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A Study of the Analysis Method for the Surface Roughness on the Inner Bore of Diesel Engines before and after Running-in Operations †

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Abstract: In modern automotive engines, the importance of lubrication properties is increasing with the demand for optimizing mechanical durability and fuel efficiency. The running-in of engines removes microscopic irregularities from the surfaces of engine parts, thereby enhancing the lubrication performance. Therefore, the running-in of engines has the effect of enhancing engine performance and durability, thereby potentially extending their lifespan. On the other hand, running-in is a complicated procedure, and a part of it needs to be performed by consumers themselves. One solution to this problem is to machine the surfaces of the engine parts before running-in so that they have the same surface condition as that after running-in. Realizing this solution requires an appropriate evaluation and quantification of surface roughness by understanding of the changes in the surface topography of engine parts before and after running-in. This study examines the surface roughness of diesel engine cylinder liners and analyzes the differences in the surface topography before and after running-in. Furthermore, this study develops new parameters to quantify the difference in the surface textures of the cylinder liner before and after running-in. The developed parameters are compared with Rsk and Rku, which are the parameters for evaluating the surface wear of parts and are used in the ISO standards, to verify their usefulness in surface analysis.

Keywords: roughness parameter; surface texture; surface topography; automotive parts; diesel engine; running-in

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1. Introduction

In modern automotive engines, the importance of lubrication properties is increasing with the demand for optimizing mechanical durability and fuel efficiency. The running-in of engines improves lubrication by eliminating microscopic irregularities on the surfaces of engine parts [1–3]. Therefore, running-in extends engine life because it enhances the engine performance and durability. On the other hand, running-in is a complicated procedure, and some procedures should be performed by consumers themselves. One solution to this problem is to machine the surfaces of the engine parts before running-in such that they have the same surface conditions as those after running-in. Realizing this solution requires an appropriate evaluation and quantification of the surface roughness by understanding the changes in the surface topography of the engine parts before and after running-in. This study examines the surface roughness of diesel engine cylinder liners, as shown in Figure 1, and then analyzes the differences in surface topography before and after running-in. Furthermore, new parameters are developed to quantify the differences in the surface topography of the cylinder liner before and after running-in. The developed parameters are validated for their usefulness by comparing them with Rsk (Skewness) and Rku (Kurtosis), which are valid parameters for evaluating wear on the surface of a part, as specified in the ISO standard.

Figure 1. Engine cylinder liner.

2. Changes in the Surface of the Cylinder Liner before and after Running-in

This study examines the changes in the surface roughness of cylinder liners by comparing the surface roughness of the cylinder liners before and after running-in. Figure 2 shows the surface roughness of the cylinder liner before and after running-in. Figure 2a–c show the surface roughness of the upper, middle, and lower parts of the cylinder liner, respectively, before running-in. Figure 2d–f show the surface roughness of the upper, middle, and lower parts of the cylinder liner, respectively, after running-in. A comparison of these roughness values shows some changes before and after running-in. First, comparing Figure 2a–c, the roughness of the cylinder liner is uniform in any part before running-in. Next, comparing Figure 2a,d, wear progresses on the roughness of the upper part of the cylinder liner after running-in. Then, a comparison of Figure 2b,e shows that wear progresses on the roughness of the middle part of the cylinder liner after running-in, although to a lesser extent than that on the upper part of the cylinder liner. Finally, comparing Figure 2c,f, little wear progressed on the surface of the lower part of the cylinder liner after running-in. Therefore, the most significant wear progression by running-in is in the upper part of the cylinder liner, whereas the lower part shows significantly little wear progression. This suggests that the wear conditions of the cylinder liners can differ significantly based on their position.

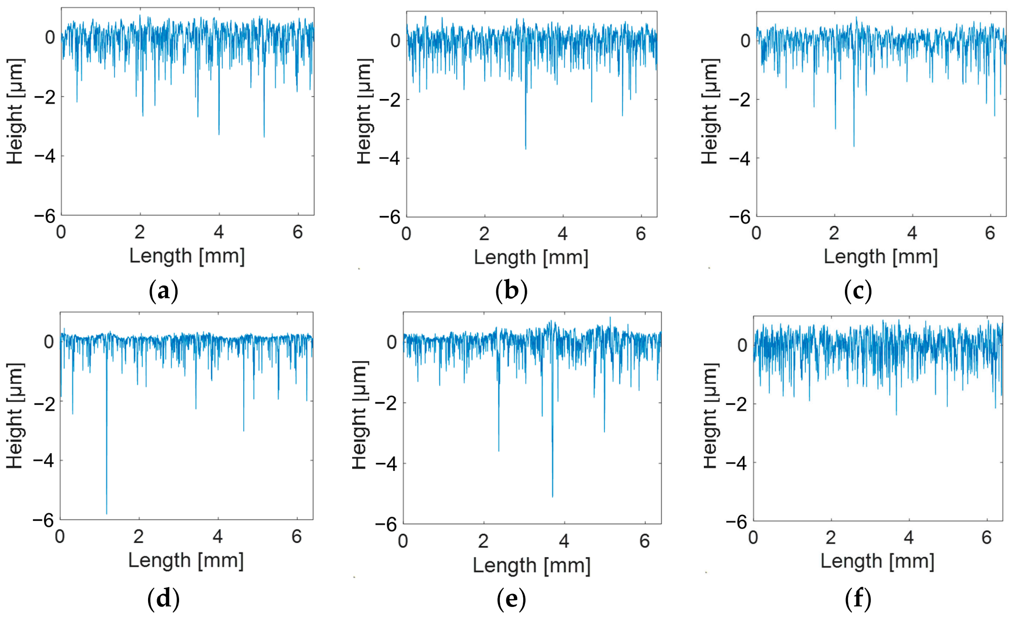

Figure 2. Profiles comparison. (**a**) Upper part of cylinder liner before running-in. (**b**) Middle part of cylinder liner before running-in. (**c**) Lower part of cylinder liner before running-in. (**d**) Upper part of cylinder liner after running-in. (**e**) Middle part of cylinder liner after running-in. (**f**) Lower part of cylinder liner after running-in.

3. Development of Parameters

The surface topography of the cylinder liner differs before and after the running-in. The development of parameters to quantify these differences is important to improve the effectiveness of cylinder liner surface evaluation. This study attempts to develop new parameters that can quantitatively evaluate the changes in the cylinder-liner surface caused by running-in. The surface roughness of the cylinder liner is significantly changed by the effect of running-in. Quantifying this change may be valuable for understanding the effect of running-in. The following sections describe the newly developed parameters to quantitatively evaluate the differences in the cylinder liner surfaces before and after running-in.

3.1. Parameter Using the Volume near the Peak

The volume near the peak is considered to potentially affect the anchoring effect and intermolecular forces. Based on this, a new parameter, pPsm, is developed. The procedure for calculating pPsm is as follows. (1) Detect the peak point of surface profile. (2) As shown in Figure 3, after the detection of peak points, five points are detected: two points in front of the detected peak and two points behind it. (3) As shown in Figure 3, the volume, S_i, is calculated between the five detected points using trapezoidal integration. (4) Finally, the total volume calculated in step (3) is divided by the total number of peaks, n_m, to obtain an average. This is pPsm as in Equation (1).

$$\text{pPsm} = \frac{1}{n_m}\sum_{i=1}^{n_m} S_i \quad (1)$$

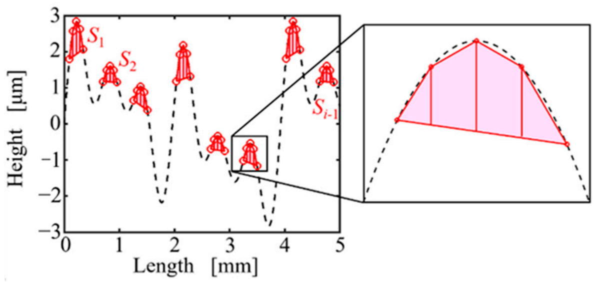

Figure 3. Schematic diagram of calculation method on pPsm.

3.2. Parameter Focusing on the Anchor Effect

The following describes a new parameter devised based on physical considerations of the anchoring effect. A new parameter, pPmotif, is developed by applying the motif method [4,5], considering that the anchor effect involves microroughness between the peaks of an uneven structure. Figure 4 is a schematic diagram showing the detection of global peaks (blue circles in Figure 4) and local peaks (red circles in Figure 4) necessary for calculating pPmotif. The calculation procedure for pPmotif is as follows. (1) Detect the peak points of the surface profile. (2) Detect the global peaks using the motif method from the detected peak points, and then calculate the distance, AR_i, between the global peaks. (3) Extract the local peaks that exist between ARi from the peak points detected in step (1), and then count the number of local peaks, n_i. (4) Divide n_i by AR_i. (5) Calculate the average from the values obtained in step (4), as shown in Equation (2).

$$\text{pPmotif} = \frac{1}{n}\sum_{i=1}^{n} \frac{n_i}{AR_i} \quad (2)$$

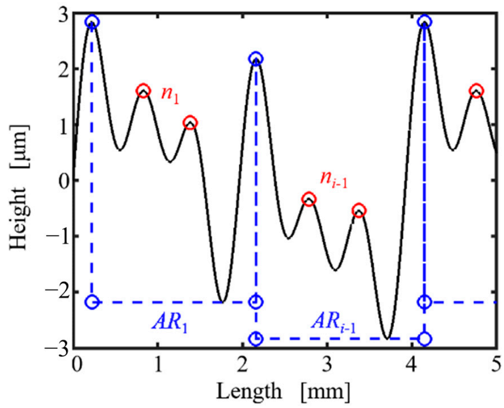

Figure 4. Schematic diagram of calculation method of pPmotif.

3.3. Analysis by Rsk and Rku

Rsk and Rku are described as effective parameters for evaluating the wear on part surfaces according to ISO standards [6]. Figure 5 is a schematic diagram of Rsk. The parameter Rsk evaluates the symmetry of the peaks and valleys of the surface profile. Rsk takes a value of zero in the case of a normal distribution and shows a negative value in the case of a worn surface. Rsk is calculated as follows Equation (3) [6]. The parameter Rku evaluates the sharpness of the peaks and valleys of the surface profile. Figure 6 is a schematic diagram of Rku. Rku takes a value of thee in the case of a normal distribution. Rku is calculated as shown in Equation (4) [6].

$$\mathrm{Rsk} = \frac{1}{Rq^3}\left[\frac{1}{lr}\int_0^{lr} Z^3(x)dx\right] \tag{3}$$

$$\mathrm{Rku} = \frac{1}{Rq^4}\left[\frac{1}{lr}\int_0^{lr} Z^4(x)dx\right] \tag{4}$$

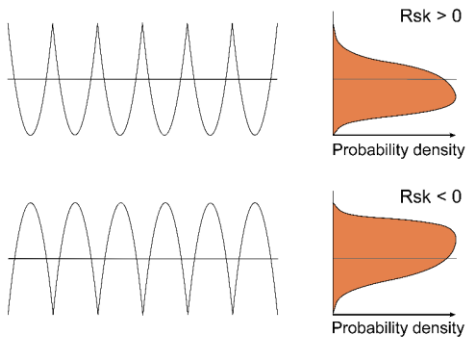

Figure 5. Schematic diagrams of Rsk.

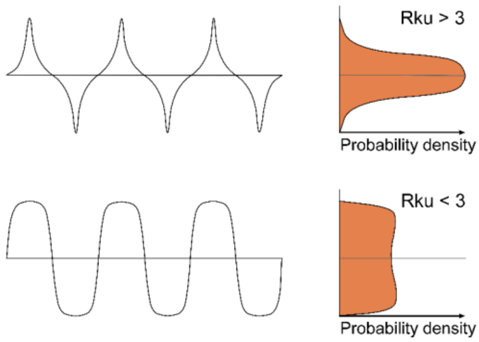

Figure 6. Schematic diagrams of Rku.

4. Evaluation of the Effectiveness of Developed Parameters

This study examines the effectiveness of the developed parameters by applying the developed parameters, Rsk and Rku, to the surface profiles of a cylinder liner before and after running-in. Figure 7 shows the calculation results of pPsm. The error bars in the figure represent the standard deviation.

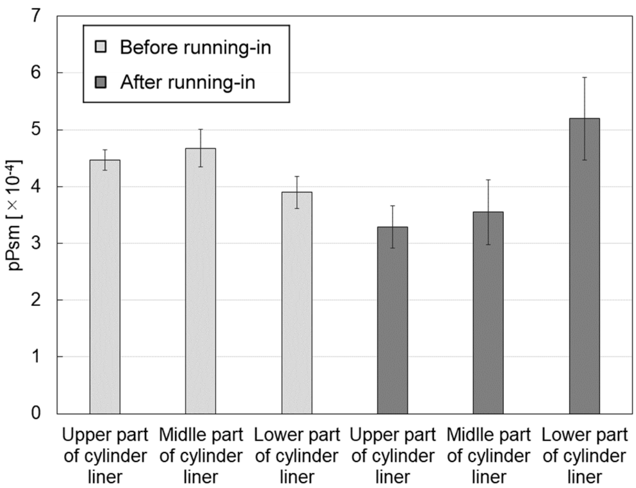

Figure 7. Results of pPsm.

As shown in Figure 7, the value of pPsm in the upper and middle parts of the cylinder liner after running-in is lower compared to the lower parts. This result agrees with the progression of the plateau formation in the upper and middle parts of the cylinder liner after running-in, as shown in Figure 2. Therefore, the value of pPsm is considered to characterize the progression of plateau formation. As shown in Figure 7, the value of pPsm is higher in the lower part of the cylinder liner after running-in than in the other parts. This result is considered to be influenced by the rougher surface profile of the lower part of the cylinder liner after running-in compared to other parts. Comparing the profiles of the lower part of the cylinder liner in Figure 2, the profile of the lower part of the cylinder liner after running-in seems to be rougher than that before running-in. This is considered that by running-in, the surface in the lower part of the cylinder liner is scratched.

Figure 8 shows the calculation results of pPmotif. As shown in Figure 8, pPmotif exhibits a constant value in all parts of the cylinder liner before running-in. Additionally, after running-in, the value of pPmotif is the highest at the top of the cylinder liner and decreases in the middle and bottom, in that order. These results are similar to the changes in the cylinder liner surface profile before and after running-in, as shown in Figure 2. Therefore, pPmotif is considered a suitable parameter for quantifying the differences in the surface of the cylinder liner before and after running-in. However, the pPmotif cannot characterize differences in the surface profiles of all parts because the error bars overlap between the upper and middle parts of the cylinder liner after running-in. Therefore, since pPmotif has problems with accuracy, further improvements are required.

Next, the result of pPmotif is compared with those of Rsk and Rku. Figures 9 and 10 present the calculation results of Rsk and Rku, respectively. From Figures 9 and 10, Rsk and Rku show results that are almost similar to those of pPmotif. However, both Rsk and Rku have more overlap of error bars than pPmotif in all parts of the cylinder liner after running-in. Therefore, the effectiveness of Rsk and Rku is considered lower than that of pPmotif, although they are possible to quantify the differences in the cylinder liner surface before and after running-in. In conclusion, pPmotif is considered highly effective for quantifying the surface texture of the cylinder liner before and after running-in.

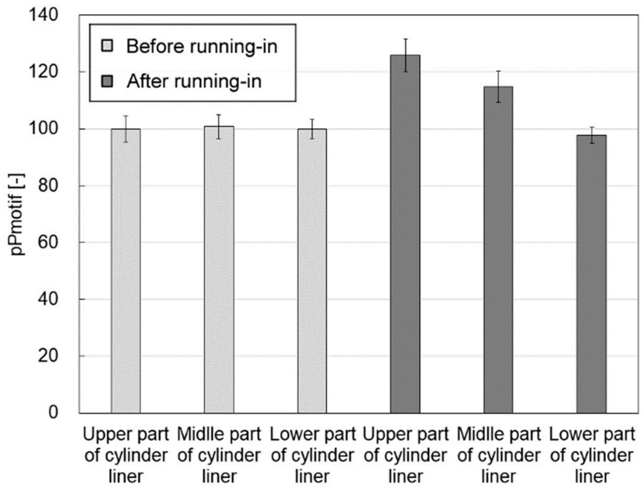

Figure 8. Results of pPmotif.

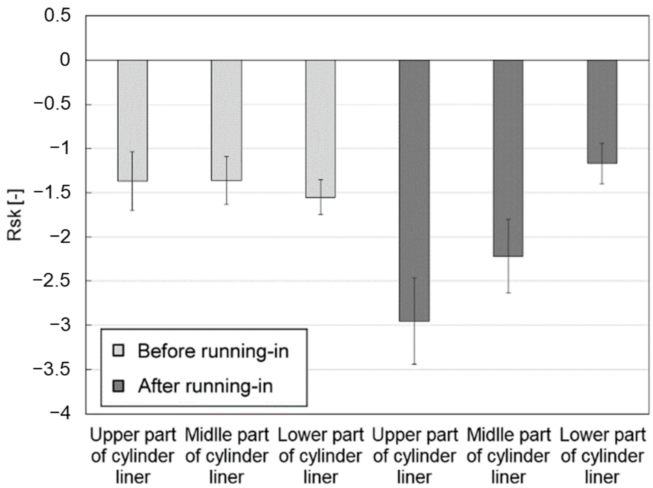

Figure 9. Results of Rsk.

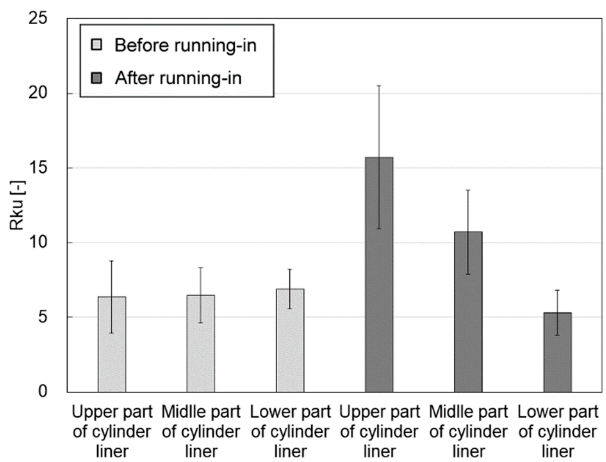

Figure 10. Results of Rku.

5. Conclusions

In this study, we developed new parameters for quantifying the differences in the surfaces of cylinder liners before and after running-in with the aim of contributing to the development of a method to omit the running-in. The newly developed parameters are a parameter using the volume near the peak, pPsm, and a parameter focusing on the anchor effect, pPmotif. We experimented with pPsm, pPmotif, Rsk, and Rku; as the result, pPmotif showed the best results. However, pPmotif and pPsm have a problem in that they cannot fully characterize the differences in surface profiles among all parts of the cylinder liner after running-in. Hence, we plan to develop new parameters to address this problem in our future study.

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