KSTLE International Journal, Vol. 3, No. 2, December 2002, pp. 75-78

Fractal Dimension for Morphology Analysis of Rubbed Surface with Hydraulic Members

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Abstract: The surface morphology of oil-lubricated surfaces for hydraulic piston motors is believed to be extremely effective in contact mechanics, adhesion, friction and wear. In order to describe morphology of various rubbed surfaces on driving conditions, the wear test was carried out under different experimental conditions in an oil-lubricated system. And fractal descriptors were applied to rubbed surfaces of hydraulic members and analyzed through an image processing system. These descriptors to analyze surface structure are fractal dimension. Surface fractal dimensions can be determined by sum of intensity difference of surface pixel. The morphology of rubbed surfaces can be effectively obtained by fractal dimension.

Key words: Surface morphology, rubbed surface, image processing system, fractal dimension

Introduction

Generally, high-tensile brass and bronze casting materials have superior wear resistance, so these materials are widely used in wetting the dynamic materials of slipper-pad in the hydraulic piston motor.

In order to diagnose the working conditions and damage of wetting dynamic members used as high tension brass and bronze, friction and wear characteristics of these materials must be researched certainly.

Generally, the stylus profiling, the electronic microscope, and the optical method are used to analyze rubbed surfaces in lubricating systems. Stylus profiling is most general method to analyze surface roughness and status. But it depends on the stylus radius and surface direction. The electronic microscope method has the advantage to measure microscopic portion precisely, but It requires very expensive equipments and technical knowledge. The optical method by the CCD camera is only used to save captured images in computer hard disk drive and needs to be observed by an experienced person. This algorithm has not yet been constructed to get objective shape information of rubbed surfaces with complex and various morphology in captured images. Thus, it is necessary to construct such an algorithm. For that, the digital image processing and the fractal dimension is proposed to analyze shape characteristics of rubbed surfaces in lubricated system.

The fractal dimension pioneered by Mandelbrot defines the irregularity of natural objects, and is numerical parameter of natural morphology such as a roughness, a break and a crack.

Therefore, in this paper, for the purpose of applying fractal parameters practically, a method with fractal parameters will be suggested which will establish the morphological characteristics of rubbed surfaces, and we carried out lubricated friction and wear experiments by using a Pin-On-Disk type tester. The material was high tension brass and bronze which are used for lubricated members as slipper-pad in the hydraulic piston motor. Fractal dimensions of rubbed surface shape are calculated by digital image processing.

Using fractal dimensions by the image processing and fractal parameters, morphology of rubbed surface can be effectively obtained.

Experiment

In this study, The Pin-On-Disk type tester was used for this friction and wear experiment. The pin specimen was a STB2 (780Hv) bearing ball, 5 mm in diameter, disk specimen was HBsC3(160Hv) and LBC3, 50 mm in diameter. The disk specimens are precisely grinded on emery paper #1200 and surface roughness is fixed by 0.2 μm Rmax for the friction and wear experiment. Oil used in experiment was pure paraffin base oil. In the experiment conditions, The load was 29.4 N, 58.8 N, 88.2 N, 117.6 N and 147 N, and the sliding distance was 0~234 m and 0~624 m. The wear particles generated in each experimental condition were extracted by 0.45 membrane filter. Lubricating oil is supplied on the contact position of the disk and ball specimen by silicon tube and rotary pump. And oil is returned in the oil bath equipped under the contact department. Disk specimen regularly rotates at 7.23 mm/s under the applied load, and pin specimen is pressed on the disk specimen.

Extracting rubbed surface by image processing

Image information of rubbed surfaces was extracted by the image processing system. Images were captured by color CCD

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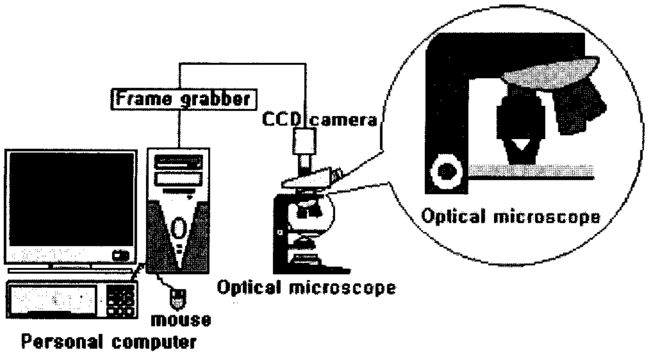

Fig. 1. Schematic diagram of image processing system.

camera on the optical microscope, and saved to HDD (hard disc drive) by a frame grabber in the computer. The resolution of image was 640 × 480 pixels, and the grayscale was 8 bits per pixel. The optical microscope had an objective and ocular 10 lens of magnifications.

Light source is irradiated on rubbed surface by incidence angle of 45° from 4 directions of 90°. This was done to remove shadows by light direction and to gain the irregularity of rubbed surface by light intensity. Red LED of monochromatic light was used to minimize error by diffraction of light, as shown in the Fig. 1.

The rubbed surface images in random positions are captured by an objective lens of 10 times and by an ocular lens of 10 times in all disk specimens for each experiment. The light intensity of the rubbed surfaces is cleared by image processing of red color filtering in each rubbed surface image.

From the light intensity of rubbed surfaces extracted by image processing, shape fractal characteristics were calculated. And using the light intensity difference of rubbed surfaces, 3D modeling is processed.

The Fractal dimension of rubbed surfaces

The Fractal dimension is used to describe the irregularity of certain objects as a numerical value. It has the advantage of representing an objective expression as is said to be "Complicate" or "Slow" after seeing a coastline or a mountain as a subjective expression. In this study, rubbed surfaces are analyzed by application of fractal dimension. Fig. 2 shows the method of calculating fractal dimension in rubbed surfaces. In rubbed surface images, for the purpose of finding Fractal dimensions, the sum of light intensity differences (SID) among pixels for different step sizes along a column or row of the surface image was calculated, and then steps and SID values were transformed into logarithm values. And, at the logarithm coordinate system, the gradient of the line of best fit was found as using these values and defined as 1-D, where D was fractal dimension.

Fig. 3 shows the algorithm for calculating fractal dimensions. In this study, when the pixel step size is set up in 3 stages of 2, 4, 6 steps, 4, 8, 12 steps and 6, 12, 18 steps in each rubbed surface image, the fractal dimensions of rubbed surfaces were calculated. And surface roughness Ra in each experiment condition was compared with fractal dimensions

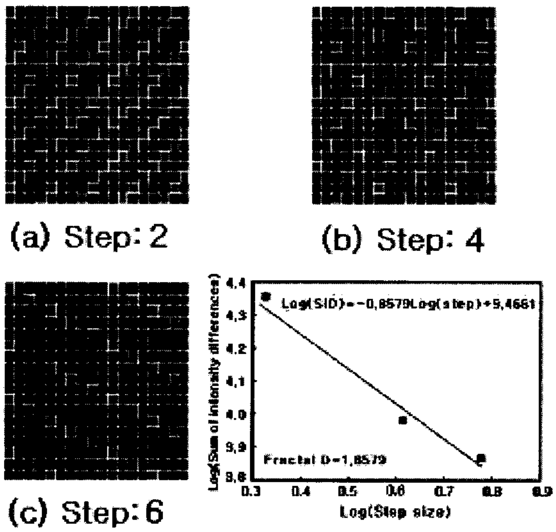

Fig. 2. Determination method of surface fractal dimension.

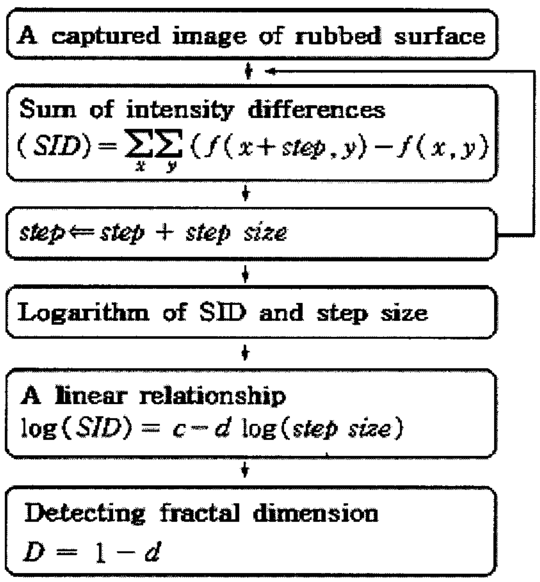

Fig. 3. Flow chart of algorithm for fractal dimension.

through using a surface roughness tester.

Result and discussion

The surface roughness of rubbed surface

Fig. 4 shows the surface roughness Ra for the applied load in 624 m sliding distance. According to an increase of applied load, surface roughness was increased. It is possible that much more abrasive and adhesion wear occurred because temperature and contact pressure increases in the rubbed surfaces with the increase of the applied load.

And, the surface roughness of LBC3 is lower than HBsC3 under the applied load of 88.2 N. But over the applied load 88.2 N, surface roughness of LBC3 is higher than HBsC3. It is possible that rubbed surface conditions were good under the relatively low applied load 88.2 N because of an effect of Pb

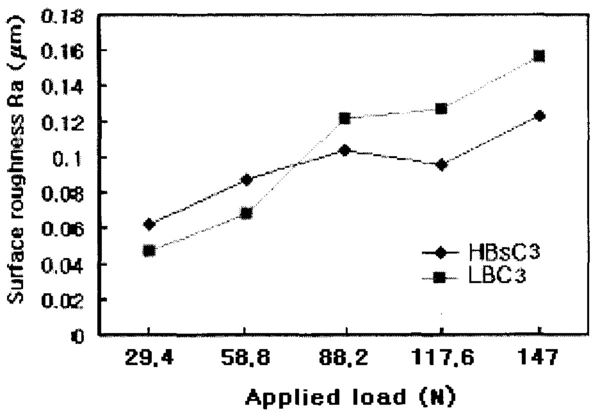

Fig. 4. Relation between surface roughness and load.

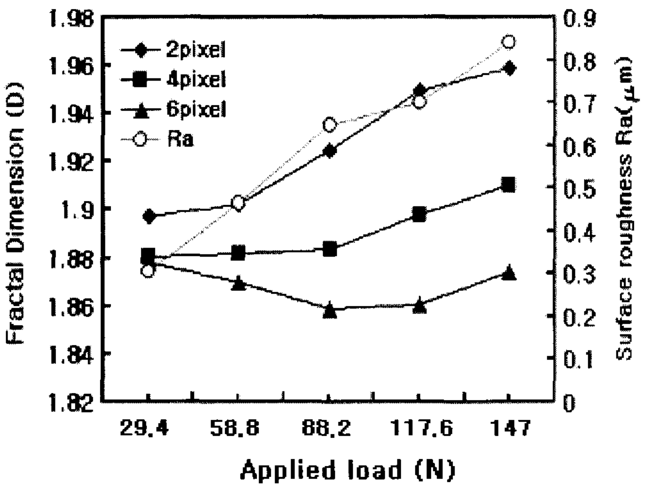

Fig. 5. Relation between fractal dimension, surface roughness and applied load.

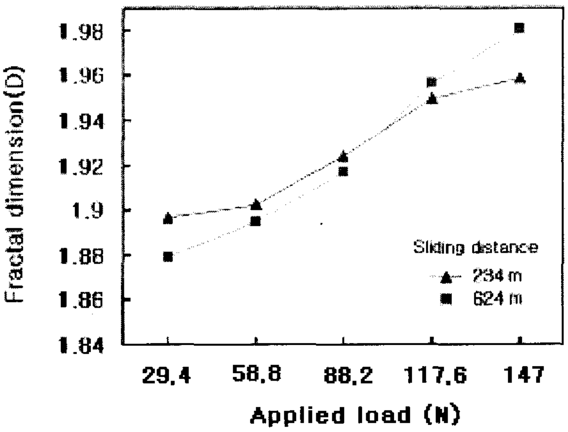

Fig. 6. Effect of load on fractal dimension.

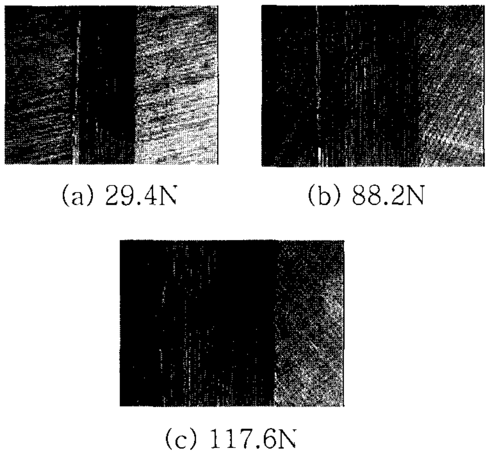

Fig. 7. Image of rubbed surface on load, sliding distance: 234 m.

added in the LBC3 for lubrication improvement. But rubbed surface conditions were worse over the relatively high applied load 88.2 N because of much more abrasive and adhesion wear than on HBsC3 with relatively high hardness by increase of applied load.

The step size of pixels and fractal dimension

In order to calculate the fractal dimensions, it is necessary to find the sum of light intensity differences for the given step sizes. For the purpose of setting up the suitable step size, the fractal dimensions were calculated through the different step sizes on each condition.

The relation of surface roughness and the fractal dimension for each applied loads in the step size with 2, 4, 6 pixels and the sliding distance 234 m is shown in Fig. 5.

It is demonstrated that the fractal dimensions according to increase of applied load is similar to the variation of the surface roughness Ra in the step size of 2 pixels. And the tendency is not cleared in step size of 6 pixels.

Therefore, in this study, the step size is set up at 2 pixels for researching the fractal dimensions of the rubbed surfaces.

The fractal dimensions on the applied load

Fig. 6 shows fractal dimensions of HBsC3 for the applied loads in sliding distances 234 m and 624 m. Fractal dimensions increase according to the increase of the applied loads in all sliding distance conditions. This represents that the status of the rubbed surface is rougher and more complex according to the increase of the applied load, and fractal dimensions are lower in the long sliding distance than the short under the applied load 88.2 N as shown in the Fig. 6. Over 117.6 N, fractal dimensions are higher in long distances. This represents that the surfaces have much more oxides in the long sliding distance under the 88.2 N and it is result of more abrasive wear occurring by the contact pressure over the 117.6 N. And Fig. 7 shows rubbed surface images of HBsC3 according to the applied load in the sliding distance 234 m. The width of the rubbed track is wider in high loads. In addition, the abrasive wear occurred on the surface more widely.

Fig. 8 shows the 3D model of rubbed surfaces for applied loads. This represents that the minute shape of rubbed surface is also rougher and more complex according to the increase of the applied load and an oxidized substance occurring on the

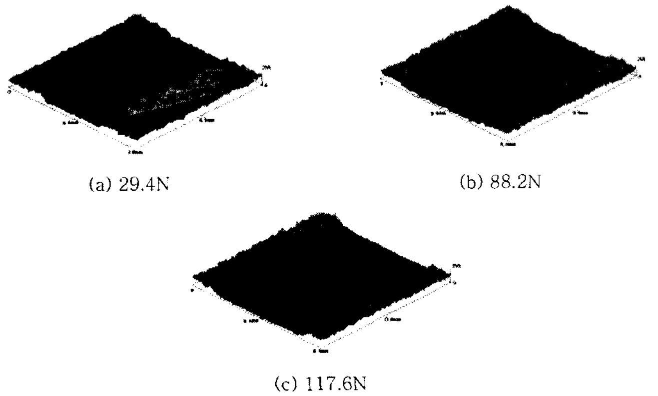

Fig. 8. 3D model of rubbed surface on load, Sliding distance: 234.

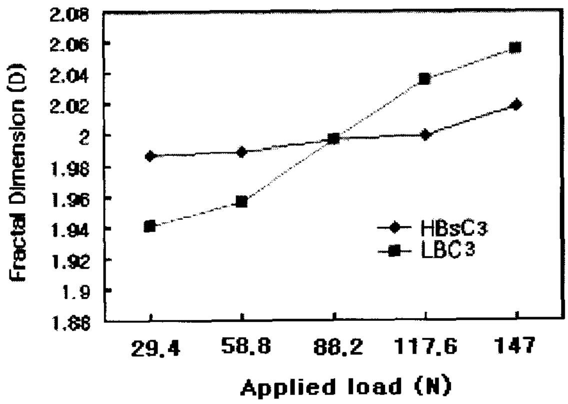

Fig. 9. Effect of load on fractal dimension.

rubbed surface because of oxidation according to temperature increase.

Fig. 9 shows the variations of fractal dimensions for applied loads in the HBsC3 and LBC3, sliding distance 624 m. This represents that fractal dimensions of LBC3 are lower than the HBsC3 value similar in surface roughness under the applied load 88.2 N but higher over the applied load 88.2 N. In this result, fractal dimensions well represent the characteristics of rubbed surface roughness instead of Ra. Fractal dimensions are also very useful to describe the characteristics of rubbed surfaces with various and complex shapes for the working conditions.

Conclusions

After performing the friction and wear experiments using the pin-on-disk type in each experiment condition, and using the image processing, fractal dimensions were calculated from the rubbed surface images of the each disk captured by the CCD camera. After analyzing morphological characteristics of the rubbed surface, we have concluded the following result;

(1) The surface roughness Ra is increased by a rise of surface temperature and contact pressure according to the increase of the applied load.
(2) When we compared the fractal dimension with the surface roughness Ra, increases of fractal dimensions were similar to increases of surface roughness Ra.
(3) According to increases of the applied load, the status of rubbed surfaces is rough and complex and abrasive wear increases.
(4) The fractal dimensions are low under the applied load 88.2 N in the sliding distance 624 m, but higher over the 117.6 N.
(5) In the material HBsC3, in applied loads lower than 88.2 N, fractal dimensions in the long sliding distance are lower than in the short sliding distance. But the fractal dimensions are higher over the 117.6 N.

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