Surface Finish Analysis

April 2 2014
Overview

- The Basics
- Equipment
- Measuring Conditions & Correlation
- Parameters Definitions
- Parameters and Function
Measure What?

- The primary metrological features of a surface are:
  - Size
  - Position
  - Form (or Contour)
  - Waviness
  - Roughness
Why Measure Surface Roughness?

- It’s on the print
- ISO 9000 and QS 9000 compliance
- Find the bad parts
- **Process Control**
Process Control

- Turning and Milling, a great indicator of tool life
- Grinding, when to Redress
- Lapping and Honing
- Extrusion and Injection Molds
The Standards

- ASME B46.1-2002 Surface Texture
- ASME Y14.36-1996 Drawing Indication
- ISO 3287-1995 Instruments
- ISO 4288-1997 Methods
- ISO 4287-1995 Parameters
- ISO 11562-1997 Filtering
- ISO 13565- Plateaued Surfaces
- JIS 0660-1998 Terminology
- JIS 0651-1996 Instruments
- JIS 0610-1997 Waviness
- JIS0601-1994 Designation
True Surface
Suppress Overall Contour
Curve Removal

- **Original Profile**
  - Ra 500µin

- **Curve Removed with λc filter**
  - residual error
  - Ra 35µin

- **Curve Properly Removed**
  - Ra 15µin
Tilt (Inclination)

Compensation

Before

After
Primary Profile

Profile obtained from a quantized measurement profile to which a low-pass filter of cutoff value $\lambda_s$ is applied.

- Any curve or tilt are removed using appropriate compensation
- Lambda s low pass filter applied to eliminate noise
Primary Profile
Waviness Profile

Contour profile obtained by subsequent application of the profile filter $\lambda f$ and the profile filter $\lambda c$ to the primary profile, suppressing the long wave component using the profile filter $\lambda f$, and suppressing the short wave component using the profile filter $\lambda c$. 
Waviness Profile
Roughness Profile

Contour profile obtained from a primary profile by suppressing the long wave component using the high-pass filter of cutoff value λc.
The System

- Motorized Drive Unit with Feedback
- Detector
- Analyzer
Hardware

Detector

Drive Unit

Analyzer
Skid Measurement

• Skid measuring instruments are used to measure roughness only
• Less prone to noise
• Most commonly used
The Skid

- The skid mechanically filters waviness
Skidless Measurement

• Skidless Measuring instruments are used to measure both Roughness and Waviness
• No Skid means you can measure in confined areas
• Skidless Systems are prone to vibration
Cutoff, $\lambda c$, sampling length

<table>
<thead>
<tr>
<th>Ra Range</th>
<th>Sampling length ($\ell$)</th>
<th>Evaluation length ($\ell n$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(0.006) &lt; Ra \leq 0.02 , \mu m$</td>
<td>0.08 mm</td>
<td>0.4 mm</td>
</tr>
<tr>
<td>$0.02 &lt; Ra \leq 0.1 , \mu m$</td>
<td>0.25 mm</td>
<td>1.25 mm</td>
</tr>
<tr>
<td>$0.1 &lt; Ra \leq 2.0 , \mu m$</td>
<td>0.8 mm</td>
<td>4 mm</td>
</tr>
<tr>
<td>$2.0 &lt; Ra \leq 10.0 , \mu m$</td>
<td>2.5 mm</td>
<td>12.5 mm</td>
</tr>
<tr>
<td>$10.0 &lt; Ra \leq 80.0 , \mu m$</td>
<td>8 mm</td>
<td>40 mm</td>
</tr>
</tbody>
</table>
"Roughness filter cutoff length is determined in part by the x and z aspects of the surface under evaluation as related to the intended function of the surface. The roughness filter cutoff length should be chosen by the designer in light of the intended function of the surface. When choosing the appropriate roughness filter cutoff, one must be cognizant that surface features not measured within the roughness cutoff bandwidth may be quite large and may affect the intended function of the surface....."
Lc Filter Distortion

• Wrong Cutoff

• Right Cutoff
Pre and Post

Sample Length

Evaluation Length

Length of Travel
Filter Types

- **Gaussian**  50% Wavelength transmission, Digital Filter, Less Error, Default

- **2RC 75 PC**  Emulated 75% pass RC filter, Phase Corrected, Prone to Gibbs

- **2RC 75**  Emulated 75% pass RC filter, Non-Phase Corrected, Prone to Gibbs, Most common in older equipment

- **Gaussian λs**  50% Digital Filter, ISO BandPass, Less Prone to Stylus and Equipment Variation

- **Gauss Spline**  50% Digital Filter, ISO BandPass, Less Prone to Stylus and Equipment Variation, Little or No Edge Effects
Terminology

Sample Length is a segment of the measured profile used in determining localized occurrences. Always equal to the cutoff length. Referred as $L$, $lr$, $ln$, $le$, but not limited to.

Cutoff Length is the window size used to filter the measured profile. Always equal to the sample length. Commonly referred to as $l_c$, $\lambda c$.

$N$ is number of sampling lengths. Sometimes referenced with subscripts.

Evaluation Length is total of all the sampling lengths used in an evaluation. Commonly referred to as $L_m$.

Pre and Post Lengths is starting and ending lengths used in filtered evaluations. A minimum of $l_c/2$ for gaussian, $l_c$ for RC. Commonly referred as $lr$, start length, end length.

Length of Travel is the total measured length. Commonly referred to as $L_t$.

$L_m = \lambda c * 5$

$L_t = \lambda c * 5 + \frac{\lambda c}{2} \text{pre} + \frac{\lambda c}{2} \text{post}$
Graphical representations of surfaces are scaled much greater vertically than horizontally for the purpose of illustrating vertical deviations.

Aspect ratio (Z:X) = 25:1

Aspect ratio (Z:X) = 1:1
**Stylus Shape**
An ideal shape stylus is a conic stylus with a spherical tip.
Tip radius: \( r_{\text{tip}} = 2 \, \text{\(\mu\)m}, 5 \, \text{\(\mu\)m}, 10 \, \text{\(\mu\)m} \)
Taper angle of cone: \( 60^\circ, 90^\circ \)
In ideal surface roughness testers, the taper angle of each cone is \( 60^\circ \) unless otherwise specified.
**Stylus**

### Relationship between a Cutoff Value and a Stylus Tip Radius

The following table lists the relationship between a roughness profile cutoff value $\lambda_c$, stylus tip radius $r_{tip}$, and cutoff ratio $\lambda_c/\lambda_s$.

<table>
<thead>
<tr>
<th>$\lambda_c$ mm</th>
<th>$\lambda_s$ $\mu$m</th>
<th>$\lambda_c/\lambda_s$</th>
<th>Maximum $r_{tip}$ $\mu$m</th>
<th>Maximum sampling length $\mu$m</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.08</td>
<td>2.5</td>
<td>30</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>0.25</td>
<td>2.5</td>
<td>100</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>0.8</td>
<td>2.5</td>
<td>300</td>
<td>2 Note 1</td>
<td>0.5</td>
</tr>
<tr>
<td>2.5</td>
<td>8</td>
<td>300</td>
<td>5 Note 2</td>
<td>1.5</td>
</tr>
<tr>
<td>8</td>
<td>25</td>
<td>300</td>
<td>10 Note 2</td>
<td>5</td>
</tr>
</tbody>
</table>

Note 1: For the surface under the condition of $Ra>0.5\mu$m or $Rz>3\mu$m, a significantly large error will not usually occur in a measured result even if a stylus of $r_{tip}=5\mu$m.

Note 2: If a cutoff value is 2.5$\mu$m or 8$\mu$m, the attenuation characteristic due to the mechanical filtering effect of a stylus with the recommended tip radius appears outside the defined pass band. Therefore, a small error in a stylus tip radius or shape does not affect parameters calculated from measurements. If a specific cutoff value is required, the ratio must be defined.
Calibration

- Calibrate only when needed, verify as frequently as possible
- ASME says calibration is necessary if verification varies by 10% or more, if using 116uin expect ±2uin on a new patch
- Use High side of standard to calibrate gain, Low side to verify diamond
What most effects correlation?

Setup must be exactly the same - Cutoff Length, Filter Type, Stylus Radius, Measuring Speed, Data Density

Use the same master to calibrate all instruments
Parameter Groups

- Averaging Parameters - $Ra$, $Rq$
- Extreme Amplitude Parameters – $Rz$, $Rt$, $Rp$, $Rv$, $Ry$, $Wt$, $Pt$
  - Peak to Valley Height
  - Single Flaw
- Spatial and Slope Parameters – $Pc$, $Rdq$, $Sm$
- Bearing Ratio Parameters – $tp$, $tpi$, $mr$, $mrd$, $mrc$
  - $Rk$ Family, $Rpq$, $Rvq$, $Rmq$
- Length Ratio\ Scale Parameters
  - $Lo$, $Lr$
  - Fractals
Ra - Average roughness of the evaluated profile

Ra is the arithmetic mean of the absolute values of the profile deviations ($Y_i$) from the mean line.

$$Ra = \frac{1}{n} \sum_{i=1}^{n} |Y_i|$$
Same Surface?

Ra 3.05

Ra 3.08

Ra 3.04
$Rq$ - Mean square roughness

More sensitive to peaks and valleys than Ra, but less robust. Commonly referred to as RMS

$$Rq = \sqrt{\frac{1}{N} \sum_{1}^{N} |Z^2(n)|}$$

$$R_q \approx \sqrt{\frac{Z_1^2 + Z_2^2 + \ldots + Z_n^2}{n}}$$
**Rz** - Average peak to valley height

\[
Rz = \frac{1}{N} \sum_{1}^{N} \left( Z(n)_{\text{max}} - Z(n)_{\text{min}} \right)
\]

\[N = 5\]

- Most versatile process control parameter
- Very sensitive to process changes
- Relatively Robust
- Usage Milled, Turned, Ground, Lathe, Polished Surfaces
- Common usage for DIN/New ISO/ASME
Rz (JIS/Old ISO) - Ten point average peak to valley height.

\[ Rz = \frac{1}{Ni} \sum_{i=1}^{N} \sum_{1}^{i} Z(i)_{\text{max}} - Z(i)_{\text{min}} \]

\[ N = 5, i = 5 \]

• Sensitive to process changes
• Robust
• Usage Milled, Turned, Ground, Lathe, Polished Surfaces
• No longer commonly used
**Rc** - Average peak to valley height with no limit to the amount of peaks and valleys

\[ Rc = \frac{1}{N} \sum_{1}^{N} Z(n)_{\text{max}} - Z(n)_{\text{min}} \]

\[ N = \text{NumberOfPeaks} \& \text{Valleys} \]

- Potential process control parameter
- Very sensitive to process changes
- Most Robust of Amplitude Parameters
- Possible Milled, Turned, Ground, Lathe, Polished Surfaces
- Not commonly used, DIN
$R_p - \text{Maximum peak height}$

\[ R_p = \frac{1}{N} \sum_{1}^{N} Z(n)_{\text{max}} \]

$N = 5$

- Monitor Witness Marks / Clean-up
- Sensitive to process changes
- Usage Ground, Polished, Honed Surfaces
- Common usage for DIN/New ISO
- $R_p$ is the single largest peak in ASME B46.1
$R_v$ - Maximum valley depth

$$R_v = \frac{1}{N} \sum_{1}^{N} Z(n)_{\text{min}}$$

$N = 5$

• Not sensitive to process changes
• Relatively Robust
• Susceptible to inherent material qualities/ porosity
• Great scratch identifier
• Usage Ground, Polished, Honed Surfaces
Ry/Rz1max - Max local peak to valley height.

\[ R_y = Z(n)_{\text{max}} - Z(n)_{\text{min}} \]

\[ N = 5 \]

• Single Flaw Parameter
• Very sensitive
• Max type
Rt- Largest peak to valley height.

\[ Rt = Z_{\text{max}} - Z_{\text{min}} \]

- Very sensitive to anything
- Least Robust
- Single Flaw Parameter
- All Type
Bearing Area Curve (BAC)

- Used primarily for the analysis of load carrying surfaces
- A.k.a. – Wear Curve, Abbott-Firestone curve, Abbott Curve (Firestone dropped after tire problems), Tp Curve
Bearing Area Curve (BAC)

• A Graph of the Material Distribution
• Simply the cumulative distribution of the measure data points
Material Ratio

Typically a **Cut** is specified in %
**Depth** in µm
The calculated **Mr (tp)** value is %
The differences in depth between two specified percentages referred to as the reference depth and slice depth. Used to help guarantee a particular shaped distribution. I.e. flat.
Rk is the core roughness, determined by convolving a 40% line across the Bearing Area Curve. A three line fit is used to quantify the shape of the BAC. Developed for Surfaces with a strong plateau characteristic.
• Rpk is the reduced peak height protruding up from the core roughness
• Used to assure peakless surface with good break-in qualities
Rvk

• Rvk is the reduced valley depth protruding down from the core roughness
• Used to assure adequate valleys for liquid retention, heat dissipation, and removed material reservoirs
Mr1 is the material ratio 1 which is a measure of the amount of peaks.

Used to monitor peak removal.
Material Ratio 2

- Mr2 is the material ratio 2 which is a measure of the amount of peaks and bearing surface, exclusive of valleys.
- Used to monitor material removal and valley volume.
• Vo is a measure of valley volume
• Oil Retention
Pc, HSC, Sm, S

- **Pc** - a measure of the number of peaks per cm (or inch), used to determine texture/aesthetics/adhesion/paintability
- **HSC** – Pc with only an upper threshold
- **Sm, S** – Average Peak Spacing
Cylinder Bore

Rmr = 75% max c = 0.5um from a 5% reference line
Rmr

$Rmr = 75\%$ max $c = 0.5\mu m$ from a $5\%$ reference line
Custom Callouts

Rz1max 120um
Rpmax 90um
Rvmax 30um
2.5mm Lc
12.5mm Le

No more than 3 failures allowed per test