Surface Texture Measurement Fundamentals

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Presentation Scope

• Examples of Why We Measure Surface Texture
• Stylus Based Instruments
• Stylus Tracing Methods
• Filters and Cutoff
• Basic Parameters
• Best Practices
• Correlation Checklist
• Review and Recommendations
• References
Examples of Why We Measure Surface Texture
Examples of Why We Measure - for **Product Quality**

- **Body Paint**
  - *Pc* – Adhesion

- **Cylinder Bore**
  - *Rk* – Oil Consumption
  - *Rvk* – Engine Life

- **Cylinder Head**
  - *R3z, Wt* – Compression

- **Axle Bearing**
  - *Rz, Rmr* – Performance

- **Brake Rotor**
  - *Rz* – Efficiency
Examples of Why We Measure - for *Process Control*

- Surface data has different wavelengths and amplitudes
Examples of Why We Measure – for *Size Control*

- Roughness peak to valley can be >4 times $R_a$
- Surface texture specification should be in appropriate for diameter tolerance
Surface Texture Measurement
Stylus Based Instruments
Classification of Profiling Instruments

- **Stylus Instruments**
  - Capacitance
  - Ultrasonic
  - Inductive
  - Laser

- **Optical Instruments**
  - Focus Detection
  - Interferometry
  - Projected Light

- **Scanning Microscopy**
  - Electron Microscopy
  - Electron Probe Microscopy

- **Non-Conventional Non-Contact**
  - Capacitance
  - Ultrasonic
  - Inductive
  - Laser

- **Inductive Detection**
  - Differential Detection
  - Critical Angle
  - Foucault Method
  - Defect of Focus Method

- **Interferometry**
  - Phase Shift
  - Astigmatic Method
  - Skew Beam Method
  - Confocal Method

- **Projected Light**
  - SEM
  - STM
  - AFM
Early Analog Instrument

- Analog probe
- Analog electronics
- Paper chart recorder
- Mechanical drive, similar to present day
Early Digital Instruments

- Analog probe
- Digital conversion
- Dedicated processors
  - Digital readout
  - Later – CRT display
Portable Instruments

- Battery Operated
- Inductive, skidded pick-up
- Integral or Separate Drive
- LCD Display
- Printer and Output Available
PC-Based Instrument

- Analog probe
- Digital conversion
- Windows® OS
- Surface Analysis Software
Surface Texture Measurement
Stylus Type Tracing Methods
Tracing Surface Irregularities

- Traces are typically done 90° to “lay,” with a conical diamond stylus
- To separate surface wavelengths, a filter is applied to the profile data
Surface Irregularities

Profile (no filter)

Waviness (low pass filter)

Roughness (high frequency toolmarks)
The skid and the diamond are independent, and are in contact with the surface. The skid and diamond follow the surface during measurement.

The surface deviations are measured by the change in the diamond position relative to the plane of the skid.
Skidded Measurement

- Skidded instruments measure **only** Roughness parameters (R…)
- Waviness is filtered out by the skid following the surface.
- Most portable instruments are skidded.
Skidless Measurement

- The diamond alone follows the surface during the measurement.
- Deviations are measured by the change in the diamond position relative to the plane of the drive datum guide.
- Skidless instruments are more expensive than skidded instruments, due to the required straight datum guide.
Skidless Measurement

- Skidless instruments measure Roughness, Waviness and Profile
- Skidless measurements are more accurate than measurements done with a skid
Conical Diamond

60 or 90 degrees

Radius 2, 5, 10µm
Surface Texture Measurement Filters and Cutoff
Measurement Lengths

- Evaluation length of 5 cutoffs is typical for Roughness parameters
Roughness Filters

- A filter is used to isolate the roughness wavelength band
- Filters are Mechanical and Digital
  - Mechanical filters
    - Diamond Radius (valley suppression by diamond radius)
    - Skid (greater or lesser skid “bridging” effect of skid on surface valleys, dependent on skid geometry), also filters out waviness
  - Digital Filters
    - RC (Simulated old analog electrical “resistor capacitor”)
    - Gaussian
- The user selects the “Cutoff” setting used by the filter to isolate the roughness wavelength band
- Filters typically have transmission curves
- Filtered data is centered around a mean line
The Role of Roughness “Cutoff” ($\lambda_c$)

- For roughness, the cutoff value is the longest nominal wavelength to be included in roughness.
- Longer wavelengths are filtered out. Shorter wavelengths are included in roughness.
- Wavelengths longer than the roughness cutoff are usually included in waviness.

Cutoff functions in a method similar to this screening machine – sorting mixed material via screens, into size categories
(\lambda_c) Roughness Cutoff Lengths

- The cutoff selected must be short enough to exclude long wavelengths (waviness)
- The cutoff selected must be long enough for a valid sample (at least 10 toolmarks per cutoff)
- Lengths are defined in ASME and ISO standards
- Cutoff default formerly was .8 mm, now must be defined on the drawing (ASME)

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<td>25.0</td>
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Filter Transmission and Cutoff

- $\lambda_s$ short wavelength cutoff for roughness
- $\lambda_c$ long wavelength cutoff for roughness
- $\lambda_{sw}$ short wavelength cutoff for waviness
- $\lambda_{cw}$ long wavelength cutoff for waviness
Effect of Roughness Cutoff Setting

$\lambda_c = 0.08 \text{ mm}$

$Ra = 1.149 \mu m$
$Wa = 0.229 \mu m$
$Wt = 1.187 \mu m$

$Ra = 0.560 \mu m$
$Wa = 0.827 \mu m$
$Wt = 4.592 \mu m$
Effect of Roughness Cutoff Setting

\( \lambda_c \, 0.08 \, \text{mm} \)

\[ \begin{align*}
R_a &= 0.560 \, \mu\text{m} \\
R_t &= 5.555 \, \mu\text{m} \\
W_a &= 0.827 \, \mu\text{m} \\
W_t &= 4.592 \, \mu\text{m}
\end{align*} \]

\( \lambda_c \, 0.80 \, \text{mm} \)

\[ \begin{align*}
R_a &= 1.149 \, \mu\text{m} \\
R_t &= 6.294 \, \mu\text{m} \\
W_a &= 0.229 \, \mu\text{m} \\
W_t &= 1.187 \, \mu\text{m}
\end{align*} \]
Basic Parameters

\[ R_a, R_q, R_z, R_{\text{max}}, R_p, R_{\text{pm}}, R_v, R_t, W_t \]
Typical Surface Texture Callout

- Typical of ASME Y14.36M-1996
- Other formats are common
Roughness Average ($R_a$)

\[ R_a = AA = CLA \]
\[ R_a \neq RMS \]
\[ R_q = RMS \]

- $R_a$ is the most commonly specified parameter in USA
- Roughness average ($R_a$) is the arithmetic average of the absolute values of the roughness profile ordinates.
Step 1: Calculation of $R_a$

Filtered roughness profile with mean line, peak to valley is 10
Step 2: Calculation of $R_a$

Absolute value is applied to the profile data
Step 3: Calculation of $R_a$

$$R_a \approx \left( \frac{|Z_1| + |Z_2| + \ldots + |Z_n|}{n} \right)$$
Different Surfaces, *Same* $R_a$

- Surface performance is different due to bearing contact
- $R_a$ is often specified and is valuable for monitoring process stability, other parameters may be needed to monitor for surface function
Step 1: Calculation of $R_q$

Filtered roughness profile with mean line, peak to valley is 10
Step 2: Calculation of $R_q$

$$R_q \approx \sqrt{\frac{Z_1^2 + Z_2^2 + \ldots + Z_n^2}{n}}$$
Calculation of $R_z$ (DIN, ASME)

\[ R_z = \frac{(R_{z1} + R_{z2} + \ldots)}{5} \]
Calculation of $R_{\text{max}}$

\[ R_{\text{max}} = R_{z5} \]

Diagram showing the calculation process with labels $\lambda c^1$, $\lambda c^2$, $\lambda c^3$, $\lambda c^4$, $\lambda c^5$, and corresponding $R_{z1}$, $R_{z2}$, $R_{z3}$, $R_{z4}$, $R_{z5}$ for the mean line.
Calculation of $R_p$

$R_p$  \( \lambda c^1 \)  \( \lambda c^2 \)  \( \lambda c^3 \)  \( \lambda c^4 \)  \( \lambda c^5 \)

Mean Line
Calculation of $R_{pm}$

\[ R_{pm} = \frac{(R_{p1} + R_{p2} + \ldots)}{5} \]
Calculation of $R_v$

\[ \lambda c_1 \quad \lambda c_2 \quad \lambda c_3 \quad \lambda c_4 \quad \lambda c_5 \]

Mean Line

$R_v$
Calculation of Waviness Height $W_t$

Generally, a maximum peak-to-valley measurement of waviness (roughness has been filtered out)
Best Practices and Correlation
Best Practices - Mechanical

• Check the following:
  - Skid flush and parallel with surface being measured
  - Skidless drive datum level to surface being measured
  - Drive X axis parallel with part axis
  - Measurement on OD top dead center or bottom of bore
  - Tracing arm assembled properly (set screw or other method)
  - Part held in rigid mount
  - Drive stable and set up free from ambient vibration
  - Surface to be measured clean
  - Measurement 90 degrees to “lay” unless otherwise specified
Best Practices - Mechanical

- Skid or pickup parallel or level to the surface being measured
Best Practices - Mechanical

- Skid or pickup on “top dead center”
- Alignment parallel with part centerline
Diamond Condition

Diamond radius is gone, now a “crater”

Triangle Reference Specimen

Trace of reference specimen indicates diamond is damaged
Correlation Checklist

• If you have a correlation problem on surface finish measurement here are some things to check:
  - Instrument calibration to manufacturer’s method
  - Parameter ($R_a$…) and Standard (ISO, JIS, ASME…)
  - Filter (Gaussian, RC)
  - Cutoff
  - Diamond Radius and included angle
  - Diamond condition
  - Stylus force
  - Skidded or Skidless
  - Part alignment/stability
  - Ambient vibration
  - Data density (X and Z)
  - Measurement location and orientation to lay
Review and Recommendations

• To study surface texture, we filter surface data into wavelength bands.
• The wavelength bands are called Roughness and Waviness.
• Skidded stylus instruments measure only Roughness parameters ($R_\ldots$). Most portable instruments are skidded.
• Skidless stylus instruments measure Roughness, Waviness and Profile.
• Cutoff default formerly was .8 mm, now must be defined on the drawing.
• Use the same cutoff, number of cutoffs, diamond radius, filter type (Gaussian or RC), and parameter(s) that your customer uses and specifies.
• Be aware of standard authority (JIS, ISO, DIN, ASME). Do not assume that parameters are the same!
• Routinely check calibration and diamond condition.
American National Standards

- ASME B46.1-2002 is the current USA standard for Surface Texture
- ASME Y14.36M-1996 (reaffirmed) contains the USA standard for Surface Texture Symbols used on drawings
References


Note: Parameter calculations in this presentation are shown for discussion and purposes of illustration only. Refer to the ANSI/ASME B46.1 - 2002 Surface Texture, Surface Roughness, Waviness and Lay for actual calculations and methods of evaluation.