

Surface Finish

INTRODUCTION

The actual cross-section of a ground surface viewed at high magnification is far different from the ideal flat, cylindrical or curvilinear surface indicated on a drawing. Geometrically, the surface is seen to have a large number of minute irregularities (peaks and valleys) superimposed on more widely spaced undulations (waviness). Metallurgical examination of hardened steel components will show that the transition from an amorphous layer through re-hardened and tempered zones which finally merge with the original structure obtained by heat treatment. Analysis by sophisticated methods will reveal the presence of tiny cracks and changing residual stress patterns at different depths below the surface.

All these features determine to a great extent the behaviour of the part in service. Thus, for example, surface finish has a significant effect on the frictional and lubricant-retention properties of the surface. Waviness determines whether mating will be accurate so that leakage can be avoided in sealed joints, metallurgical damage affects the wear resistance of the part and residual stresses influence the fatigue strength of critical parts besides causing harmful deformations. Therefore, it is evident that 'surface quality' is of critical importance and its proper evaluation is of utmost interest to the shop engineer.

SURFACE FINISH

Elements of Surface Finish

The term surface finish is well known but the concept is understood more in qualitative terms than in quantitative terms. This is evident from the fact that many industries continue to specify finish as rough, good, smooth, glossy, mirror etc. None of these terms are sufficiently accurate and besides, they tend to convey different meanings to different people. It is in the common interest to adopt a quantitative method of evaluation with appropriate inspection techniques which will eliminate the variable subjective factor.

When different surfaces are compared, it is possible to distinguish them in terms of reflectivity (dull or shiny appearances), smoothness, the presence of chatter marks, or the visual scratch pattern. However, analysis shows that conclusions drawn from such observations are often incorrect. A typical example is the widespread belief that highly reflective surfaces have a better surface finish than those which are dull in appearance. As a matter of fact, precision lapped surfaces usually have a dull appearance even though they may have the best possible surface finish.

The conclusion caused by the subjective element in surface finish measurement can be eliminated by using various machines (discussed later) which can record the surface profile with a very large magnification in the vertical direction. The surface profile is usually measured in a direction perpendicular to the lay of the surface - i.e. the predominant direction of the scratch marks. A typical profile is shown in Fig. 1. Analysis shows that the profile is composed of three distinct types of irregularities. The first type of irregularity is a form of error which is usually of a magnitude which can easily be detected by conventional measuring methods. The second type of irregularity consists of waviness with fairly regular spacing which can be attributed to vibrations of the machine. The third type of irregularity consists of closely spaced peaks and valleys superimposed on the first two types of irregularities. These peaks and valleys can be correlated with the shape, size and motion of the cutting tool.

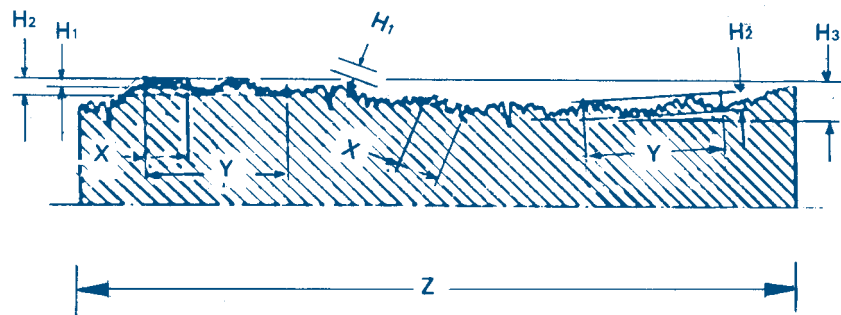
It is clear that surface finish should be related to the height of the irregularities. However, depending on the length (X, Y, Z) over which measurements are made and the relative heights of the different types of irregularities, it is possible to get widely varying values (H_1 , H_2 , H_3). Each value may be relevant depending on the functional properties desired - viz; bearing area, flatness (or straightness), smoothness (for appearance or corrosion resistance) etc.

Evidently a common system is necessary so that shop-floor personnel can choose the correct process technology and compare different values.

The international consensus of opinion has been to relate surface finish to the height of the closely spaced irregularities over a short length. This length which is called the cut-off length, is specified so that variations due to waviness or form errors are excluded. Since the peaks and valleys have different heights it is evident that some kind of average height should be determined. Here again, the consensus has been to choose an arithmetical average value. Depending on the system of measurement, this

value is called the centre line average (CLA) in microinches or the roughness average (Ra) in microns.

The profile shown in fig. 2 is a highly magnified sectional view of the surface. Within the selected cut-off length, it is possible to draw a centre line in such a way that the areas of the peaks above the line are equal to the areas of the valleys below the line. The theoretical average deviation of the profile from the centre-line can be determined by integration which is the basis on which the relevant electrical instruments function. However, sufficiently accurate results will also be obtained by measuring the ordinates (vertical height or depth) at various points on



TOOL TEXTURE



VIBRATION TEXTURE



ERROR OF FORM



Fig. 1

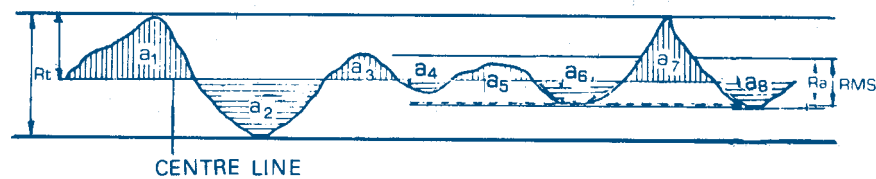


Fig. 2

the profile and calculating the average value by the following equation :

$$\text{Average value} = \frac{h_1 + h_2 + \dots + H_n}{n}$$

The average value is expressed in microinches (millionths of an inch) or microns (millionths of a meter) depending on the system of measurement.

Besides the arithmetical average value, two other systems are also used quite often. The system which was popular till recently gave a root-mean-square (RMS) value which is derived by the following equation :

$$\text{RMS value} = \sqrt{\frac{h_1^2 + h_2^2 + \dots + h_n^2}{n}}$$

The International Standards Organisation (ISO) has recently evolved a scale for surface finish with twelve divisions, the finest finish is designated by No.1 and the coarsest by No.12 (see Table 1). Successive scale divisions have CLA, Ra and RMS values differing by multiples of 2. It is worth noting that the Rt values are not directly proportional to the other values. From numerous measurements, it has been established that the ratio between Rt and Ra values varies from about 8-12 for lapped and superfinished surfaces, to 5-6 for ground surfaces and 4-5 for more roughly machines surfaces.

CUT-OFF LENGTH

It was explained earlier that surface finish is related to the closely-spaced irregularities only, and other defects like waviness and form error should be disregarded. In practice, selectivity is achieved by making measurements over limited distances which are designated as cut-off lengths. This length has to be chosen in such a way as to include a sufficient number of primary irregularities for the purpose of averaging. Evidently, a large cut-off length is necessary for turned or shaped surfaces where individual tool marks are widely spaced, compared to ground or lapped surfaces produced by the overlapping trajectories of tiny abrasive grains. The recommended cut-off lengths for different surface finish values are also

shown in Table 1.

The instruments used for measuring surface finish are usually designed to work with different cut-off values in progression 0.003", 0.01", 0.1 and 0.3". When a particular cut-off value is chosen, it means that the instrument will not react to irregularities with a wavelength greater than this value. The importance of choosing the correct cut-off values can be seen from the examples in Fig. 3. The profilographs of different surfaces are shown on the left and the corresponding CLA values at different cut-off lengths are shown on the right. The first surface (Fig. 3a) had only closely spaced irregularities without any waviness. Therefore, the CLA value was almost constant irrespective of the cut-off length. The next surface (Fig. 3b) had some high points about 0.02" apart. This resulted in a low CLA value at 0.003" and 0.01" cut-off lengths while higher cut-off lengths gave a constant roughness reading. The other surfaces (Fig. 3c and 3d) had a distinct waviness pattern with a wavelength (peak-to-peak distance) of about 0.1". In these cases, the CLA value was small for cut-off lengths below 0.1" and then increased sharply. This example shows how important it is to choose the correct cut-off length as otherwise, invalid conclusions may be drawn.

INSTRUMENTS USED FOR MEASURING SURFACE FINISH

Most of the instruments available commercially are based on a mechanical-cum-electronic principle. A diamond-tipped stylus is mechanically moved over the surface and the deflections of the stylus are converted into electrical signals are then amplified electronically and passed through an analyzer (or computer) which indicates the appropriate value on a suitably calibrated scale. In some cases there is provision for recording the surface profile in the form of a graph.

A great majority of the instruments have pick-up heads with spherical skids. These skids provide a datum surface which follows the major form errors of the measured surface and helps in eliminating the effect of such errors on the surface finish value.

It is perhaps worth pointing out that the cut off

length is not related to the stroke length of the pick-up head. The latter value is chosen to suit the dimensions of the workpiece. Thus, for example, a short stroke would be required on a piston ring and a longer stroke on a large spindle though cut-off values may be identical in both cases. Longer stroke lengths or repetitive measurements are desirable so that individual defects (like deep scratches etc.) do not unnecessarily result in rejections).

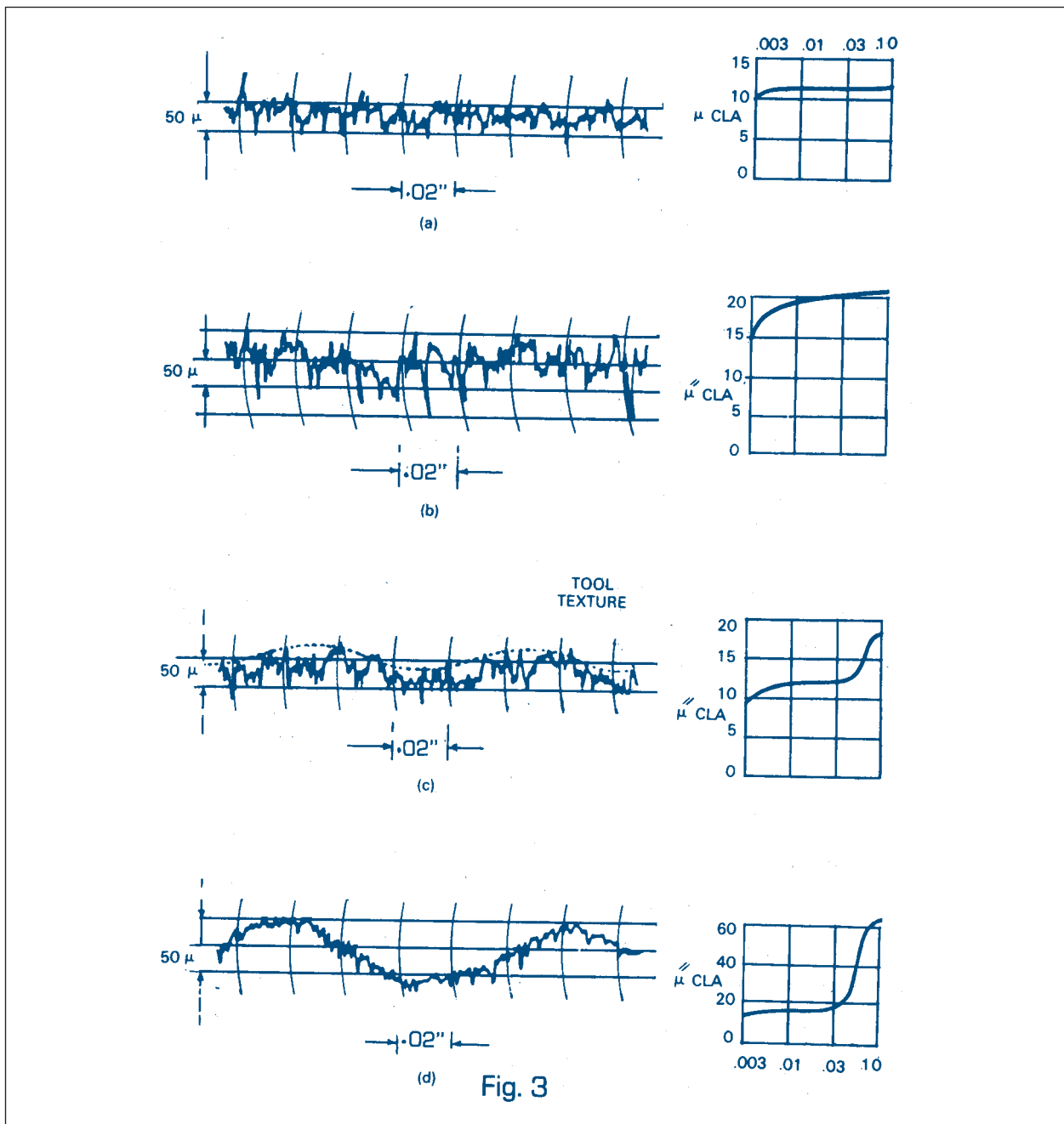
TROUBLE SHOOTING

Problems of poor finish are often encountered

during grinding. A rational solution to such problems can be found if due consideration is given to all the relevant process parameters.

The precision grinding processes are basically intended for jobs with a surface finish requirement of 0.2-0.8 microns Ra (8-32 microinches CLA). Coarser finishes are rarely specified and can be easily achieved. Finer finishes are possible under controlled conditions but other processes like honing, superfinishing or lapping are preferable.

The prerequisites for achieving the desired finish include the proper choice of grinding wheel



specification (especially in terms of grit size), use of the right machine tools with minimum vibrations and the splitting-up of the grinding process into roughing and finishing operations, when stock removal is high.

Even when process selection is correct, problems can arise if operating conditions are not optimised. Some of the critical parameters are listed below.

SPARK-OUT - This term refers to the portion of the grinding cycle when wheel is stopped or reduced to a very small value. It has been found that proper spark-out improves the surface finish considerably; and even coarse grit wheels can often be used with satisfactory results. This approach has the added advantage of improving productivity. A point which should be noted is that finish initially improves when spark-out duration is increased and beyond a point again tends to deteriorate. This is because a certain minimum value of cutting force is necessary to take up any play or backlash in the system. If spark-out is prolonged the vibration amplitude increases and mars the surface finish.

DRESSING - Proper dressing techniques are

an invaluable aid in achieving the desired finish and varying the cutting efficiency of grinding wheels. A fine-dressed wheel (using low depth-of-cut and traverse feed for the diamond dresser) gives a much better finish than a coarse-dressed one. In fact, experiments have shown that a 60 grit wheel can give finishes ranging from 0.3 to 1.0 micron Ra by merely varying the dressing technique. This method of varying surface finish with a given wheel is particularly effective in jobbing-work and where form-retention problems do not pose constraints on grit size selection.

CUTTING PARAMETERS - Precision grinding machines enable variation in cutting parameters over a wide range. Thus, finish can be improved by using higher wheel speeds (within the constraints of safety), lower infeeds and a reduced job speed (rpm and/or table traverse).

CUTTING FLUIDS - It has been found that straight cutting oils and higher concentrations of soluble oils improve finish to some extent. What is perhaps even more important is to ensure proper filtration of the fluid as suspended swarf can cause random deep scratches on the job.

TABLE 1
 SURFACE FINISH CONVERSION CHART

N	Rt	Ra	CLA	RMS	Cut-off length	
					Inches	mm
1.	0.3	0.025	1	1.1	0.003	0.08
2.	0.5	0.05	2	2.2	0.01	0.25
3.	0.8	0.1	4	4.4	0.01	0.25
4.	1.2	0.2	8	8.8	0.01	0.25
5.	2.0	0.4	16	17.6	0.01	0.25
6.	4.0	0.8	32	35.2	0.03	0.8
7.	8.0	1.6	63	64.3	0.03	0.8
8.	13	3.2	125	137.5	0.1	2.5
9.	25	6.3	250	275	0.1	2.5
10.	50	12.5	500	550	0.1	2.5
11.	100	25.0	1000	1100	0.3	8.0
12.	200	50.0	2000	2200	0.3	8.0

N = New ISO scale numbers

Rt = Roughness, total in microns

Ra = Roughness, average in microns

CLA = Centre Line Average in microinches

RMS = Root Mean Square in microinches