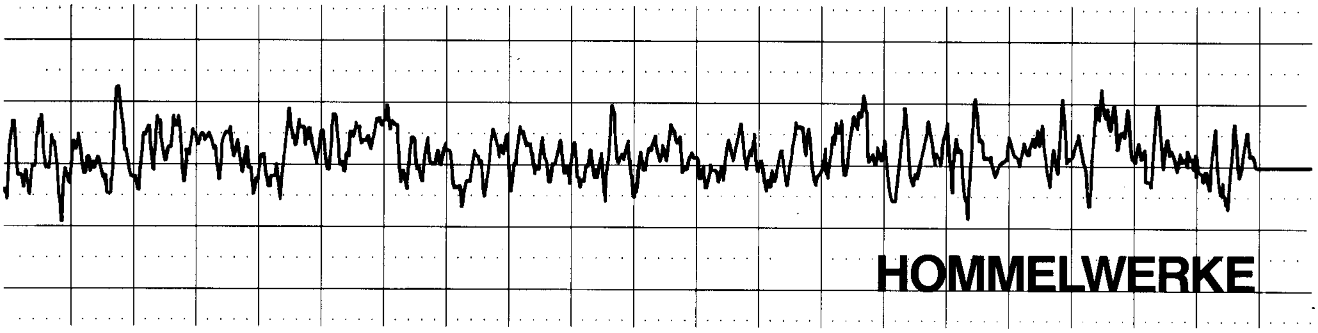
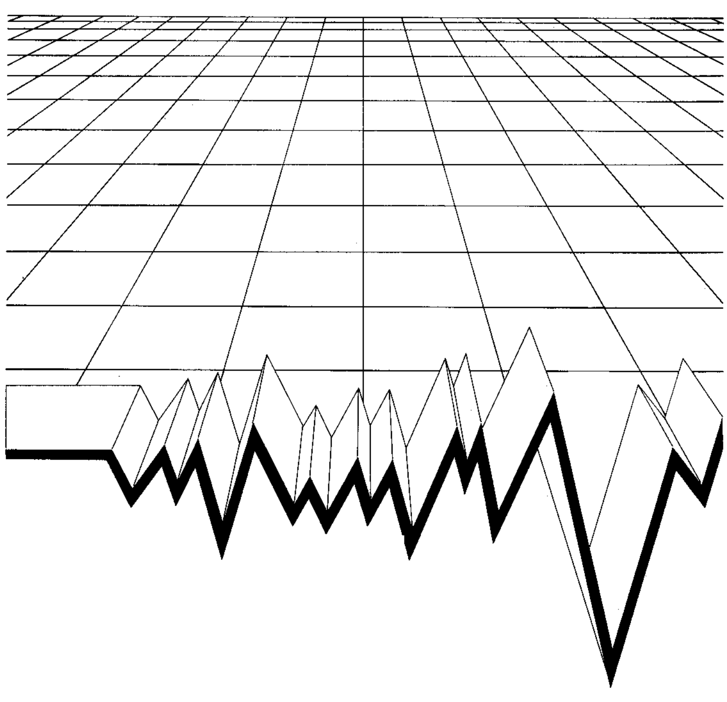


HOMMELWERKE

SURFACE ROUGHNESS MEASUREMENT
THEORY



SURFACE DEFECTS – SURFACE MEASUREMENT

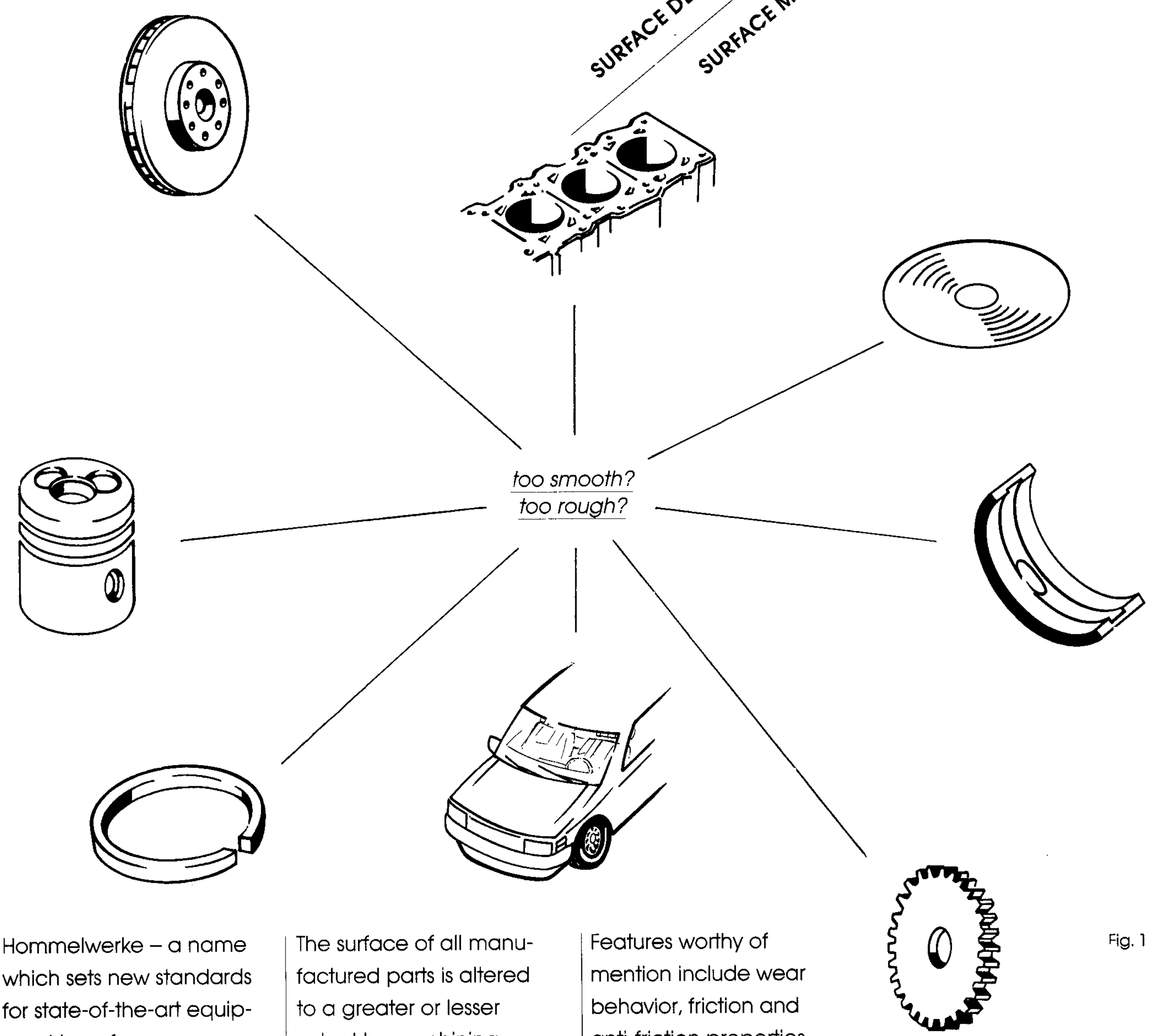


Fig. 1

Hommelwerke – a name which sets new standards for state-of-the-art equipment in surface measurement and dimensional metrology.
This is due to an innovative spirit, flexibility and advanced technology. The company also offers in-depth advisory services. This pamphlet is intended to provide a theoretical insight into surface measurement techniques.

The surface of all manufactured parts is altered to a greater or lesser extent by machining, regardless of the machining methods used.
A magnified image of this surface is comparable to a mountain landscape with valleys of various depths and widths.
It is a fact that surface defects, e.g. deviations from the geometrically ideal form, are crucial to the subsequent functional behavior of a machine component.

Features worthy of mention include wear behavior, friction and anti-friction properties, lubricity, sealing properties, fatigue strength, corrosion susceptibility and fit characteristics. One further factor is that, as experience has shown, 50 % of the dimensional tolerance, which is required by production, particularly in the case of closely toleranced fits, is "wasted" by surface defects.

Because of this, a simple dimensional inspection is not sufficient to judge part quality or function.

The benefit of measuring surface topography is to detect surface flaws which are generaled by the manufacturing process. This allows specific steps to be taken to hold the surface finish within tolerances permitting the correct function of the part.
It should be remembered though, that the task of surface measurement is not to create as smooth a surface as possible.
A highly finished surface is far more expensive to manufacture and may also function less well than a rougher surface. Take as an example, the surface of a sliding bearing. If it is finished with an excessively smooth surface, the oil pockets, found in a rougher surface may not be present causing the lubrication film to break down, which may lead to overheating and seizing of the bearing.

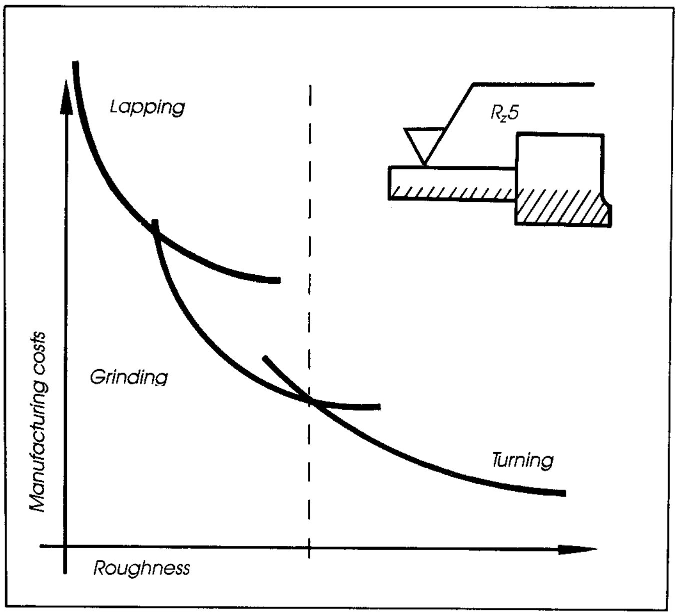


Fig. 2 *Can you afford to over-finish?*

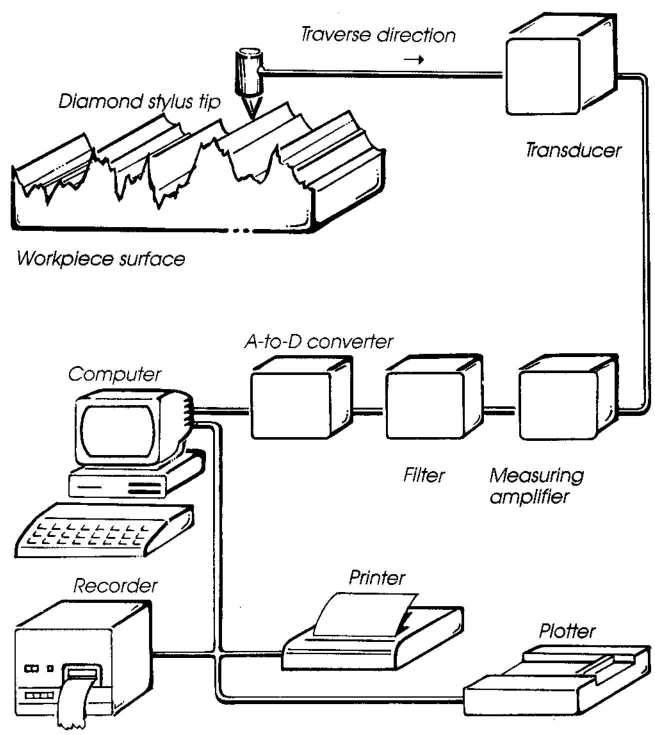


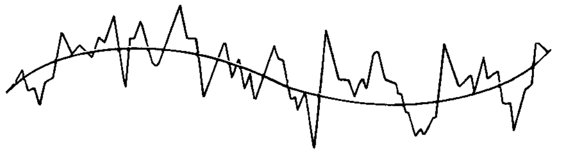
Fig. 3
Block diagram of a typical surface measuring instrument

A modern stylus-type surface measuring instrument functions in a manner similar to a home record player. (see Fig. 3). In this illustration, you can see the stylus tip on the surface of a workpiece. It is moved over the surface in order to provide us with a two-dimensional profile measurement.
The displacement of the stylus tip is detected and converted to an electrical signal by a transducer. Displacements in the order of magnitude of 0.001 micrometers (0,04 millionths of an inch) can be detected with highly sophisticated roughness analyzers. The electrical signal is amplified and converted to digital information which is finally processed by a computer.
Of course, modern technology permits all of these components to be accommodated in a compact unit. After the "raw" data from the profile have been transferred to the computer, the actual process of analysis can commence.

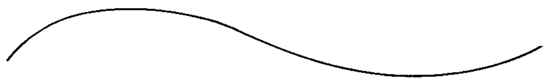
In the field of surface measurement, we distinguish between:

<u>The geometrically ideal surface</u>
This is the boundary of the imaginary, ideal technical body which is, however, not achieved in practice.

<u>The design or nominal surface</u>
This is specified by the designer and is required for proper function of the component.



Unfiltered, actual profile (form error, waviness, roughness)



Waviness profile with components of the form error (roughness filtered out)

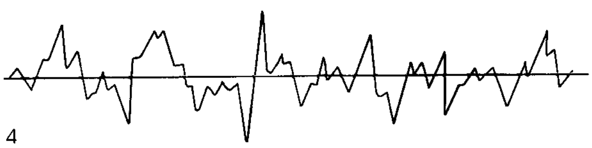


Fig. 4

Roughness profile (long-wave errors filtered off)

<u>The actual surface</u>
This is the actual surface of the manufactured part.

A mixture of different surface deviations which are superimposed may occur on the surface
In accordance with DIN 4760, these are subdivided into 6 error classes, the so-called form errors (see Fig. 5).

Form error	Profile	Nature of error
1st order Geometrical error		Deviation from: Straightness, flatness, roundness, cylindricity
2nd order waviness		Waviness
3rd order		Roughness
4th order		Scoring Scaling
5th order	Cannot be represented graphically	Structure
6th order	Cannot be represented graphically	Crystal structure

Fig. 5

General surface measurement covers only the form errors of the 1st to 4th orders.

Detecting the form errors of the 5th and 6th orders is covered in the field of material testing.

SELECTION OF THE PICK-UP SYSTEM

The pick-up systems are subdivided into two main groups:

<u>A) Datum plane system (skidless pick-up system)</u>
On these pick-up systems, the measuring system is guided on a high-accuracy datum plane (see Fig. 6). This datum plane represents the geometrically (straight) ideal profile.
After levelling the datum plane with the measurement plane, this pick-up system makes it possible to measure waviness and geometrical errors as well as roughness, if these can be detected within the selected sampling length. Due to the small size of the pick-ups, they are also suitable for measurements in small bores.

<u>B) Skid pick-up system</u>
With the skid pick-up system, the measuring system is supported by one or two skids on the workpiece surface. The displacement of the diamond stylus tip is measured with respect to the skid which bridges the roughness valleys. The small tip radius permits the diamond stylus tip to enter the surface valleys. Dependent upon the design of the pick-up system, the shape of the skid and its radius may differ. The skid radius is usually in the range of 0.3 and 25 mm. The skid may also have a cylindrical shape. In addition, the distance between the stylus tip and the skid may be between 0 and several millimeters.

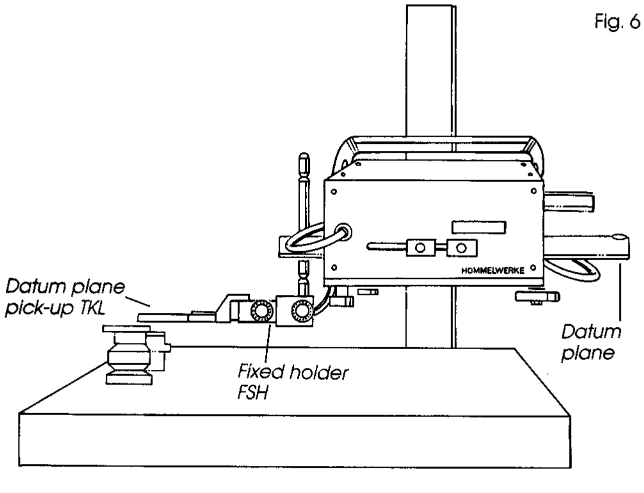


Fig. 6

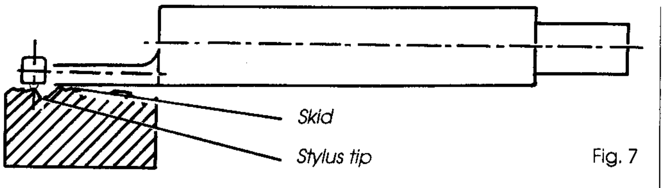


Fig. 7

We distinguish between:

<u>a) Single skid pick-up:</u>
The single skid pick-up permits all roughness parameters to be detected. Such pick-ups are particularly easy to use since they only need to be approximately level to the surface being measured. These pick-ups are also relatively insensitive to mechanical vibrations (e.g. on the clamped workpiece). The small skid also means that the pick-up can be used on short measurement surfaces (see Fig. 7).
In the same way as the DATUM PLANE PICK-UPS, they are also suitable for measurement in small holes

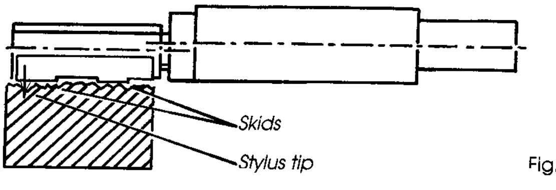


Fig. 8

<u>b) Double skid pick-up</u>
These pick-ups with their broad skids bridge not only the 3rd and 4th order form errors but also, within certain limits, form errors of the 2nd order. They are thus able to detect roughness and fine waviness, depending on the design of the skid, up to a wavelength of 4 mm. One advantage of these pick-ups is the ease of use since the suspended measurement system aligns itself automatically to the workpiece. Bores upwards of 12 mm (0.5 inch) can be measured (see Fig. 8).

THE ROUGHNESS FILTER (CUT-OFF LENGTH) (DIN 4768)

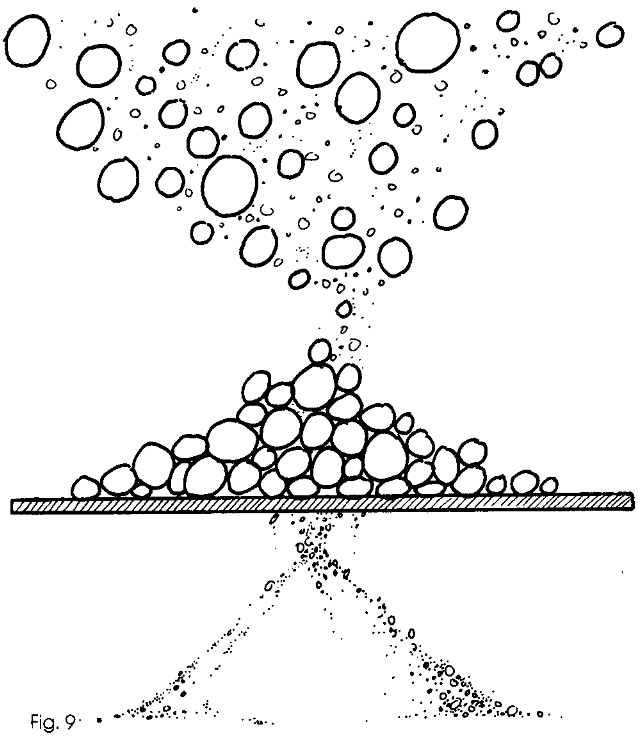


Fig. 9

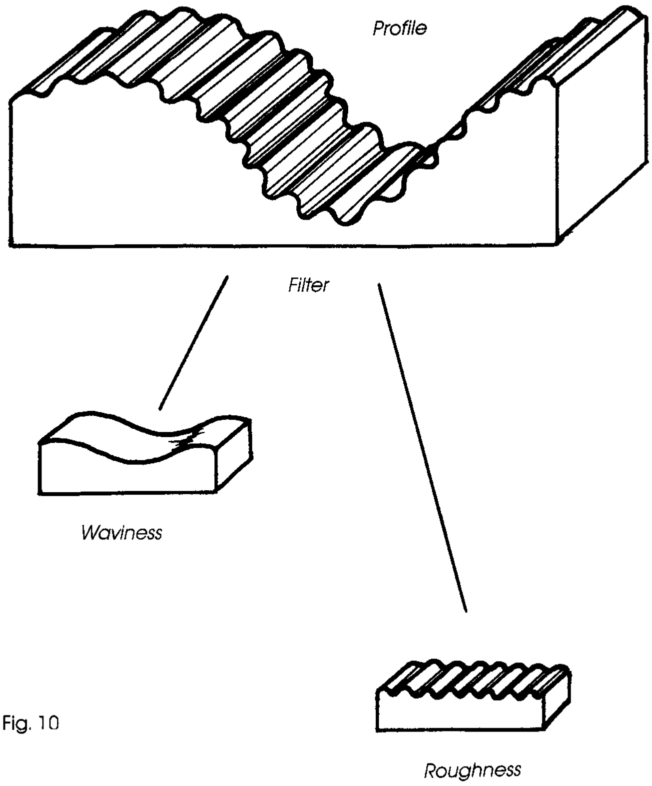


Fig. 10

The process of filtering surface profiles can be compared to putting dirt through a sieve. If we place a pile of dirt on a sieve, the stones which do not pass through the sieve openings will be separated from the finer grains of sand. Thus, the size of the openings determines what is a stone and what is a grain of sand for us (see Fig. 9).

The process of filtering surface profiles is a similar process. A roughness filter separates the profile into waviness and roughness (see Fig. 10). The influences of waviness and straightness are eliminated. The cut-off length of the filter determines what is allowed to pass and what is not allowed to pass, precisely in the same way as the holes in the sieve in our example. Note that we re-obtain our original profile by combining the roughness and waviness profile. Thus, filters do not change the initial profile, they only change the way in which we view the profile.

TRAVERSING AND SAMPLING LENGTHS (DIN 4768)

The overall distance traversed during the measurement corresponds to the **traversing length l_t**. This is the sum of the:

start-up length l_v – the first part of the traversing length which is not used for evaluation of the roughness parameters. It allows the filter to settle.

SELECTION OF THE TRAVERSING LENGTH L_T AND THE WAVE FILTER (CUT-OFF LENGTH)

SURFACE PARAMETERS

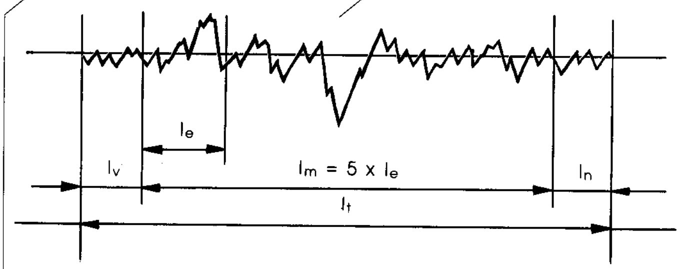


Fig. 11

Sampling length l_m – the length of that part of the roughness profile used for evaluation. It is made up of 5 equal **single sampling lengths l_e**.

The single sampling length l_e, is equal to the cut-off wavelength λ_c.

Run-out length l_n – the last section of the traversing length which is not used for evaluation of the roughness parameters. It serves to allow the filter to settle (decay phenomena) (see Fig. 11).

Periodic profiles	Random profiles		Cut-off length	Single sampling length	Sampling length	Traversing length
Groove spacing ar (mm)	R_Z, R_{max}, R_{3Z} (µm)	R_a (µm)	λ_c (mm)	l_e (mm)	l_m (mm)	l_t (mm)
> 0.01-0.032	–	–	0.08	0.08	0.4	0.48
> 0.032-0.1	0.5	0.1	0.25	0.25	1.25	1.5
> 0.1-0.32	> 0.5-10	> 0.1-2	0.8	0.8	4	4.8
> 0.32-1.0	> 10-50	> 2-10	2.5	2.5	12.5	15
> 1.0-3.2	over 50	over 10	8	8	40	48

Fig. 12

So that everyone "speaks a common language", the selection of the filter is determined by the peak spacing of the roughness profile. Since the sampling length should also be specifically related to the groove spacing of the roughness and of the filter, this is also standardized.

A number of standardized surface roughness parameters (R_a, R_Z, R_t, R_{max}, tpi, and tpa etc.) are available for determining the magnitude of surface flaws and characterizing the surface profile.
Dependent upon the type of parameter measured, these are calculated from the unfiltered, measured profile, the filtered roughness profile or the filtered waviness profile.

Please refer to the brochure "Hommel surface measurement – terms and definitions" for a detailed description and illustrations.

ROUGHNESS SPECIFICATIONS ON DRAWINGS

The following table (see Figure 13) serves to convert surface specifications from DIN 3141 to DIN-ISO 1302.

Comparison of DIN 3141 and DIN-ISO 1302.

Surfaces with roughness limit value	DIN 3141	Surface symbols	∇				∇∇				∇∇∇				∇∇∇∇			
		Series	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
		R_z maximum value in µm	160	100	63	25	40	25	16	10	16	6,3	4	2,5	-	1	1	0,4
	DIN-ISO 1302	R_z maximum value in µm	160	100	63	25	40	25	16	10	16	6,3	4	2,5	-	1	1	0,4
		R_a maximum value in µm	25	12,5	6,3	3,2	6,3	3,2	1,6	1,6	1,6	0,8	0,4	0,2	-	0,1	0,1	0,025
		Roughness class	N11	N10	N9	N8	N9	N8	N7	N7	N7	N6	N5	N4	-	N3	N3	N1

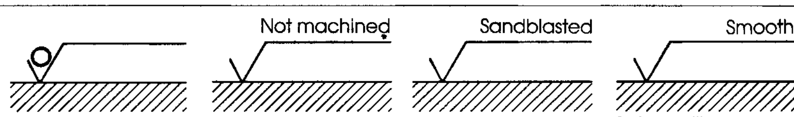
Surfaces without symbols — DIN 3141 and DIN-ISO 1302:

Surfaces of which no specific requirements are made. The conventional manufacturing methods ensure and adequate final condition.

Surfaces with any roughness — DIN 3141:

Surfaces to which only the requirements of greater uniformity and improved appearance apply.

Surfaces with any roughness — DIN-ISO 1302:



- Surfaces where material removal is prohibited (e.g. which remain in the original condition.
- Surfaces which are not to be machined. Irregularities may be subsequently machined.
- Surfaces which are not to be machined. They must be sandblasted for cleaning.
- Surfaces with more stringent roughness requirements.

Fig. 13

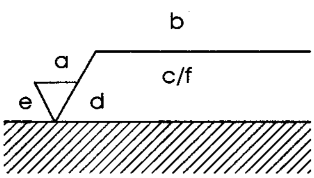


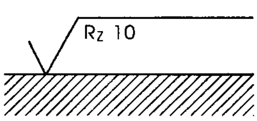
Fig. 14

Additional information conveyed with symbols

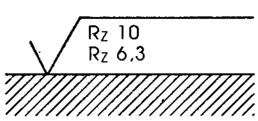
The following information can be included in the individual symbols (see Fig. 14):

a = Roughness value R_a in µm (or microinch)
b = Manufacturing method, surface treatment, coating
c = Reference length
d = Direction of lay
e = Machining allowance
f = Other roughness parameters, e.g. R_Z, R_{max}, P_t.

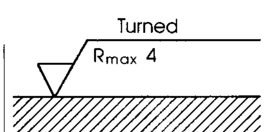
The individual additional information must be specified only if required for function, manufacture or inspection.



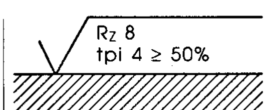
B_1: With a maximum mean peak-to-valley height $R_Z = 10$ µm



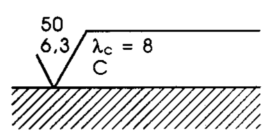
B_2: With a maximum and a minimum mean peak-to-valley height $R_Z = 10$ µm $R_Z = 6.3$ µm



B_3: With a maximum individual peak-to-valley height $R_{max} = 4$ µm Machining method: Turning



B_4: With a maximum mean peak-to-valley height $R_Z = 8$ µm and a bearing ratio equal to or greater than 50 % with a cutting depth of 4 µm



B_5: Roughness between R_a 50 and R_a 6.3, cut-off length $\lambda_c = 8$ mm. Lay concentric with center.

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