**Contemporary Engineering Sciences, Vol. 11, 2018, no. 78, 3883 - 3892**
**HIKARI Ltd, www.m-hikari.com**
**https://doi.org/10.12988/ces.2018.88426**

# Probability Parameters and Estimated Firestone Abbott Plateau Honing Curves

**Milton Coba Salcedo[1], Guillermo Valencia Ochoa[2] and Carlos Acevedo Peñaloza[3]**

[1] Mechanical Engineering, Dept. of Mechanical Engineering
Faculty of Engineering, Universidad del Atlántico
Carrera 30 Número 8 - 49, Puerto Colombia – Colombia

[2] Mechanical Eng., Efficient Energy Management Research Group – Kaí
Universidad del Atlántico, Carrera 30 Número 8 – 49
Puerto Colombia – Colombia

[3] Mechanical Engineering. Universidad Francisco de Paula Santander
Mechanical Engineering Department, Avenida Gran Colombia No. 12E-96,
Cúcuta, Norte de Santander, Colombia



## Abstract

This paper developed a methodology for estimating Abbott-Firestone curves from the roughness parameters of the material probability curves. The surface roughness profile obtained in plateau-honing processes is the superposition of the effects of the two processes used to generate it. At first, a honing is performed with which the characteristics of valleys are generated, honing base, and after this honing base, a finishing honing is performed, a plateau operation to reduce the peaks of the base honing profile without modifying the characteristics of the valleys of the base profile. In the functional behaviour of the surface, the valleys will contribute to the retention of oil and the flat areas will contribute to reducing friction with the oil retained in the valleys and to improving watertightness. To characterize this type of roughness obtained by the superposition of the roughness generated by two processes, material probability curves are suitable, in which the roughness of each process is characterized by the slope of a line, and the point of intersection of both lines corresponds to the transition zone between plateaus and valleys. The roughness parameters other than those of the probability curve do not adequately characterize the roughness obtained by processes such as plateau-honing, since they are calculated on the total height of the roughness profile and do not separate the effects of the processes that have been used to obtain it, which means that the contribution of each of the processes to the roughness profile cannot be differentiated.

**Keywords**: Honing, plateau honing, curves materials

## 1. Introduction

The surface profiles generated by abrasive processes such as honing have a more or less symmetrical distribution of heights and this has led many researchers to assume that the representation of this distribution of heights of the profile with a Gaussian model is convenient even though it does not exactly approximate this one [1]. This allows for the introduction into the surface characterization of a series of statistical tools that are extensively described in the literature [2]. One of these is the representation of the cumulative distribution of the profile heights generated by the honing as a function of the percentage of material, is the Abbott-Firestone material percentage curve. This curve usually hasn't shape. If this cumulative distribution (Abbott-Firestone curves), instead of being represented as a function of the percentage of material, is represented as a function of the standard deviation, the probability curve is obtained. These curves, when the profile heights are represented as a function of the standard deviations, approach a straight line. In the case of plateau-honing, the two straight lines corresponding to the two accumulated distributions of each of the profiles that characterize each of the stages of the process, base honing and finishing honing are obtained. The slope of each of the lines will represent the roughness Rq of each of the stages of the process, as mentioned above, and the point of intersection plateau-valley is determined by the parameter Rmq. All this allows the individual effect of each process to be studied. This is the independence of the parameters of the probability curve, as each parameter provides information specific to each stage of the process.

In the European PROHIPP project, functional life tests were carried out on the piston seals of mechanized hydraulic cylinders with different plateau-honing finishes to determine the plateau-honing that caused a lower level of wear on the seals and therefore a greater number of hours of correct operation and life of the seals. Once the most suitable type of plateau-honing has been determined, characterised by the roughness parameters Rvq, Rpq and Rmq [3], the corresponding probability curve is determined from the values of these parameters and from this the estimated percentage curve of Abbott-Firestone material is obtained, corresponding to the base honing process as a function of the Rvq, and the Abbott-Firestone curve corresponding to the finishing honing process as a function of the Rpq.

If the Abbott-Firestone curve estimated from the probability parameters is to be obtained, errors associated with the fact that the honing and plateau-honing processes are not entirely Gaussian are made in the procedure for obtaining the curve, and small errors are also made when considering the probability curves formed by perfect lines and when relating the standard deviations with the percentages from the perfect Gaussian bell. Basically, small errors are made at the ends of the lines and in the equivalence between the standard deviations and the percentages deduced from considering a perfect Gauss bell. To check whether the error made when using the estimated Abbott-Firestone curves is significant or not, the estimated Abbott-Firestone curves from the probability parameters have been compared with the measured Abbott-Firestone curves, for different machining conditions, in order to quantify the degree of error made if the estimated curves are used. The differences between the corresponding sums of the heights below the curves have been compared and it has been found that the errors committed are acceptable and are within the level of dispersion that is obtained by the process itself.

## 2. Methodology

**2.1. Representation of the probability curve as a material percentage curve.**
According to ISO 13565-3 [4], the material probability curve is the representation of the material percentage curve in which the percentage of material length is expressed as a Gaussian probability, in standard deviation values, drawn linearly on the horizontal axis, as shown in Figure 1.

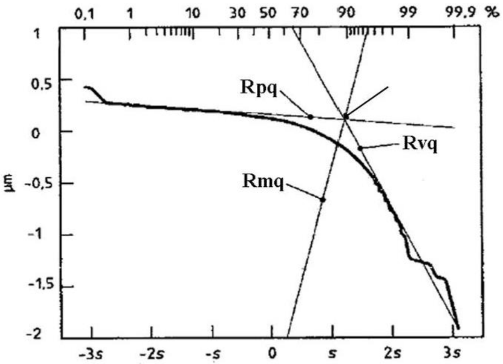


Figure 1. Probability curve of the height distribution as a function of percentage and standard deviation.

The probability curve is the Abbott-Firestone curve, but where the cumulative distribution of profile heights is plotted according to the standard deviation scale and not according to the percentage of material as in the Abbott-Firestone curve. Whitehouse suggested this method [5], of graphing the cumulative distribution of the profile heights as a Gaussian probability function, so that in the case of plateau-honing it would show two straight lines that would reflect the cumulative distribution of each of the processes that have been used, by means of their Gaussian probability functions, since these would always be reflected in the profile as shown in Figure 2.

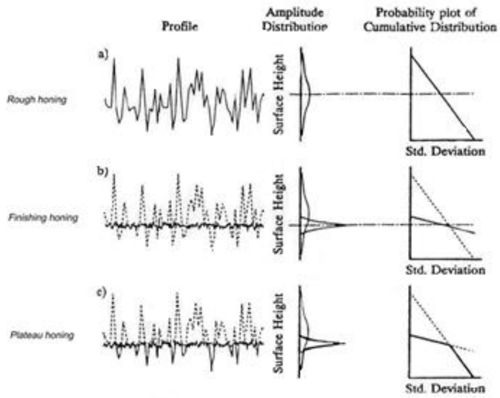


Figure 2. Gaussian probability function in the plateau-honing profile [73].

## 3. Results and Discussion

In this section the probability curves are constructed from the corresponding values of the roughness parameters of the probability curve. The starting values are obtained from experimental tests. The profile heights generated will then be plotted according to the percentage of material to obtain the Abbott-Firestone curves and finally these estimated curves will be compared with the Abbott-Firestone curves measured on the surfaces obtained in the experimental tests. Figure 3, shows an estimated curve that has been calculated using this method with the corresponding measured curve.

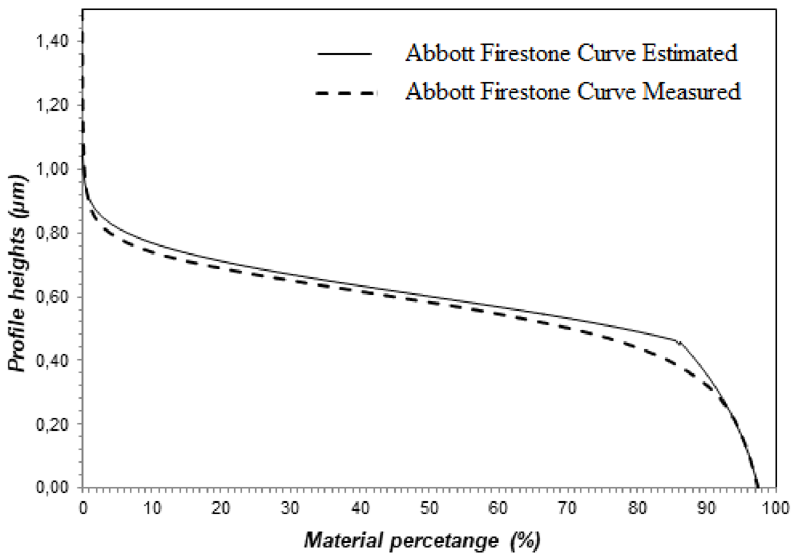


Figure 3. Comparison diagram of Abbott-Firestone curves.

The probability curve is represented by some parameters, such as the Rmq, which is the intersection point between the slope of the roughing area and the slope of the finishing area, it is represented in % of material, the Rpq that is the slope of the finishing area represented in µm, and the Rvq, slope of the initial roughing or honing zone, it is represented in µm.
The ratio of the standard deviations to the material percentages % is then determined and, taking this ratio into account, the corresponding estimated Abbott-Firestone curves are obtained, which give the distribution of the profile heights as a function of the material percentages %. To compare these estimated curves with the Abbott-Firestone curves measured above the surface, the 0 µm reference point of the estimated curve profile heights is set at 97.5% of material. This for the measured curves has already been explained in the previous chapter how to do it. Here, so that the generated curve is at 97.5%, it is determined that this percentage is equivalent in the probability graph to a standard deviation of 1.95996S, so that the end of the slope of the valley zone is set at that point as shown in Figure 4.

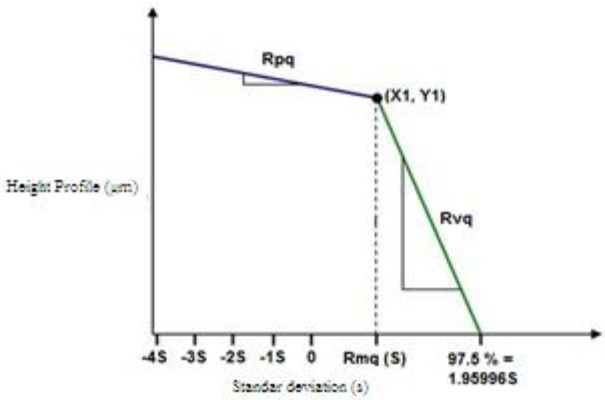


Figure 4. Diagram of the construction of the probability curve.

From the equation of the straight line, the lines for the finishing area and the roughing area are then defined:

$$Y - Y1 = m\cdot(X - X1) \quad (1)$$

Where *(X1, Y1):* Point on the line and *m:* Slope.
Using the intersection points on the line:

$$X1 = Rmq\ (S) \quad \text{and} \quad Y1 = Rvq \cdot (1{,}95996 - Rmq\ (S)) \quad (2)$$

The slope of each of the lines is related to the parameters of the probability curve. The equations that define the lines for each of the zones of the probability curve will be:

$$Y = -Rvq\cdot(X - Rmq(S)) + Rvq\cdot(1{,}95996 - Rmq(S)) \quad (3)$$

$$Y = - Rpq\cdot(X - Rmq(S)) + Rvq\cdot(1{,}95996 - Rmq(S)) \quad (4)$$

These equations allow the different values of profile heights to be generated according to the parameters of the probability curve. This methodology has been developed by the authors, Buj, Vivancos and Coba [6], and validated to estimate the volume of material removed in the finishing honing stage, to a surface with honing base, in order to obtain the desired plateau finish.

### 3.1. Characteristic values of the parameters of the probability curve for the construction of the estimated curves.

To obtain characteristic values of the parameters of the probability curve, 9 tubes with plateau-honing have been machined. The material of the tubes is St- 52 calibrated steel, the length is 386 mm and the initial diameter is 45 mm. An initial honing has been carried out with B64 abrasive stone, and a B20 abrasive stone has been used for the finishing honing, plateau operation. All the pipes have been machined on the industrial machine model BVD 450I, from Honingtec, a manufacturer of honing machines. The base honing has been performed under the conditions of Table 1.

Table 1. Experimental conditions honing base.

| **Abrasive stone (FEPA)** | **Density (FEPA)** | **Aglomeranting** | **Axial velocity (m/min)** | **Tangential Velocity (m/min)** | **Specific pressure ($N/cm^2$)** |
|---|---|---|---|---|---|
| B64 | 50 | L26 | 35 | 35 | 510 |

The finishing process was then carried out with different numbers of passes of the abrasive stone (6, 8 and 10), and 3 tubes were machined for each of the test conditions. Table 4.2 shows the machining conditions used for each of the tubes.

Table 2. Experimental honing conditions of plateau finish.

| **Experiment** | **Abrasive stone (FEPA)** | **Density (FEPA)** | **Pass** | **Pressure ($N/cm^2$)** | **Tangential velocity (m/min)** | **Axial velocity (m/min)** |
|---|---|---|---|---|---|---|
| **P1** | B20 | 40 | 6 | 400 | 30 | 25 |
| **P2** | B20 | 40 | 6 | 400 | 30 | 25 |
| **P3** | B20 | 40 | 6 | 400 | 30 | 25 |
| **P4** | B20 | 40 | 8 | 400 | 30 | 25 |
| **P5** | B20 | 40 | 8 | 400 | 30 | 25 |
| **P6** | B20 | 40 | 8 | 400 | 30 | 25 |
| **P7** | B20 | 40 | 10 | 400 | 30 | 25 |
| **P8** | B20 | 40 | 10 | 400 | 30 | 25 |
| **P9** | B20 | 40 | 10 | 400 | 30 | 25 |

Once the tubes had been machined, the roughness was measured with the roughness meter of the Metrology Laboratory. The measurement conditions have followed the methodology described in the previous chapter for the roughness meter, the measurement position, the measurement points, the data sampling, the roughness parameters and the data filtering. The average Abbott-Firestone material percentage curve has been obtained for each of the experiments, as described in the previous chapter, and will be used later in the curve comparison process. The values of the parameters of the material probability curve, obtained in each of the experiments, are shown in Table 3.

Table 3. Results of the measurement of the roughness parameters.

| ***Experiment*** | ***Rmq (%)*** | ***Rpq (µm)*** | ***Rvq (µm)*** |
|---|---|---|---|
| **P1** | 80,57 | 0,151 | 0,523 |
| **P2** | 79,82 | 0,170 | 0,541 |
| **P3** | 80,73 | 0,162 | 0,531 |
| **P4** | 89,42 | 0,139 | 0,531 |
| **P5** | 87,19 | 0,133 | 0,512 |
| **P6** | 87,99 | 0,120 | 0,536 |
| **P7** | 93,29 | 0,107 | 0,584 |
| **P8** | 93,14 | 0,119 | 0,499 |
| **P9** | 90,38 | 0,123 | 0,436 |

The means and standard deviation of each group of 3 tubes have also been calculated in order to adequately analyze the differences of each group of conditions. Table 4.

Table 4. Average of the roughness parameters for each group of pipes.

| ***Exp.*** | ***Mean Rmq*** | ***Deviation Rmq*** | ***Mean Rpq*** | ***Deviation Rpq*** | ***Mean Rvq*** | ***Deviation Rvq*** |
|---|---|---|---|---|---|---|
| P1-P3 | 80,37 | 0,485 | 0,161 | 0,009 | 0,532 | 0,009 |
| P4-P6 | 88,20 | 1,129 | 0,131 | 0,009 | 0,526 | 0,013 |
| P7-P9 | 92,27 | 1,638 | 0,116 | 0,008 | 0,506 | 0,074 |

**3.2. Material probability curves determined from the parameters.**

The following characteristic curves were constructed from the roughness values of the probability curve parameters and the corresponding equations.

- 6 passes of B20

The values of the probability parameters that characterize this group of machined surfaces are: *Rmq = 80.37% , Rpq = 0.1615 µm and Rvq = 0.532 µm*

The probability curve determined is shown in Figure 5.

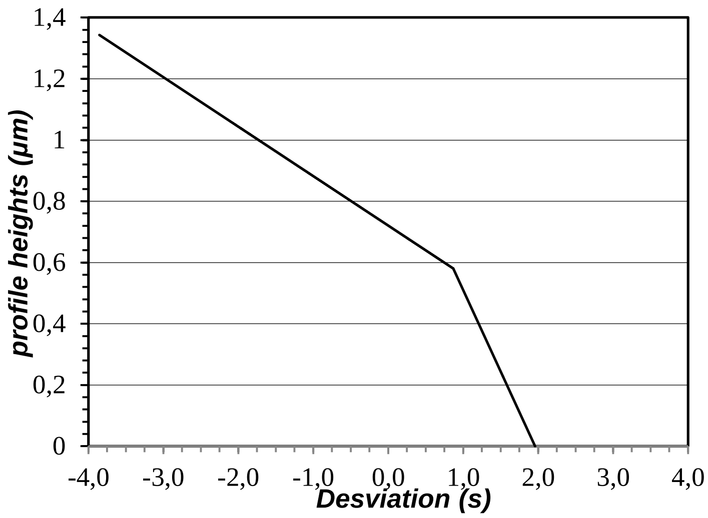


Figure 5. Probability curve determined for roughing B64 and 6 finishing passes B20.

### 3.2. Comparison between the estimated Abbott-Firestone curves and the actual Abbott-Firestone curves of the measured *plateau-honing* surfaces

The Abbott-Firestone curves measured are now compared with the estimated curves. This allows us to check the goodness of estimating Abbott-Firestone curves from the parameters of the probability curve.

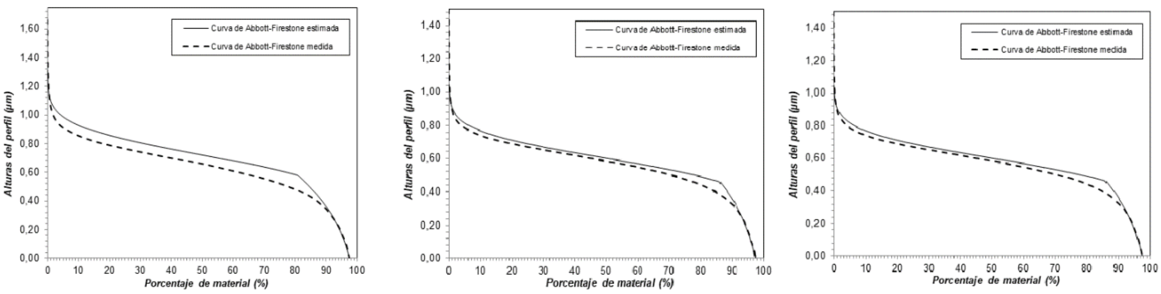


Figure 6. Comparison between the estimate and actual Abbott-Firestone curves

### 3.3. Calculation of the difference between the estimated curves and the measured curves.

In order to study the real difference between the measured curves and the estimated curves, the difference in the sum of the heights between them is analyzed, since the area under each curve will be the sum of the products of each height by the length interval of the profile and since these length intervals are constant and equal for both curves being compared, it is simplified using only the sum of the heights of the profile. To do this, the sum of the heights of each Abbott-Firestone curve is calculated, both for the estimated and for the experimental measurement, and then the relative error is calculated using the expression:

$$\%\text{Relative error} = \frac{(\sum \text{Heights of the estimated curve} - \sum \text{Heights of the measured curve})}{\sum \text{Heights of the measured curve}} \text{x}100 \quad (5)$$

It can be seen in Table 5. that the differences between the sums of the heights of the curves estimated from the parameters of the probability curve and the measured curves is around 10%, which is an acceptable value taking into account the dispersion of the data handled.

Table 5. Differences in the summation of the heights of the Abbott-Firestone curves.

| | | *6 Passes* | *8 Passes* | *10 Passes* |
|---|---|---|---|---|
| Estimated Abbott Curve | *SLM(hi)* | 686,95 | 578,77 | 429,00 |
| Abbott Curve Measurement | *SLM(hi)* | 626,48 | 555,74 | 413,82 |
| Relative difference | *%* | 9,65 | 4,15 | 3,67 |

Table 6 shows the sum of the initial heights of each surface before the finishing passes and the sum of the final heights after the corresponding finishing operation. It can be seen that with the increase in the number of passes, the profile heights are lowered more, but the percentage of heights of material lowered per pass is lowered.

Table 6. Percentage of material removed in passes.

| | | *6 Passes* | *8 Passes* | *10 Passes* |
|---|---|---|---|---|
| **Initial Abbott Curve** | SLM(hi) | 1165,6 | 1062,4 | 1085,2 |
| **Final Abbott Curve** | SLM(hi) | 626,48 | 555,74 | 413,82 |
| **Percentage reduced** | % | 46,25 | 47,69 | 61,86 |
| **Reduced percentage x pass** | % | 7,71 | 5,96 | 6,18 |
| **Parameter Rmq** | % | 80,37 | 88,20 | 92,27 |

## 4. Conclusions

A methodology has been developed to obtain the estimated Abbott-Firestone curves from the values of the roughness parameters of the probability curve, and to verify that the error made by comparing the estimated Abbott-Firestone curve with the measured Abbott-Firestone curve is less than 10%. It was also observed that the amount of material removed per pass decreases as the number of passes increases. It will be important to define the number of passes required to obtain the desired *plateau.*

## References

[1] S. Rief and F. Ströer, S. Kieß, M. Eifler, J. Seewig, An Approach for the Simulation of Ground and Honed Technical Surfaces for Training Classifiers,

*Technologies*, **5** (2017), no. 4, 66.
https://doi.org/10.3390/technologies5040066

[2] V. Havran and M. Sbert, Surface Reflectance Characterization by Statistical Tools, in *Proceedings of the 31st Spring Conference on Computer Graphics*, (2015), 39–46. https://doi.org/10.1145/2788539.2788544

[3] R. Joliet, M. Kansteiner and P. Kersting, A process Model for Force-controlled Honing Simulations, *Procedia CIRP*, **28** (2015), 46–51.
https://doi.org/10.1016/j.procir.2015.04.009

[4] ISO 13565-3:1998. Geometrical Product Specifications (GPS) -- Surface texture: Profile method; Surfaces having stratified functional properties -- Part 3: Height characterization using the material probability curve.

[5] M. C. Malburg, J. Raja and D. J. Whitehouse, Characterization of Surface Texture Generated by Plateau Honing Process, *CIRP Ann.*, **42** (1993), no. 1, 637–639. https://doi.org/10.1016/s0007-8506(07)62527-x

[6] I. Buj, J. Vivancos-Calvet and M. Coba, Método para el control de un proceso de bruñido de superficies para generar rugosidades con valles y mesetas planas, 2012.

**Received: August 25, 2018; Published: September 12, 2018**