TECHNICAL PAPER

FC90-229

# A New Approach to the Use of Bearing Area Curve

## author

MIKE STEWART
Research and Development Engineer
Micromatic Textron
Holland, Michigan

## abstract

Tribologists have demonstrated that an ideal bearing surface is a smooth one with relatively deep scratches to hold and distribute lubricant, but quantifying and specifying these surfaces has always been a problem. Since its introduction, the bearing area curve has been recognized as the only effective way to characterize these surfaces but is rarely used in specifications. The normalized abscissa and highest peak reference commonly used for plotting the bearing area curve limits its use for quantitative analysis, but when plotted on an absolute scale with a mean line reference, it becomes a powerful analytical tool for evaluating and specifying bearing surfaces. The techniques presented in this paper are beneficial for plateau honing operations and bearing wear tests.

## conference

International Honing
Technologies and Applications
May 1-3, 1990
Novi, Michigan

## index terms

Surface Roughness
Engines
Abrasives
Metrology
Finishing
Statistical Analysis

Society of
Manufacturing
Engineers
1990


Society of Manufacturing Engineers • One SME Drive • P.O. Box 930
Dearborn, Michigan 48121 • Phone (313) 271-1500

**Introduction**
The Bearing Area Curve (**BAC**),or Abbott - Firestone Curve, has been used to evaluate surfaces since it's introduction in 1933 by Abbott and Firestone. Despite the fact that it is a complete and concise means of describing or specifying a surface, it has found little use in industry. This is probably due to the inconvenient manner in which it is commonly presented. The approach presented here puts the **BAC** in a more usable form, making it a powerful tool for solving one of the most difficult problems in surface metrology - characterization of a plateau honed surface. The primary focus will be on the evaluation of internal combustion engine cylinder walls, but the concepts can be applied to any load bearing surface.

It has long been recognized that the ideal load bearing surface is a smooth one with relatively deep scratches to hold and distribute lubricant, but quantifying the roughness of this type of surface has always been a problem. The heart of the problem is that the statistics being used were derived for randomly distributed data exhibiting little or no **skewness**, which can be relatively high for these surfaces. The student of statistics should recognize that a mean and standard deviation are adequate for describing a "**normal**" or Gaussian distribution but for a non-normal distribution, the statistics get more complicated. The third moment is used as a measure of skewness ($\mathbf{R_{sk}}$) but is of little use in surface metrology because it tends to be too unstable for use as a process control. Most of the other surface finish parameters do not have such statistical roots and also suffer from a lack of stability, especially when dealing with skewed surfaces. More sophisticated statistics are quite common in other disciplines but have not been implemented in surface metrology, possibly due to the rigorous mathematics involved. Here we will discuss a graphical and more intuitive approach to characterizing these skewed surfaces with the use of the Bearing Area Curve.

**Defining the Bearing Area Curve**

Abbott and Firestone may not have recognized that the curve they proposed to evaluate surfaces with was exactly what statisticians call the **Accumulative Distribution Curve**. By definition it is the integral of the Amplitude Distribution Function (**ADF**), also known as the **probability distribution** or **histogram**;

$$\mathbf{BAC} = \int \mathbf{ADF} = \int P(y)dy \qquad \text{eq. 1}$$

where y is the height measurement made across the surface. The first bearing area curves were generated by hand, from strip chart recordings of surfaces as described in the standards (see figure 1). The crossectional areas (lengths) or $L_i$**'s** at each level (depth = **c**) are summed and the total length is plotted as a function of level (usually expressed as a percentage of the total length).

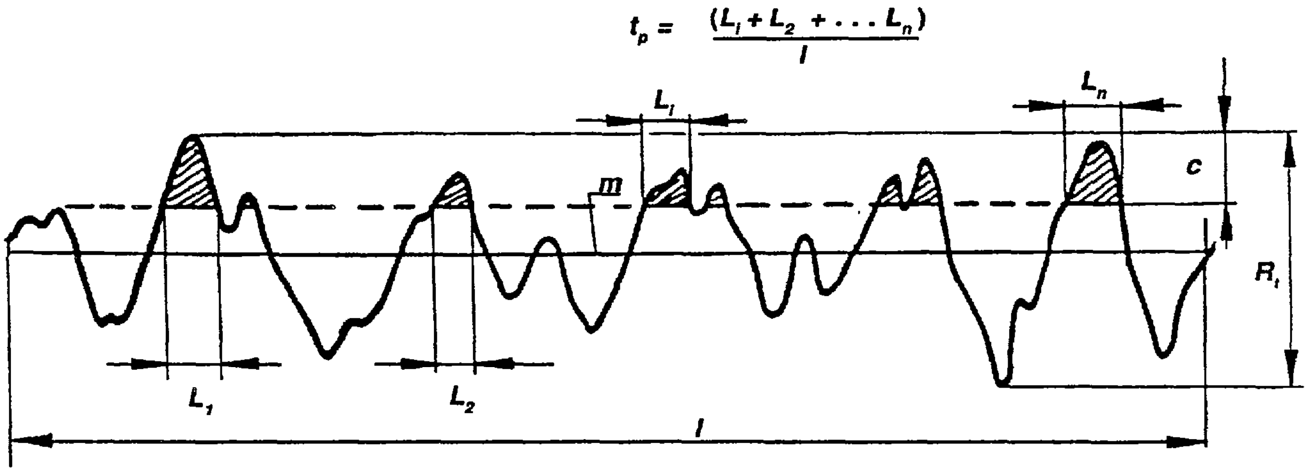


figure 1

As you might guess, this was a tedious and time consuming task, one that is best suited for a digital computer. Before the utility of a computer can be exploited however, the surface must be **digitized** and represented as a table or array of data values, as opposed to a continuous trace. Once digitized, a statistical approach exploiting the relationship in equation 1 can be used to generate the **BAC**, as opposed to the graphical approach described in the standards.

**Creating the BAC**

One commonly used method of creating the **BAC** is to first generate and then integrate the **ADF**. Another approach is to sort the original sampled data in descending order and plot the sorted data, from 0 to 100% where 100%=N (number of data points taken). Both methods yield an ordered, indexed array making further calculations from the curve quite simple. Taking a simple case with N samples, the depth at X% bearing area can be found as the X/Nth entry in the sorted data array.

Though the **BAC** is an extremely accurate and complete description of a surface, it is rarely used in specifications or process control. This may be due to the manner in which it is presented. The curve is commonly plotted with a **normalized** abscissa - from 0 to 100% $R_t$ (highest peak - lowest valley) as in figure 2. This is convenient in that it ensures that all the data will be "on scale" but as $R_t$ changes, so does the scaling of the **BAC**. This makes it very difficult to compare curves, for example, the **BAC** of a 5uin $R_a$ surface could look the same as that of a 60uin $R_a$ surface and one deep scratch can make the **BAC** of a conventionally honed surface look like that of a plateau honed surface. The solution to this problem is to plot the data on an **absolute** or specified scale instead of a normalized scale. In this manner we ensure that every **BAC** will be scaled the same, making direct comparisons possible.

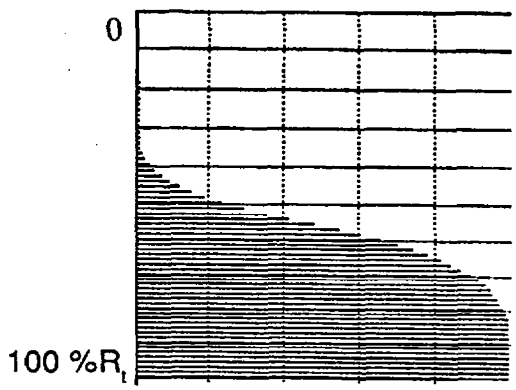


figure 2

Another common convention is to reference the curve from the highest peak, which is probably the least stable point on the curve (except for possibly the lowest valley). This causes the relative position of the rest of the curve to be unstable. A more logical reference point would be the mean line, as commonly used in statistics. Some measurement equipment have the capability to list the **BAC** with respect to the mean line in tabular form but there are no readily available systems which plot the **BAC** with absolute scaling and a mean line reference. Still another common yet inconvenient convention is to treat the bearing area ($t_p$) as a function of height (y) or **BAC** = $t_p$(y) were here we will treat height as a function of bearing area or **BAC = y($t_p$)**.

To dramatize the difference between the two plotting schemes, examine the three **BAC**'s in figure 3 produced by a popular system using normalized scaling and peak reference. The

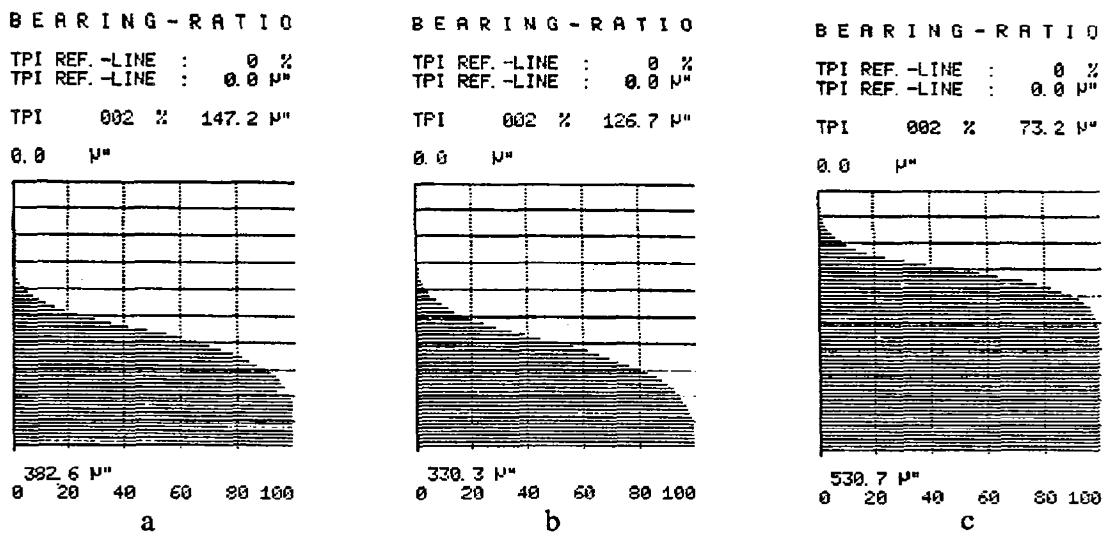


figure 3

data was taken from a .5in x .5in sample cut from a cast iron engine block. Note there is little similarity between these curves even though they were taken from the same sample. Figure 3c appears to be that of a plateau honed surface while the other two do not. To the casual user this may suggest that the surface is inconsistent, but on closer examination we see that the scaling changes from 382.6 uin and 330.3 uin for figures 3a and 3b respectively to 530.7 uin for figure 3c. Quite often a user will try to rescale the data manualy in order to make a direct comparison, but quickly discovers this is not a practical alternative.

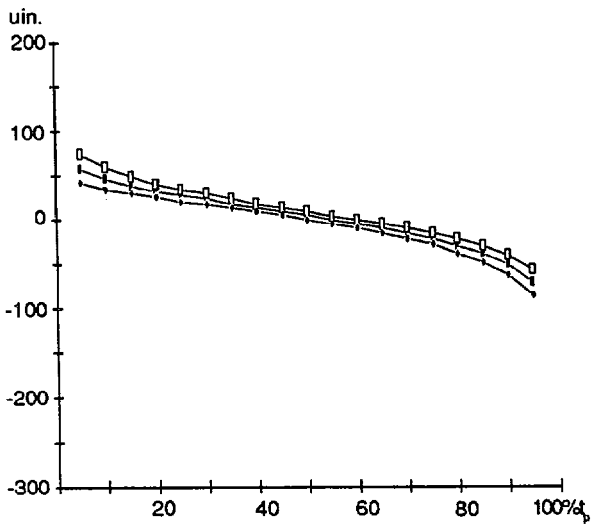


figure 4

In contrast, the center curve in figure 4 is an average of twenty **BAC**'s which were calculated in absolute units, referenced from the mean line. The upper and lower curves are "control limits" generated by calculating ±3 standard deviations about the average. The data was taken from a sample of 20 blocks from which the previous sample was cut. In comparison, figures 5 and 6 are similarly plotted **BAC**'s from identical blocks manufactured at two other facilities. The narrow control limits indicate the surfaces within a sample are much more consistent than the curves in figure 3. A comparison of the average curves indicates a significant difference between samples, even though they all conform to the same specification.

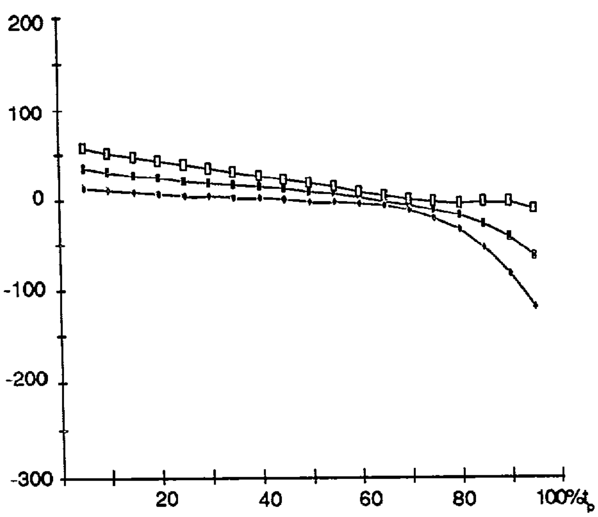


figure 5

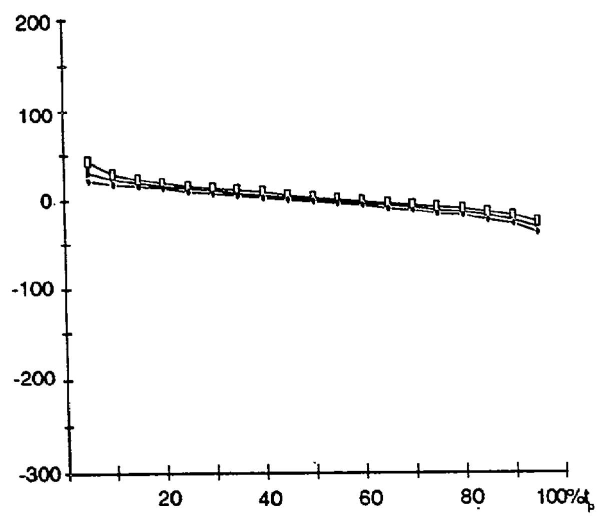


figure 6

This points out the relative sensitivity of the **BAC** compared to the "standard" parameters being used in the specification ( $\mathbf{R_a}$, $\mathbf{R_{pm}}$, $\mathbf{R_{3z}}$).

The plots in figures 4, 5 & 6 were generated with popular spread sheet software with data from a specially developed surface finish measurement system but data from any instrument capable of listing the **BAC** can be used, even if the system uses the highest peak as the reference. The data can be converted to mean line reference data by adding $R_p$ to all the height values at the selected levels of bearing area:

$$h_m(x\%t_p) = h_p(x\%t_p)+R_p \qquad \text{eq.2}$$

were $h_m$ is the height with respect to the mean line, $h_p$ is the depth below the highest peak, $x\%t_p$ is the bearing area for which the height is being plotted and $R_p$ is the height of the highest peak with respect to the mean line.

**Mode Line Reference**

So far the mean line reference has been emphasized but their is yet a better reference point known as the mode or peak of the **ADF**. This is the point in which the most data exists and is consequently the most stable point on the **BAC**. For a surface with a symmetric or normal **ADF**, the mode and the mean are coincident so the mean line and mode line reference are equivalent. Unfortunately there is no readily available equipment which uses the mode line reference so we will focus our attention on what we can do with the mean line reference.

**Plateau Honing**

Plateau honing is often described as cutting off the peaks of a rough honed surface to produce a "worn in" surface. The result is a skewed **ADF** and **BAC** where a conventional honing operation will produce an **ADF** which is symmetric about the mean line and closely resembling a normal distribution. Here we will define conventional honing as honing with a single abrasive grade and a constant feed force (no spark out). Under these conditions, an abrasive will produce a surface with a constant roughness ($R_a$) and a near normal or Gaussian **ADF** in which case $R_a$ or $R_q$ is an adaquate description.

Plateau honing will be defined here as a combination of two conventional honing operations, making two Gaussian surfaces; one superimposed on the other. To produce a plateau hone finish, a relatively coarse honed finish must be produced first and a smoother finish is put on top of the coarse finish without removing the valleys of the coarse finish. The degree of "plateauness" can be characterized by the contrast in roughness between the two surfaces and the amount of material removed from the rough surface.

The **BAC** and **ADF** in figure 7 show two distinct normal distributions, a narrow one (finish hone) superimposed on what is left of a wider one (rough hone). There is a roughness ($R_a$ or $R_q$) associated with each of these distributions, but we are primarily interested in the roughness of the part which is to be our load bearing surface (figure 8). This is often measured by calculating the slope of the **BAC** in the "linear" (near linear) region (figure 9). Here it helps to compare the **BAC** with the **ADF** since most engineers are familiar with the use of histograms and the standard deviation ($R_q$, **RMS** or **sigma**). The slope of the **BAC** corresponds to the width of the **ADF** which in turn is proportional to the standard deviation. Various specifications have been written to evaluate the slope between two points on the curve (i.e. between $20\%t_p$ and $60\%t_p$).

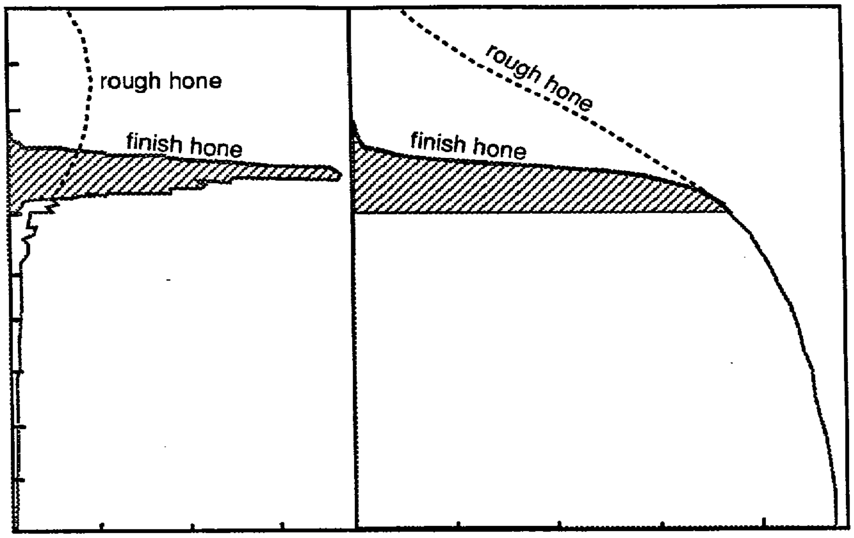


figure 7

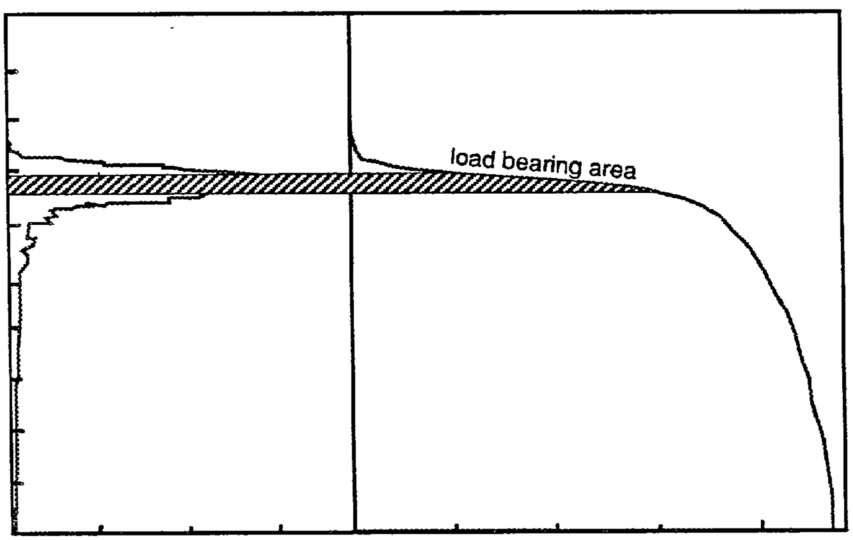


figure 8

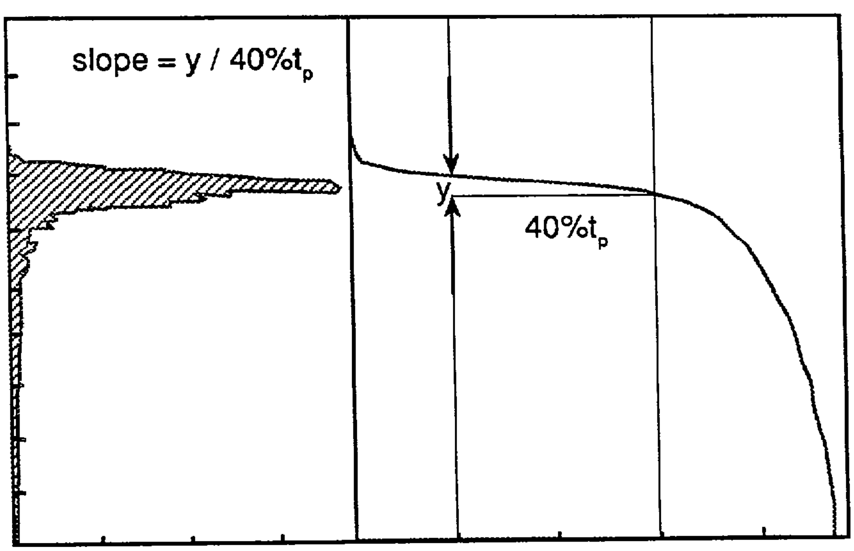


figure 9

This technique allows the portion of interest to be isolated but unfortunately, the slope is often reported as the unitless quantity **%$R_t$ / %$t_p$** from the normalized scales, making the slope a function of **$R_t$** which is very unstable. The same result can be achieved by measuring the depth between the two points instead of the slope, since the distance in %$t_p$ is constant, and the confusion with the scaling is avoided.

The volume of lubricant retained by the valleys of a honed surface has become an important issue in the reduction of oil consumption and the volume of material existing as peaks is of interest for predicting "wear in" rates. Various algorithms have been developed to calculate the areas of the corresponding regions of the **BAC** (figures 10 & 11) and making correlations to volume but these techniques have not been proven reliable or repeatable.

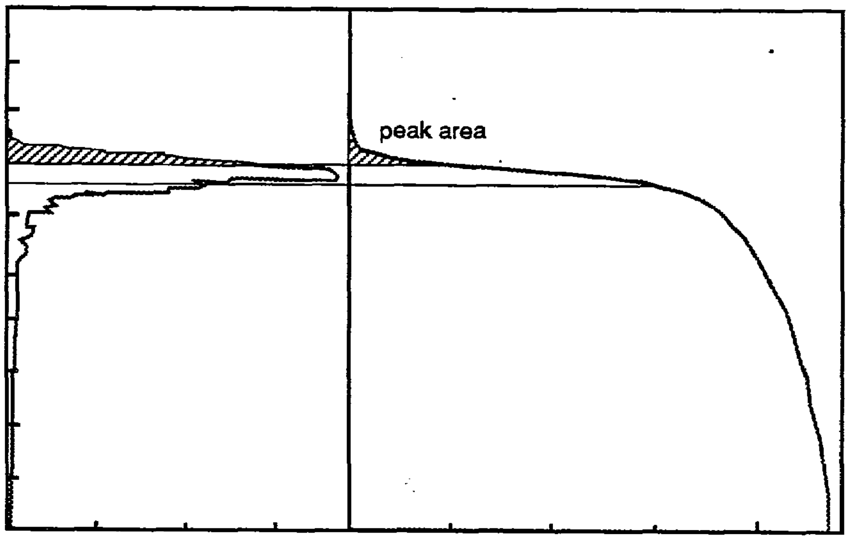


figure 10

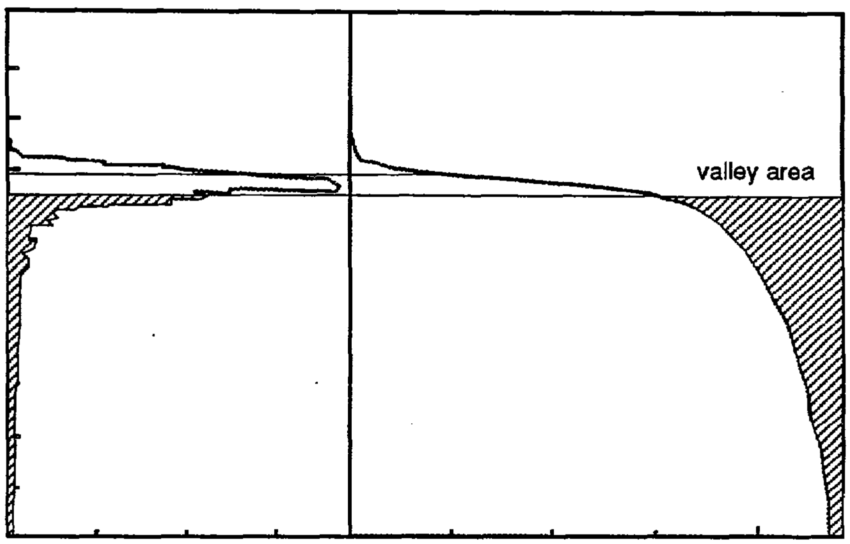


figure 11

Extremely accurrate material removal measurements can be made for the plateau hone operation by overlaying the finish hone **BAC** with the rough hone **BAC** and matching up the lower part ( 80 to 100%$t_p$) of the curves as in figure 12 (note that this can only be done if the curves are plotted with absolute scaling). Since the finish hone does not alter the valleys of the rough surface, that part of the curves should match exactly and the area

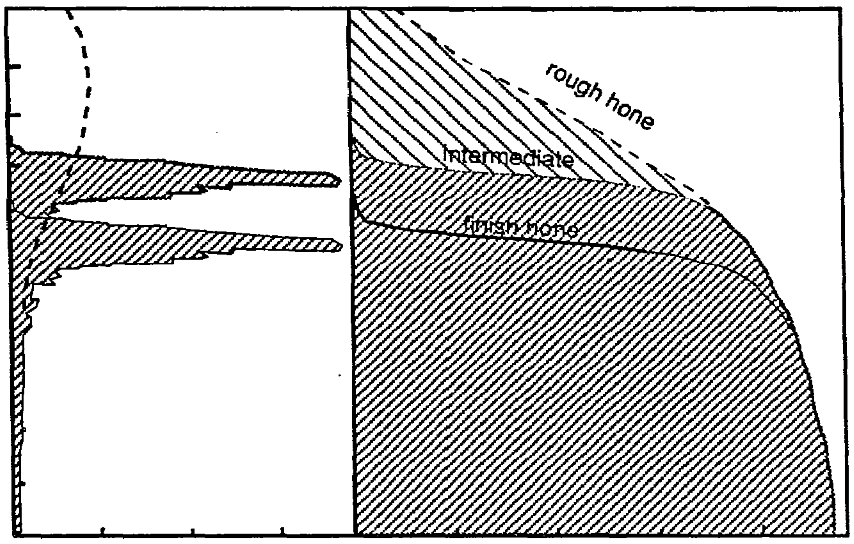


figure 12

between the curves (in the upper portion) is the amount of material removed by the finish hone. Figure 12 shows three superimposed curves where the upper curve is that of the rough hone surface the lower is that of the finished surface and the intermediate curves were acquired by interrupting the finish honing cycle and taking measurements. The lower sections of the **BAC** line up exactly and the slope in the load bearing area remains constant while the length increases and the height changes corresponding to the material removal. Similar measurements could be made during surface wear or engine tests. Figure 13 shows the **BAC** from an engine liner which has been run for 25 hours. Note that the load bearing area (flat spot) created by the rings only extends to about 38%$t_p$. The dashed line in figure 14 shows what the surface looked like before the test and the area between the lines is the material removed by the piston rings.

**$R_k$ Parameters.**

A recent attempt to standardize the Bearing Area Parameters appears in the **DIN 4776**, with the introduction of the **$R_k$,$R_{vk}$,$R_{pk}$** parameters. These parameters, now gaining interest in America, encompass a good crossection of the ideas behind most of the evaluations done up to their introduction. These parameters may be well suited for process control, but the engineer must understand the implications of the bearing area curve and how these parameters are derived from the curve before putting them into use.

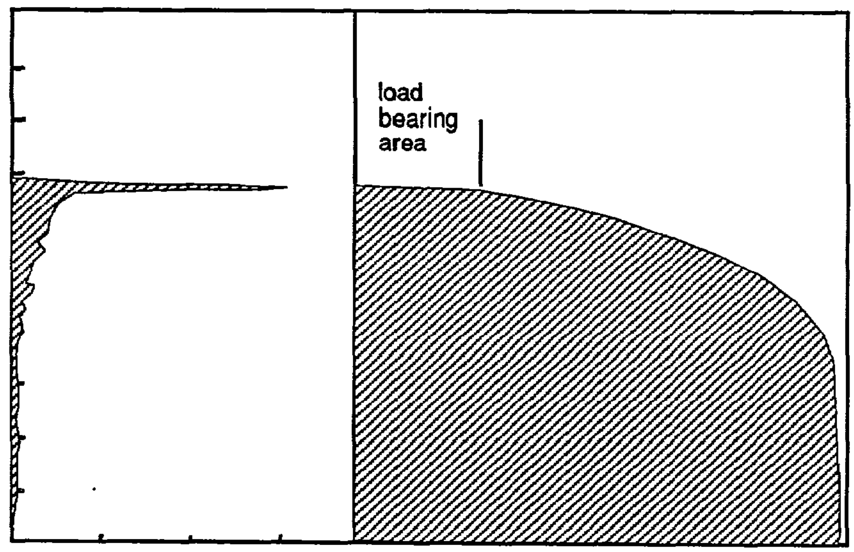


figure 13

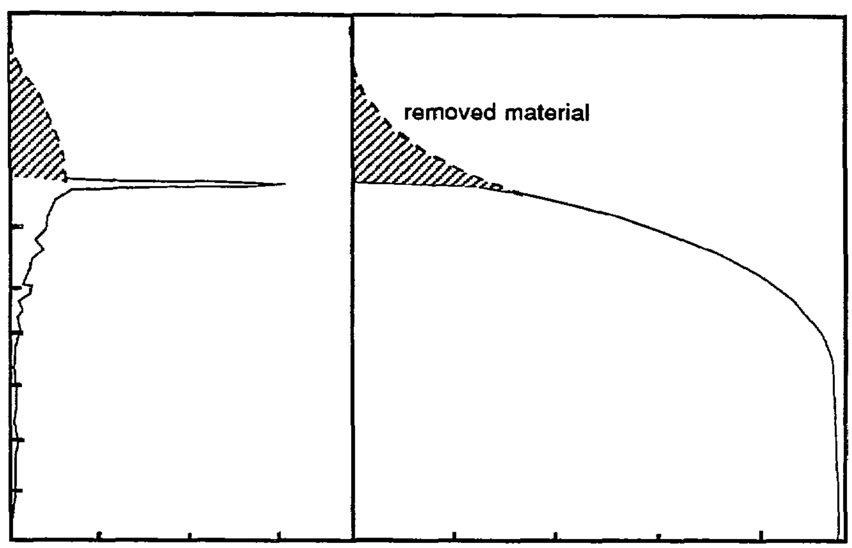


figure 14

**Probability plotting**

On of the most promising developments in the use of the **BAC** is the implementation of the **normal probability** scale, often used by statisticians to test for "**normality**". If normal or Gaussian curve is plotted on a normal probability scale, it will form a straight line; much the same as plotting exponential functions on a logarithmic scale. With both types of functions, the slope of the line is proportional to the exponent but with a Gaussian function, the exponent contains the standard deviation (**$R_q$** or **RMS**). When the **BAC** of a plateau honed surface is plotted on a normal probability scale, it forms two straight lines (figure 15), one for each of the distributions; consequently, the roughness of the upper and lower surfaces can be deduced independently by measureing the slope of the lines.

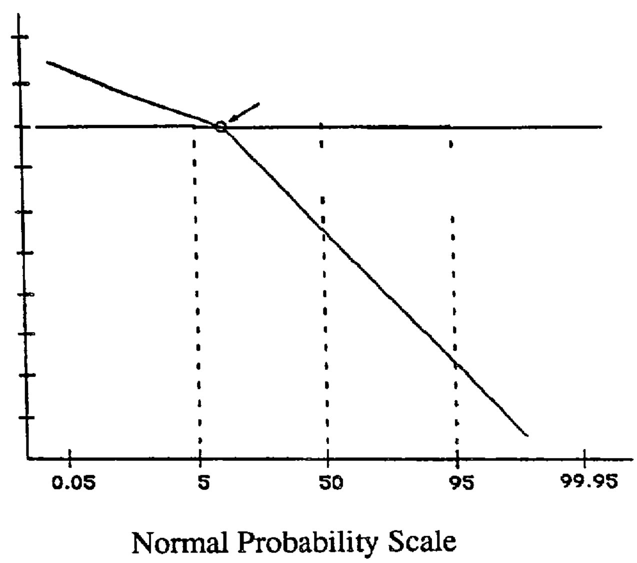


figure 15

**Conclusion**

The advent of digital surface finish measurement equipment has transformed strip chart records representing surfaces into large arrays of numbers, turning a subjective graphical interpretation problem into an exact mathematical solution. Quite often the metrologist does not recognize that once the surface has been digitized, it is no longer a metrology problem; signal processing and statistics are the tools needed to do the actual quantifications. With this in mind, the **BAC** (of pure statistical nature) can be used as an accurate and intuitive description of a surface.

## BIBLIOGRAPHY

**ANSI/ASME B46.1 - 1985** Surface Texture (Surface Roughness, Waviness, and Lay). ASME, New York, 1985.

**DIN 4776** German Standard, Measurement of Surface Roughness - Parameters Rk, Rpk, Rvk Mr1, Mr2 for Describing the Material Portion in the Roughness Profile. German National Standards, draft, Nov. '85.

**ISO 4287/1** Surface Roughness - Terminology - Part 1: Surface and its parameters. International Organization for Standardization, 1984.

**Zipen, R. B.** Analysis of the Rk Surface Roughness Parameter Proposals. Sheffield Measurement Division.

**Ostle, Bernard** Statistics in Research. Iowa State University Press, 1969.

**Whitehouse, D. J.** Assessment of surface finish profiles produced by multi-process manufacture. Proc Instn Mech Engrs, Vol 199 No B4, 1985,

**Feinpruef Corp.** Definitions, Surface parameters. Reference card Edition 01, Nov. '84.

**Thomas, T.R.** Rough Surfaces. Longman Inc., New York, 1982.

**Weniger, W.** Material Ratio Curve. Rank-Taylor-Hobson,1988.

**Weniger, W.** Rk. Rank-Taylor-Hobson,1988.