Characterization of Surface Texture Generated by Plateau Honing Process

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Abstract

The plateau honing operation is being widely used for finishing of cylinder liners for internal combustion engines. Plateau honing has been shown to significantly reduce the costly running-in period due to the fact that very little further modification of the texture is required once the liner is put into operation. In order to better understand, control, and ultimately "engineer" plateau honed surfaces, a comprehensive means of characterizing this texture is required. In this paper the techniques currently used are briefly reviewed and an alternate approach is proposed. The proposed approach is based on analyzing the cumulative distribution plot on a normal probability graph.

Key Words: Surfaces, Honing

1.0 Introduction

The plateau honing operation has gained a great deal of popularity in the finishing of cylinder liners for internal combustion engines. The surface generated by the plateau honing process is an "engineered surface", designed to have the functional characteristics suitable for liner-ring interface. Plateau honing significantly reduces the costly running-in period due to the fact that the generated surface resembles a run-in surface.

In order to better understand, control and ultimately "engineer" plateau honed surfaces, a comprehensive means of characterizing this texture is required. Surface texture parameters such as R_a, described in national and international standards is being used to characterize texture in nearly every possible application. However, parameters of this type are based on models of single process texture. The use of these parameters in the analysis of multi-process texture is not adequate to describe the texture.

Plateau honing is achieved by rough or base honing followed by fine honing or plateauing and hence, the surface generated has texture from two processes. The traditional parameters computed based on the total profile do not provide information regarding the individual processes, namely, roughing and plateauing. Since these two textures have different function, they need to be assessed and controlled separately. In this paper, methods currently used for characterizing plateau honed surfaces are briefly reviewed and then an alternate method for characterizing plateau honed surface that provides information for process control is presented.

2.0 Analysis of Plateau Honed Surface Texture

Plateau honing was developed to generate surfaces that resemble run-in surfaces. The required surface is generated using two processes, the first process is a base honing process using a rough honing stone. The second process is the plateauing process and it is accomplished using a fine honing stone. The fine honing stone truncates the texture generated by the base hone operation. The resulting texture shown in figure 1, provides good lubrication retention and proper bearing surface for the rings.

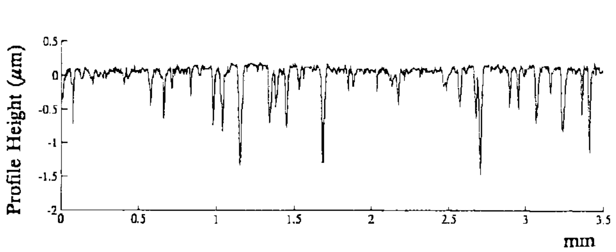


Fig. 1 - Plateau Honed Surface Texture.

The average roughness parameter, R_a, is widely used for characterizing surface texture. This parameter is not well suited for surfaces generated by multi-process manufacture because the average gives no indication of the special texture obtained by combining two processes. One proposed method that uses R_a to characterize plateau honed surface assumes that the plateauing is ideal and relates the R_a value to the truncation level[1]. In reality the plateaus have their own texture, due to the finer stone used in the final stage of the process.

Another method of characterizing plateau honed surface is by the linearization of the bearing area curve, figure 2 [2,3]. An advantage of this method is that it attempts to describe the profile as two independent operation, each of which is modelled separately by a line. The slope of each of these lines gives an indication of the peak to valley height of the triangular wave responsible for that particular line. Thus, an attempt can be made to characterize the base honing operation and the plateauing operation. This linearization is often very subjective due to the very smooth nature of plateau honed surface bearing area curves. Linearity in the bearing area curve is the direct results of triangularity in the profile, figure 3.

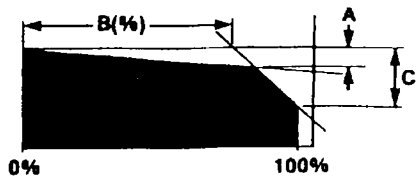


Fig. 2 - Two Line approximation to a Bearing Area Curve.

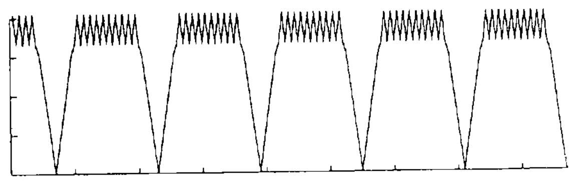


Fig. 3 - Surface Model for Two Line Approximation to a Bearing Area Curve.

The abrasive grains in the honing stone are randomly arranged and furthermore they randomly wear and fracture, exposing new cutting edges to the workpiece. The results of this process is a texture which is very random in nature thus rendering the triangular model inadequate. Santochi and Tantussi proposed a method in which the surface is modelled based on parameters derived from the profiles [4]. The parameters that describe the profile is based on a model similar to the one used in the bearing area linearization method.

A common methodology for characterizing plateau honed surface is using R_k parameters, specified according to DIN 4776 [5]. This approach divides the texture into three regions namely, extreme peaks, core and extreme valleys, figure 4. The implementation of this scheme is based on the computation of a minimum slope line obtained within a 40% t_p window, thus

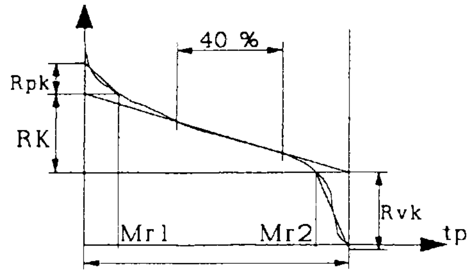


Fig. 4 - Summary of R_k Family of Parameters.

designating the core of the profile. Subsequent computation of parameters based on this line and the regions above and below it result in the following parameters.

R_k - kernel or core roughness depth

R_{pk}- reduced peak height

R_{vk}- reduced valley depth

M_{r1}- material ratio 1: This parameter establishes a measure of the bearing ratio at the depth where the profile core meets the peaks.

M_{r2}- material ratio 2: This parameter establishes a measure of the bearing ratio where the profile core meets the profile valleys.

Studies conducted by a major engine manufacturer have shown no correlation between these parameters and engine performance. In addition, the studies also stressed the need for an accurate assessment of the plateau-to-valley transition point which was intended to be addressed by M_{r2}.

The DIN 4776 method attempts to approximate a two component texture (plateaus & valleys) with a three component model. The desire to understand the two process texture in terms of its basic components namely, plateau roughness, valley roughness and the placement of the plateau roughness within the valley roughness, has led to the development of an alternative method of characterization. The following sections describe the details of the alternate method for characterizing plateau honed surface texture.

3.0 An Alternative Method for Characterizing Plateau Honed Surface

The texture generated by the honing process is essentially the fingerprint of the honing abrasive. Since the abrasive grains within the honing stone are very random in nature, a Gaussian model of each component of the plateau honed surface texture is appropriate, figure 5. The cumulative distribution (bearing area curve) of this Gaussian signal is generally an "s" shaped curve. This "s" shaped curve is very smooth in nature and has an inflection point at the 50% mark which also corresponds to the mean amplitude. This smooth, continuous curve has no distinguishing points along it and is therefore very difficult to utilize in any analysis procedure. However, this curve plots as a straight line on a normal probability paper, figure 6.

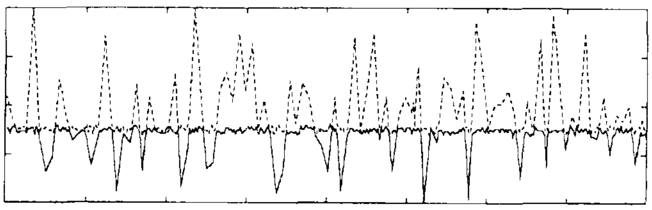


Fig. 5 - Plateau Honing Operation Modeled as Two Gaussian Surfaces.

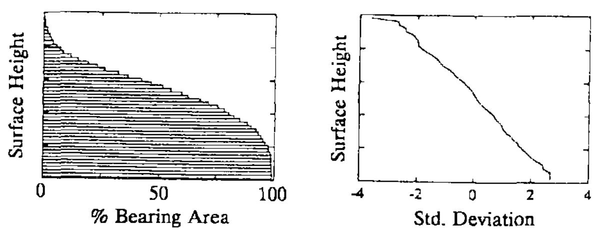


Fig. 6 - Cumulative Distribution of a Gaussian Surface and its Probability Plot.

In terms of the probability plotting of surfaces cumulative distributions (bearing area curves), the slope can be expressed in micrometer per standard deviation and the intercept in micrometers. These parameters are also significant in terms of traditional surface texture analysis techniques. The y intercept, which is the profile mean, is the reference for the evaluation of many surface parameters. Furthermore, the slope of the line is the statistical parameter known worldwide as R_q or the root mean square roughness.

The probability plotting of a surface's bearing area curve was first used by Williamson [6] and subsequently by other researchers [7] to study the run-in process. More recently Whitehouse suggested the use of the probability plotting method for studying the effect of individual processes in a multi-process manufacture [8]. Plateau honing involves two separate stages of honing and thus can be modeled as two Gaussian processes. The plateau honing operation can thus be graphically summarized by presenting the profiles, amplitude distributions, and probability plots of the cumulative distribution is shown below in figure 7 [9]. Figures 7a and 7b represent each individual stage of the plateau honing operation and figure 7c, displays the truncation of the rough honed surface by the plateau surface. The amplitude density function changes slightly with truncation as shown in figure 7c. This is a result of the gaps induced in the original plateau profile by the deep valleys in the rough profile. The area under the amplitude density curve remains unity.

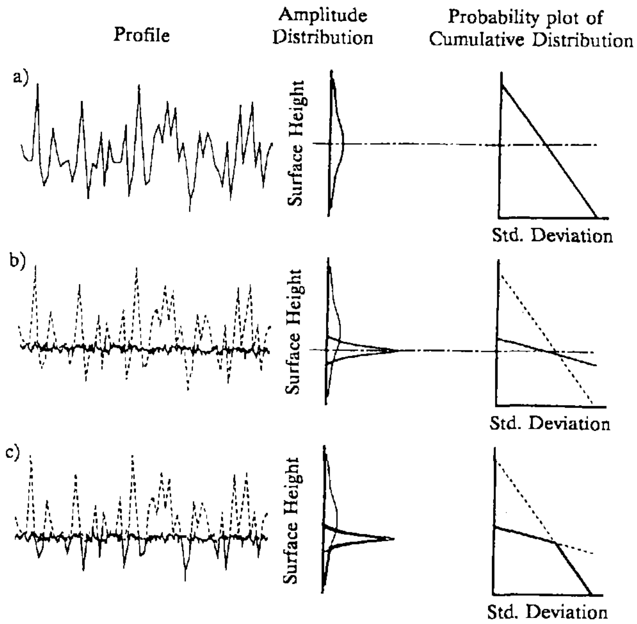


Fig. 7 - Plateau Honing Operation with Gaussian Surfaces.

4.0 Numerical Characterization Based on Probability Model

As a result of the combination of two manufacturing processes, the surface texture, the amplitude density function, and probability plot all show evidence of each process. The probability plot, however, provides quantitative information not readily available in the final plateau honed surface profile. With the probability plot an estimate of the roughness, R_q, of the rough honed surface (valleys) can be made as it is the slope of the lower line. This estimate would be difficult based solely on the profile graph. Similarly, R_q, for the plateauing stage can be determined as the slope of the upper line. These rms roughness values for each process are important in that they provide information regarding fine and rough honing processes which can be used to control the manufacturing operation.

The intercept for each line gives the amplitude of the mean of the respective process. Thus the level of plateauing can be assessed as the difference between these means. In cylinder liners the final plateaus are typically below the meanline of the base-honed surface and the actual plateau depth relative to the base-honed mean line is closely controlled. Graphically this distance can be determined as shown in figure 8.

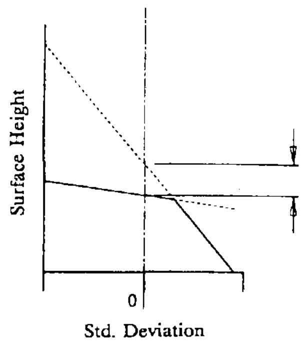


Fig. 8 - The Depth of the Plateau Relative to the Base-Honing.

4.1 The Transition Region

The intersection point of the two lines in the probability plot is also significant in terms of the functionality of the surface. This point defines the separation of plateau and base textures and is an important feature of the model. The rationale behind the two process surface is the fact that each component of the texture makes its own functional contribution. The plateaus and valleys each serve to provide a very different function and an ideal method of characterization would provide information regarding each component separately.

The primary function of the plateaus is to act as a load bearing surface. The ability of a surface to carry or bear loads is indicated by the bearing area curve. The probability plot of the bearing area curve contains this same information. Moreover, the probability plot provides a distinct point at which to distinguish the transition between plateaus and valleys. The bearing area at this transition point (the intersection of the lines) provides a means of assessing the total load carrying capacity of the surface.

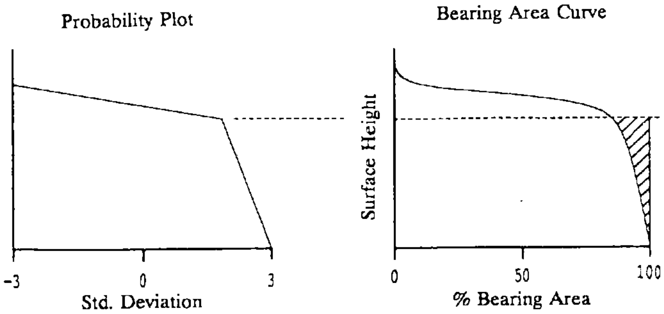


Fig. 9 - The Evaluation of Oil Holding Volume.

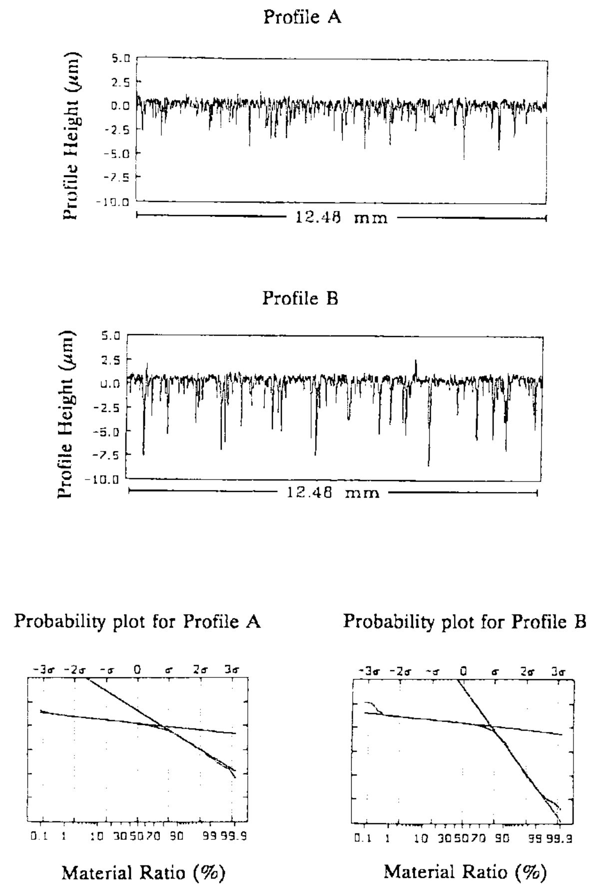
The valleys also have an important role in the function of the plateau honed surface. Their purpose is to serve as reservoirs for lubrication. The oil holding volume of a surface can be measured based on the bearing area curve in terms of the non-material area below a specified depth. In the analysis of plateau honed surfaces the transition point between the plateaus and valleys can serve as the depth at which to begin the assessment of the oil holding volume. This point is often difficult to determine based solely on the linear plot of the cumulative distribution but is readily apparent on the probability plot. This procedure is implemented as shown in figure 9. The region indicated on the linear cumulative distribution plot (bearing area curve) is the area of the two dimensional profile which is associated with the oil holding valleys. This area can be normalized based on the length of the profile and then extruded to form a volume per unit area of the surface. It should be noted that this area can also be assessed on the probability plot. However, due to the X axis scaling in terms of standard deviations rather than linear percentages, it is much easier to transfer the transition depth to the linear plot.

5.0 Results

The proposed method provides three parameters, namely plateau roughness, valley roughness and depth of plateauing. These parameters can be directly related to the honing process through the selection of honing stones, depth of plateauing and selection of process parameters such as the pressure and surface speed. Since this approach independently characterizes the components of two-process texture, process control can be much more specific. One example given below, figure 10, shows the ability of the technique to identify variation in valley roughness due to change in the honing stone. The plateau roughness for the two profiles shown are the same, however the valley roughness is different. Similar results have been obtained for changes in plateau roughness. The results from this analysis have also been used to control the depth of plateauing. This type of characterization provides valuable information that is very useful for process control.

6.0 Conclusion

The Gaussian modeling and subsequent characterization based on the linearization of the probability plot of the bearing area curve has been shown to be an optimal means of modeling and analyzing plateau honed surface texture. This technique has been applied in the analysis of cylinder liner profiles and has proved very useful in controlling the manufacturing process. This modeling and characterization scheme could prove to be very useful in the design, manufacture, and control of plateau honed surface texture with specific functional requirements.



R_q - plateau: 0.361 μm
R_q - valley: 2.044 μm

R_q - plateau: 0.354 μm
R_q - valley: 4.453 μm

Fig. 10 - Analysis of Valley Roughness of Plateau Honed Surface Profiles.

7.0 References

[1] Stout, K. J., Spedding, T. A., 1983, The Characterization of Internal Combustion Engine Bores, Wear, Vol. 83, No.2:311-326.

[2] Hasis, G., An Introduction to Plateau Honing of Engine Cylinder Bores, Report by NAGEL.

[3] Trautwein, R., 1978, Characteristic values for Determining and Evaluating the Surface of Cylinder Bores, Mecury Marine Company.

[4] Santochi, M., Tantussi, G., 1984, Surface Parametrical Mircogeometry and Functional Models: A New Approach, Precision Engineering, Vol. 6., No. 4:201-206.

[5] DIN 4776, 1990, Measurement of Surface Roughness; parameters R_k, R_{pk}, R_{vk}, M_{r1}, M_{r2} for the description of the material portion (profile bearing length ratio)in the Roughness Profile; Measuring conditions and evaluation procedures.

[6] Williamson, J. P. B., 1985, Microtopography of Surfaces, Proceeding of the Inst. of Mech. Engrs., Vol., 182, part 3K: 21 - 30.

[7] Thomas, T. R. 1982, Rough Surfaces, Longman Group limited, U.K.

[8] Whitehouse, D. J., 1985, Assessment of Surface Finish Profiles Produced by Multi-Process Manufacture, Proceeding of the Inst. Mech. Engrs. , Vol. 199, No. 4: 263 - 270.

[9] Malburg, M. C., 1989, The Characterization of Surface Texture Generated by Multi-Process Manufacture, M. S. Thesis.