homogeneous surface.

In the future, experimental models predicting the roughness (and the friction) as a function of the tool wear could be created leading to optimization opportunities.

Acknowledgements

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References

[1] http://www.dieselnet.com/standards/eu/hd.php, March 2013
[2] Holmberg K, Andersson P and Erdemir A 2011 Global energy consumption due to friction in passenger cars *Tribology International* **47** 221-34
[3] S. Johansson, P. H. Nilsson, R. Ohlsson, C. Anderberg, B.-G. Rosén, 2008 New cylinder liner surfaces for low oil consumption, *Tribology International* **41** 854-9
[4] Z. Dimkovski, F. Cabanettes, H. Löfgren, C. Anderberg, R. Ohlsson, B.-G. Rosén, 2012 Optimization of cylinder liner surface finish by slide honing *Proceedings of the Institution of Mechanical Engineers, Part B Journal of Engineering Manufacture* **226** 575-84
[5] http://www.volvocars.com/uk/all-cars/volvo-v40/specifications/pages/technical-spec.aspx, March 2013
[6] http://www.nanofocus.de/en/produkte/usurf/usurf-cylinder/, March 2013
[7] http://www.kla-tencor.com/mems-wafer-inspection/microxam-1200.html, March 2013
[8] http://www.jenoptik.com/en_home, March 2013
[9] F. Cabanettes, J. Claret-Tournier, J. Mohlin, P.H. Nilsson, B.-G. Rosén, L. Xiao 2009 The evolution of surface topography of injection cams, *Wear* **266** 570-3
[10] B.-G. Rosén, J. Garnier 2010 Uncertainties and optimized sampling in surface roughness characterization, *Wear* **271** 610-5
[11] http://www.digitalsurf.com, March 2013
[12] J. Schmid 2010 Friction optimization of cylinder surfaces from the perspective of production technology, *MotorTechnische Zeitschrift* **6** 8-12