MINNEAPOLIS • MAY 20-24, 2018

METHOD TO CALCULATE WEAR VOLUME OF CYLINDER LINERS FROM THREE-DIMENSIONAL SURFACE PROFILES, PART I

TRACK OR CATEGORY

Wear

AUTHORS AND INSTITUTIONS

Robert Erck and Nicholaos Demas

INTRODUCTION

In tribological research, workers measure friction and wear of components or component parts using benchtop test equipment. It is generally easy to measure the coefficient of friction during sliding (unidirectional or reciprocating), but the measurement of wear is difficult because the wear displacement is often on the order of nanometers, or wear mass is on the order of nanograms, which cannot be measured. A method is presented here to calculate the wear volume from the bearing area curve (Abbott) using three-dimensional profiles of the test sample, obtained before and after sliding. We describe the theory of the method, which uses data from three-dimensional profiling software. We then validate the method using prototype surfaces where the wear volume is known exactly and compare results. Here we concentrate on surfaces with surface roughness and honing marks, such as cylinder liners samples.

RESULTS

The precise measurement of wear of realistic components with surface roughness and honing marks is difficult. Here we discuss a method based on optical profilometry of a surface before and after testing that can be used to determine wear, provided that the amount of wear remains low enough that the deepest honing grooves are largely unaffected.

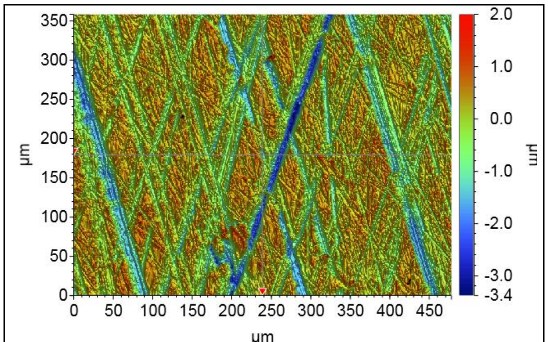

Fig 1. Sample pseudo-color image from 3-dimentional profilometry of segment of cylinder liner

An optical profilometer, or non-contact profilometer, is a common laboratory device, which can be white light, confocal, vertical-imaging, digital holography, or other types. 3-D surface information can be obtained, limited by resolution of camera and optics. Stewart [1] has described in detail the definition of the Abbott or bearing area curve (BAC) in helping to analyze such surfaces. The BAC, or Abbott-Firestone curve, can be determined from line or surface profile scans, and is the cumulative probability density function. The BAC plots the surface height “z” as a function of the fraction (in %) of surface area that contains volume *above* that height.

For many wear processes, material removal occurs from the peaks of the surface topography, but not from the valleys. This is commonly a feature of a cylinder liner, piston rings, or piston skirts. Thus the valleys, being unworn, can be used as a “reference” to adjust BAC curves. The y-axis has units of distance, x-axis has units of percent of area where area is size of image. Thus area of BAC is the “volume” when multiplied by image area. In this example Fig 1., the actual area of the image is 357 µm x

475 µm or 170,000 µm^2. There is no absolute height value when performing a profile scan. Many imaging machines set the average value to an arbitrary value, often zero. But if the BAC curves are adjusted in height properly to each other, the areas between two curves represents volume difference between two surfaces (Fig. 3).

This method of matching the valley areas to obtain wear volume would not be appropriate for a process where removal from the valleys occurred, or where material deposition into the valleys occurred. This procedure will not work if wear is so large that all reference levels, i.e., the valleys, are obliterated. For volume loss from an entire part, assuming uniform wear, this number would need to be multiplied accordingly.

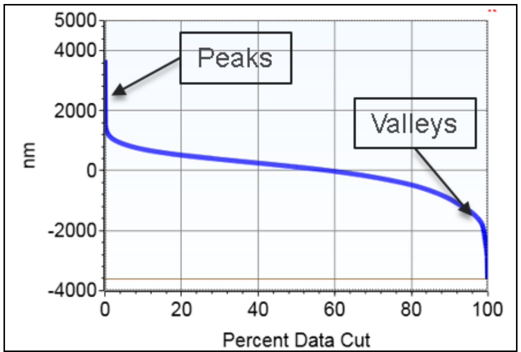

Fig 2. Depiction of BAC. Y-axis is height and has units of distance, X-axis has units of percent of the area of an image

It can be noted that BAC is defined for a continuous surface function. For a pixelated image, each pixel has fractional area of (pixel size)/(total image size). Thus in practice for pixelated images, the BAC is easy to obtain by sorting (x, y, z) coordinates according to height. It is necessary to normalize x-axis to obtain percent instead of bin number.

The valley-matching approach was used by Kumar [2] to determine the amount of wear on a cylinder liner using a C++ computer program. In that work, Kumar used 90% as the point that is identical before and after the wear, and the analysis is linear, and not areal.

To match curves the user must process BAC data so that curves have alignment in the valley areas. In particular, the BAC curve alignment may be done at a particular point (e.g. 98%) or over an integrated region (e.g., 90-100%). If the user has possession of the full 3-dimensional information, it is possible to alternatively perform vertical alignment and do direct subtraction to obtain wear volume. However, alignment is easier using the BAC approach.

Fig. 3 shows schematically how this process is done in a graphing program; the user must add or subtract differences to their BAC curves to make the valley positions equal. Then subtraction of BAC curves (multiplied by area) will produce the desired numbers. For multiple scans obtained periodically during wear, the area between the original curve and the subsequent curve is equal to the material volume lost during each of the wearing steps.

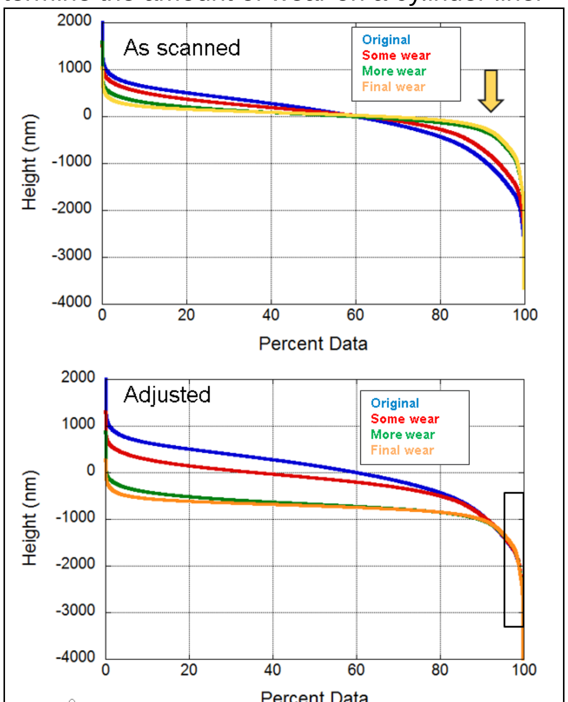

Fig 3. As-scanned BAC curves (top) and BAC curves adjusted in 98% region

The method looks plausible, but it should be shown that integrating BAC curves to produce wear volume gives identical volume as direct subtraction of the image datafiles. In the following section, the BAC method is compared with the direct subtraction method. To do this, a different cylinder liner was imaged. The average height was about 2000 nm.

A series of truncated surfaces based on the original cylinder liner were generated using blunt truncation of the datafiles at various heights. That is, 2500 nm, 2000 nm, 1500 nm, and 1000 nm. Fig. 4 shows a series of pseudo-color isometric images with flattened mountain tops and their associated BACs. Here, the valleys are aligned perfectly. The tops of the rough topography are removed at defined levels, BAC areas are calculated and listed in the table, and differences are shown in the third column. Also, wear volumes were calculated using direct subtraction of the 3-dimensional profiles (last column). This was accomplished using a graphing program where differences of all of the z-values are summed up for all of the x and y pixel data in an image.

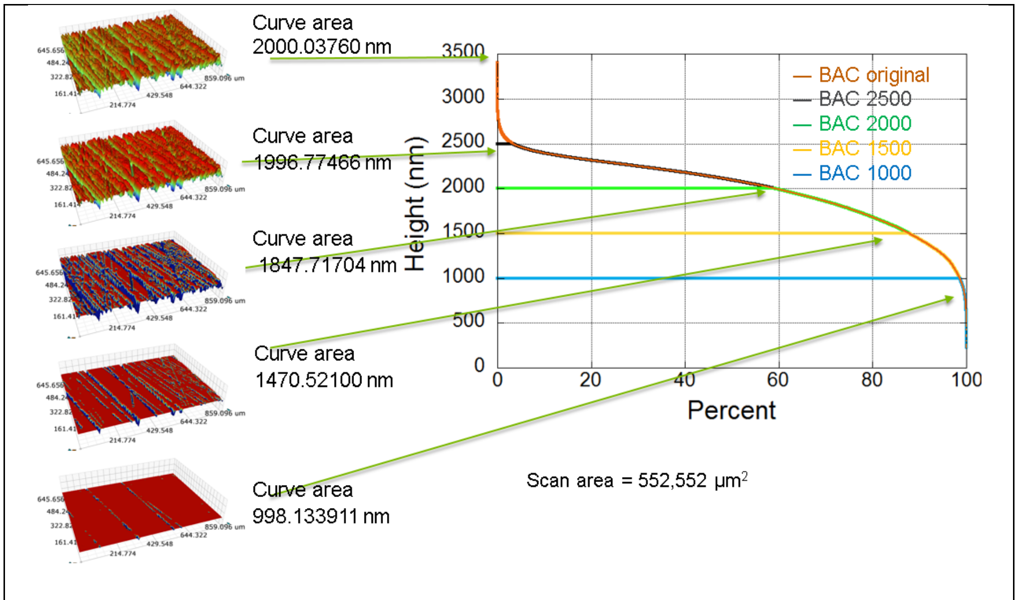

Fig 4. Truncated isometric views of images and associated BACs on graph

When compared, the BAC method and direct subtraction method gave identical results to the precision of the calculating program as shown in the following table. The small discrepancy between the two methods may be attributed to rounding errors in precision of datafiles. That is, rounding errors may accumulate if a (typically) million z-values from (x, y, z) coordinates are summed to obtain a volume number.

3-D surface	Integrated BAC area (nm)	Area difference (nm)	BAC volume (μm^3)	Volume by direct subtraction (μm^3)
Original	2000.03760			
Truncated 2500 nm	1996.77466	3.26293945	1802.94373	1802.87671
Truncated 2000 nm	1847.71704	152.320557	84165.0313	84170.2188
Truncated 1500 nm	1470.52100	529.516602	292585.469	292589.906
Truncated 1000 nm	998.133911	1001.90369	553603.875	553606.625

ACKNOWLEDGMENTS

The submitted manuscript has been created by UChicago Argonne, LLC, Operator of Argonne National Laboratory (“Argonne”). Argonne, a U.S. Department of Energy Office of Science laboratory, is operated under Contract No. DE-AC02-06CH11357. The U.S. Government retains for itself, and others acting on its behalf, a paid-up nonexclusive,irrevocable worldwide license in said article to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the Government.

REFERENCES

[1] Stewart, M, 1990, “A New Approach to the Use of Bearing Area Curve,” *Soc. Mfg. Eng.* **FC90-229**, pp.1-11.

[2] Kumar, S, Prakash, B, Sethuramiah, A., 2000, “Assessment of Engine Liner Wear from Bearing Area Curves,” *Wear*, **239**(2), pp. 282-286.

KEYWORDS

Wear, cylinder liner