Characterization of Surfaces

Introduction

During the fabrication process of any surface of a material, anomalies to the surface can be created. The irregularities of the fabricated surface during a process can have an important effect in the optical, mechanical and electrical properties of the surface of the material. The irregularities can also cause changes in the behavior characteristics of the material in terms of its weariness, water resistance, friction, bearing, lubrication, corrosion, etc. For this reason, it is very important to control the fabrication process by monitoring the surface structure of the material at key process points.

Classification of irregularities

A surface can have the following kind of irregularities:

1) Form and position errors

2) Waviness

3) Roughness

Form and position errors are large-scale z-axis process errors, while waviness and roughness are of small-scale z-axis process errors (waviness being of low frequency form and roughness of high frequency form).

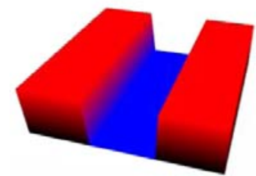
If a system is characterizing the surface form, the system is called a profilometer. In contrast, if the system is evaluating the waviness or the roughness of the surface, the system is called a roughness profilometer.

According to metrology definitions, surfaces are classified as following:

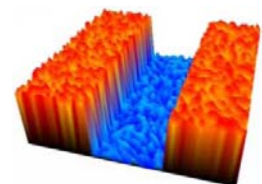
• **Nominal surface**: This is the ideal surface defined by the design. In practice this surface does not exist.

• **Real surface**: This is the physical surface that limits the body.

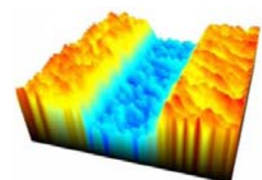
• **Measured surface.** This is the obtained surface by any measurement system.



Nominal Surface



Real Surface



Measured Surface

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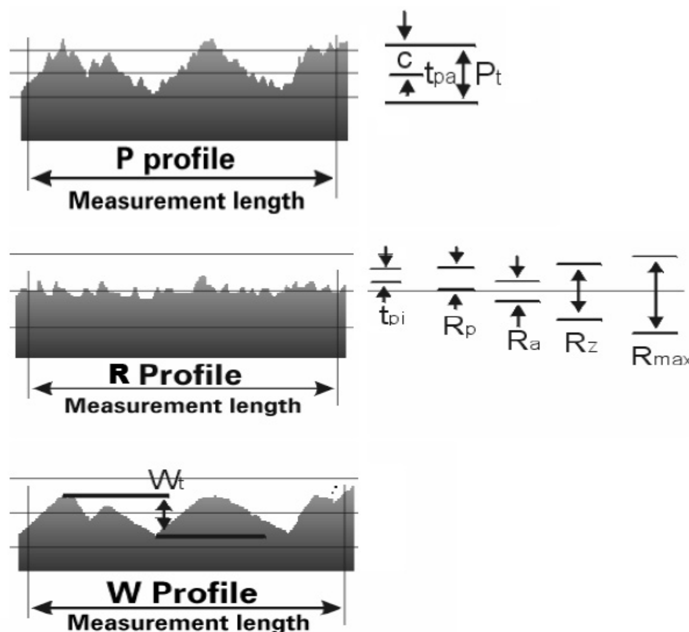
Basis of the irregularities

The performance of a processed surface depends on its irregularities (form, waviness and roughness). The definition of many surfaces is standardized by the measurement of a bi-dimensional profile. In practice, this profile is taken in the direction of greater irregularities. After measurement, the components of the profile may indicate if the surface has low or high frequencies, its skewness and the kurtosis.

The parameters being calculated from the measured surface can be filtrated according to the desired irregularities. For roughness parameters the profile is filtrated with a roughness filter, and the same for waviness.

The non-filtered profile (P profile) has all the irregularities. The parameters Pt and Tpa determined inside the measurement length contain both, the roughness and the waviness irregularities. In contrast, a filtered profile for roughness (R profile), does not contain the waviness irregularities, allowing to calculate the Rz, Rmax, Ra, Rp and Tpi parameters. For a waviness profile (W profile), the roughness is taken off.



Short wavelength

Large wavelength

Sharp surface

Round surface

Periodic

Random

The first requirement for a good evaluation of the correct parameters is the reference line.

All the parameters of the P profile must not contain any position error. In the same way, for the evaluation of the roughness parameters, the profile must not contain any waviness. The reference line is evaluated mathematically so that the area contained from the upper part of the measurement is equal to the area contained from the low part.

In contrast, the roughness and waviness profiles have to be previously separated. The process is done with a filtration. In a contact machine the filtration is done with a RC circuit. For digital instruments, the filtered profile is evaluated as the convolution product:

$$Z'(x) = \int_{-\infty}^{\infty} S(x) Z(x + x_1) dx_1$$

where S(x) is the applied filter and Z(x) is the original profile.

The filters S(x) can be an RC, emulating an electrical filtration, of a Gaussian, for low pass.

These two types of filters can be expressed as:

$$S(x) = \frac{A}{\lambda_c}\left(2 - \frac{A|x|}{\lambda_c}\right) e^{-\frac{A|x|}{\lambda_c}}$$

for the 2RC filter, where A=3.64, and λ_c is a parameter called *long wavelength roughness cutoff.*

For the Gaussian filter the expression is:

$$S(x) = \frac{1}{\alpha\lambda_c} e^{-\pi\left(\frac{x}{\alpha\lambda_c}\right)^2}$$

where $\alpha = \sqrt{\ln 2/\pi} = 0.4697$ and λ_c the same *long wavelength roughness cutoff* parameter.

According to ASME B46.1 standard, the value λ_c has to be chosen depending on the roughness of the surface. The following table shows these values.

Values of λ_c				
Periodic profiles	Non periodic profiles		Cut-Off	Evaluation length
Sm (mm)	Rz (µm)	Rz (µm)	λ_c (mm)	L_e/l_m (mm)
>0.01 – 0.04	up to 0.1	up to 0.02	0.08	0.08/0.4
0.04 - 0.13	0.1 –0.5	0.02 – 0.1	0.25	0.25/1.25
0.13 – 0.4	0.5 – 10	0.1 – 2	0.8	0.8/4
0.4 - 1.3	10 – 50	2 – 10	2.5	2.5/12.5
1.3 – 4	>50	>10	8	8/40

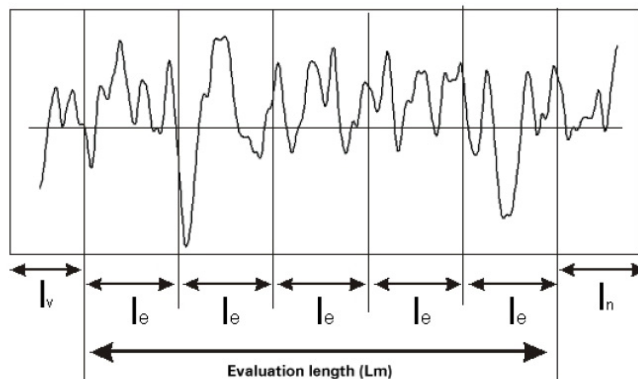
To evaluate the roughness parameters, the R profile is calculated by subtracting the original values from the convolution product of the original data with the filter.

$$R(z) = Z(x) - S(z) \otimes Z(z)$$

To evaluate the waviness parameters, the W profile is directly the product convolution between the original data and the filter.

The roughness parameters are evaluated along the total length called evaluation l_m, which is divided in equal parts called sampling length λ_e. The final parameter is the average of the previous ones.

In a Stylus instrument two more parts are taken in the right and left side to avoid acceleration. These additional parts are not taken into account and are called l_v and l_n.



Surface parameters definition

The key quantities that define a profile are the main deviations from the nominal profile and the distances between these deviations. There are several mathematical deviations that can be applied to the numerical data to describe these deviations.

Height roughness parameters

• **Ra** (*roughness average*)
This is the average value of the absolute profile's data inside an evaluation length, divided by the total length.

$$Ra = \frac{1}{L}\int_0^L |z(x)|\,dx$$

• **Rq** (*root mean square*)
This is the average of the square value of the data of the profile inside an evaluation length.

$$Rq = \sqrt{\frac{1}{L}\int_0^L z^2(x)dx}$$

• **Rp** (*maximum profile peak height*)
Distance between the highest point and the median line.

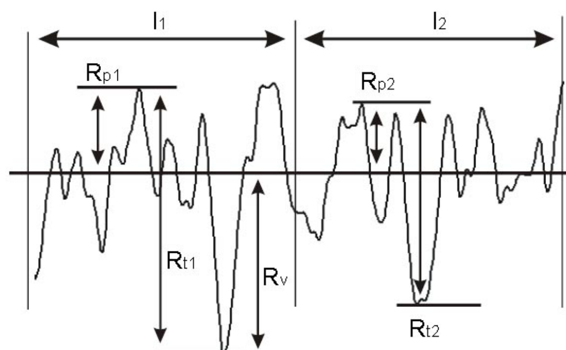
• ***Rv*** (*maximum profile valley depth*)
Distance between the lowest point and the median line.

• **Rt** (*maximum height of the profile*)
Vertical distance between the highest and the lowest point.

$$Rt = Rp + Rv$$

In the DIN 4768 normative, the evaluation length equals to five sampling lengths.

• **Rpi**
Distance between the highest point and the main line for a given sampling length i.



• **Rpm** (*average maximum profile peak height*)
The average of all Rpi for the full evaluation length.

• **Rti**
Vertical distance between the highest and the lowest point for a sampling length i.

• **Rz** (average maximum height of the profile)
Average of all Rti for the full evaluation length.

• **Rmax** (*maximum roughness depth*)
The highest Rti for all the sampling lengths inside the full evaluation length.

Height waviness parameters

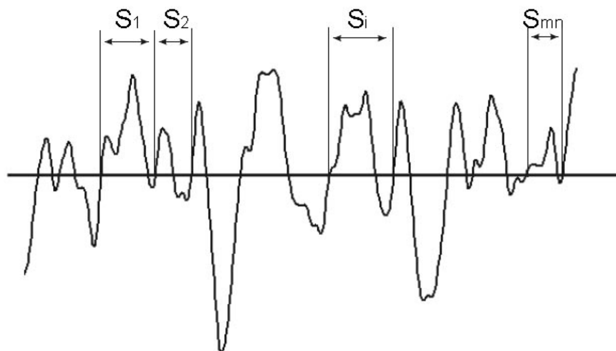
• **Wt** (*waviness height*)
Vertical distance between the highest and the lowest point for a waviness filtered profile.

Space parameters

• **Sm** (*mean spacing of profile irregularities*)
Average of the values of the spacing between irregularities Smi of the profile inside an evaluation length.

• **SAE peak**
An irregularity that crosses twice the main line.

• **Pc** (*peak density*)
The SAE peak density per length unit.



Form parameters

• **ADF(z)** (*amplitude density function*)
Probability density of the profile data height. Usually this is known as the Histogram.

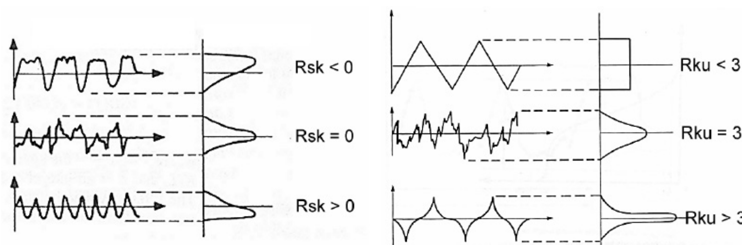
• **BAC** (*bearing area curve*)
This is the addition of the data heights of all the points contained between one parallel line of the main line and the lowest point.

• **Rsk** (*skewness*)
Asymmetry of the profile from the main line. The analytical expression is:

$$Rsk = \frac{1}{R_q^3}\frac{1}{L}\int_0^L Z^3(x)dx$$

• **Rku** (*kurtosis*)
Sharpness measurement of the profile. The analytical expression is:

$$Rku = \frac{1}{R_q^4}\frac{1}{L}\int_0^L Z^4(x)dx$$



Hybrid parameters

• Δ a (*average absolute slope*)
Average of the profile derivative. The expression is:

$$\Delta a = \frac{1}{L}\int_0^L \left|\frac{dZ}{dx}\right| dx$$

where dZ/dx is the local slope. The local derivative can be calculated as:

$$\frac{dZ_i}{dx} = \frac{1}{60d_0}(z_{i+3} - 9z_{i+2} + 45z_{i+1} - 45z_{i-1} + 9z_{i-2} - z_{i-3})$$

being d_0 the distance between two points.

• Δq (*root mean square slope*)
Average of the square points of the derivative of the profile.

$$\Delta q = \sqrt{\frac{1}{L}\int_0^L \left|\frac{dZ}{dx}\right|^2 dx}$$

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