

The Identification of the Characteristic of Running-in Surface Based on Wavelet and Fractal Dimension

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Abstract. The experiment of running-in was carried out on the pin-disk test machine. Then the images of surface topography were taken by OLYMPUS optical digital microscope. In order to identify these images, the arithmetic of discrete wavelet transform(DWT) and fractal box dimension which used to describe the images were produced. Thus, the qualitative and quantitative description for the image characteristic of surface topography were realized. The study indicated that the DWT method can descomposed more details and be beneficial to analyze the image. Moreover the fractal box dimensions of surface topography are identical with the roughness of running-in surface in the rule. At the last, the conclusion can be acquired that the box dimension is capable of acting an characteristic parameter to evaluate the level of running-in surface.

Introduction

Running-in is a course of auto-adjust and convergence of dynamic tribology system, the change of surface topography is an important property of running-in[1]. To predominate the rule and character of surface topography is a key issue that control the process of running-in and design surface topography. So far, the parameter described the surface topography is a statistical value, can not reflected the surface state practically[2]. The wavelet transform is a powerful tool of time-frequency analysis[3], it transfers image into a series of wavelet coefficient, these coefficients are used to analyze image subtly[4]. The fractal theory study on the geometry body that have characteristic of non-smooth, non-regulation, self-similitude[5][6]. It is a quantitative method that be used to depict the complicated objects conveniently which was incapable of quantitative description previously[6]. In this paper, the united method of wavelet transfer and fractal dimension was employed to identify the image of surface topography that obtained from the test, and attempted to describe the image characteristic quantificationally.

Two-dimensional Discrete Wavelet Transform

Discrete wavelet transform is obtained by discrete the scale j and displace k according to two exponential, the expression as[3]

$$\psi_{j,k} = 2^{j/2} \phi(2^j t - k) \quad j, k \in \mathbb{Z} \quad (1)$$

Based on the theory of multi-resolution analysis, if the functions cluster of binary scale discrete wavelet $\{\psi_{j,k}(t); j, k \in \mathbb{Z}\}$ has constituted orthonormal basis in the $L^2(\mathbb{R})$, then the time-varying signal $x(t) \in L^2(\mathbb{R})$ had orthogonal wavelet solution

$$x(t) = \sum_{j=1}^N \sum_{k \in \mathbb{Z}} d_k^j \psi_{j,k}(t) + \sum_{k \in \mathbb{Z}} c_k^j \phi_{j,k}(t) \quad (2)$$

Where N is the layers of transform, d_k^j is the coefficients of wavelet transform, c_k^j is the coefficients of scale transform for the number of j layer, $\phi_{j,k}(t)$ is the binary scale functions cluster that obtained from basis scale function $\phi(t)$.

$$\phi_{j,k}(t) = 2^{j/2} \phi(2^j t - k) \quad j, k \in \mathbb{Z} \quad (3)$$

The coefficients matrix of wavelet transform and scale transform was obtained by solved equation(2)

$$\begin{cases} c_{j,m_1,m_2} = \sum_{k_1 \in \mathbb{Z}} \sum_{k_2 \in \mathbb{Z}} h_{k_1-2m_1} h_{k_2-2m_2} c_{j+1,k_1,k_2} \\ d_{j,m_1,m_2}^1 = \sum_{k_1 \in \mathbb{Z}} \sum_{k_2 \in \mathbb{Z}} h_{k_1-2m_1} g_{k_2-2m_2} c_{j+1,k_1,k_2} \\ d_{j,m_1,m_2}^2 = \sum_{k_1 \in \mathbb{Z}} \sum_{k_2 \in \mathbb{Z}} g_{k_1-2m_1} h_{k_2-2m_2} c_{j+1,k_1,k_2} \\ d_{j,m_1,m_2}^3 = \sum_{k_1 \in \mathbb{Z}} \sum_{k_2 \in \mathbb{Z}} g_{k_1-2m_1} g_{k_2-2m_2} c_{j+1,k_1,k_2} \end{cases} \quad (4)$$

Where $\{h_k, g_k\}$ is corresponding with the function of one-dimensional scale and wavelet $\{\varphi, \psi\}$ filter, and $\sum h_k = \sqrt{2}$.

Two-dimensional discrete wavelet transform obtained a group of decomposed signals of low frequency and high frequency as analysis signal pass through one low-pass filter and one high-pass filter. These signals include the approximate coefficient c_j , the coefficient of high frequency at vertical direction d_j^1 , at level direction d_j^2 , and at diagonal direction d_j^3 . These coefficients reflect the detail characteristic of image from various view. The wavelet transform decomposed low frequency signal continuously. By decomposing various layers, the signals of low frequency and high frequency is half of original signal in the length. Therefore the results are authentic that neither non-redundancy nor lose the information of original signal.

The Fractal Box Dimension Arithmetic

The image information $x(j) \subset X$, here X is an arbitrary subset that non-empty and bounded in the R^n that is n dimension Euclidean space. The R^n was divided into plenty of square grids, the square grid's width is δ that should be smallest. If N_δ is the smallest grids in X set that grid width is δ and cover the discrete space, that is the number of box. The box dimension of information $x(j)$ given as[6]

$$D = \lim_{\delta \rightarrow 0} \frac{\lg N_\delta}{-\lg \delta} \quad (5)$$

The number of box N_δ demonstrated that image information has the properties of complex and non-regulation in the scale of δ . It related to the state of analyzed image. The box dimension indicates that the extent of complex property is acuteness in ratio with the decrease of δ .

The limit as the expression (5) could not be solved according to the define of $\delta \rightarrow 0$ during the calculating. It is used a series of square grids that the scale is $k\delta$ to cover the non-scale domain for fractal object. Then the number of grids $N_{k\delta}$ that covered effectively in a series of scales within the field of $(k_1\delta, k_2\delta)$ were acquired. The method of the optimal least square method was used to interpolation the line of $-\lg(k\delta) \sim \lg(N_{k\delta})$, the slope of interpolation line is the fractal box dimension D .

Experiment and Method

The Samples Preparation

The pin samples were cut from piston ring of diesel engine by line incising, the size is $5 \times 9.5 \times 17$ mm, and the initial surface roughness R_a is $3.1 \mu\text{m}$, hardness is 220HB. The disk samples

were machining from the cylinder of diesel engine by machining, the diameter is $\Phi 30\text{mm}$, the thickness is 10mm, the original surface roughness R_a is $0.8\mu\text{m}$, hardness is 240HB.

Experimental Instruments

The experiment was carried out on the tester of rub and wear. The model of TR-200 instrument of surface roughness was used to measure the roughness of disk samples after test. The length of sample is 0.8mm. The model of OLYMPUS- DSX500 digital microscope is used to observe the surface topography of disk samples.

Experimental Method

The experiment was conducted under the condition of room temperature, fixed rotation and varied load. The loads are 100N, 300N and 600N respectively. The room temperature is 20°C . The rotation is 500r/min. The tester operated 6 hour continuously. The mode of lubrication is dropping, and lubrication oil is special running-in oil.

Image Taken and Identification

Image Taken

The OLYMPUS optical microscope was used to view and take the image of disk samples under the illumination specifically. The domain of collection is the field of rub imprint. The megascopic multiple is 520. Fig.1 shows the grey images of taken under varies loads. From Fig.1 one can described the state of running-in surface qualitatively as a whole, but can not analyze the detail properties deeply, so need to further decomposition.



Fig.1. The surface topography of samples of disk under varied loads

The Identification of Image

As wavelet transform has the favorable property of localization in the time and frequency domain synchronously. The time-frequency resolution is varied with the scale of decomposition. Due to the surface image is typical two-dimension signal, so the two-dimension discrete wavelet transform was adopted to decompose the details of grey images. $f_0(x, y)$ is a grey image of running-in surface, collected db10 as wavelet basis function to decompose the images at three scales, the results was shown in Fig.2. From Fig.2 one can view the lower and higher frequency details, include lower frequency component and higher frequency component at the three direction such as level, vertical and diagonal respectively. And the lower frequency component(top-left) is able to view the details of width and distributing density of polishing scratch contrasting to the initial image clearly. The higher frequency component(top-right) can view the rubbing-in state of gully at horizontal direction. The image of bottom-left can observe the range of distribution for polishing scratch. The image of bottom-right can survey little information, the reason is that the longitudinal veins distribution at diagonal direction. Contrasting to the decomposition results under varied loads, one can discover that the width of polishing scratch is consistency and uniform density, the gully are shallow and uniform distribution on the whole surface. The polishing scratch distributes in nice homogeneity. The study indicated that the surface state after running-in under 600N is optimum than others.

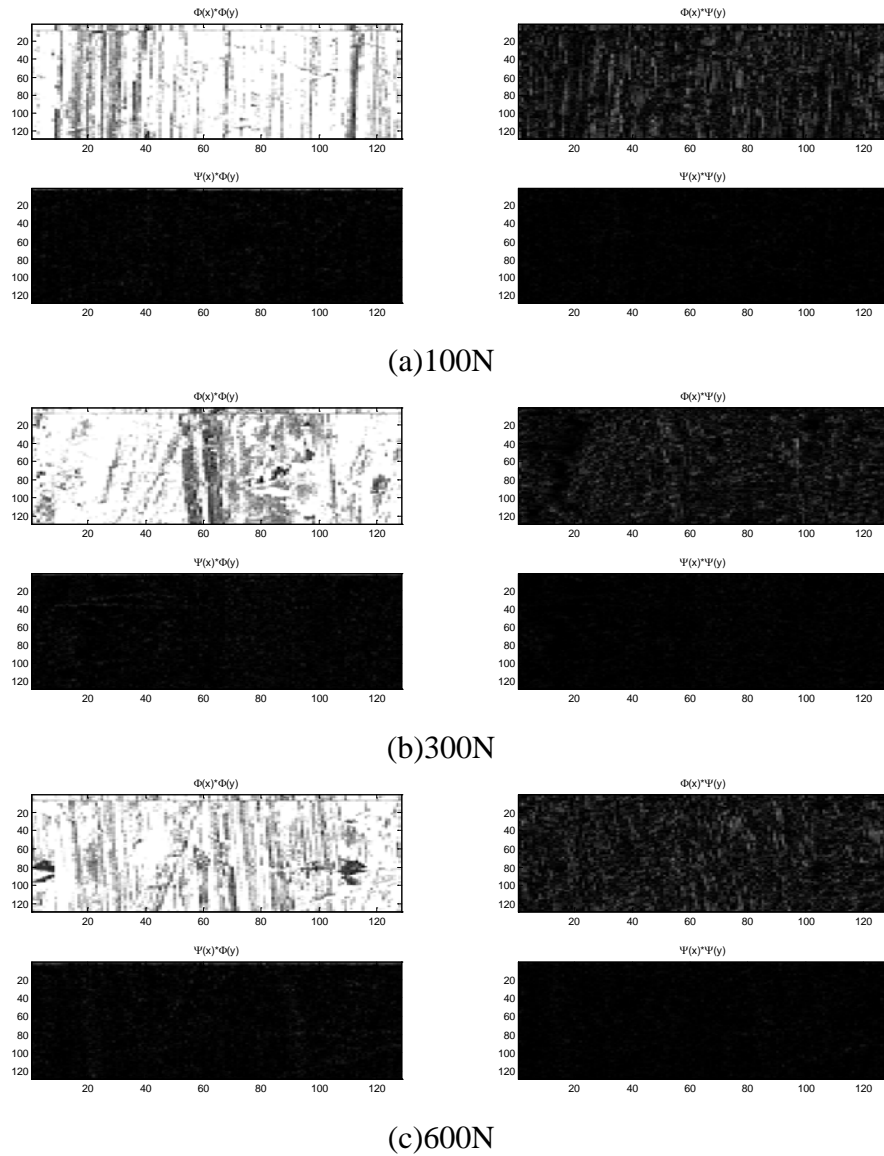


Fig. 2. The results of wavelet decomposition of surface topography under varied loads

The Calculating of Fractal Box Dimension and Analysis

In order to quantitative description the running-in surface, the calculating method of fractal geometry was introduced to build the relationship correspondingly between the fractal box dimension and initial roughness. The method of fractal box dimension calculated images include initial image, the lower frequency component image, the higher frequency component image at different direction, and reconstructed image. Fig.3 is shown the fractal box dimension of reconstructed image, the fractal dimension of reconstructed images is the line slope that was interpolation by discrete dots. The results of calculating was given in Table.1. From the Table.1, one can finds that the varied rule of fractal box dimension of reconstructed image are consistent with roughness of initial surface. But varied rule of the others fractal box dimension disagree with initial surface, it is because that there is redundancy information in the images. So that, one can used the fractal box dimension describe roughness of running-in surface.

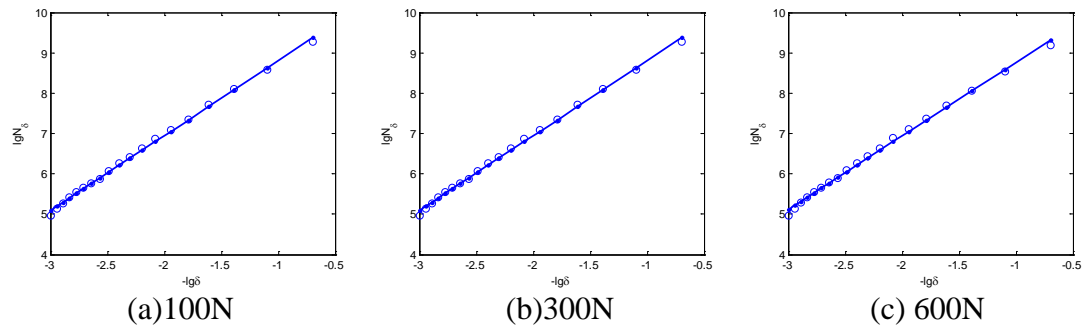


Fig.3. The calculating fractal box dimension of reconstructed surfaces under varied loads

Table. 1 The fractal box dimension and roughness of surface under varied loads

Load/N	Fractal box dimension						
	roughness(μm)	initial	lower-frq	horizontal	vertical	diagonal	reconstructed
100	0.6250	1.7559	1.9732	1.9113	1.5303	1.4784	1.8389
300	0.5660	1.8546	1.9702	1.9010	1.5719	1.4802	1.7968
600	0.4200	1.8244	1.9741	1.9250	1.5544	1.4821	1.7599

Conclusion

The images information of running-in surface were taken by digital microscope. Then two-dimension discrete wavelet transform was adopted to decomposed images. Afterwards, the lower and the higher frequency component of the detail information that used to describe the running-in surface were obtained by using the method. Further, the state of running-in surface was analyzed qualitatively based on the decomposing details at three directions clearly. In order to describe the images quantitatively, the calculating method of fractal box dimension for image was founded, and was adopted to calculate the fractal box dimension such as initial image, lower and higher frequency component that wavelet decomposition and reconstruction image. The calculating resultes of reconstruction surfaces have shown that there are identical with roughness of surface in rule, and the fractal box dimension augment with the increase of roughness. It is indicated that fractal box dimension can be as a characteristic parameter to describe the level of ruing-in surface quantitatively.

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