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Indian Standard

ASSESSMENT OF SURFACE ROUGHNESS

(Incorporating Amendment Nos. 1, 2, 3 and 4)

UDC 620.179.118 : 539.211

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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Indian Standard
ASSESSMENT OF SURFACE ROUGHNESS

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(*Continued on page* 2)

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Indian Standard
ASSESSMENT OF SURFACE ROUGHNESS

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 22 September 1967, after the draft finalized by the Engineering Metrology Sectional Committee had been approved by the Mechanical Engineering Division Council.

0.2 There are various methods of evaluating the roughness of a surface, out of which the most prominent ones today are the 'M' and the 'E' systems. The 'M' system, also known as the Centre Line Average Method (CLA) or the Mean Line System, expresses the arithmetical average departure of the actual surface both above and below a mean line, within a specified sampling length, and in a plane substantially normal to the direction of the surface. This system was developed and is used in U.K. A similar system, based on the mean line but expressing the departure of the actual surface as a root mean squared (rms value) was in use in USA; but this has been discarded now in favour of CLA value.

0.3 The 'E' system also known as the envelope method, has been developed in Germany and is, of late, being increasingly used. This system expresses the arithmetical average departure of a surface both above and below a 'mean' curve. This mean curve is developed from what is known as a 'contacting envelope' by displacing it to a position where the areas enclosed by the profile above and below the mean curve are equal. The contacting envelope, in its turn, is obtained by rolling across the surface a sphere, with a radius '*r*' which is normally 25 mm. The locus of centre for this circle is displaced towards the surface by an amount equivalent to '*r*'. This curve now obtained is called the 'contacting envelope'.

0.4 The 'M' system is a more useful and a satisfactory means of controlling, at the point of production, the consistency of results from a process when the production parameters have been established. However, the 'M' system has a limitation that it is unable to control the functional qualification of a surface when associated with a machine process. On the other hand, the 'E' system is more easily applied to the surface finish instruments based on the interference type and also the definition of the 'E' system peak to peak measure is superior to the 'M' system.

0.5 Although it is quite possible that the 'E' system will be more widely accepted in the foreseeable future, the Sectional Committee responsible for the standard decided to adopt the 'M' system for the following reasons:

a) The 'M' system is fairly widely used and all the instruments for measuring surface roughness available in the country are designed to measure in this system.

b) The 'E' system is still in its early stage of development and although a few designs of instruments for evaluating the parameter defined in the 'E' system have been developed, the measuring instruments designed for 'E' system are not as easily available as the corresponding instruments in 'M' system.

0.6 The objects of this standard are to provide, firstly a defined basis for a simple numerical assessment of the roughness of a surface under conditions which will ensure reasonable consistency between the results obtained from different instruments designed to measure the same characteristics of the surface, and secondly a series of recommendations which it is expected may help in preventing undesirable growth of conflicting practices in the use of terms.

0.7 This standard, being based on the 'M' system, gives the preferred 'R_a' values for specifying surface roughness. This value is very useful for comparison of various surfaces obtained by similar operations but this value does not indicate the limits of irregularity. The peak to valley value 'R_{Max}' is recognized as the most direct of all surface roughness values and is perceived by looking at the profile and by touching the surface. The 'R_{Max}' value is useful in identifying surfaces for comparison and record purposes. However, in view of there being no fixed relation between 'R_a' and 'R_{Max}' values, provision for specifying R_{Max}' values in drawing has been excluded from this standard.

0.8 This standard lays down the essential information which shall be provided in statements relating to surface roughness but, being primarily concerned with the evaluation of surfaces, the requirements by which surface roughness is to be indicated are excluded. This standard neither attempts to define what degrees of surface imperfections are acceptable for any specific purpose, nor it is concerned with the other surface qualities, such as lustre, appearance, colour, corrosion resistance, wear resistance, hardness, and absorption characteristics, any of which may be governing considerations in specific applications.

0.9 It shall be realised that investigations are still being conducted in the field of the surface roughness and there is yet limited surface phenomena in engineering practice. For this reason, the present standard has been expressed in simple terms to serve an immediately useful purpose.

0.10 Recognizing that many of the users of this standard are not directly concerned with the more academic aspects of the subject, this standard is devoted exclusively to mandatory and immediately essential requirements. General information and guidance on surface roughness assessment is given in Appendix A. The user who is not well coversant with the subject is advised that there are limitations in making numerical evaluations of surface characteristics and it is recommended that a careful study of Appendix A be made before putting this standard into practice.

0.11 While preparing this standard assistance has been derived from:

Draft ISO Recommendation No. 221 Surface roughess. International Organization for Standardization.

B.S. 1134-1961 Centre-line-average height method for the assessment of surface texture. British Standards Institution.

0.12 This edition 1.4 incorporates Amendment No. 4 (December 1986). One more sampling length suitable for different types of machined surfaces was included in Table 3 of this standard through Amendment No. 3. Inadvertently the values were wrongly represented which have now been rectified through Amendment No. 4. Side bar indicates modification of the text as the result of incorporation of the amendment. Amendment Nos. 1, 2 and 3 had been incorporated earlier.

0.13 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard relates to:

a) terminology and parameters to be employed in statements relating to surface roughness,

b) preferred values of surface roughness for grading of surfaces,

c) standard sampling lengths to be used in graphical procedure and instrument construction,

d) instruments and methods to be employed in the quantitative assessment of surface roughness, and

e) information to be given in statements relating to surface roughness

2. TERMINOLOGY

2.0 For the purpose of this standard, the following terms and definitions shall apply.

2.1 Real Surface — Surface limiting the body, separating it from the surrounding space.

2.2 Geometrical Surface — Surface prescribed by the design or by the process of manufacture, neglecting errors of form and surface roughness.

2.3 Effective Surface — Close representation of a real surface obtained by instrumental means (Fig. 1).

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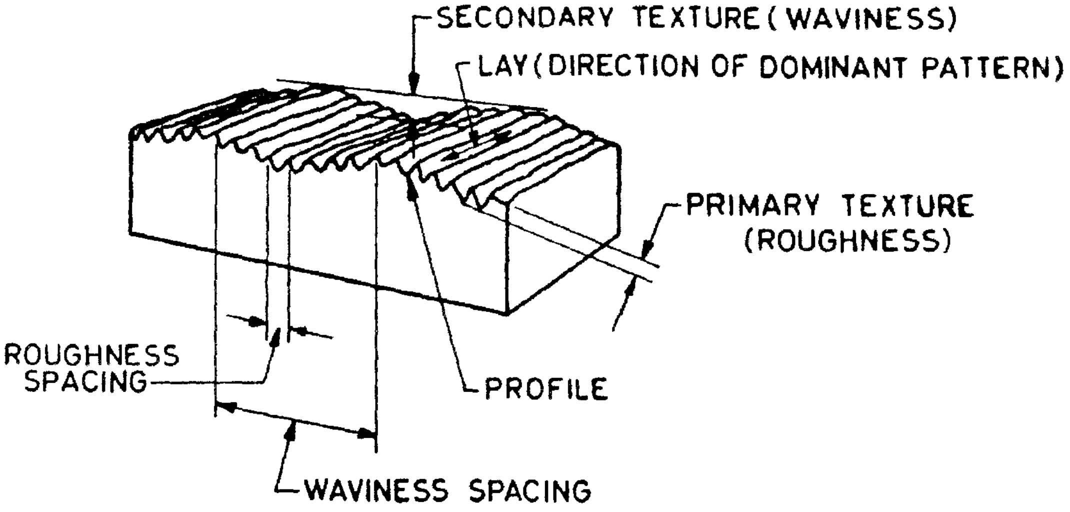
*Rules for rounding off numerical values (*revised*).



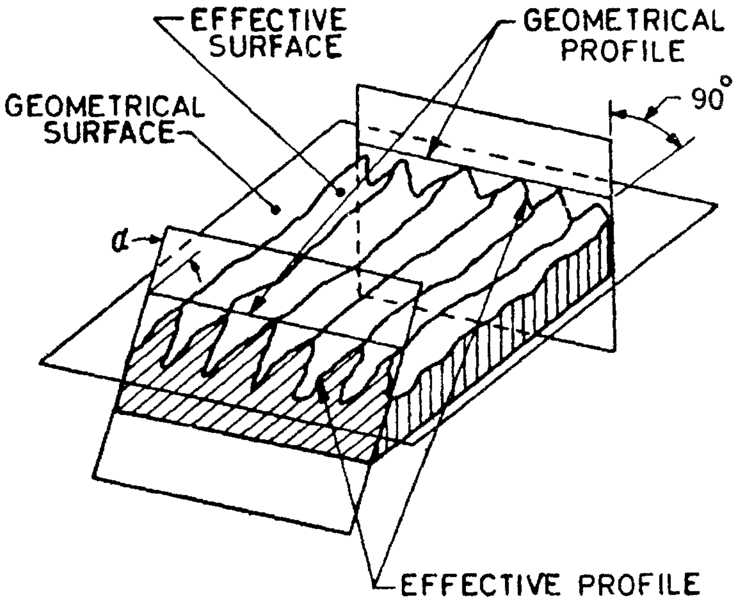


FIG. 1 SURFACE CHARACTERISTICS

2.4 **Surface Roughness** — All those irregularities which form surface relief and which are conventionally defined within the area where deviations of form and waviness are eliminated.

2.4.1 *Primary Texture* (*Roughness*) — The irregularities in the surface roughness which result from the inherent action of the production process. These are deemed to include traverse feedmarks and the irregularities within them (*see* Fig. 1 and 2).

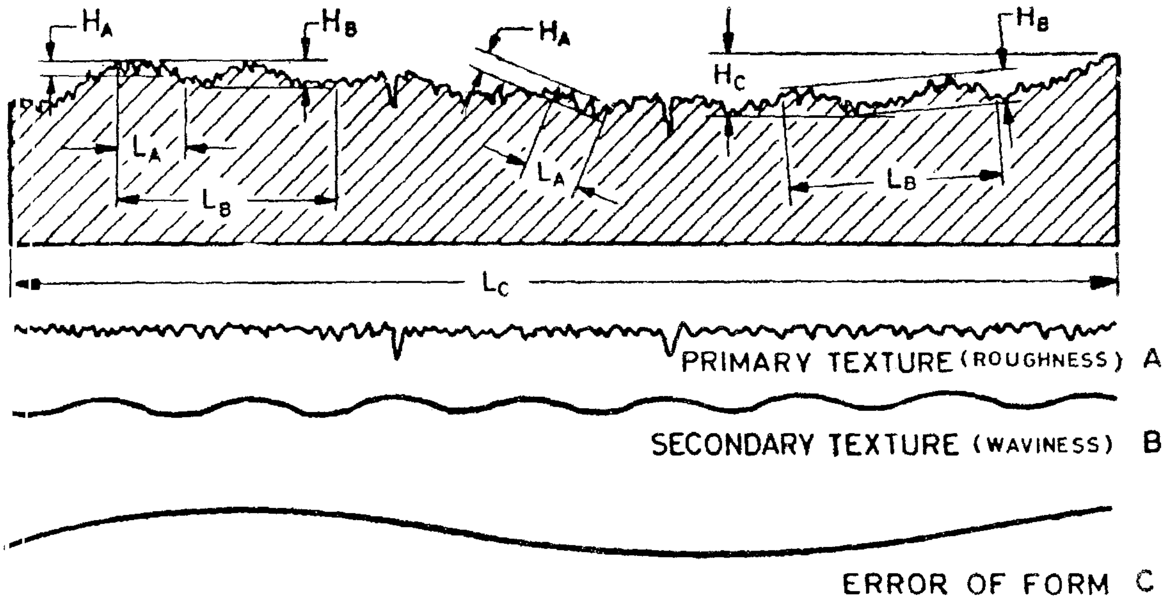


FIG. 2 SURFACE TEXTURE REPRESENTING THE COMBINED EFFECTS OF SEVERAL CAUSES

2.4.2 *Secondary Texture* (*Waviness*) — The component of surface roughness upon which roughness is superimposed. Waviness may result from such factors as machine or work deflections, vibrations, chatter, heat treatment or warping strains (*see* Fig. 1 and 2).

2.5 **Real Profile** — Contour that results from section of the real surface by a plane defined with respect to the geometrical surface. The plane sectioning geometrical surface may meet the plane at an angle α which may have any value up to 90°.

2.6 **Geometrical Profile** — Contour that results from section of the geometrical surface by a plane defined with respect to this surface. The plane sectioning geometrical surface may meet the plane at an angle α which may have any value up to 90°.

2.7 **Effective Profile** — Contour that results from section of the effective surface by a plane defined with respect to the geometrical surface. The plane sectioning geometrical surface may meet the plane at an angle α which may have any value up to 90°.

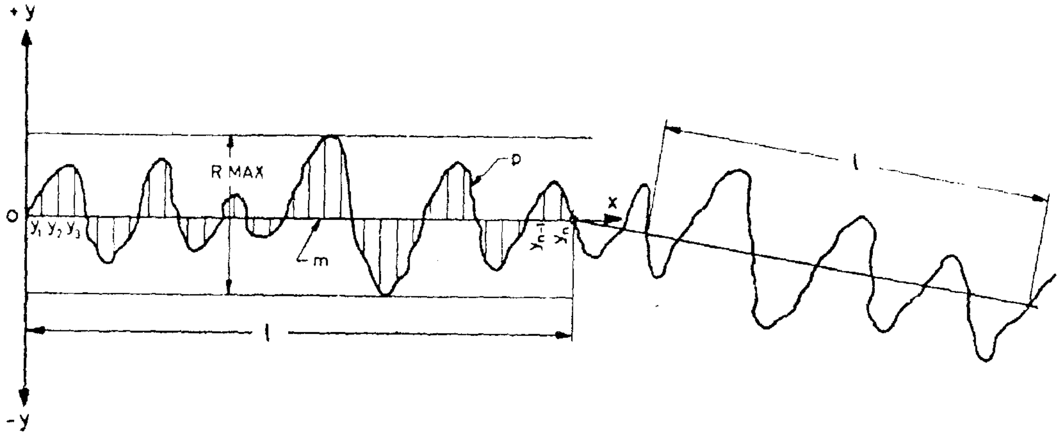
2.8 **Reference Line** — A line chosen by convention to serve for the quantitative evaluation of the effective profile.

2.9 **Lay** — The direction of the predominant surface pattern, ordinarily determined by the production method used (*see* Fig. 1 and 7).

2.10 **Traversing Length** — Length of the profile necessary for the evaluation of the surface roughness parameters.

NOTE — The traversing length may include one or more sampling lengths.

2.11 Sampling Length, *l* — Length of profile necessary for the evaluation of the irregularities to be taken into account (*see* Fig. 3). This is measured in a direction parallel to the general direction of the profile. This is also called the 'Instrument Cut-Off' in regard to measuring instruments.



l = Sampling length
m = Mean line
p = Effective profile
R_{Max} = Maximum height of irregularity

FIG. 3 SAMPLING LENGTH

2.12 Spacing of the Irregularities — Mean distance between the more prominent irregularities of the effective profile, within the sampling length.

2.13 Mean Line of the Profile, *m* — Line having the form of the geometrical profile and dividing the effective profile so that within the sampling length the sum of the squares of distances (Y_1, Y_2......Y_n) between effective profile points and the mean line is a minimum (*see* Fig. 3).

2.14 Centre Line of the Profile — The line parallel to the general direction of the profile for which the areas embraced by the profile above and below the line are equal. When the wave form is repetitive, the mean line and the centre line are equivalent.

NOTE — The difference between 'Mean Line' and 'Centre Line' is always present in the case of practical investigations, because true repetitiveness does not result even from the most carefully controlled manufacturing process which, in theory, should produce a repetitive pattern (for example, turning). In view of its insignificance in relation to other errors of measurement of surface geometry by index, the mean line and the centre line may be considered to be equivalent for practical purposes.

2.15 Arithmetical Mean Deviation from the Mean Line of the Profile, R_a — Average value of the ordinates (Y_1, Y_2.......Y_n) from the mean line (*see* Fig. 3).

The ordinates are summed without considering their algebraic signs:

$$R_a = \frac{1}{l}\int_o^l |y| \ dx$$

Approximately:

$$R_a = \frac{\sum_l^n |yi|}{n}$$

where n is the number of divisions over the sampling length l.

2.16 Ten Point Height of Irregularities, R_z — Average difference between the five highest peaks and the five deepest valleys within the sampling length measured from a line, parallel to the mean line and not crossing the profile (*see* Fig. 4).

$$R_z = \frac{(R_1 + R_3 + ... + R_9) - (R_2 + R_4 + ... + R_{10})}{5}$$

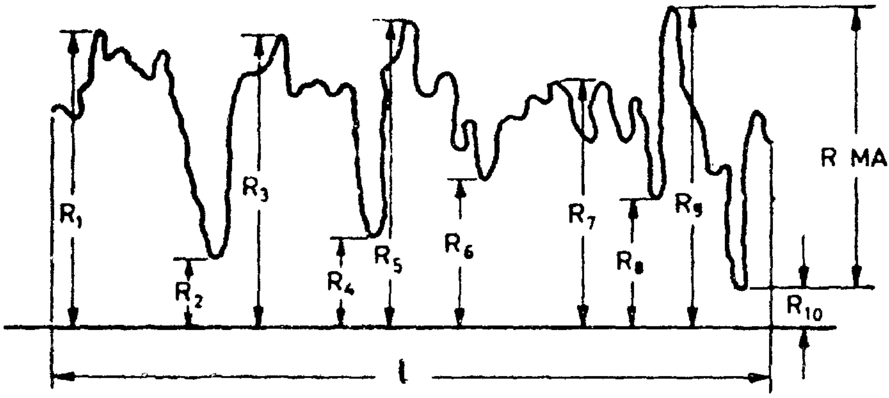


FIG. 4 TEN-POINT HEIGHT ASSESSMENT OF IRREGULARITIES

2.17 Maximum Height of Irregularity, R_{Max} — Distance between two lines parallel to the mean line and touching the profile at the highest and lowest points within the sampling length (*see* Fig. 3 and 4).

3. PREFERRED VALUES FOR R_a, R_z AND SAMPLING LENGTHS

3.1 The preferred values for R_a and R_z shall be selected from Tables 1 and 2.

3.2 Sampling Length — For measuring surface roughness, the value of the sampling length l shall be selected from the following series:

0.08, 0.25, 0.8, 2.5, 8, 10 and 25 mm.

TABLE 1 ARITHMETICAL MEAN DEVIATION R_a, µm

(*Clause* 3.1)

0.025	1.6
0.05	3.2
0.1	6.3
0.2	12.5
0.4	25
0.8	—

TABLE 2 TEN POINT HEIGHT OF IRREGULARITIES R_z, µm

(*Clause* 3.1)

0.05	0.4	3.2	25
0.1	0.8	6.3	50
0.2	1.6	12.5	100

3.3 Selection of Sampling Lengths — Sampling lengths suitable for different types of machined surface are given in Table 3, and for non-machined surface in Table 4. Where a range of value is given, the shorter value will generally be suitable for the finer and the longer for the coarser grade of a given process.

TABLE 3 SUITABLE SAMPLING LENGTHS FOR VARIOUS MACHINING SURFACES

PROCESS	SUITABLE SAMPLING LENGTHS, mm						
Milling	—	—	0.8	2.5	8	10	—
Boring	—	—	0.8	2.5	8	10	—
Turning	—	—	0.8	2.5	—	—	—
Grinding	—	0.25	0.8	2.5	—	—	—
Planing	—	—	—	2.5	8	10	25
Reaming	—	—	0.8	2.5	—	—	—
Bronching	—	—	0.8	—	—	—	—
Diamond boring	—	0.25	0.8	—	—	—	—
Diamond turning	—	0.25	0.8	—	—	—	—
Honing	0.08	0.25	0.8	—	—	—	—
Lapping	0.08	0.25	0.8	—	—	—	—
Superfinishing	0.08	0.25	0.8	—	—	—	—
Buffing	—	—	0.8	2.5	—	—	—
Polishing	—	—	0.8	2.5	—	—	—
Shaping	—	—	0.8	2.5	8	10	—
Spark machining	—	—	0.8	—	—	—	—

TABLE 4 SUITABLE SAMPLING LENGTHS FOR TYPICAL NON-MACHINED SURFACES

(*Clause* 3.3)

PROCESS	SAMPLING LENGTHS, mm	
Burnishing	0.8	2.5
Drawing	0.8	2.5
Extrusion	0.8	2.5
Moulding	0.8	2.5
Electro-polishing	0.8	2.5

4. DETERMINATION OF R_a

4.1 The R_a values are preferably determined as mean results from the measurement of several sampling lengths taken consecutively along the profile. These may be determined graphically in accordance with **4.2** or by direct reading instruments (*see* **5.1.3**). The direction in which the measurement is made should, in general, be approximately at right angles to the 'lay' if the surface texture has a directional quality (*see* Fig. 1).

4.2 Graphical Determination of R_a Values — The following procedure shall be observed in determining R_a values from graphical recordings. It will be assumed for the moment that the surface is nominally flat, and that the record is produced in rectilinear co-ordinates in which a truly flat surface is represented as a straight line. It is necessary to first determine the mean line of each successive sampling length of the record. (*see* Fig. 5).

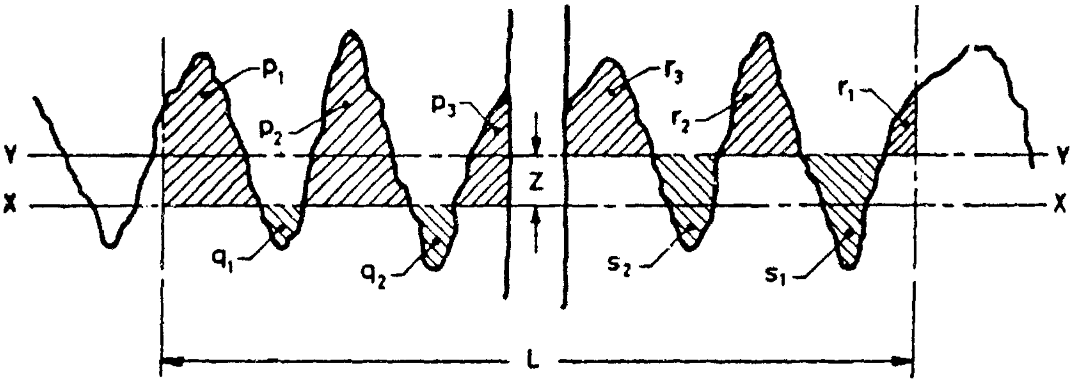


FIG. 5 DETERMINATION OF THE CENTRE LINE AVERAGE FROM A TRACE

4.2.1 Any straight line *XX* is drawn parallel to the general course of the record over the sampling length. The direction, but not the actual position of this line can usually be determined with sufficient accuracy by the eye. Where the texture has a distinguishable periodicity, the sampling length shall be a whole number of wavelengths, even though this may not be a standard sampling length. The sum of all the areas p_1,

p_2, etc, and q_1, q_2, etc, are then determined either by measuring ordinates or by the use of a planimeter, throughout the chosen sampling length, and the algebraic sums of these areas are calculated and divided by L:

$$Z = \frac{\text{sum of areas } p - \text{sum of areas } q}{L}$$

4.2.2 The resulting value gives the distance between the line *XX* and the required centre line *YY* which can be drawn parallel to *XX*. The sums of the areas r_1, r_2 etc, will then be equal to the sum of the areas s_1, s_2, etc. Lastly, the arithmetical sum of all the areas r and s is determined, and

$$h = \frac{\text{sum of areas } r + \text{sum of areas } s}{L} \times \frac{1\,000}{M}$$

gives the value of h which is the R_a value expressed in microns where r_1, r_2......, s_1, s_2......, etc, are expressed in square millimetres; L = the representation of the sampling length, in millimetres, as measured on the record; and M = the vertical magnification of the record.

4.2.3 If the profile under examination is not nominally straight, or if the nature of the recording instrument is such that the record is produced on a curved base line, the R_a value could still be determined, by a similar procedure, in relating to a mean line of appropriate curvature or alternatively by first developing the record so that the base line is straightened. Some instruments, when operating on a curved surface under appropriate conditions, will produce records in which the nominally curved base line is automatically straightened. In other cases, profile records may be made on plastic replicas taken from curved surfaces and flattened out (*see* **A-7**).

4.2.4 Some recording instruments operate in such a way that the recording pen moves not in a straight line, but in an arc of a circle. This slightly distorts the geometry of the record but does not affect the determination of the R_a value, which could still be carried out in the manner mentioned above.

5. INSTRUMENTS

5.1 Measuring instruments of the stylus type employed for the determination of surface roughness shall comply with the following requirements.

5.1.1 *Stylus* — For graphical recording instruments, a stylus having a nominal tipped radius of 0.003 mm may be used. For the determination of R_a values, with direct reading instruments, a stylus tip with a nominal radius of 0.012 5 mm be used. The variation in the tip radius of the stylus shall be within 30 percent of its nominal dimension or 0.003 mm whichever is greater.

The shank may be conical or pyramidal, and in either case the included angle of the cone shall not exceed 90°.

The maximum force between a stylus and a surface under test shall not exceed that given by the following:

$$\text{Maximum force (grams)} = 0.016 \times (\text{tip radius in microns})^2$$

5.1.2 *Skid* — If a single skid is employed, its radius in the direction of the traverse shall be not less than 50 times the sampling length. If two operative skids as shown in Fig. 19 are used, their radii shall be not less than 8 times the sampling length.

5.1.3 *Electrical Integrating Instruments* — Electrical integrating instruments giving direct scale-and-pointer indications of R_a values take, in effect, an automatic average over a succession of sampling lengths determined by the cut-off of the instrument.

5.1.3.1 *Circuit construction* — Instruments of the electrical type shall be constructed so that the speed of traverse divided by the frequency cut-off is equal to one of the standard sampling lengths given in **3.2**. More detailed information is given in Appendix A.

5.1.3.2 *Transmission characteristics* — It should be noted that at the ends of the cut-off range, the transmission does not fall to zero abruptly but falls off gradually. The cut-off shall be assessed at between 70 and 80 percent of the maximum transmission as shown in Fig. 6.

The preferred rate of attenuation shall be equivalent to that produced by two RC networks with equal time constants in series. This describes a system in which the straight part of the attenuation curve has a maximum slope of 12 dB per octave.

6. STATEMENTS OF SURFACE ROUGHNESS

6.1 The following information shall be given in statements relating to surface roughness.

6.1.1 *Surface Roughness Values* — These shall normally be expressed as the R_a value in microns (µm). If a single R_a value is stated it is understood that work with any R_a value from zero to that stated is acceptable.

6.1.2 *Limiting Values* — When both minimum and maximum R_a values need to be specified these shall be expressed as follows:

Example:

$R_a{}^{8.0}_{16.0}$ or alternatively — R_a 8.0 — 16.0

6.1.3 *Sampling Length* (*Instrument Cut-Off*) — The sampling length shall be indicated in parenthesis following the roughness value.

Example:

R_a 8.0 (2.5)

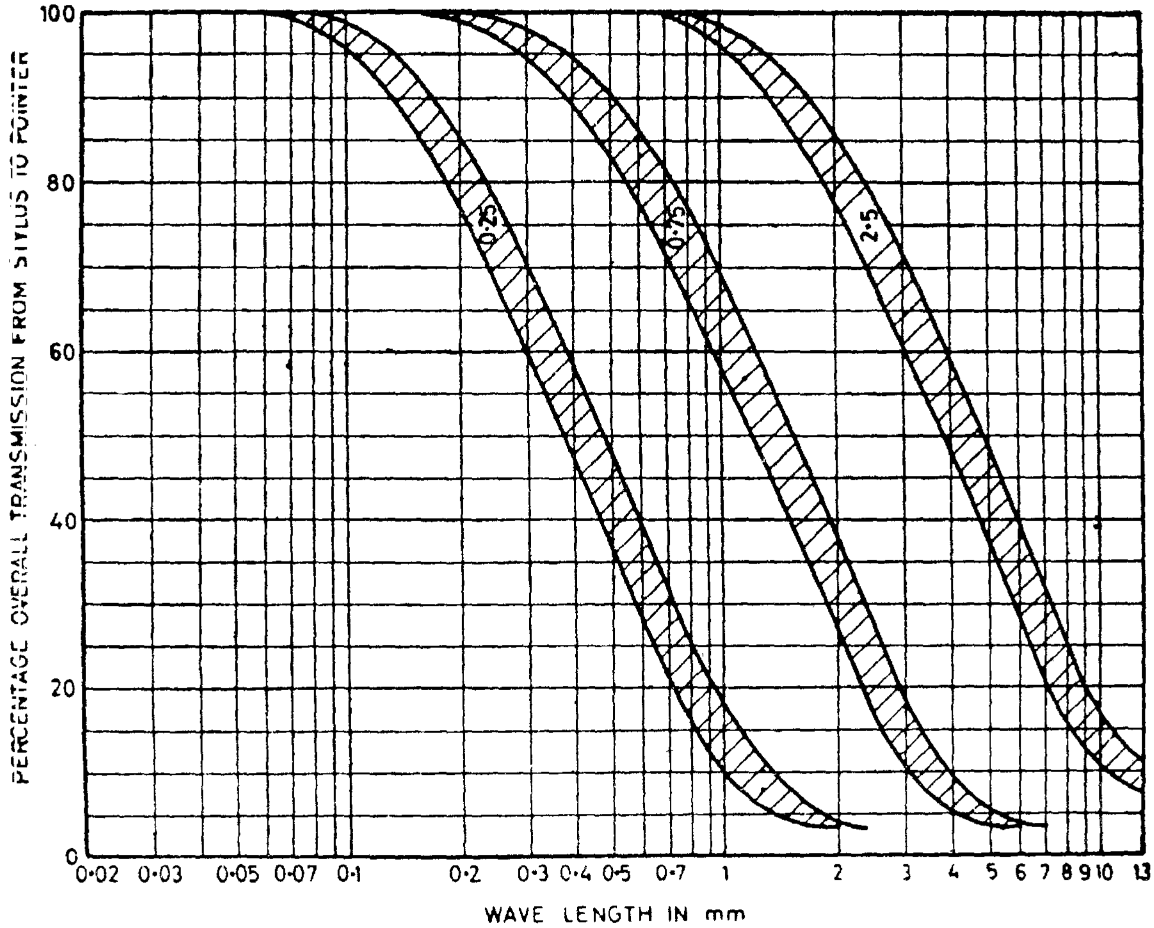


FIG. 6 TRANSMISSION CHARACTERISTICS

6.1.4 *Lay* — It is sometimes necessary to specify the direction of the lay, in which case it would be defined as shown in Fig. 7, and expressed in accordance with the following example:

Example:

R_a 1.6 Lay Circular

Unless otherwise specified, the implication is that the surface roughness shall be measured across the direction of the lay.

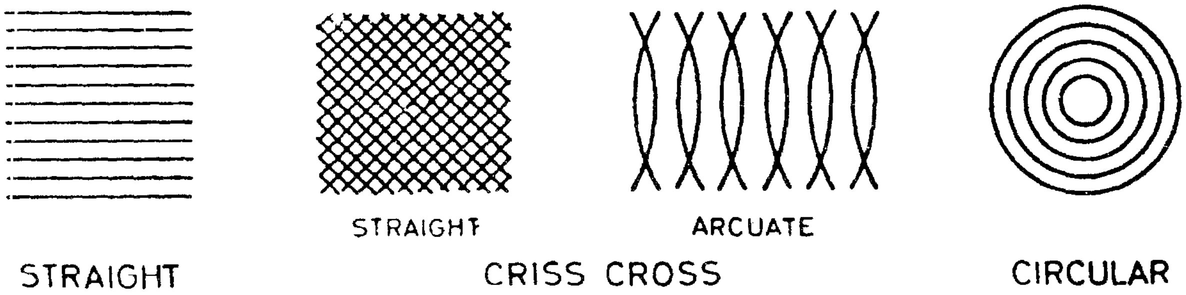


FIG. 7 DIRECTION OF LAY

6.1.5 *Process* — When it is necessary to limit the production of a surface to the use of one particular process, the process shall be stated (*see* Tables 3 and 4, and Appendix A).

6.2 Surface Roughness Symbols

6.2.1 R_a should be considered as the main surface roughness criterion in practice.

6.3 Indication of Surface Roughness on Drawings — The methods of indication surface roughness on drawings shall be as given in Section 5 of IS : 696-1972*. The roughness grade numbers, namely, N1 to N12 shall be defined in the manner indicated below. The relationship between the roughness grade numbers and the commonly used and generally accepted system of indicating surface roughness by symbols is also given below for guidance. These symbols are classified into five groups. The maximum permissible value for roughness in each group is that of the coarsest grade of each one of these groups, namely, N11, N9, N6, and N3.

ROUGHNESS GRADE NUMBER	ROUGHNESS VALUE, R_a µm	ROUGHNESS SYMBOL
N12	50	~
N11 N10	25 12.5	∇
N 9 N 8 N 7	6.3 3.2 1.6	∇ ∇
N 6 N 5 N 4	0.8 0.4 0.2	∇ ∇ ∇
N 3 N 2 N 1	0.1 0.05 0.025	∇ ∇ ∇ ∇

6.4 To obtain an approximate idea of the surface roughness that can be achieved from various production processes, Table 5 may be referred to.

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*Code of practice for general engineering drawings (*second revision*).

TABLE 5 SURFACE ROUGHNESS EXPECTED FROM MANUFACTURING PROCESSES

(*Clause* 6.4)

Sl No.	Manufacturing Process	R_a in µm (0·012, 0·025, 0·050, 0·10, 0·20, 0·40, 0·80, 1·6, 3·2, 6·3, 12·5, 25, 50, 100, 200)
1	Sand casting	5 ▨ 50
2	Permanent mould casting	0·8 ▨ 6·3
3	Die casting	0·8 ▨ 3·2
4	High pressure casting	0·32 ▨ 2
5	Hot rolling	2·5 ▨ 50
6	Forging	1·6 ▨ 25
7	Extrusion	0·16 ▨ 5
8	Flame cutting, Sawing & Chipping	6·3 ▨ 100
9	Radial cut-off sawing	1 ▨ 6·3
10	Hand grinding	6·3 ▨ 25
11	Disc grinding	1·6 ▨ 25
12	Filing	0·25 ▨ 25
13	Planing	1·6 ▨ 50
14	Shaping	1·6 ▨ 25
15	Drilling	1·6 ▨ 20
16	Turning & Milling	0·32 ▨ 25
17	Boring	0·4 ▨ 6·3
18	Reaming	0·4 ▨ 3·2
19	Broaching	0·4 ▨ 3·2
20	Hobbing	0·4 ▨ 3·2
21	Surface grinding	0·063 ▨ 5
22	Cylindrical grinding	0·063 ▨ 5
23	Honing	0·025 ▨ 0·4
24	Lapping	0·012 ▨ 0·16
25	Polishing	0·04 ▨ 0·16
26	Burnishing	0·04 ▨ 0·8
27	Superfinishing	0·016 ▨ 0·32

APPENDIX A

(*Clauses* 0.10, 5.1.3.1 *and* 6.1.5)

GENERAL INFORMATION AND GUIDANCE ON THE ASSESSMENT OF SURFACE ROUGHNESS

A-1. GENERAL

A-1.1 The following clauses contain information and guidance on some of the more important factors affecting surface roughness measurements and are intended to supplement and explain some of the reasons for the requirements of this standard.

A-2. GENERAL REMARKS ON SURFACE ROUGHNESS

A-2.1 Whereas the shape and size of a component are usually specified as though its surface could be perfectly smooth and of simple geometric form, in practice the manufactured surface always departs to some extent from absolute perfection. The imperfections take the form of a succession of hills and valleys which may vary both in height and in spacing, and result in a kind of texture which in appearance or feel is often characteristic of the machining process and its accompanying defects.

A-2.2 The departures from a truly smooth surface may arise from a variety of causes and may be of several kinds. There will be a certain texture or 'roughness' in the form of a succession of minute irregularities which result directly from the particular process, for example turning, grinding, or lapping, employed to finish the surface. In general, the finer grades of surface roughness, those produced by abrasive process, such as lapping or honing, tend to be irregular and non-directional in character; surfaces produced by straight and cylindrical grinding tend to have irregularly spaced but directional roughness; while the roughness on surfaces produced by single point cutting tends to be both uniformly spaced and directional. In the case of machined surfaces there may be, in addition to the characteristic roughness produced by the tool, more openly spaced components of roughness resulting from faults in the machining operation. In practice, the complete roughness commonly represents a combination of irregularities of various kinds and magnitudes arising from several different causes. The individual effects of the separate contributing factors cannot always be readily distinguished.

A-2.3 A complete study of surface roughness would involve the measurement and analysis of all its component elements and an assessment of the effect of the resulting combined texture on the functioning of the part. In view of the complex nature of the problem such an idea is incapable of attainment in ordinary routine workshop control by any method yet devised. What is immediately desirable, therefore, is a practical method of assessment, the result of which can be readily compared with a specified requirement of quality, preferably on a numerical basis.

A-2.4 In general, each manufacturing process has its own characteristic surface roughness and it is this that enables a surface adequately to be defined by a single number in conjunction with the name of the process (*see* **6**).

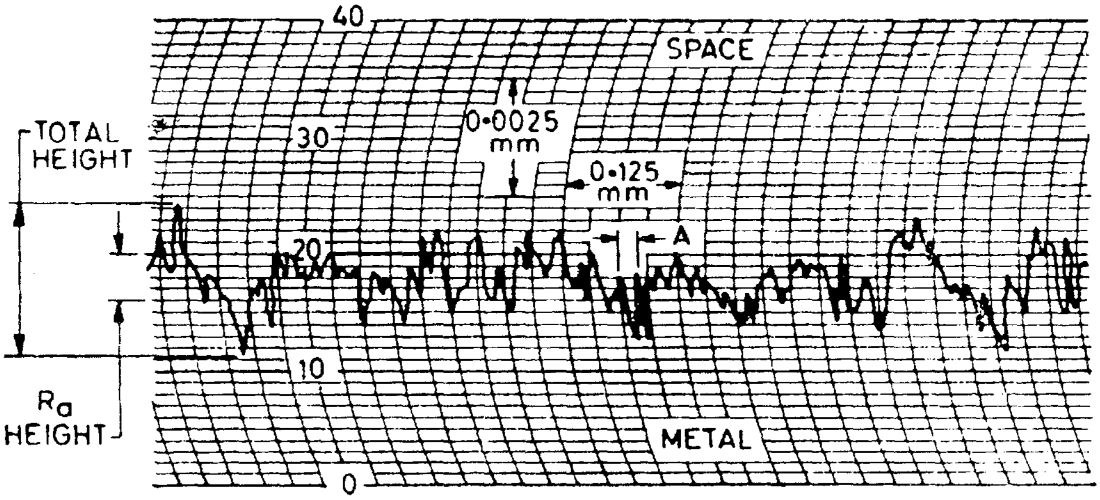
A-2.5 The problem of surface roughness measurement is essentially one of geometry and the fundamental definitions are therefore expressed in geometrical terms, whatever short-cuts may be taken in practical methods of assessment. Of the later, probably the simplest is the provision of a series of sample surfaces, of appropriately graded texture, produced by specified processes, with which the surface of the actual product could be directly compared by sight or touch. Such comparisons, however, are essentially qualitative rather than quantitative and in any case the grading of the samples themselves shall have been determined by independent measurement.

A-2.6 Basically, the measurement of surface roughness presents a problem in three-dimensional geometry, but in practice it is reduced to one of two-dimensional geometry by confining individual measurement to the profiles of plane sections taken through the surface. In some cases, where the roughness is non-directional in character, it may be immaterial what plane is chosen for the purpose, but it shall not be forgotten that, where the texture has a directional quality, quite different results may be obtained from measurements made in different planes (*see* **A-4**).

A-2.7 The standard practice, unless otherwise specified, is to make the measurement in a direction approximately at right angles to the direction of the predominant surface markings or 'lay' (*see* Fig. 2 and 13). In special cases measurement in other directions may also be necessary.

A-2.8 The process of measurement is thus reduced to one of analysing the form of the profile revealed by a plane section through the surface. Various instruments are available for this purpose. Most of these provide a magnified record of the profile such as is shown, for example, in Fig. 8. Some provide, in addition, a direct reading on an indicating meter of the mean height of the departures from a reference surface. All types of instruments are subject to certain limitations which have to be taken into consideration in formulating any statement relative to the specification and measurement of surface texture. The more important of these are discussed briefly in **A-5**.

A-2.9 It is, therefore, necessary to specify conditions with which the instruments shall comply in order that different types should give consistent results. It is also necessary that the sections of the profile record considered (sampling lengths) should be identical in length with the meter cut-off value associated with electrical integrating instruments. This, in effect, excludes from the measurements those components of roughness having spacings exceeding the prescribed meter cut-off (*see* **5.1**).



Ratio of Magnification, Vertical : Horizontal = 50 : 1

FIG. 8 TYPICAL SURFACE FINISH CHART

A-2.10 The determination of more widely spaced irregularities is referred in **A-6**.

A-2.11 It is not possible to state any specified value for spacing which could be regarded as forming a definite line of demarcation between roughness and waviness. The scale of each of these features will depend on the class of work and the manufacturing process employed. For this reason this standard includes a series of alternative standard instrument cut-off values from which the most suitable for any particular case may be selected (*see* **3.2** and Tables 3 and 4).

A-2.12 Similarly, no theoretical value could be assigned to the maximum spacing which should be included in measurements of waviness. As the spacing increases, however, waviness tends to become merged in more general errors of geometric form and it is necessary in practice to set some limit in order to define the measuring range of instruments intended for the measurement of waviness.

A-2.13 As may be seen from Table 3 it has been found that an instrument cut-off of 0.8 mm is generally satisfactory for the majority of fine engineering work. An upper limit of 25 mm is commonly accepted as suitable for most waviness measurements.

A-3. NOTES ON SURFACE PROFILES AND THEIR MEASUREMENT

A-3.1 Profiles — The shape of the hills and valleys which constitute surface roughness can best be studied in a cross-section normal to the surface. An example of a trace of the cross-section of a short length of ground surface as obtained with a stylus instrument is shown in Fig. 8.

A-3.1.1 Since the irregularities of the surface which it is desired to examine are minute in depth, it is necessary for graphical representations of them to be shown to a considerable degree of magnification for example up to 50 000 times or even greater. It will be appreciated that to the same scale of magnification, even so short a length of surface as 0.1 mm would require a graph as long as 5 metres which would be quite unmanageable. Fortunately, the pitch of successive irregularities is usually much greater than their height and it is therefore customary for instruments used for obtaining graphical representations of surface profiles to have different magnifications for the vertical and horizontal scales, the former being usually from 50 to 300 times the latter. The extent to which this alters the appearance of the trace will be seen by comparing the true trace of a short length of surface taken at the same vertical and horizontal magnification as shown in Fig. 9, with its condensed version shown by the small section 'A' of Fig. 8.

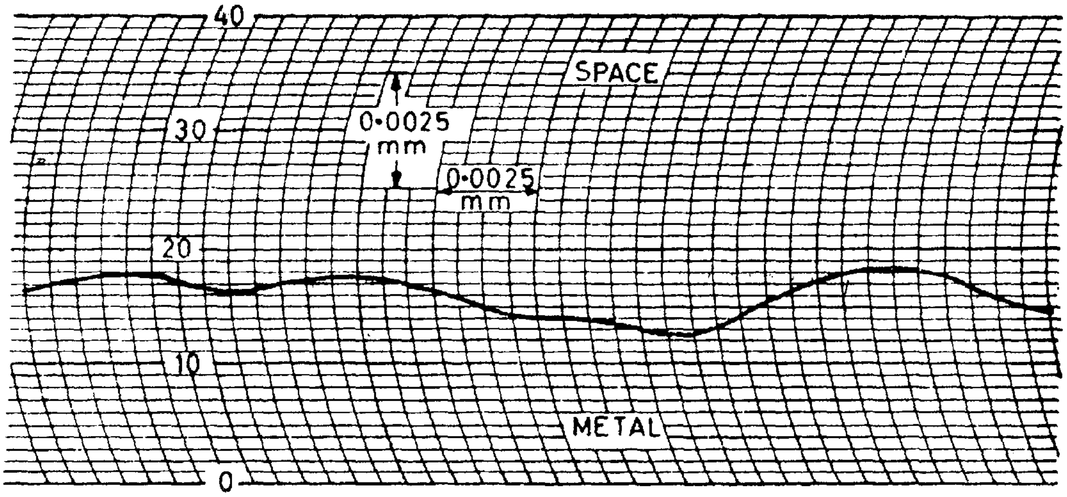


FIG. 9 PORTION A OF FIG. 8 WITH HORIZONTAL MAGNIFICATION EXTENDED TO EQUAL THE VERTICAL MAGNIFICATION

A-3.1.2 The two principal quantities to be noted on the graphs are the height of the irregularities (which may be measured in various ways, for example, total height values or average values) and the separation of their crests. The latter is referred to as the spacing; but when the irregularities are comparatively uniform in shape and size, as in Fig. 10 and are repeated at regular intervals, the distance between the successive peaks may be described as the pitch, or dominant spacing. It is essential to realize that the 'roughness' of a surface, in the ordinary sense of the word, involves both the size and shape of the irregularities.

A-3.1.3 A great variety of very different surfaces may exhibit the same height of departure from the nominal profile, consider, for example, 'a' to 'f' in Fig. 11; 'a' represents the profile of a perfectly smooth flat surface

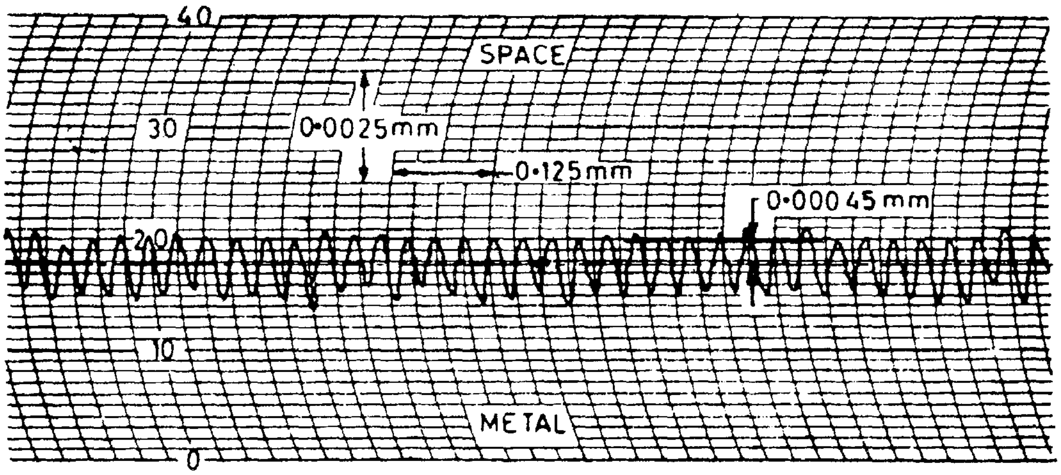
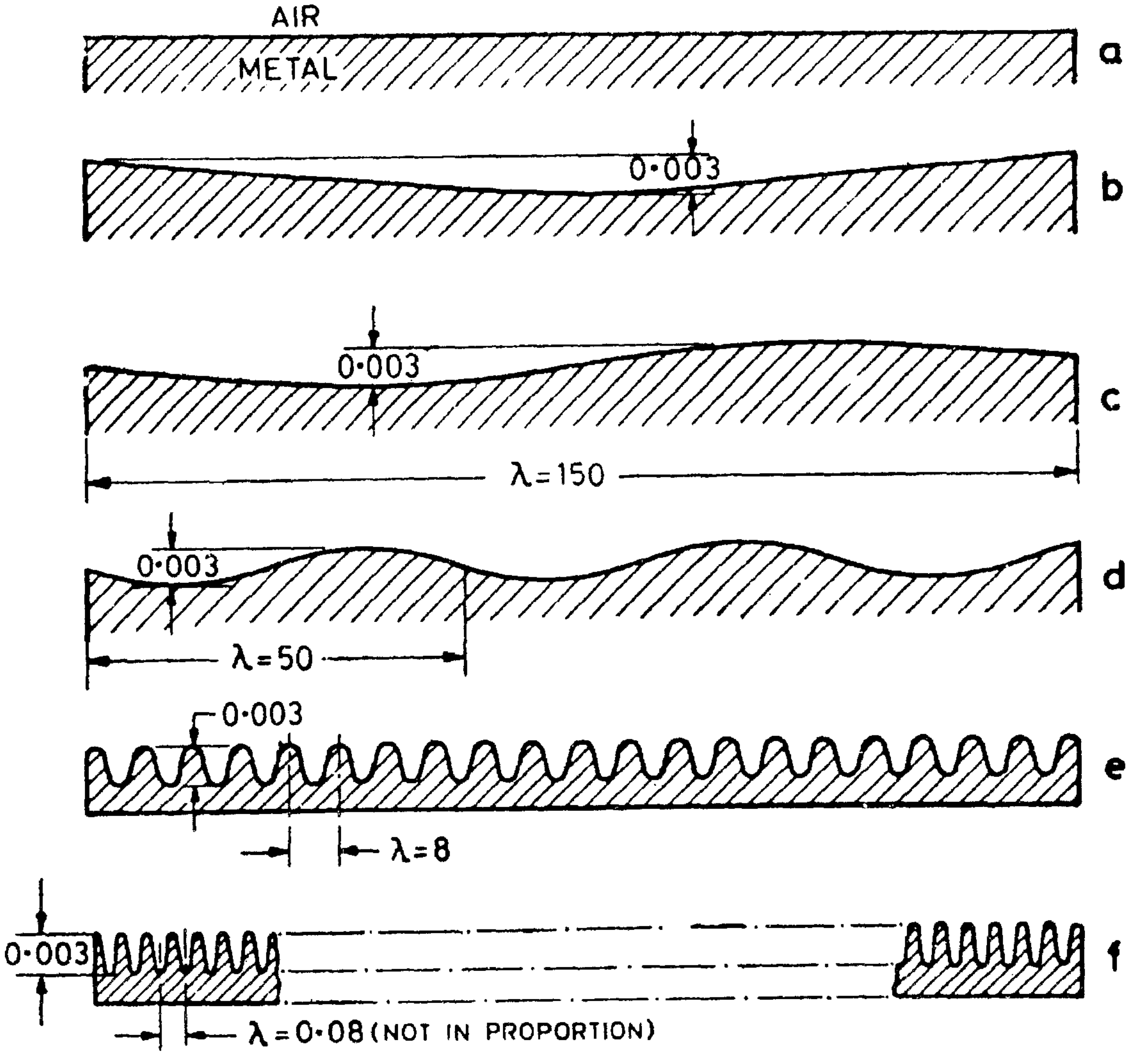


FIG. 10 TYPICAL DIAMOND TURNED SURFACE



All dimensions in millimetres.

FIG. 11 VARIOUS PROFILES HAVING THE SAME HEIGHT OF DEPARTURE FROM THE NOMINAL PROFILE of, say, 150 mm long, 'b' shows the same length of surface, concave to the extent of 0.003 mm, and successive figures indicate waves of 150 mm, 50 mm, 8 mm, 0.08 mm pitch respectively, but all except 'a' have the same height of 0.003 mm. The first three surfaces, namely, 'a' to 'c' though two of them have errors of geometric form, would appear smooth, but as the spacing changes the quality of the surface changes. This would be noticeable to the eye although the same height of wave has been maintained in each of the diagrams. The errors of 'b' to 'd' would be practically undetectable in surface texture measurements and would need to be determined by ordinary metrological methods.

Those of 'd' and 'f' would be revealed by a waviness recorder and by normal surface roughness measurement respectively. Consider also the difference between the various forms shown in 'a' to 'e' in Fig. 12 all of which have both the same spacing, and the same total height, but vary in character.

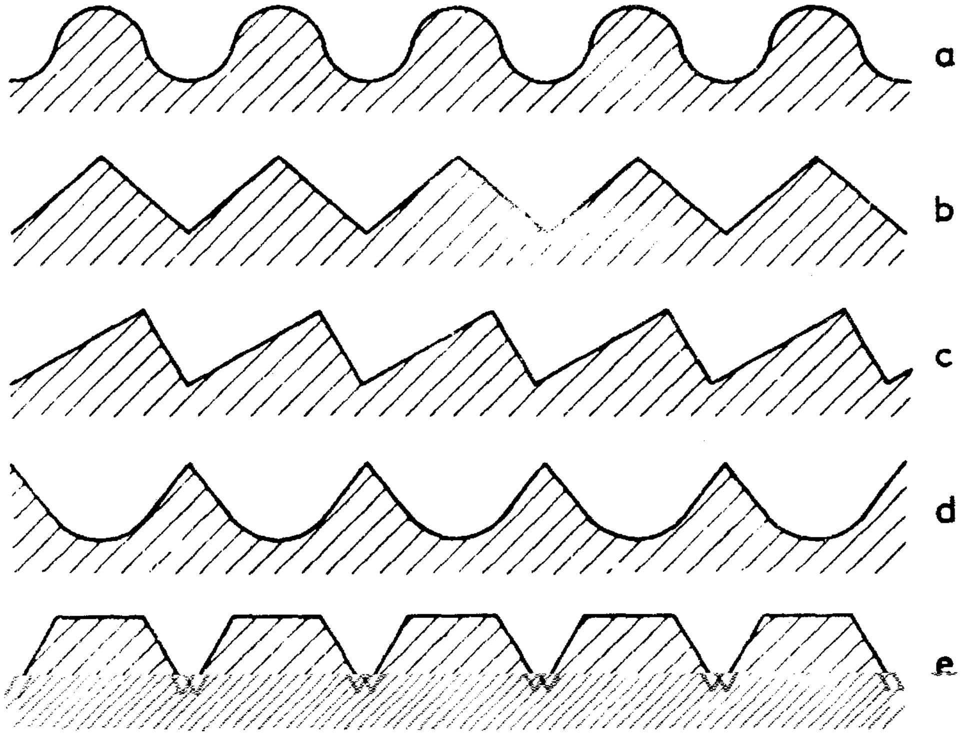


FIG. 12 VARIOUS PROFILES HAVING THE SAME SPACING AND SAME AVERAGE HEIGHT

A-3.1.4 It is not suggested that all, or any, of these diagrammatic forms are likely to occur exactly in practice, but approximations to most of them, as well as many other more complicated forms undoubtedly do. The functional properties of such differing surfaces may vary greatly and hence arises the impossibility of expressing the *complete* roughness characteristic of a surface by means of any single number. It is for this reason that it is necessary in principle, in any statement of surface roughness requirements, to specify the process of manufacture which serves to produce the type of roughness, as well as the R_a value which serves to define its quality or grade.

A-3.2 Measurement

A-3.2.1 Surfaces commonly met with in practice are usually not so simple in type, but often represent combined effects due to several contributing causes. Consider, for example, Fig. 2 which shows diagrammatically surface containing roughness A, waviness B and imperfection of shape C. If the measurement is confined to a short sampling length L_A of the surface, the value obtained for the total height will be H_A (total height being considered here for reasons of demonstration). This is a measure of the roughness neglecting the occasional deep scratches; it is nominally the same for all parts of the surface and it neglects the irregularities of greater pitch altogether. As the sampling length is increased, however, the height will eventually increase until, for a length L_B, it reaches a new value H_B, which takes into account the waviness, but which still ignores errors of geometrical form. Finally, for the whole surface, if such a measurement were practicable, sampling length L_C would give a value H_C including all irregularities and errors.

A-3.2.2 Thus, various values could be obtained for the value of the surface according to the length of surface selected for measurement. It might seem that the length of surface which most fairly expresses the quality of the surface roughness is the greatest, that is L_C. That this may not be so is demonstrated by Fig. 13 of which 'A' represents diagrammatically a finely ground shaft which is slightly barrel-shaped while 'B' represents a more coarsely ground shaft which is free from errors in shape. The total heights are the same, but the shafts, are obviously far from being identical in quality.

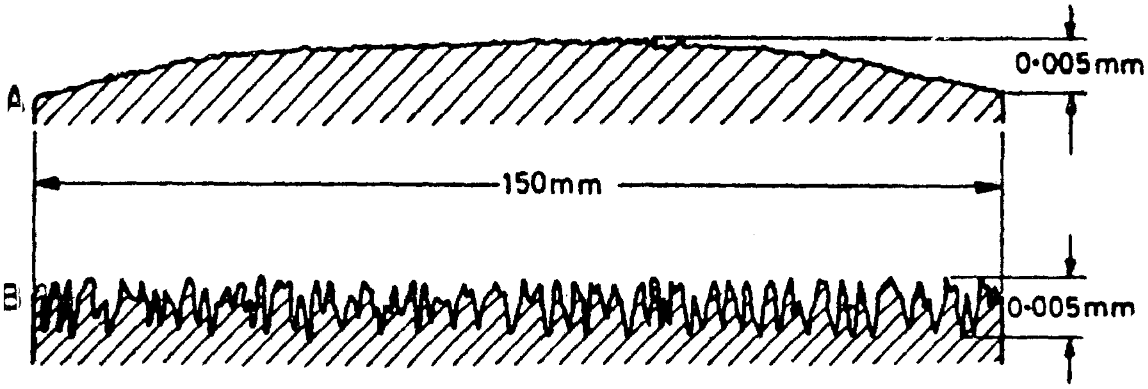


FIG. 13 SURFACE TEXTURES HAVING THE SAME TOTAL HEIGHT BUT DIFFERING ERRORS OF NOMINAL PROFILE

A-3.2.3 An obvious method of measuring the roughness 'A' regardless of the irregularities 'B' and 'C' is to limit the measurement to a sufficiently short length of the surface. In the case of the finer surfaces, however, this length becomes very small — of the order of 0.1 mm, and the difficulty is then encountered that even within a relatively small area of the surface the measured value over a sampling length may vary considerably from point to point. Such variations shall not be confused with true variations of texture in different parts of the surface, as they are merely the incidental result of the method of analysis and have to be smoothed out. This could be done, as shown in Fig. 14 by taking as the true value the mean of a number of observation.

The observations may conveniently be taken in a row along a short length of the surface. Thus, if the roughness does not exceed some given spacing, say 0.1 mm the graph may be divided into successive sections L_1, L_2, L_3, etc, each 0.1 mm long and the average height of each section found separately. Taking the mean value from a few (say five) consecutive sections will usually suffice to eliminate the effect of variations between the individual sections. The effect of this procedure is to eliminate from A in Fig. 14 the more widely spaced components of the texture and to measure only those components the spacing of which is less then 0.1 mm, as shown in the modified profile, B in Fig. 14.

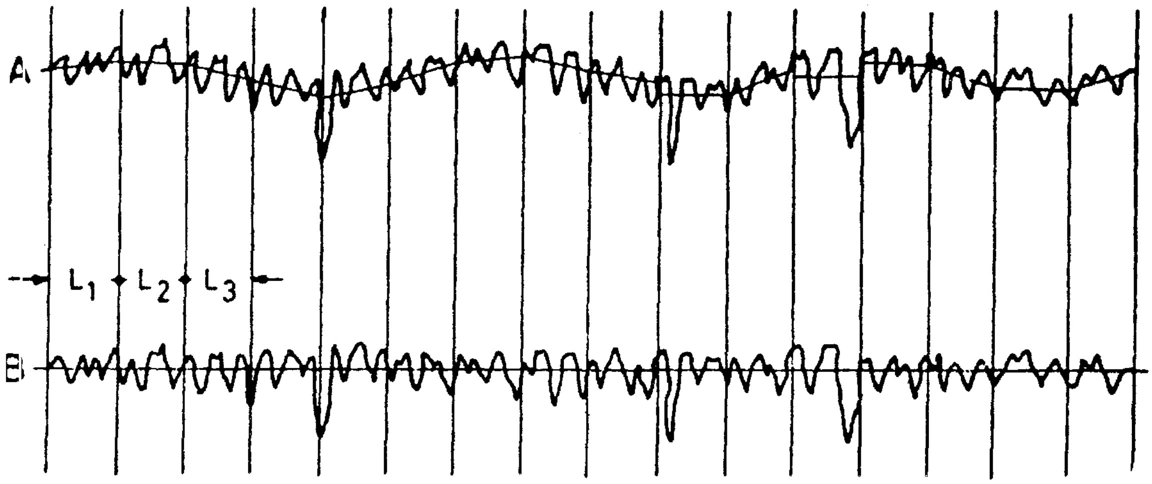


FIG. 14 ANALYSIS OF SURFACE ROUGHNESS CHART BY THE ELIMINATION OF LONGER SPACING ERRORS

A-3.2.4 It is clear, therefore, that, in order to obtain consistent results from surface roughness measurements, the instrument cut-off shall be specified as well as the manufacturing process and the R_a value. It is for this reason that the use of standard instrument cut-offs is essential. The instrument cut-off selected for this purpose should be sufficient to give a satisfactory average of those components of the texture which it is desired to control, but not so great as to include other components of wider spacing. The instrument cut-off 0.8 is considered to be suitable for a large proportion of ordinary engineering work (*see* Tables 3 and 4).

A-4. NOTES ON THE DIRECTION OF MEASUREMENT

A-4.1 When the surface roughness has a directional quality, measurement taken in different directions across the surface may differ simply because of the change in the effective spacing of the crests, as revealed by different sections. For example, consider Fig. 15 in which the horizontal lines represent successive ridges in a simple uniformly spaced texture and the short lines A, B, C, etc, represent a succession of equal instrument cut-offs, taken in different directions.

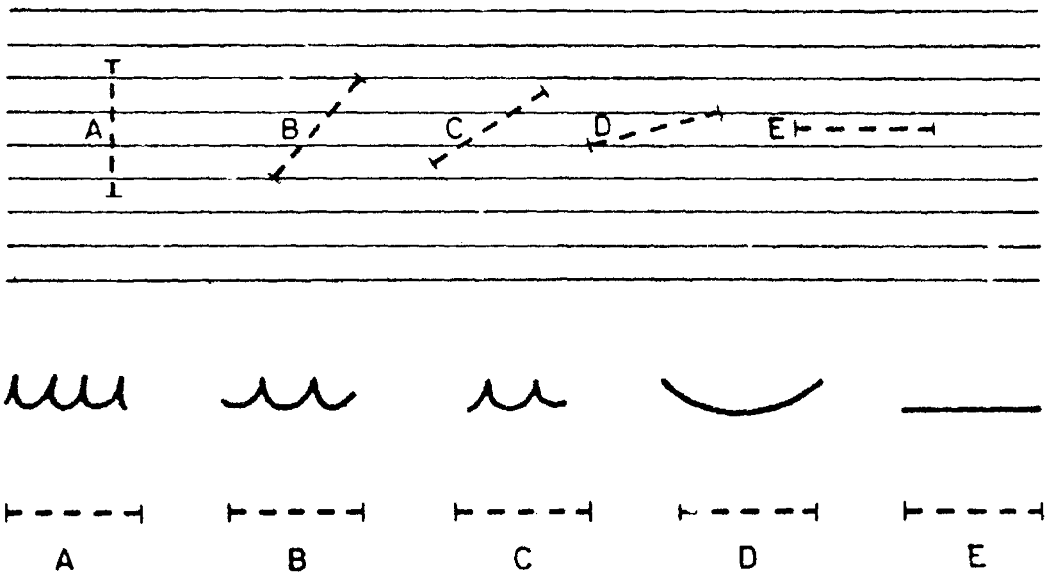


FIG. 15 INFLUENCE OF DIRECTION OF MEASUREMENT ON THE EFFECTIVE SPACING OF PROFILE CREST

A-4.2 The usual direction of measurement is shown by a line A at right angles to the lay. A slight error in direction such as that represented by the line B is not likely to affect the measured average height materially. As the inclination of the direction of measurement increases, however, the number of ridges spanned by the sampling length diminishes, until at D only one complete spacing is included in the measurement. Beyond this point the limitation imposed by the instrument cut-off comes into play and the full value of the average height is not recorded. In the extreme case, at E, where measurement is made parallel to the lay, a minimum result would be obtained.

A-4.3 On multidirectional textures, distinction may be made between an irregular pattern (for example lapping, honing, super-finishing) and a periodically recurring criss-cross pattern (for example end milling, plane milling and cup wheel grinding). On the latter the determination of R values is more difficult and may require the use of greater sampling length than would normally be used for similar grades of roughness (*see* **A-6**).

A-4.4 Where for any reason measurement is required in some particular direction other than that at right angles to the lay this should be specially indicated on drawing. In these instances due regard should be given to the need to select the appropriate instrument cut-off.

A-5. NOTES ON INSTRUMENTATION

A-5.1 The proper application of technique of surface roughness measurement require a knowledge of the mode of operation and the limitations of the instruments employed. The importance of making sure that electrical instruments are not misused by applying them to surfaces for which their instrument cut-offs are inadequate will be apparent. When nothing is known about the specimen, the first safeguard against this misuse is by having a good look at the surface before taking a reading; dominant spacing can often be seen and measured directly with a scale. A single touch with a flat oilstone if permissible, may reveal unsuspected spacing. A trace could then be taken, using an appropriate device for generating the datum. Some electrical instruments could be provided with means for varying the instrument cut-off, and with these an expeditious safeguard lies in taking a second reading using a longer cut-off; if there is no material increase in the reading, it could be assumed that no significant irregularity just beyond the range of the first cut-off is present on the surface.

A-5.2 The Pick-Up

A-5.2.1 Most instruments in general use for the measurement of surface roughness are designed to respond to the irregularities of the surface through the agency of a stylus, which rests on the surface and is traversed across it. Movement is measured relative to a selected datum. The datum most commonly used is provided by a skid which has a relatively large radius of curvature in the direction of the traverse. This also rests on the surface but follows its general contour, riding over the crests of smaller irregularities without responding to them individually. These movements of the stylus normal to the surface, measured relative to a datum corresponding to the path followed by the skid, are recorded by the instrument.

A-5.2.2 There are two limitations on the response achieved by the stylus and skid device. Firstly, it is not possible for the stylus to have a mathematically sharp point, but could be finished with a small but finite radius. The profile of a stylus having a rounded tip as shown by the thin outline at *A* in Fig. 16. It is evident that such a stylus would just reach to the bottom of the valley in the profile immediately to the right of it. At the actual valley in the surface being deeper, the stylus could not have penetrated to its full depth. In fact the record itself affords no evidence of the non-existence of fine deep scratches in the actual surface. The behaviour of the stylus in passing over a surface with sharp grooves and ridges is illustrated in Fig. 17. The full depth of the groove is reduced by an amount, *b* (*see* Fig. 17) in the recorded profile, and the trace is also smoothed out over the sharp corners and crests. Apart from the reduction in total depth, however, these defects of reproduction would be practically unobservable in the ordinary record with the horizontal scale compressed relatively to the vertical scale, as in Fig. 8. Further, in an average reading, the loss in the valley may be fully offset by the gain resulting from the apparent rounding of the crests.

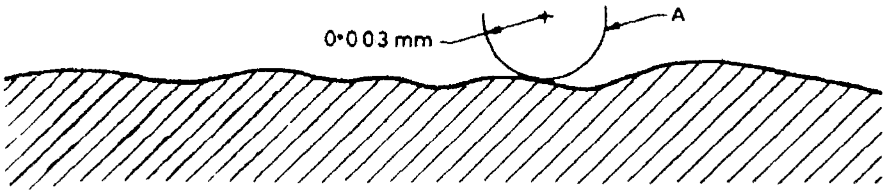


FIG. 16 RELATIONSHIP OF STYLUS POINT TO THE ACTUAL PROFILE OF THE SURFACE

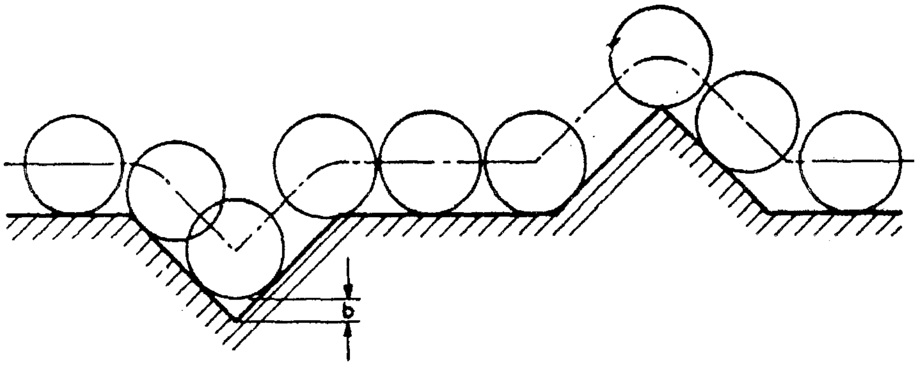


FIG. 17 BEHAVIOUR OF THE STYLUS WHEN TRAVERSING RIDGES AND GROOVES

A-**5.2.3** Fortunately, experience shows that errors due to the finite radius of the stylus are not so serious as might at first sight appear and that the irregularities on most surfaces tend to be relatively shallow, as compared with their spacing, so that the records obtained from them are not, in fact, usually subject to serious limitation from this cause. It is desirable, nonetheless, that the stylus should be as sharp as practicable. A nominal radius of 0.003 mm for the tip of the stylus is specified for profile recording instruments while a nominal radius of up to 0.012 5 mm may be acceptable for instruments giving average readings only (*see* **5.1**).

A-**5.2.4** Furthermore, if the radius of the skid is too small, it will tend to ride up and down over the peaks and valleys, representing the components of wide spacing in the texture instead of correctly following a path parallel to the general contour of the surface. Consider Fig. 18. If *AA* represents the skid on a surface which includes a series of openly spaced ridges, it will rise and fall through a distance *d* as it traverses the surface, and the record may be falsified to this extent. The magnitude of the error introduced into the record depends on the position of the stylus in relation to the skid. If the stylus is located so that it touches a valley when the skid is at its lowest point, the depth of the recorded wave-form will be reduced by an amount equal to *d*, but if the stylus is located at a point half a spacing (or any odd multiple of half a spacing) ahead of or behind the lowest point of the skid, as indicated by the vertical lines, *S*, *S′* in Fig 18, then, as could be seen from the diagram, the depth recorded will be increased by an equal amount. Any intermediate condition may of course occur with various differences in the actual form of the record produced.

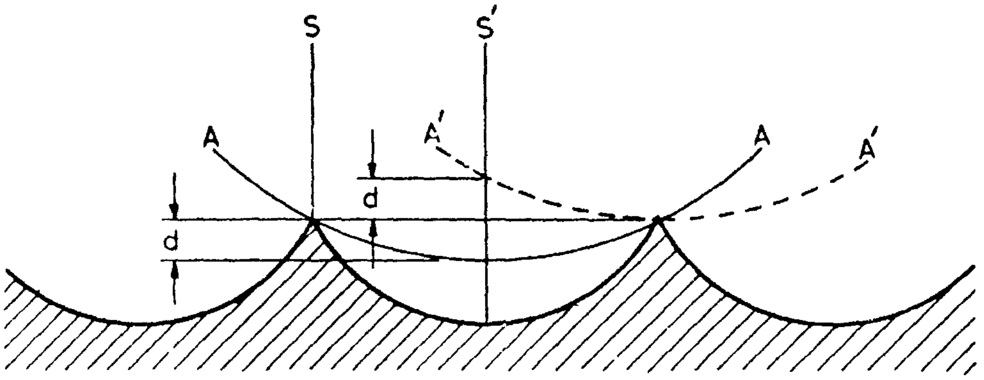


FIG. 18 RELATIONSHIP OF SKID TO WAVELENGTH OF TEXTURE

A-5.2.5 Some instruments have two skids, both touching the surface with the stylus acting midway between them. The chances of meeting extreme phase conditions are then reduced and in practice such instruments operate satisfactorily with skids having a smaller radius than is needed for the single skid (*see* Fig. 19).

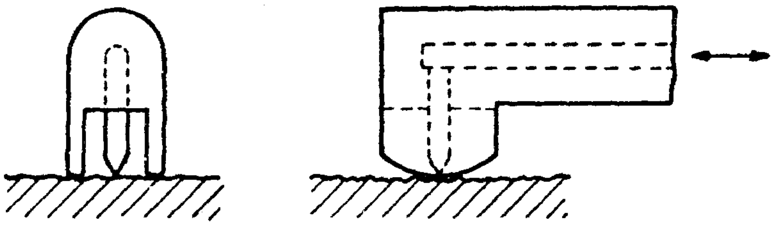


FIG. 19 STYLUS ACTING MIDWAY BETWEEN TWO SKIDS

A-5.2.6 For closely spaced textures, errors due to the skid can safely be neglected. The risk of inaccurate recording of more widely spaced features, however, increases as the square of the spacing and sets an effective limit on this form of datum device. For spacings too great for the skid, two other devices are possible. One is to use a guide in the form of a shoe, with a highly polished face shaped to conform to the general contour of the surface. The other is to use a guiding mechanism in which the datum for the stylus movement is constrained to follow a path conforming to the nominal profile of the surface, independently of any actual contact with it.

A-5.3 Electrical Measuring Instruments

A-5.3.1 Some electrical instruments could provide both profile graphs and average numbers, but there are many types destined mainly for the workship which provide meter readings only.

A-5.3.2 To ensure a high degree of fidelity, a recording instrument should have the sharpest stylus that is practicable, combined with adequate means for providing the datum, and a recorder responsive to sustained displacement of the stylus. An instrument with a stylus tip dimension in the order of 0.001 mm, a skid of long radius or a shoe sliding on the surface, or a skid sliding on a reference surface in combination with a modulated carrier pick-up and amplifying system, can generally give adequate performance. Recording instruments having generator type pick-ups (for example, moving coil and piezo pick-up) tend to respond to velocity rather than amplitude and may give a false impression of the surface.

A-5.3.3 Integrating instruments on the other hand should be designed to exclude the wider spacings and transmit to the meter only the spacings coming within the instrument cut-off. This is generally accomplished by making use of the properties of electric wave-filters, which, broadly, are able to transmit or reject alternating currents according to their frequency.

A-5.3.4 It will be clear that if the pick-up is traversed across the surface at constant speed, each spacing (if recurrent) will give rise to a definite frequency which will be equal to the speed divided by the spacing. Thus, at a speed of 3 mm per second, a spacing of 3 mm will produce fundamentally an alternating current of 1 cycle per second, while spacings for example of 0.9 mm, 0.3 and 0.03 mm will produce currents of 10, 30 and 100 cycles per second respectively. If the wave-form is other than sinusoidal, there will appear, in addition to the fundamental frequency, alternating components of higher frequency than the fundamental. These components could be accounted for by a well-known mathematical proposition known as Fourier's theorem, which shows that the form of any recurrent profile could be expressed as the sum of a series of pure sinusoidal components of appropriate amplitudes. The fundamental wavelength is that of the profile, and the wavelengths of the other components are successive simple fractions there of, for example 1/2, 1/3, 1/4, 1/5. The integrating instrument, in effect, resolves the form of the profile under examination into its sinusoidal components, shifts these components by means of the wave filter and recombines those which pass through it in such a manner as to produce, automatically an alternating current representing the irregularities coming within the instrument cut-off, this current being finally integrated by the meter.

A-5.3.5 Thus, if the whole profile of Fig. 2 were examined by an instrument having a instrument cut-off equal to L_A, the alternating current emerging from the filter and passing to the meter would look substantially like the curve A in this figure, that is, it would represent the roughness or primary texture alone. If the instrument cut-off were equal to L_B, the current passing to the meter would have the shape of A and B added together.

A-5.3.6 The wave-filter may consist of a group of resistances, condensers and/or inductances serving no other purpose than to form the filter, or of elements already having some other part to play, for example value coupling circuits or even the pick-up itself in the case of piezo devices, which could be so proportioned as to attenuate below the cut-off frequency. If the instrument is to have a instrument cut-off of, say, 0.8 mm the filter circuits are designed to transmit to the meter all frequencies higher than those produced by 0.8 mm spacing at the intended speed of traverse, and to attenuate all frequencies corresponding to a wider spacing.

A-5.3.7 Although it is usual to speak of the cut-off as though it occurred abruptly, in practice the transmission falls off gradually. What have become standard transmission limits for three cut-off values are shown in Fig. 6. Considering the upper limit for 0.8 mm cut-off by way of example, the electrical circuits transmit uniformly (that is, without substantial change in relative amplitude) all wavelengths up to 0.25 mm. Wavelengths of 0.5 mm are slightly attenuated to 90 percent of their true value, wavelengths 2.5 mm are attenuated to 25 percent and so on. This rate of attenuation would be provided by two resistance capacitance valve couplings of equal time constant in series and having a maximum rate of attenuation of 12 dB per octave. As the effect of a small amount of attenuation on the reading is negligible, it is practical to rate the cut-off not at the wavelength for which attenuation first begins to occur, but at some greater value, and the curve shown has been considered to have an effective cut-off at about 0.8 mm, where the transmission is 80 percent of the full value. In order to meet certain types of specifications where the cut-off is rated at 70 percent transmission, **5.1.3.2** permits the cut-off to be assessed at between 70 percent and 80 percent of the maximum attenuation.

A-5.3.8 A complete and precise specification of transmission involves not only the wavelength range, but also the phase characteristics and rate of attenuation at the ends of the range. However, it appears in practice that, in reasonably designed instruments, the influence of the latter factors is of secondary importance. Therefore, having regard for the still tentative state of the art, it is considered that a specification of the nominal wavelength cut-off alone will suffice for a further period.

A-5.3.9 It is convenient to express the cut-off in terms of spacing rather than frequency because it is the spacing that is a basic characteristic of the surface, the resulting frequency depending on the speed of traverse which may be anything the instrument designer chooses as being suitable for the pick-up. Traversing speeds employed normally range from 0.3 mm to 25 mm per second. It is clearly important to operate pick-ups at the designed speed. In the case of motor driven instruments this will be ensured automatically, but in the case of manually operated pick-ups the proper speed must be stated and observed.

A-5.4 Optical Interference Instruments

A-5.4.1 In these instruments interference fringes are formed between an optical flat forming a reference surface and the irregularities of the surface to be examined. The fringes are viewed through a microscope. In one type of instrument, the optical flat is held on or just above the surface, and single or multiple reflection fringes are formed directly between the two. In another, the optical flat is mounted within the instrument and a virtual image of it, seen directly or through a second objective, is formed on the surface by a semi-reflecting mirror. In some designs the optical flat within the instrument is provided by a metallized patch formed on one of the surfaces of the microscope objective.

A-5.4.2 The distance between two adjacent fringes corresponds to a change in the separation of the surfaces of the half wavelength of the light, which for green light is approximately 0.000 25 mm. The irregularities seen along each interference fringe correspond to the surface unevenness, and the extent of the irregularities may be estimated or measured as a proportion of the distance between the adjacent fringes.

A-6. NOTES ON MEASUREMENT OF SURFACES HAVING GREATER SPACING OF IRREGULARITIES

A-6.1 While the majority of surfaces that have to be measured in normal engineering practice have irregularities of less than 2 mm spacing, greater spacings could be found, especially on milled and planed surfaces, and in the domain of waviness.

A-6.2 When the surface is smooth and sufficiently reflective (in which case the search will be mainly for waviness) direct interference methods could well be used, but in other cases stylus methods are likely to be the most convenient.

A-6.3 For absolute measurement, the stylus shall traverse a sufficient length of the surface relative to a datum the errors of which are small compared with those of the surface, and this has been accomplished by using an optical flat as a reference surface.

A-6.4 The greater spacings, however, often tend to be repetitive, so that a serviceable datum could be provided by a shoe or suitably spaced system of skids sliding across the surface itself. For example, in the Tomlinson Waviness Recorder, the whole mechanism is carried on a shoe about 40 mm square having a central hole through which the stylus passes, while instruments having suitably spaced skids are used for recording waviness on gear teeth.

A-6.5 Sometimes it is useful to ignore the more closely spaced irregularities and this could be accomplished either by using a sufficiently large radius for the tip of the stylus or (in electrical instruments) by means of a wave filter.

A-6.6 In principle, instruments to give R_a readings could be designed as well for the wider as for the closer spacings, but in practice, the assessment being determined mainly from graphs and the profiles tending to be repetitive, the total height measure is generally used (*see* Fig. 8). The relative magnitude of total height and R_a value, the former from 3 to 7 times the latter for the kind of profiles here considered, should be remembered when contrasting waviness assessed in the one way and roughness assessed in the other.

A-7. THE USE OF PLASTIC REPLICAS

A-7.1 In one group of methods cellulose acetate strip (cine film), or sheet of greater thickness, is softened with a solvent such as acetone and pressed against the surface under sufficient load until set. The solvent could have a small percentage of cellulose acetate dissolved in it to fill up residual imperfections in the sheet. These replicas set in a few minutes and after removal from the surface soon harden sufficiently to permit about 80 percent fidelity to be secured using a lightly loaded stylus.

A-7.2 More recently developed materials, capable when correctly used of approaching 100 percent fidelity, are found among the synthetic resins. These materials are marketed under various trade names. Generally a powder and a liquid have to be mixed in the correct proportions and poured on to the surface from which the replica could be removed and used as soon as it has set. Some sort of wall, for example a ring of modelling clay, may have to be erected on the surface in order to contain the mixture; and setting may take from 10 minutes upwards according to material and temperature.

A-7.3 The test of whether a replica process will give a good enough reproduction for a given application should be checked by comparing the profile graph of a sample part with that of its replica. It is important to make sure that exactly corresponding portions of the sample and of its replica are compared. This could often be accomplished by scribing a cross on the trace and letting the stylus pass through the intersection. If the stylus passes to one side or the other, two marks on the graph, one from each arm of the cross, will appear, from their separation in two separated traces the necessary lateral movement to reach the intersections (where they will merge into one) could soon be found.

A-7.4 When replicas of the finer surfaces are wanted, it is as well to check the process not only on the surface itself but also on an optical flat. Any irregularities which appear in the replica shall be attributed to the replica process, and indicate the limit of smoothness for which the process is suitable Random faults such as air bubbles could generally be neglected, but systematic irregularities resulting for example from the use of a filler or from shrinkage effects normally are reasonably small compared with the irregularities to be reproduced. It has been found that the residual granularity, waviness and setting time of the synthetic resins can be considerably affected by the wetness of the mix.