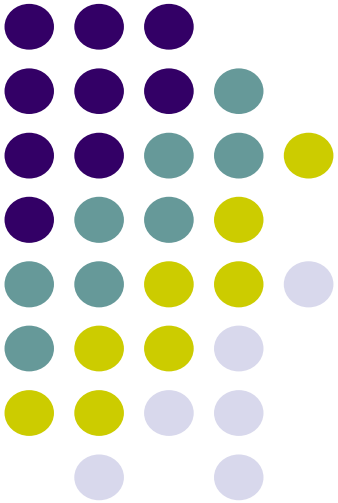
ME 472 – Engineering Metrology and Quality Control

Chp 8 - Measurement of Surface Texture



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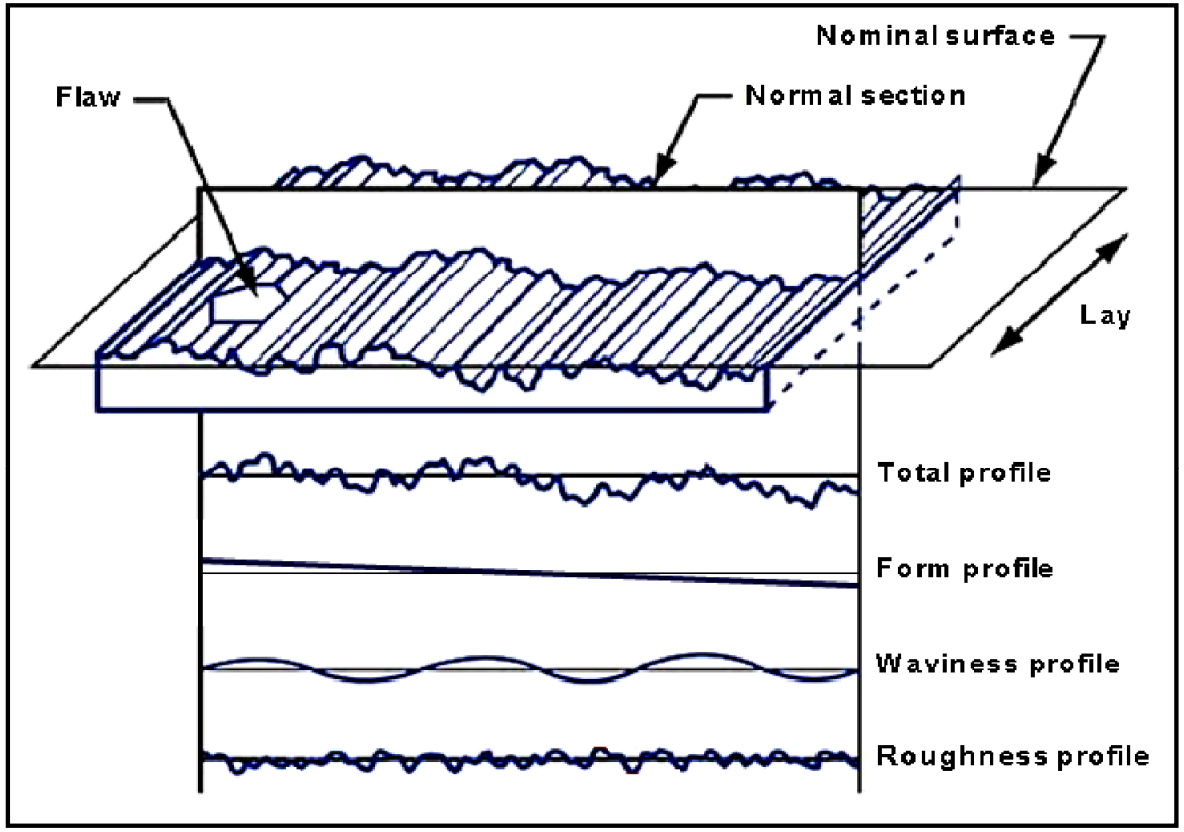
Terminology on Surface Texture

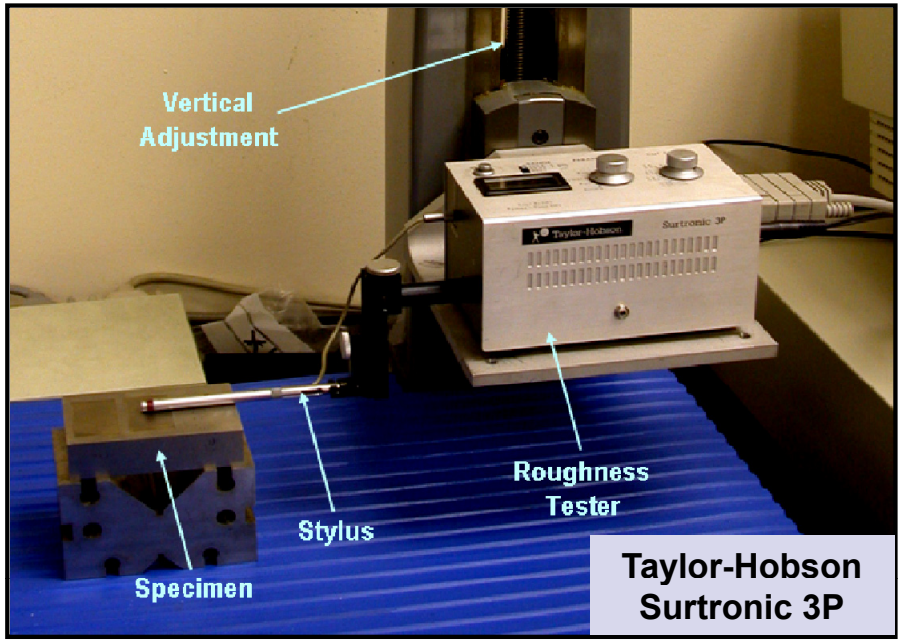
- **Flaw (defect):** random irregularities such as scratches, cracks, holes, tears, inclusions, etc.
- **Lay (directionality):** direction of the predominant surface pattern (see below for various lays).
- **Waviness:** recurrent deviation from a flat surface.
- **Roughness:** closely spaced irregular deviations on a scale smaller than that of waviness.
- **Surface texture (topography):** refers to primary (form), waviness and roughness profiles.
- **Surface finish:** refers to only roughness profile (ignoring the shape and underlying waviness).



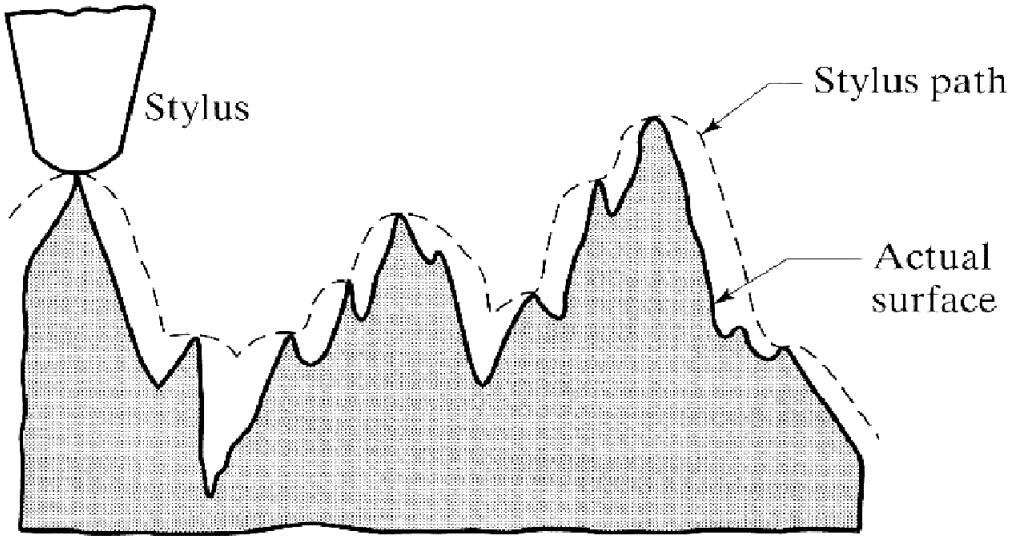
Lay symbol	Surface pattern	Description
=		Lay is parallel to line representing surface to which symbol is applied.
⊥		Lay is perpendicular to line representing surface to which symbol is applied.
X		Lay is angular in both directions to line representing surface to which symbol is applied.
M		Lay is multidirectional.
C		Lay is circular relative to center of surface to which symbol is applied.
R		Lay is approximately radial relative to the center of the surface to which symbol is applied.
P		Lay is particulate, nondirectional, or protuberant.

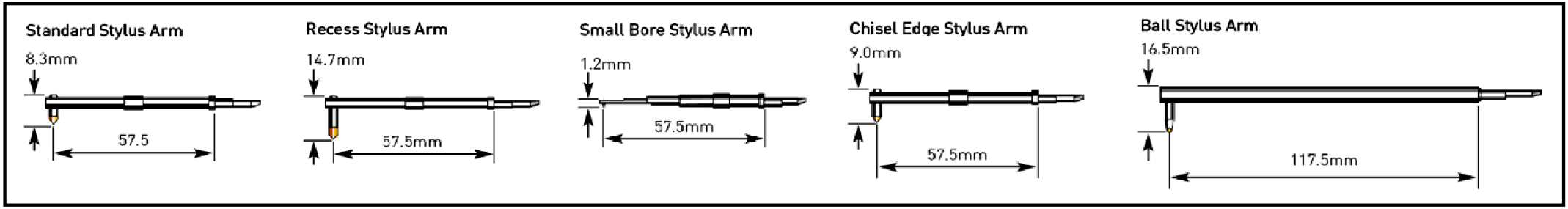
Measurement of Surface Texture

- Surface texture is measured using **a profilometer (roughness tester)**, which consists of **a stylus (tracing probe)** with a perfectly sharp tip made of hard material (e.g. diamond).
- The stylus is set vertically in a way that the tip of stylus will be in contact with the surface at all times.
- Then, the stylus is moved horizontally along the surface to be measured in order to follow the surface contours where the stylus path is smoother than the actual path.
- Various types of stylus are available for different applications.



Taylor-Hobson Surtronic 3P



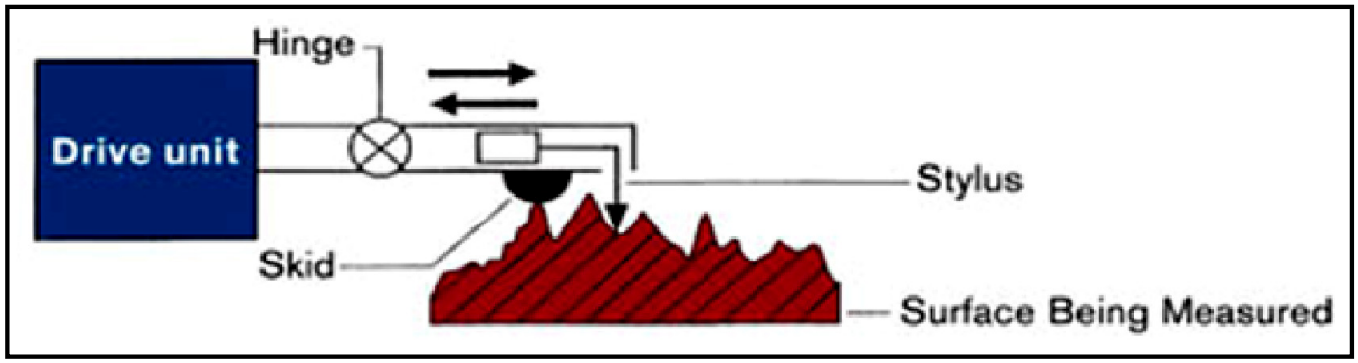


Profilometers (Roughness Testers)

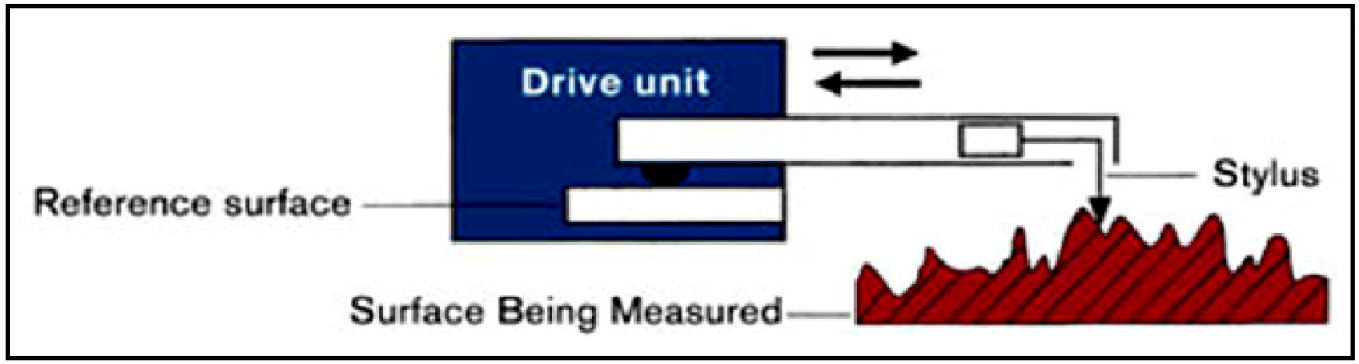
The profilometers are classified as with or without skid:

- **Profilometer with skidded gage:** In skidded gages, the sensitive diamond-tipped stylus is contained within a probe, which has a skid that rests on the workpiece. Thus, skidded gages use the workpiece itself as the reference surface to **measure roughness only**.

- **Skidless gage profilometer:** Skidless gages use an internal precision surface as a reference. This enables skidless gages to be used **not only for roughness, but also waviness and form profiles**.

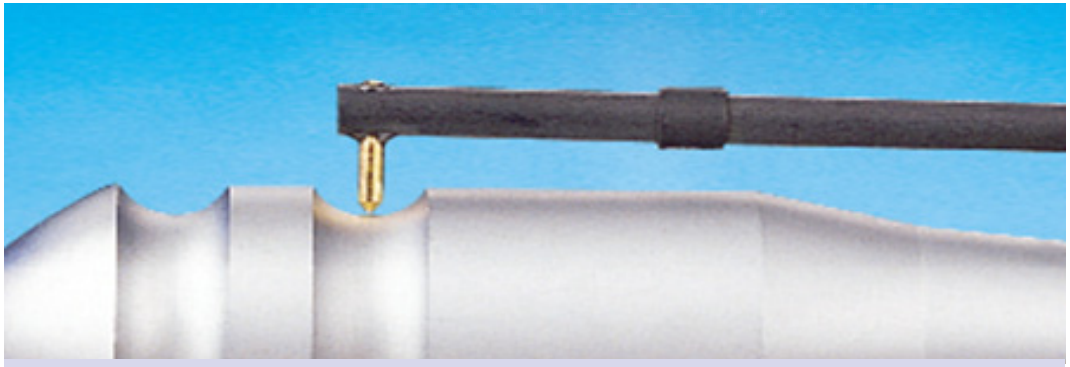


Profilometer with skidded gage

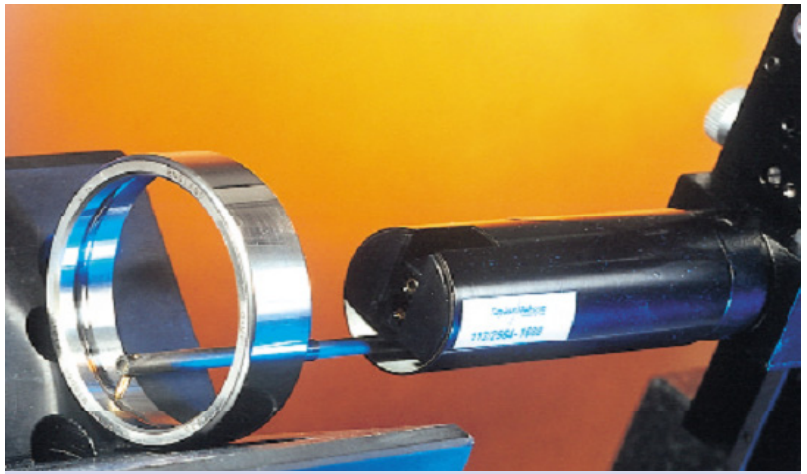


Skidless gage profilometer

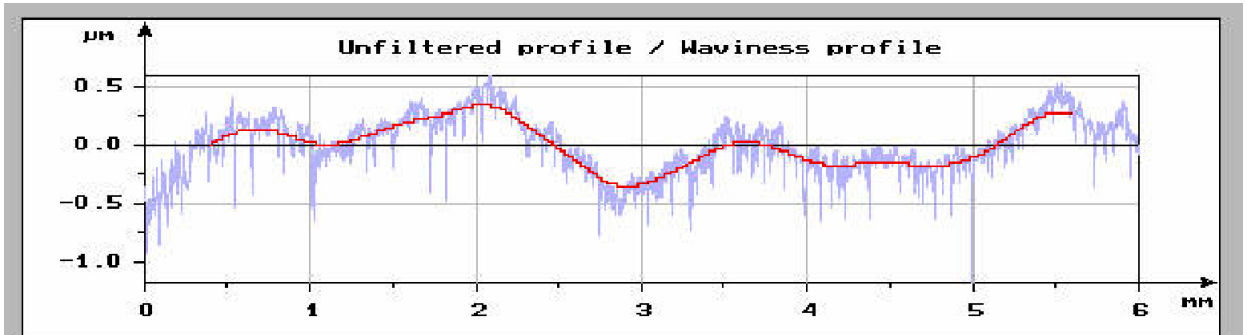
Typical Measurements



Dimension, form and texture can be measured at once over curved or straight surfaces



Measurement of ball tracks and ring grooves using skidless tracing arms



The measured profiles can be evaluated using dedicated software to suppress roughness and waviness profiles

Measurement of inner surfaces of gears

Surface Texture Parameters

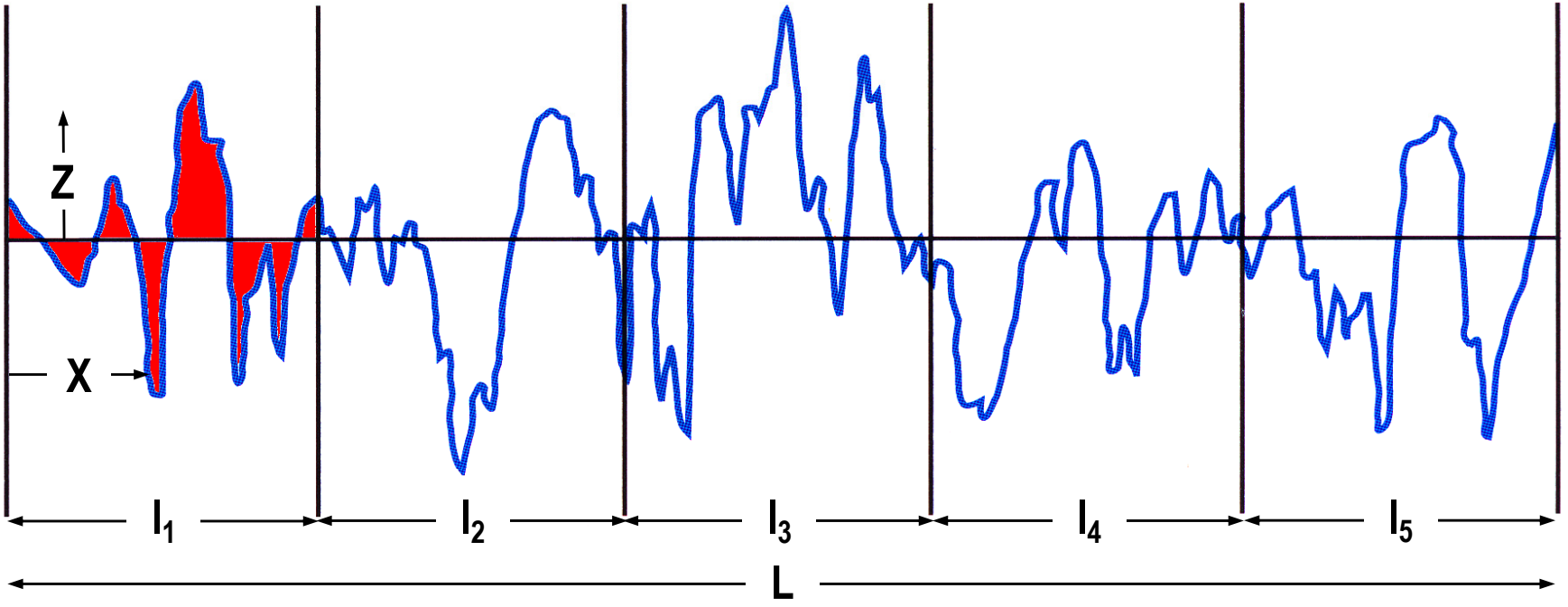
The parameters related with measurement of surface texture are divided into three groups. Table shows the parameters for **primary**, **waviness** and **roughness** measurements:

Parameter Group	Explanation	Parameters		
		Primary	**Waviness**	**Roughness**
Amplitude Parameters	The vertical characteristics of the surface deviations	Pa, Pq, Pv, Pp, Pt, Psk, Pku, Pz	Wa, Wq, Wv, Wp, Wt, Wsk, Wku, Wz	Ra, Rq, Rv, Rp, Rt, Rsk, Rku, Rz, R_{3z}
Spacing Parameters	The horizontal characteristics of the surface deviations	Psm	Wsm	Rsm, RHSC, RPc
Hybrid Parameters	Combination of both vertical and horizontal characteristics of the surface deviations	PΔq, Pλq	WΔq, Wλq	RΔq, Rλq, Rmr, Rpk, Rk, Rvk, Mr_1 and Mr_2

Assessment of Roughness Profile

The profile shown below is a typical 2D roughness profile:

- **Assesment (evaluation) length (L):** Length used for assesing the profile for roughness measurement. For this length, **at least five consecutive lengths** are taken as standard.
- **Sampling length (l):** The mean line is determined, and the profile is divided into equal sampling lengths (from l_1 to l_5).
- **Cut-off length (λ_C):** A filter to remove or reduce unwanted data to look at wavelengths in the assesment region. **Sampling length is also known as cut-off length**.

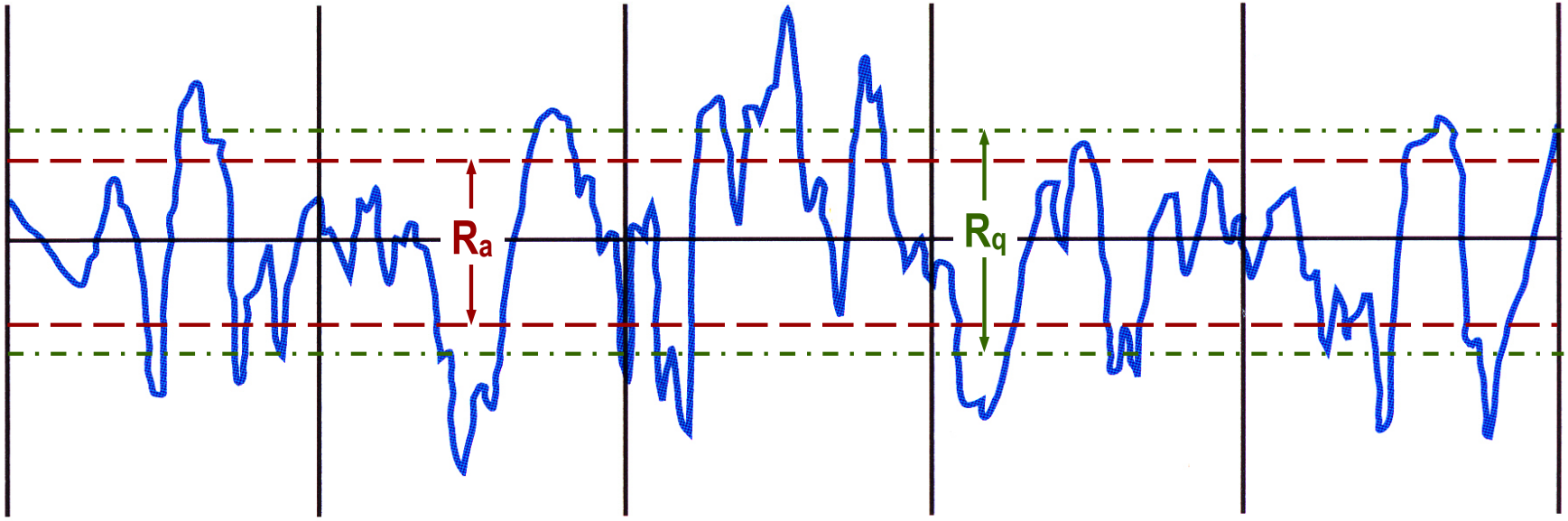


Roughness Parameters – R_a and R_q

- **Roughness Average (R_a):** Universally recognised and commonly used roughness parameter, which is the arithmetic mean of departures from the mean line. It is also known as **Center Line Average (CLA)** or **Arithmetic Average (AA)**.
- **Root Mean Square (RMS) Roughness (R_q):** It is the RMS average of roughness profile ordinates.
- **R_a** is a very stable and repeatable parameter, which makes it good for random type surfaces. However, it cannot provide distinction between peaks and valleys.
- **R_q** is more sensitive to peaks and valleys due to the reason that the amplitudes are squared.

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

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

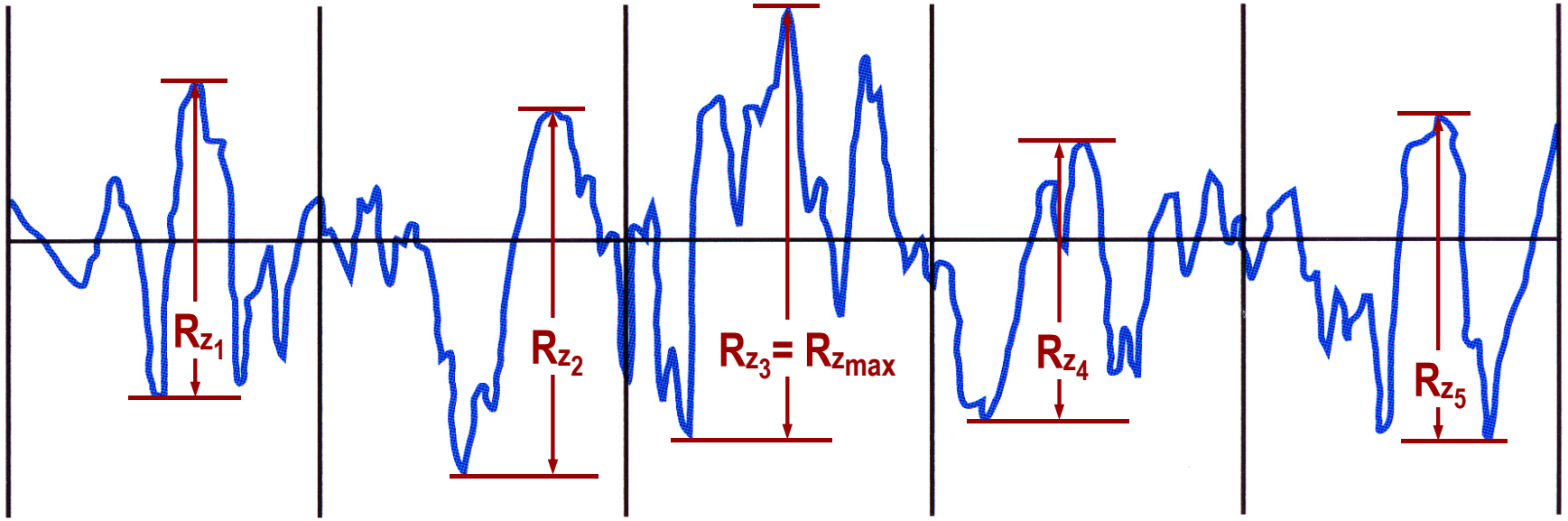


Misinterpretation of Surface Roughness based on R_a

- As said before, it is not possible to make a distinction between peaks and valleys by using **R_a**.
- Three roughness profiles shown below have **the same R_a value** although **they seem to be different**. Therefore, the assesment of these profiles using **R_a** will cause inaccurate conclusions to be made.
- For this purpose, there is need for more specific and sensitive roughness parameters in order to make a more reliable assesment.

Roughness Parameters – R_z and R_{zmax}

- **Mean Roughness Height/Depth (R_z):** The mean of roughness heights/depths at each sample length.
- **Maximum Roughness (R_{zmax}):** The largest of five roughness heights/depths at each sample length.
- **R_z** is more sensitive than **R_a** to changes on the surface as the maximum profile heights are examined rather than average of peak and valleys. In addition, **R_{zmax}** is useful for surfaces where a single defect is not permissible (e.g. a seal with a scratch).
- **R_z** and **R_{zmax}** are used together to monitor the variations of surface finish in a production process. Similar values of them indicate a consistent surface finish, while a significant difference between them indicates a surface defect in an otherwise consistent surface.
- **R_z to R_a Conversion:** Based on **BS 1134/1-1972**, **$4 < R_z / R_a < 7$** (depending on shape of the profile).

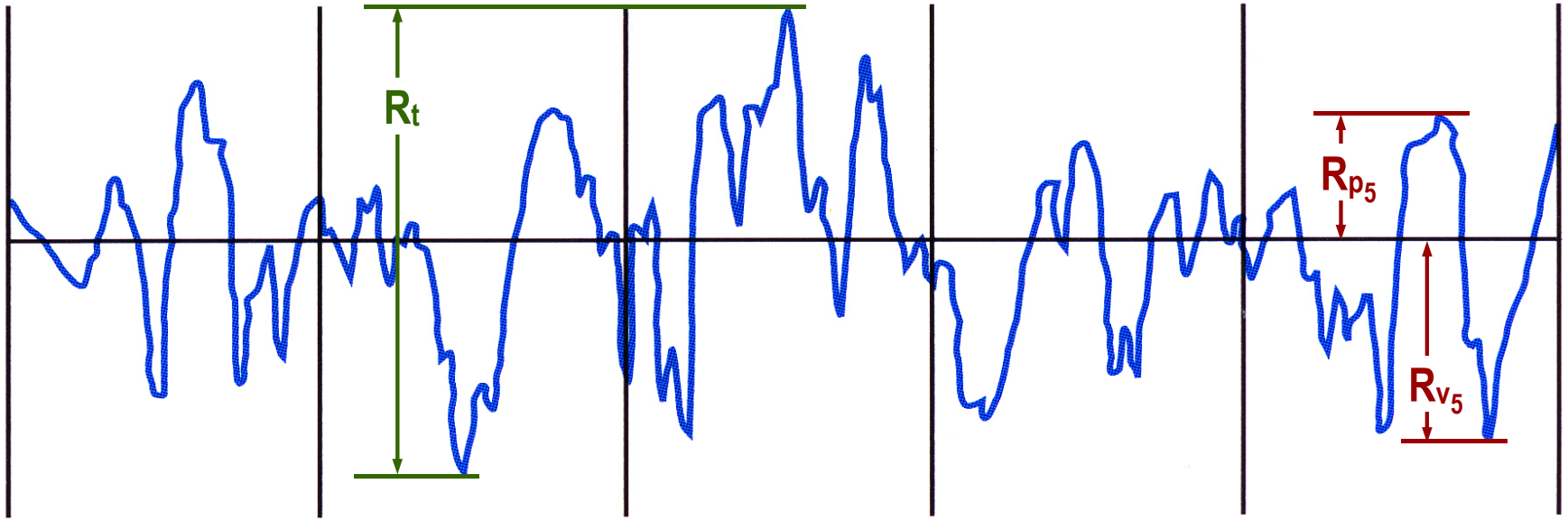


$$R_z = \frac{1}{n}\sum_{i=1}^{n} R_{z_i}$$

$$R_{z_{max}} = \left(R_{z_i}\right)_{max}$$

Roughness Parameters – R_p, R_v, R_t

- **Maximum Height (R_p):** The maximum roughness height (peak) within each sampling length.
- **Maximum Depth (R_v):** The maximum roughness depth (valley) within each sampling length.
- **Mean Levelling (R_{p_m}):** The mean of five consecutive peaks from each sampling length.
- **Peak-to-Valley Roughness (R_t):** The largest peak-to-valley in the entire profile.
- **R_{p_m}** is recommended for bearing and sliding surfaces and surface substrates prior to coating.
- A low value of **R_{p_m}** and a large value of **R_z** indicates a plateau surface.
- The ratio of **R_{p_m} / R_z** quantifies the asymmetry of profile.
- **R_v** is a good parameter where stress is a major factor whereas **R_p** is used to assess coating quality.



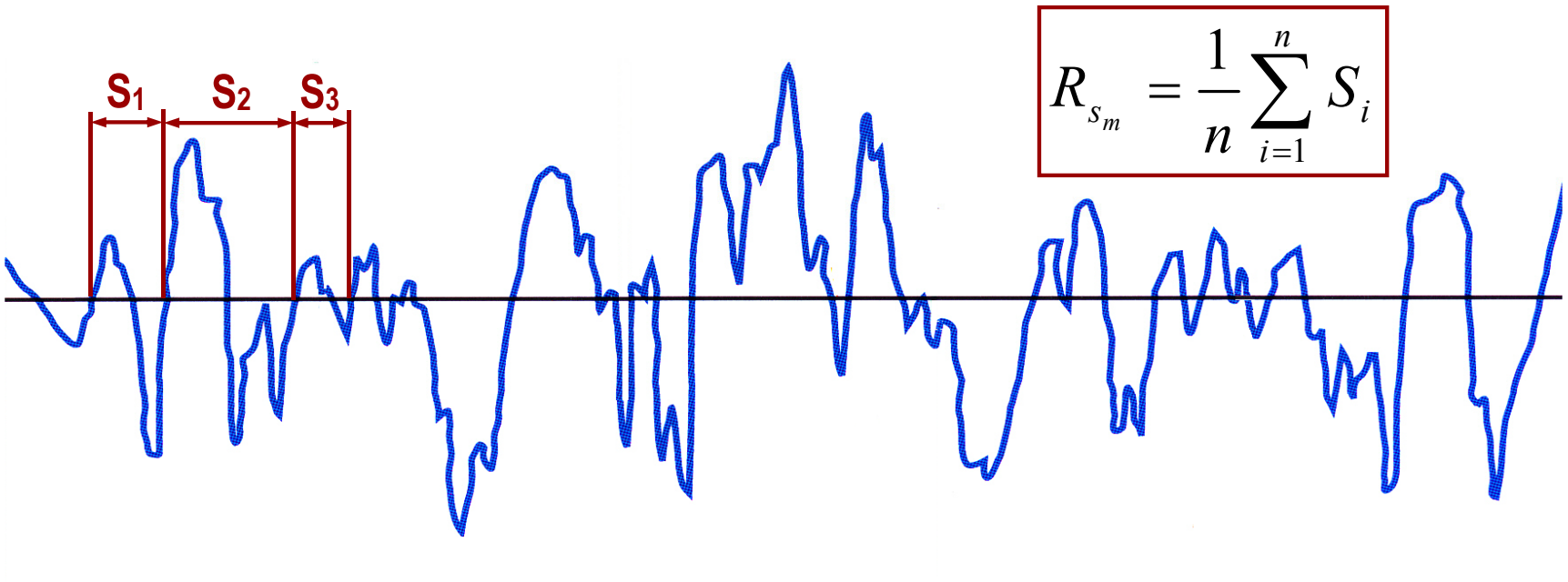
$$R_p = \left(R_{p_i}\right)_{\max}$$

$$R_v = \left(R_{v_i}\right)_{\max}$$

$$R_t = R_p + R_v$$

Spacing Parameter – R_{sm}

- **Mean Spacing (R_{sm}):** The mean spacing of **S_1, S_2, .., S_n** between profile peaks as they pass through the mean line (spacing is the distance between points that cross the mean line in an upward direction).



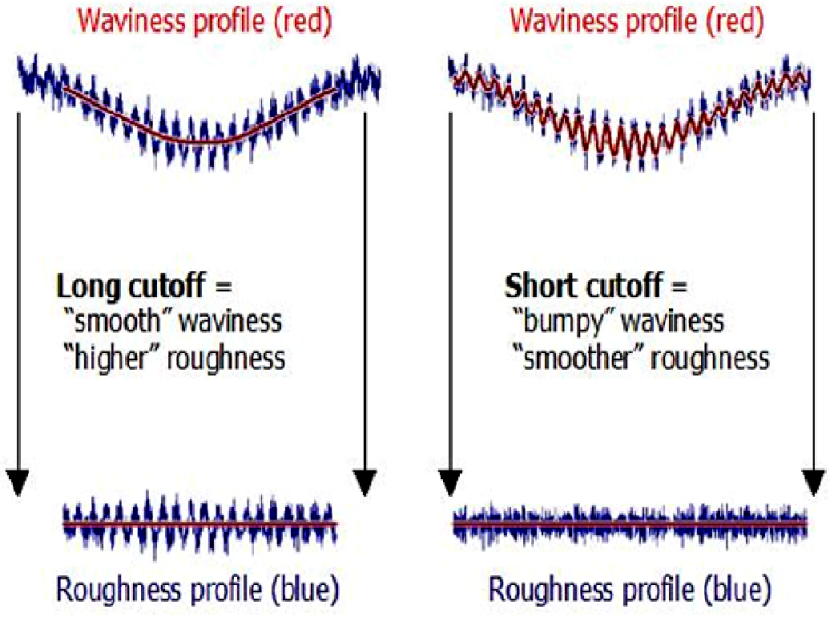
$$R_{s_m} = \frac{1}{n}\sum_{i=1}^{n} S_i$$

Selection of Cutt-off Length

- Changing cut-off value (which changes amount of "averaging" and "smoothing") can have huge impact on measurement of roughness and waviness.

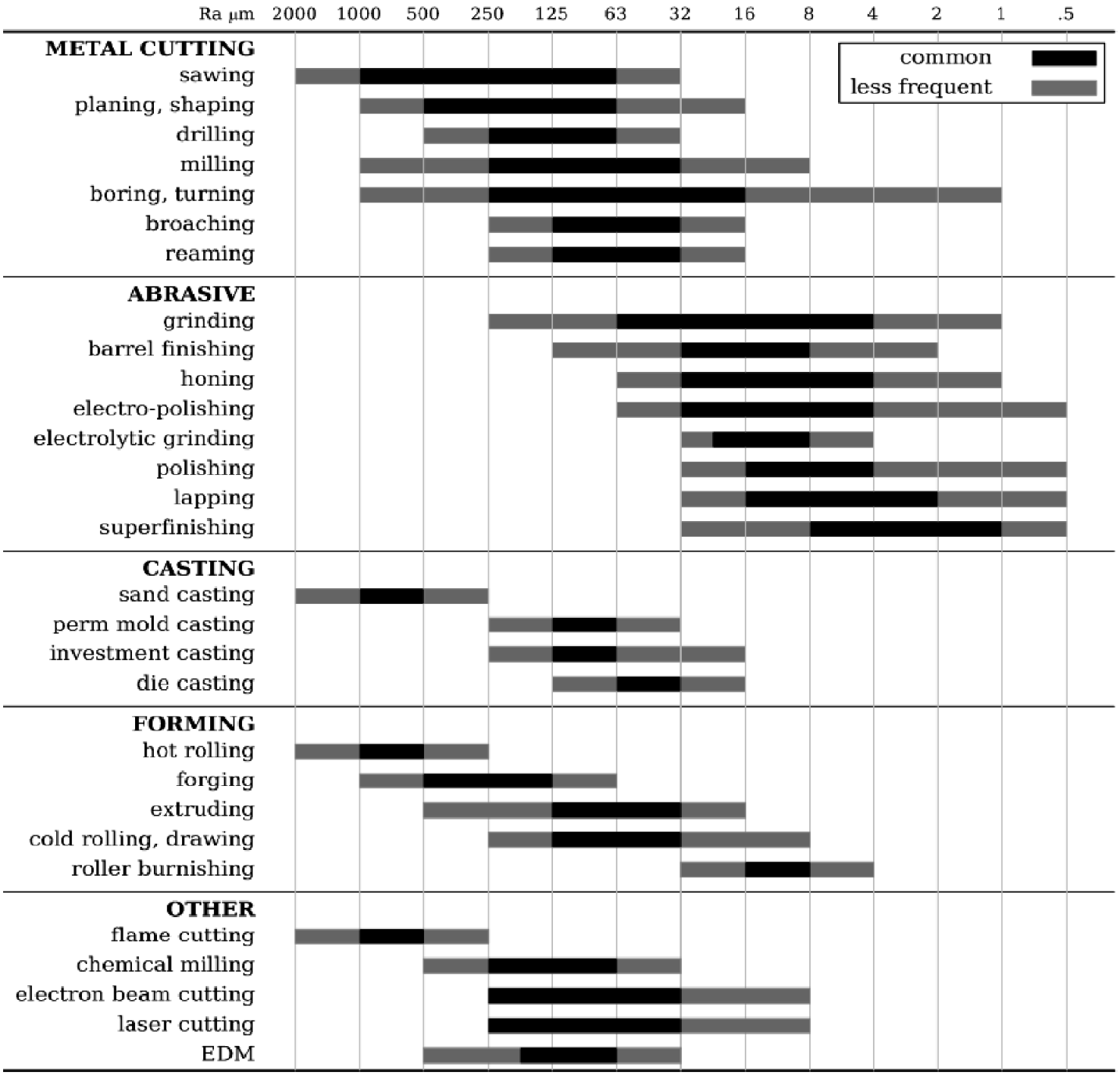
- Choosing **smaller cut-off lengths** will result in **smaller roughness values** even though the real surface could be very rough. Picture *(as shown below)* presents two profiles for the same surface with different cut-offs. The profile on the left gives twice the $\mathbf{R_a}$ value of profile on the right.

- Thus, there are **recommended values** for choosing the appropriate cut-offs *(as given in table below)*, which were defined by **ISO 4288-1996**.



RECOMMENDED CUT-OFF LENGTHS (ISO 4288-1996)				
Periodic Profiles	**Non-Periodic Profiles**		**Cut-offs**	**Evaluation Length**
S_m (mm)	**R_z (µm)**	**R_a (µm)**	**λ_c (mm)**	**L (mm)**
>0.013 to 0.04	(0.025) to 0.1	(0.006) to 0.02	0.08	0.4
>0.04 to 0.13	>0.1 to 0.5	>0.02 to 0.1	0.25	1.25
>0.13 to 0.4	>0.5 to 10	>0.1 to 2	0.8	4
>0.4 to 1.3	>10 to 50	>2 to 10	2.5	12.5
>1.3 to 4	>50 to 200	>10 to 80	8	40

Surface Finish Tolerances in Manufacturing



ISO Standards on Surface Texture

ISO 1302 - 2001	Indication of Surface Texture
ISO 3274 - 1996	Nominal Characteristics of Contact (Stylus) Instruments
ISO 4287 - 1997	Terms, Definition and Surface Texture Parameters
ISO 4288 - 1996	Rules and Procedures for Assessment of Surface Texture
ISO 5436-1 - 2000	Calibration, Measurement Standards
ISO 5436-2 - 2000	Calibration, Soft Gages
ISO 8785 - 1999	Surface Imperfections - Terms, Definitions and Parameters
ISO 11562 - 1996	Metrological Characteristics of Phase Correct Filters
ISO 12085 - 1996	Motif Parameters
ISO 12179 - 2000	Calibration of Contact (Stylus) Instruments
ISO 13565 - 1996	Characterization of Surfaces Having Stratified Functional Properties

☝ **More information on surface texture measurements: http://www.taylor-hobson.com/faqsurface.php**