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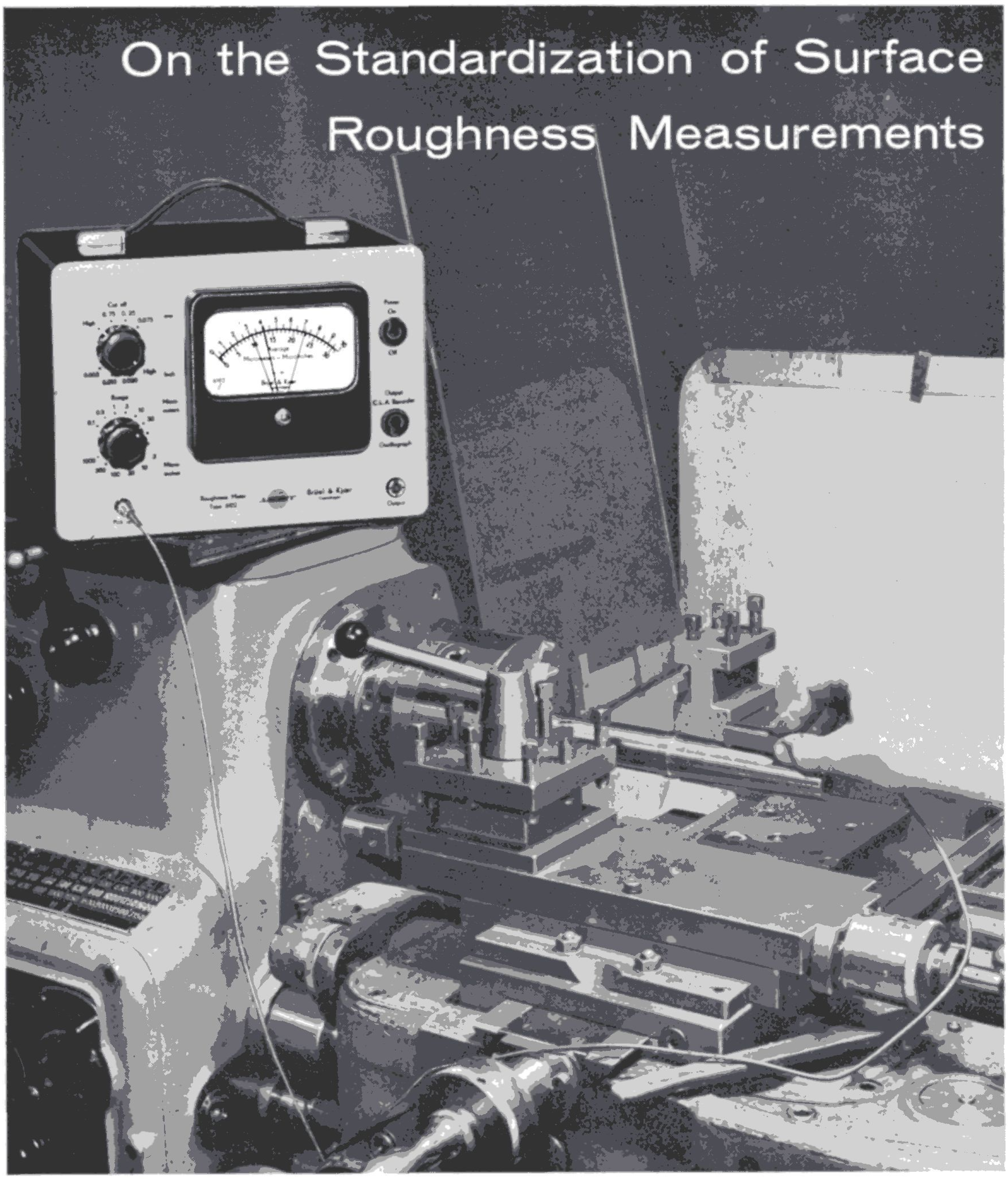
On the Standardization of Surface Roughness Measurements



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DET BERLINGSKE BOGTRYKKERI

Professor K. V. Olsen is head of the Research Institute for Machine Tools at the Danish Technical University in Copenhagen (D.T.H.) and teaching professor of hand and machine tools. He has been very actively engaged in the study of surface roughness and was chairman and head of the group who worked on the Danish standard. (Finally approved November 1958.) Prof. Olsen is a member of the Danish Academy of Technical Sciences.

On the Standardization of Surface Roughness Measurements

by

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ABSTRACT

After a short survey of the need for well-defined surface roughness measurements in modern industry, the difficulty in characterizing the micro-geometrical "landscape" of the surface roughness by means of only one or a few numerical values is stated.
The different definitions used for determining both the roughness depth and the roughness width of a surface profile are described in detail. The two most commonly employed measurement reference systems, the mean-line system (M-system) and the envelope system (E-system) are then described.
Finally outlines of the various national surface roughness standards per October 1961 are summarised, and the tendency of the "newest" standards to follow the recommendations of ISO is mentioned.

SOMMAIRE

Après avoir fait ressortir le besoin impérieux pour l'industrie de pouvoir réaliser des mesures objectives et normalisées de rugosité, l'article décrit les problèmes généraux posés par la définition d'une méthode de mesure commode du relief microscopique constituant la rugosité.
En prenant la récente normalisation danoise, très voisine des normalisations les plus généralement employées à l'heure actuelle, comme exemple, les différentes définitions de mesures verticales (hauteur de rugosité) et horizontales (pas de rugosité) sont examinées en détail – L'utilisation des mesures de pas pour la détermination des aires de contact (courbes d'Abbott) est indiquée brièvement.
Les deux systèmes de référence principaux: le système M basé sur la ligne moyenne, et le système E basé sur les enveloppes respective de deux cercles de rayons 25 et 250 mm roulant sur la surface, sont décrits et comparés.
Enfin l'article contient un rapport donnant l'état des normalisations de mesure de rugosité dans de nombreux pays à la date du ler octobre 1961 ainsi qu'un résumé des recommandations proposées par l'Organisation Internationale de Normalisation (ISO) qui semblent indiquer la tendance générale des normalisations nationales apparues ces dernières années.

ZUSAMMENFASSUNG

In der modernen Industrie besteht ein Bedarf nach wohldefinierten Oberflächen-Rauheits-Messungen. Es ist jedoch schwierig, die mikrogeometrische »Landschaft« der Oberflächen mit nur einer oder wenigen Zahlenwerten zu beschreiben.
Die verschiedenen Begriffe der Rauheit und Welligkeit eines Oberflächenprofils werden im einzelnen beschrieben. Anschliessend werden die für Messzwecke gebräuchlichsten Bezugssysteme behandelt, nämlich das Mittelliniensystem (M-System) und das Envelopesystem (E-System).
Abschliessend werden die verschiedenen nationalen Oberflächennormen nach dem Stande Oktober 1961 unter dem Gesichtspunkt der ISO-Empfehlungen zusammengefasst.

Introduction.

Surface roughness problems have, from a very modest start in the mid-thirties, attracted attention at a steadily increasing rate. Since then the surface geometry has become a field of major technical importance which in step with other scientific advances has helped to improve overall physical knowledge with a consequent increase in evolution. A complete understanding of the surface geometry of workpieces, — both the macro- and micro-geometry, — is essential in mechanical as well as production engineering. It is obvious that the magnitude as well as the character of the roughness and waviness of machined parts will have a great influence on the wear, friction and durability. Other quantities such as tolerances and precise fitting are also influenced by the surface geometry. This factor also holds good in similar spheres such as the final appearance and brilliance. These facts, which in the main refer to the function of various machined parts will be of interest mostly to designers, who during design should devote the necessary attention to the surface geometry by specifying the requirements for the final surface on the drawings. As this is a new field, the various relationships are only clarified to a small extent and a great deal of important research work remains to be done. It is therefore frequently difficult to lay down exact specifications for surfaces intended for a particular function. This inaptitude will to an increasing degree be remedied, as the field of surface roughness becomes more thoroughly investigated and the vital importance of all the factors fully recognized.

By proceeding in an opposite direction, i.e. by noting the surface of parts whose functions are already known to be correct, valuable information can be passed to designers. Such results will cause further corrections to surface data and initiate new tests thus arriving at still better operation and reduction in production costs.

In workshop practice the specification for the surface is of great importance, for only in this way can exact information be given on the finish of the final surface. Such information obviously should be given and ought to be placed on level with such data as diameter, length, tolerance, etc. A subjective judgement of a surface in modern production conditions will no longer suffice. For if exact information is given, the tendency to make too fine and thus too expensive surfaces just to be safe, will disappear. Similarly, many discussions as to whether a surface is good enough or not, will be superfluous. Also for the inspection department it means considerable simplification as subjective judgement is replaced by measurable quantities which can be expressed in figures. Additionally, surface specifications should give a hint to which method of production should be employed and to what kind of machines and cutting tools are most suitable. Finally a thoroughly specified surface will give a more exact basis for piece-work calculations, as all parties will know in advance to what degree the given surface should be treated as the quality will be designated by means of a figure.

Basic Measuring Systems.

Machined surfaces which are of particular interest for measurements display a great variety of both macro- and micro-geometrical dimensions. The magnitude of the values which it may be necessary to record may in many cases be in the order of 0.01 μm or even smaller, i.e. they are normally considerably smaller than the quantities which can be measured within normal workshop accuracy, they actually approch the lower limits of possible laboratory measurement. When such minute quantities are considered, it is obvious that visual inspection or sensing by means of a finger are futile.

Thus for exact specification of a particular surface there exists a requirement for a special measuring system with many new conceptions; a system which bears a relation to ordinary measuring techniques, and to which it is possible to attach suitable measuring instruments. Such systems have been developed in a number of countries in the form of surface specification standards and endeavours are being made to lay down an international standard in this field.

Any measurement of surface data is based on the geometrical surface of the test specimen. The effective surface is then being compared to the geometrical surface. Commencing with the effective surface and then analysing various deviations between this and the geometrical surface, the resultant deviations can be placed in various cathegories. Deviations of the first order include errors of form and are macro-geometrical. Deviations of the second order are waves, while the deviations commonly referred to as surface roughness include deviations of a third and higher order. In the *measurement* of surface roughness only deviations of the second and higher order (waves and roughness) are of interest.

All surfaces will, when suitably magnified, display a picture of a landscape with high mountains and deep valleys. It is impossible to carry out a thorough measurement of the complete surface of a body. An idea of the character of the surface, however, may be obtained by means of optical instruments with suitable magnification allowing successive exploration of the complete surface. On the other hand, to practical measurements, certain small areas of the surface are selected for a more thorough investigation. The number and location of these areas must be chosen so that the measured results obtained are representative for the whole overall surface.

Actually the measurement of any surface should be three-dimensional. However, the difficulties involved in making such measurements cause the various definitions to be transformed into a two-dimensional plane, where they are easier to overlook. For this purpose the surface being investigated is cut by a plane which, unless otherwise specified, is perpendicular to the geometrical surface of the test specimen. The line of intersection between the cutting plane and the real surface is called the real profile. This profile is an imaginary one, but the closest possible approximation to it — obtained by a recorder or other kind of measuring instruments — can be made visual and is called the effective profile.

Within a certain length of this — the sampling length — the surface is then investigated.
This method of investigation exactly corresponds to what happens when the surface is investigated by means of a stylus type instrument. For here the stylus is moved with a constant velocity in a straight line over a particular length of the real surface. The up-and-down movement of the stylus relative to a suitable datum will, when suitably magnified, then depict the deviation of the real surface from the geometrical surface within the accuracy of the instrument.
In the various national standards two basic measuring systems are used, the M (mean line) system and the E (envelope) system. Up to now the M-system is used in by far the majority of countries and only a small number have based their standard on the E-system. Some countries have in their standards included the M- as well as the E-system and defined the various surface measures under both systems, even if they seem to prefer the one or the other.

The M (mean line) System.

As a typical example of a standard based on the M-system, Fig. 1 shows a profile taken from the Danish standard No. 940 where in addition many roughness values are defined. The system concists of the mean line L_m and two with L_m parallel upper and lower reference lines $L_ø$ and L_n within the sampling lenght l.

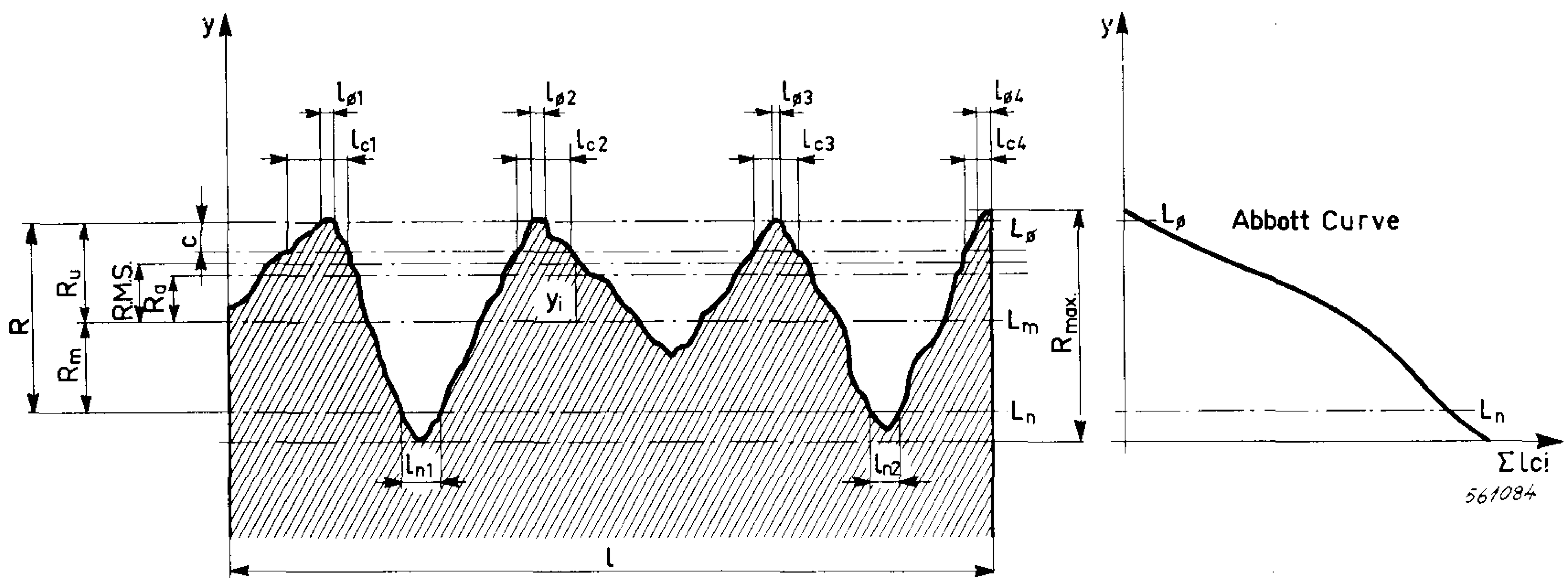

Fig. 1. Basic surface measures according to the M (mean line) system. The definitions of the various roughness measures are given in the text. To the right is shown the Abbott curve, see also text.

The mean line L_m is a line having the form of the geometrical profile[1]) within

1) The description in English of the M and E system is rather difficult due to the lack of fixed English terms for many of the conceptions and the corresponding surface roughness measure figures which are in use on the continent.
Wherever possible the English terms are used. Where no English terms exist an attempt has been made to translate the terms and definition either from German and/or Danish to English in the closest way. Such selfmade terms are put in “ ” and followed by the German terms in ( ). Although this may be a little confusing it is hoped that the real meaning will be understood.
In the reference to the ISO recommendation the terms from this recommendation are used directly.

the limits of the meter cut-off, and are so placed that within the meter cut-off the sum of the squares of the deviations of the profile from the mean line is a minimum.

This line is unique in position and direction but its graphical determination is somewhat difficult. Electrical integrating instruments refer to the mean line of the alternating current flowing through them and which represents the profile. The mean line is therefore in practice determined as a line parallel to the general direction of the profile for which the areas embraced by the profile above and below the line are equal. In this form the line is called the centre line. When the wave-form is repetitive the two definitions are equivalent[1]).

The reference lines $L_ø$ and L_n are in most standards touching the highest peak and the lowest valley within the sampling length l. In the Danish and Swedish standards the exceptions are excluded systematically by determining the lines so that $\Sigma\, l_ø = 0.05\ l$ and $\Sigma\, l_n = 0.10\ l$. The definition of the different roughness values which are to be used is now based on the mean line.

The stylus apparatus which is in use for measuring the surface roughness is designed in such a way that the up-and-down movement of the stylus relative to a suitable datum is magnified and registered. The datum should confirm with the nominal shape of the surface to be tested. This can be realized by using a straight-line datum device or more commonly the datum is generated by a skid or a shoe sliding across the surface. The chosen value of l determines if it is the surface roughness (primary texture) alone which is registered, or if the result also includes smaller or greater contribution of waves (secondary texture). In this basic measuring system a number of roughness values can be defined (see later). In this connection it must be pointed out that normally a surface cannot be sufficiently characterised by one of these values only as each of them expresses certain properties of the surface. Most commonly it is necessary to use several values for a satisfactory description of the surface. How many values and which, has to be decided in each case.

I Depth Measures.

a) The peak to valley value, R, (Rauhtiefe) is the distance between the upper and the lower reference lines $L_ø$ and L_n. This value is a measure of the total depth of the surface irregularities within the sampling length and therefore the most direct of alle surface roughness values. It is the peak-to-valley value which is perceived by looking at and touching the surface. The peak-to-valley value is influenced by scratch and tool marks from the production process.

b) If larger sampling lengths are used the peak-to-valley measurement will indicate the sum R + H of the roughness (primary texture) and the waviness (secondary texture). The size of the sampling length chosen determines to which extent the measurement will include smaller or greater contribution of the waves.

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1) Definition according to BS 1134, 1961.

c) The "levelling depth", depth of smoothness, R_u, (Glättungstiefe) is the distance between the mean line L_m and the upper reference line $L_ø$. R_u is a measure for how much $L_ø$ is to be displaced by levelling out the profile. R_u is small when the real (for effective) surface consists of solid peaks and narrow valleys and big when it consists of sharp narrow peaks and wide valleys.

d) The average peak-to-valley depth, "mean depth", R_m, (mittlere Rauhtiefe) is the distance between the mean line L_m and the lower reference line L_n

$$R_m = R - R_u$$

e) The centre line average value, R_a, is the arithmetical average value of the departure of the whole of the profile both above and below its centre line throughout the prescribed meter cut-off in a plane substantially normal to the surface. Mathematically it can be expressed as:

$$R_a = \frac{1}{l} \int_0^l |y| \, dx$$

The measure thus defined determines a levelled out value of the profile. It therefore gives no direct conception of the character of the surface. Nevertheless, this value is to a great extent used in many countries and especially in the English speaking world, being due to the convenient manner in which it is determined by electrical instrumentation.

It is important to point out that there exists no fixed relationship between the peak-to-valley value R and the R_a value.

As a rough estimate the proportion $\frac{R}{R_a} \sim$ 3-5 may perhaps be used depending upon the numerical size of the roughness itself and the production method of the surface. However, in general the proportion may be within so widespread limits as 2-30 according to the roughness of the surface and its character.

The centre line average value is in Great Britain abbreviated to CLA and in U.S.A. to AA (Arithmetical Average). In ISO TC57 it is termed R_a.

f) The root-mean-square value, RMS, is the geometrical average value of the departure of the whole of the profile both above and below its centre line throughout the prescribed meter cut-off, in a plane substantially normal to the surface. The mathematical expression is:

$$RMS = \sqrt{\frac{1}{l} \int_0^l y^2 \, dx}$$

What is relevant for the R_a value is also valid for the RMS value. The RMS value was formerly used in the U.S.A. standard but has in 1955 been replaced by the R_a value.

II Horizontal Measures.

These measures include the wavelength l_b and the spacing A_r of the surface irregularities, Fig. 2. At present time it is rather seldom to specify these measures but in many cases they may be of importance. The bearing length defined as $B_b = \sum_{1}^{n} l_{ci}$ is for many applications a very important measure as it gives data on the size of the bearing proportion. This factor is determined as

$$k_b = \frac{B_b}{l} 100\,\%.$$

Assuming now that the profile extends uniformly across the surface in the

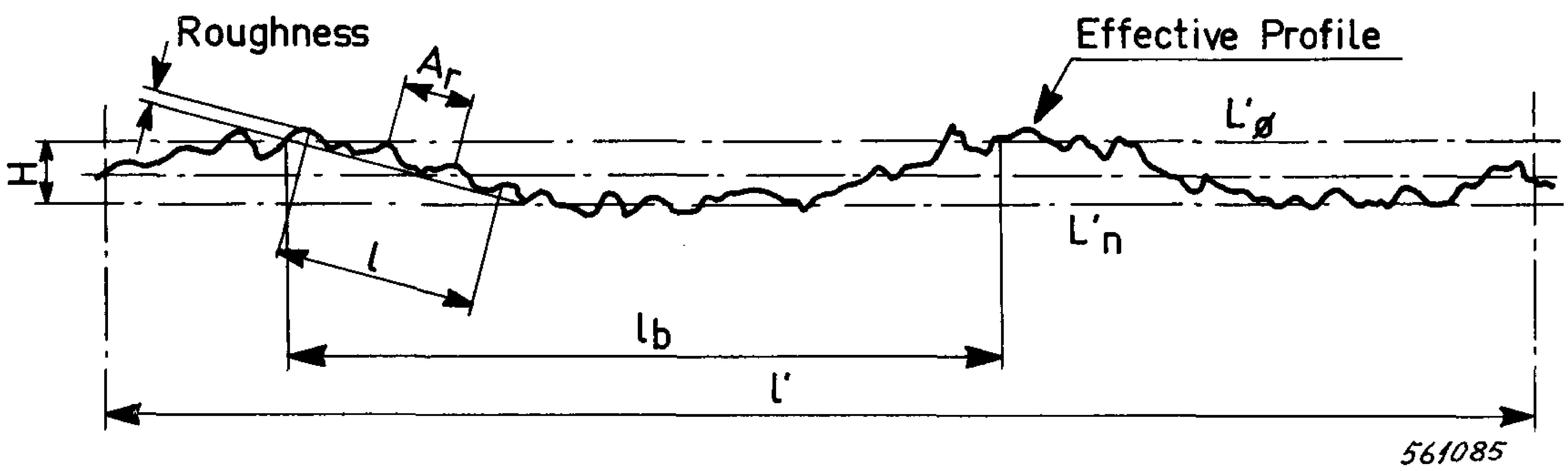


Fig. 2. A surface with roughness as well as waviness.

direction normal to the intersecting plane, k_b will indicate the bearing area which is to be expected after a given amount of lapping or wear.

The bearing area is to a high degree determined by the horizontal extension of the peaks and by measuring B_b in different distances, c, from the upper reference line $L_ø$ it is possible to draw important conclusions concerning the properties of the surface. From the knowledge obtained on B_b or k_b it is possible to judge different conditions such as the resistance to wear, bearing and sliding properties etc., e.g. in journal bearings and guideways etc.

The position of the bearing line is determined by the distance, c, below the upper reference line $L_ø$ according to the requirements, and this distance is frequently expressed as a fraction of the peak-to-valley value R.

If the bearing length is measured along a number of lines at various distances, c, from $L_ø$, the bearing length can be used for obtaining the so-called Abbott curve which gives an indication of the rate of wear, see also Fig. 1.

III Proportion Measures.

This kind of measure is formed by taking the proportion between two other measures. Most common is the "filling out factor" $k = \frac{R_m}{R}$ (Völligkeitsgrad).

This factor is a measure of to which extent the area between the two reference lines $L_ø$ and L_n is filled in with metal.

Another proportion which could be usefully introduced would be $\frac{R}{A_r}$. This factor, which is the ratio of the peak-to-valley value to the spacing between surface irregularities would give an easy and convenient picture of what could be called the opening angle of the profile.

As mentioned above a single roughness measure is seldom sufficient for the characterisation of a surface in a satisfactory way. Where an instrument only gives a single measure it ought to be supplemented by a recorder presenting a graph which can be analysed. By checking production which is of a known type, however, it is frequently possible to come out with only one measure assuming there is a definite knowledge on how the other surface measures change due to varying machining conditions, rate of tool wear, etc.

The E (envelope) System.

During the last few years another system, the E (envelope) system has been developed and is at present used as standard in some countries on the continent. This system is based on a "contacting envelope" (Hüllprofil) instead of the mean line and is roughly built up in the following way, see Fig. 3.

A circle with radius R which normally is 250 mm is rolled across the surface to be tested. The centre of the circle will describe a curve and this curve is displaced in a direction perpendicular to the geometrical profile to a position

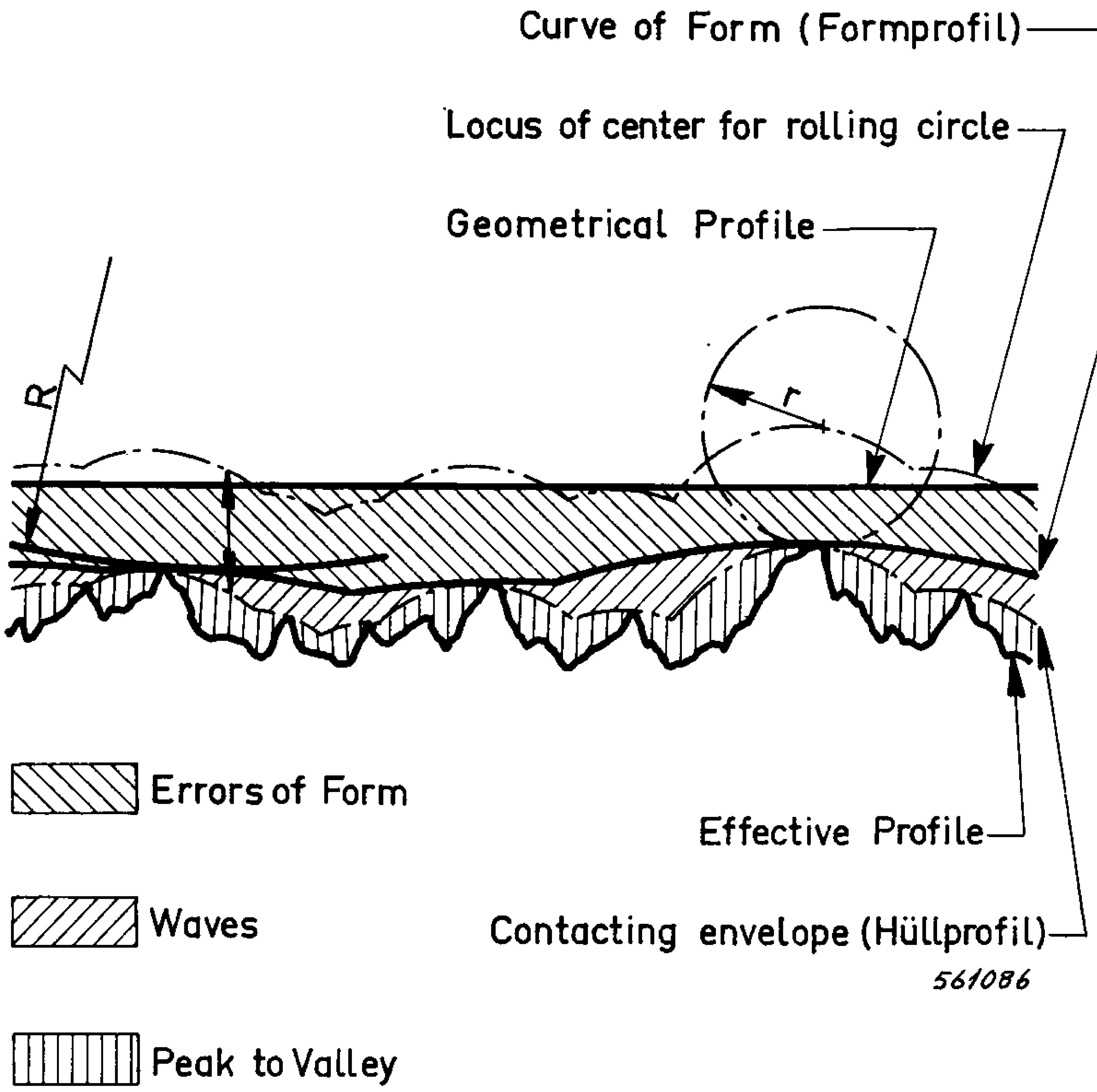


Fig. 3. Basic surface measures according to the E (envelope) system. This system is developed by two circles with radius r and R which is rolled across the surface. The locus of center for the two circles is displaced so much in a direction perpendicular to the geometrical profile that the path is touching the highest crests of the effective profile.

where it is contacting some of the highest peaks in the effective profile. The locus of centre for the rolling circle is in the position thus determined called the "curve of form" (Formprofil).

In a similar manner another circle with radius r, which normally is 25 mm is now rolled across the surface. The locus of center for this circle is also displaced in a direction perpendicular to the geometrical profile by such a degree that the curve is touching some of the highest peaks in the effective profile. In this position the locus of center for the small circle is called the "contacting envelope" (Hüllprofil). Now, in this basic measuring system it is rather easy to distinguish between the different kinds of deviation of the effective profile (effective surface) from the geometrical profile (geometrical surface), see Fig. 3. The area between the geometrical profile and the "curve of form" represents the errors of form; the area between the "curve of form" and the "contacting envelope" represents the waves (secondary texture) and the area between the "contacting envelope" and the effective profile represents the roughness (primary texture). Finally the area between the geometrical profile and the effective profile represents the total deviation of the effective profile from the geometrical profile.

The basic concept of surface texture excludes errors of form and the requirement is therefore to distinguish between errors of form and texture and between the different types of texture. All methods of numerical assessment must therefore by some means be selective. In the case of the M-system involving a reference line of predetermined shape the selection is accomplished fundamentally by basing the measurement on a sample of the surface of a defined length, the sampling length 1. In the electrical instruments used the sampling length is converted to the wavelength cut-off (meter cut-off). In the E-system the selection of what is included in the measurement is determined by the radius r and R of the rolling circles which play a somewhat similar role as the sampling length in the M-system.

From a graphic recording of the surface the contacting envelope is much easier to determine than is the mean line. This can be done simply by drawing the circles through the highest peaks in the graph.

This easy construction of the contacting envelope is often claimed as an advantage for the E-system when compared with the M-system. Yet, it must be remembered that the locus of centers for the rolling circle, according to the definition, has to be lowered in a direction perpendicular to the geometrical profile. It is therefore a requirement that the position of the effective profile relative to the geometrical profile has to be known, but this is never the case. Therefore, annomaly this position has to be judged.

In most cases the graph is compressed while using a greater vertical magnification V than horizontal magnification H which involves the fact that the rolling circles are transformed into ellipses. The radius of curvature to be used is then changed from r to $r \times \frac{H^2}{V}$. Is $r = 25$ mm, $V = 2000$ and $H = 100$ the radius of curvature in the ellipse is $25 \times \frac{100^2}{2000} = 125$ mm.

The "contacting envelope" is still further displaced to a position where the areas enclosed by the effective profile above and below it are equal. Here the curve is called the "mean curve" (mittleres Profil), and it corresponds to the mean line in the M-system.

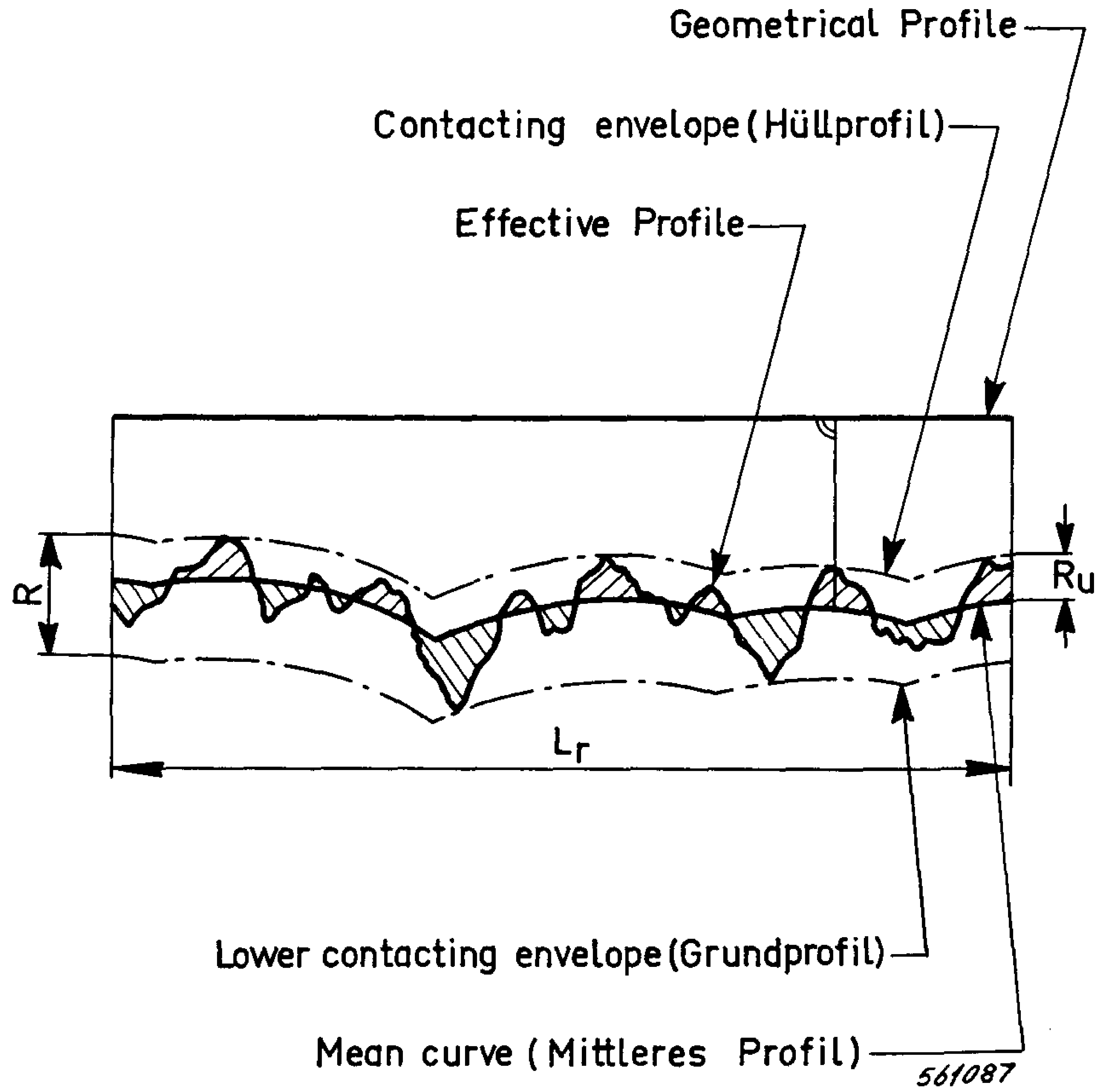


Fig. 4. The contacting envelope, mean curve and lower contacting envelope in the E-system. A few roughness measures are also indicated.

If the "contacting envelope" is displaced still further to a point where it passes through the deepest valley we have the "lower contacting envelope" (Grundprofil), see Fig. 4.

In this E-system are now obtained almost the same terms as in the M-system and in the same way with the exception that it goes out from the "contacting envelope" and the "mean curve" (mittleres Profil) instead of the mean line.

It has to be pointed out that at present no instrument has been designed to measure according to the E-system. On the other hand, when using an instrument designed for the M-system and a shoe or skid datum device the datum will to a certain extent follow the nominal shape of the surface and therefore not a straight line as laid down in the M-system. What in practice is measured is therefore something between the M- and the E-system.

ISO

Draft ISO recommendation No. 221, 5th September 1958 is based on the M-system, see Fig. 5. In this recommendation is defined the R_a value equivalent to the R_a (CLA) value in the M-system. The maximum height of irregularities R_{max} is the maximum distance between two reference lines parallel to the mean line m and touching the effective profile at the highest and lowest points within the sampling lenght l.

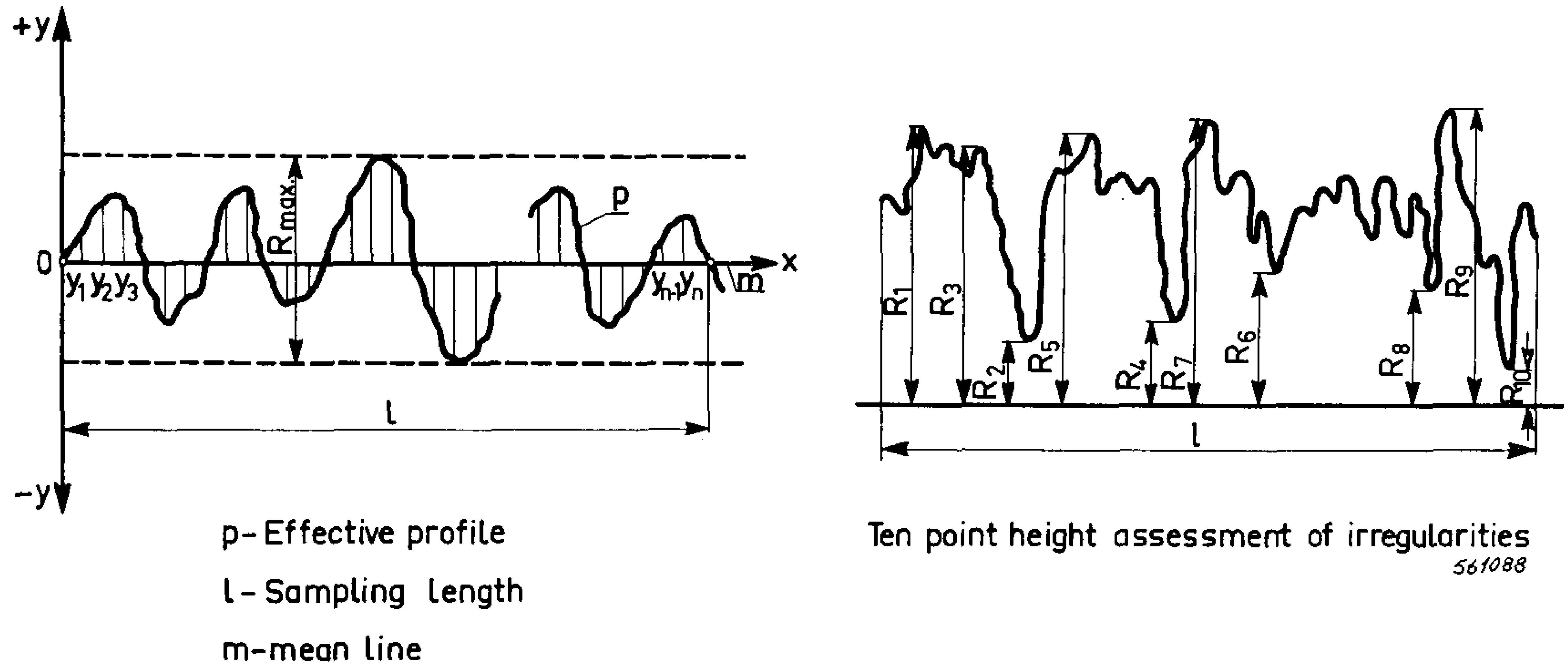


Fig. 5. The basic measuring system according to ISO recommendation ISO TC57 no. 221 of September 1958. This recommendation is based on the M-system.

Another value is the ten point height of irregularities R_z which is the average difference between the five highest peaks and the five deepest valleys within the sampling lenght l measured from a line, parallel to the mean line. The mathematical expression is:

$$R_z = \frac{(R_1 + R_3 + R_5 + R_7 + R_9) - (R_2 + R_4 + R_6 + R_8 + R_{10})}{5}$$

National Surface Roughness Standards.

During the last fifteen years a number of national standards for surface roughness have appeared and most of them have been revised during the constant development in this field. At present the situation is almost as follows: [1]

There is no surface roughness standard in Belgium, Canada,[2] Iceland, Ireland, Israel, Norway, Portugal and Yoguslavia[3]. D.S.A. has looked for standards from China, Egypt, Greece, India, South Africa and Turkey but none has been found. Australia and New Zealand are using the British Standards. At present time the standards from Argentina, Brazil and France[4] are only concerning symbols on drawings and do not include geometry, definitions etc. for basic measurements.

1) According to information obtained from the Danish Standards Association pr. 1. october, 1961.

2) It seems likely that the British Standard is used.

3) Under preparation. A draft proposal is expected to be published late in 1961.

4) A standard is under preparation.
An "Avant-Projet de Norme Française sur les Rugosites de Surface" has been
(continued p. 17)

Table 1.
National Surface Roughness Standards.
Pr. 1. October 1961.

No.	Country	Mark	Surface roughness standard no. — Geometry, Definitions etc.	Surface roughness standard no. — Others, f.i. drawing symbols, preferred values etc.	System	Unit
1	Argentina	IRAM	5065[1])	4517; 1951		
2	Austria	M	1115 March 1956 Part 1. Tentative Standard	1115 March 1956 Part 2. Tentative Standard	M	μm
3	Brazil	NB		13 R 1945	–	–
4	Bulgaria	*БДС*	782-53	782-53	M	μm
5	Czechoslovakia	ČSN	014450 1960	014450 1960 014455 1955	M	μm
6	Denmark	DS	940 Nov. 1958	58.1 Nov. 1958 58.2 Nov. 1958 941 Nov. 1958	M	μm
7	Finland[2])	SFS	BII51 TES 565–28	BII52 TES 566–28 BII53 TES 567–28 BII54 TES 568–28 BII55 TES 569–28 BII56 TES 570–28	M	μm
8	France[3])	NF	September 1961		E	μm
9	Germany	DIN	4760 July 1960 4761 Aug. 1960 4762 Bl. 1–3 Aug. 1960	4763 July 1960 4763 Beiblatt 1 1954.[4]) 4764 Dec. 1953[5]) 3141 March 1960[6]) 3142 March 1960	E	μm
10	Great Britain	BS	1134 1961	2634 1960 308 1953	M	μin

1) Has been withdrawn during examination.
2) All of May 1959.
3) Avant-Projet. Published September 1961.
4) Proposal.
5) Proposal.
6) Tentative Standard.
7) Under preparation.
8) Is at present being revised.

Table 1.
National Surface Roughness Standards.
Pr. 1. October 1961.

No.	Country	Mark	Surface roughness standard no. Geometry, Definitions etc.	Others, f.i. drawing symbols, preferred values etc.	System	Unit
11	Hungary	MSZ	4721 1958	4722–58 4724–58R 9654–58 9655–59R 9656–60	M	μm
12	Italy	UNI	3963 Sept. 1960	3963 Sept. 1960	E	μm
13	Japan	JIS	B 0601 1955	B 0651 1955 B 0652 1955 B 0653 1957 B 0654 1957 B 0655 1960	M	μm
14	Netherlands	NEN	630–I Aug. 1958 630–II March 1959	630–III March 1960 630–IV April 1960	M	ru ~ 1μin
15	Poland	PN/M	04250 1958	04251 1958 04252 1958 04254 1959 04255[7])	M	μm
16	Rumania	STAS	5730 1957	5730 1957	M	μm
17	Spain	UNE	1037 1951	1037 1951	M	μm
18	Sweden[8])	SMS	671 Dec. 1947	672 Dec. 1947	M	μm
19	Switzerland	VSM	58.300 Nov. 1960	10.320 Bl. 1–7 1944	E	μm
20	USA	ASA	B 46.1 1955	B 46.1 1955	M	μin
21	USSR	GOST	2789 1959	2789 1959	M	μm
22	International	ISO	Draft ISO Recommendation no. 221, 5. Sept. 1958		M	μm or μin

Table 2.

Pr. 1. October 1961.

Defined Surface Roughness Measures[1]).

No.	Country	Standard	Year	System	Unit	R_a	RMS	R	R_{max}	R_z	R_u	R_m	k	B_b	k_b	Used as Standard
1	Argentina	JRAM 5065														
2	Austria	M1115, Part 1	March 1956	M	μm	R_a	R_s	R_t	–	–	–	R_m	k	L_t	tap	R_t
3	Bulgaria	*БДС* 782–53	1953	M	μm	–	H_{ck}	H_{cp}	–	–	–	–	–	–	–	H_{ck}, H_{cp}
4	Czechoslovakia	ČSN 01 4450	1960	M	μm	R_a	–	–	R_{max}	R_z	–	–	–	–	–	R_a, R_z
5	Denmark	DS 940	Nov. 1958	M, (E)	μm	R_a	RMS	R[2])	R_{max}	–	R_u	R_m	k	B_b	k_b	R_a
6	Finland	BII 51	May 1959	M	μm	R_a	–	–	R_{max}	R_z	–	–	–	–	–	R_a, R_z
		TES 565–28														
7	France	NF	Sept. 1961	E, (M)	μm	R_a	–	R_v	R_{max}	–	R_p	–	–	L_c	T_c	R_a
8	Germany	DIN 4762 Bl.1–3	Aug. 1960	E	μm	R_a	–	R_t	–	–	R_p	–	–	l_t	t_p	R_a, R_t, R_p
9	Great Britain	BS 1134	April 1961	M	μin	CLA	–	–	–	–	–	–	–	–	–	CLA
10	Hungary	MSZ 4721–58	1958	M, (E)	μm	R_a	h_q	–	R_{max}	R_z	R_t	R_f	K_h	b	t_p	R_a, R_z
11	Italy	UNI 3963	Sept. 1960	E	μm	R_a	R_{aq}	R	–	–	R_e	–	–	–	–	R_a
12	Japan	JIS B 0601	July 1955	M	μm	–	–	H	–	–	–	–	–	–	–	H
13	Netherlands	NEN 630–I	Aug. 1958	M	ru∼	–	–	–	–	–	–	–	–	–	–	
		NEN 630–II	March 1959		1 μin	R_a	–	–	–	–	–	–	–	–	–	R_a
14	Poland	$\frac{PN}{M}$ 04250	1958	M	μm	R_a	–	–	R_{max}	R_z	–	–	–	L_n	N_1	R_a, R_z
15	Rumania	STAS 5730	1957	M	μm	R_a	–	–	R_{max}	R_z	–	–	–	–	–	R_a, R_z
16	Spain	UNE 1037	May 1951	M	μm	h_m	h_{rmc}	H	–	–	–	–	–	–	–	h_m
17	Sweden	SMS 671	Dec. 1947	M	μm	–	–	H[2])	–	–	–	–	–	–	–	H
18	Switzerland	VSM 58300	Nov. 1960	E	μm	R_a	R_q	R_s	R_{max}	–	R_p	–	–	t	t_c	
19	USA	ASA B46.1	Jan. 1955	M	μin	AA	–	–	–	–	–	–	–	–	–	AA
20	USSR	GOST 2789	Nov. 1959	M	μm	R_a	–	–	–	R_z	–	–	–	–	–	R_a, R_z
21	ISO	Draft ISO Recommendation No. 221	Sept. 1958	M	μm or μin	R_a		–	R_{max}	R_z –	–	–	–	–	–	R_a, R_z

1) In the head are used the letters from Fig. 1. In the table are used the letters from the national standards.

2) See text page 7.

Other countries which have surface roughness standards are listed in table 1 in alphabetical order.
The table gives the number of the different national surface roughness standards and is divided so that it can be seen which standard is dealing with the geometry, definition etc. and which is dealing with other items such as symbols on drawings, preferred roughness values etc. The system and the unit used is also given.
Table 2 also gives a list of the national standards containing geometry and definition. The number, system and unit used and year published are given. The different surface roughness measures defined in each standard are listed and where possible it is mentioned which primary is used as Standard.
In the following the content of these national standards will be explained in more detail. Definitions and symbols used in these examinations will be kept as close as possible to those used in the previous sections and Figs. 1, 2, 3, 4 and 5.

Argentina. IRAM 5065.

The quoted standard is not yet published, but it has been mentioned that it is under preparation and that it will contain definitions, preferred values etc. Another Standard IRAM 4517 from 1951 gives the surface roughness symbols used on drawings. IRAM 5065 has, however, now been withdrawn.

Austria. M 1115 March 1956 (Tentative Standard).

Preferred values for the peak-to-valley value, R, are listed in a table from 0.04 to 1000 μm following a Renard Series R 5 with the factor $\sqrt[5]{10} = 1.6$.
Part 2 in the standard contain the triangular symbols used on drawings.

▽	$40 < R < 400$ μm
▽▽	$10 < R < 40$ μm
▽▽▽	$2.5 < R < 10$ μm
▽▽▽▽	$R < 2.5$ μm

In addition there is a table where the peak-to-valley value which might be expected for various production methods are set in relation to the triangular symbols. The same table also contains values for bearing areas running from 10—40% for boring — grinding and 40—80% for lapping — honing — superfinish.

Bulgaria. БДС 782-53.

This standard is very similar to the old U.S.S.R. standard GOST 2789-1951. The roughness range is divided into three groups:

Serie 1	$0 < R < 0{,}12$	μm	Class 14-13
Serie 2	$0{,}025 < RMS < 6{,}3$	μm	Class 12-5
Serie 3	$20 < R < 200$	μm	Class 4-1

published in September 1961. The information for France given in this paper has been added during the printing.
Bureau de Normalisation de l'Aeronautique has published a standard FD L03-500 February 1959 which confirm with Draft ISO Recommendation No. 221 and also contains preferred values for surface roughness measures. It also contains tables of the roughness values which might be expected in various production processes.

where either the peak to valley value or the root mean square value are used according to the numerical size of the roughness.

The whole roughness interval is divided into 14 classes following a serie $R\,\frac{10}{3}$ with the factor 2. Class 6-14 is further subdivided into three groups and the preferred values within these classes are therefore running after the R10 series with the factor 1.25.

By comparing the tables it will be seen that:

$R = 5 \times RMS$	for $0 < R < 0.8$	μm	Class 14-11
$R = 4 \times RMS$	for $0.8 < R < 6.3$	μm	Class 10-7
$R = 3 \times RMS$	for $6.3 < R < 40$	μm	Class 6-4
$R = 2.5 \times RMS$	for $40 < R < 200$	μm	Class 3-1

The sampling length is as follows:

Class 1-4	$1 \geqq 3$ mm
Class 5-7	$1 \geqq 2$ mm
Class 8-12	$1 \geqq 1$ mm

In a table the roughness values which can be expected from various production processes are set in relation to the triangle symbols and the roughness classes.

The triangle symbols are:

∇	$40 < R < 200\ \mu m$;	$12.5 < RMS < 100\ \mu m$	Class 1-3
$\nabla\nabla$	$6.3 < R < 40\ \mu m$;	$1.6 < RMS < 12.5\ \mu m$	Class 4-6
$\nabla\nabla\nabla$	$0.8 < R < 6.3\ \mu m$;	$0.20 < RMS < 1.6\ \mu m$	Class 7-9
$\nabla\nabla\nabla\nabla$	$0 < R < 0.8\ \mu m$;	$0 < RMS < 0.20\ \mu m$	Class 10-14

The roughness indication can also be written as f. i. ∇ 3, that means machining according to class 3 which is $40 < R < 63\ \mu m$.

Within class 6-14 with subdivision the sign is ∇ 11a, ∇ 11b, ∇ 11c, etc. ∇ 11a means according to the tables $0.1 > RMS > 0.08\ \mu m$. If needed the machining process can be added f. i. $\overset{\text{Process}}{\nabla 2\ \overline{\quad}}$. This steadily changing between R and RMS within the various classes seems to be a little confusing.

Czechoslovakia. ČSN 014450 1960.

Preferred values for R_a from 0.008 to 100 μm after the R10 Series with the factor $\sqrt[10]{10} = 1.25$.

For R_z the preferred values range from 0.032 to 400 μm following the same series. Both R_a and R_z are divided into groups each containing three values the largest of which once again is chosen as the preferred value. In this way the real preferred values are taken from the Renard Series $R\,\frac{10}{3}$ with the factor 2.0.

The relation between R_z and R_a is stated as:

$$R_z = 4.5\ R_a^{0.97}$$

and it is mentioned that the relationship is theoretically

$$R_z = (3.9 - 5)\ R_a.$$

In the tables for R_z and R_a the relationship is listed as:

$$R_z = 4\,R_a.$$

The sampling length (meter cut-off) is standardized to 0.08, 0.25, - - - 25 mm and a table recommends the cut-off value for R_a in relation to the numerical value of this measure. Roughly, and with some exceptions the relations given are as follows:

$0.12 < R_a < 0.4\ \mu m$	$l = 0.25$ mm
$0.4 < R_a < 1.6\ \mu m$	$l = 0.8$ mm
$1.6 < R_a < 6.3\ \mu m$	$l = 2.5$ mm

Listed in a table is the R_a values which might be expected from various methods of machining.

The former triangular symbols are left out in this standard and an open $\surd$ with a long and a short leg is used with written figures for the R_a value.

Denmark. DS 940. November 1958.

Sampling length of 0.08, 0,25, - - - 25 mm is standard.

DS 58.1 Nov. 1958 gives triangular symbols for use on drawings:

▽	$5 < R_a < 25\ \mu m$
▽▽	$1.6 < R_a < 5\ \mu m$
▽▽▽	$0.25 < R_a < 1.6\ \mu m$
▽▽▽▽	$R_a < 0.25\ \mu m$

DS.58.2 Nov. 1958 gives the rules for cases where the R_a value is written directly on the drawings. A symbol resembling $\sqrt{}$ is used and full extended it gives information of a total of ten different surface roughness measures.

Preferred values for R_a are from 0.004 to 250 μm following the Renard Series R_a 10 with the factor $\sqrt[10]{10} = 1.25$.

If the height of the waves is to be kept within certain limits it is preferred to use values from the series R_a 5 from 1 to 2500 μm. The standard also includes symbols for the lay which are exactly similar to those in the USA standard. Finally there is a range of preferred values for the bearing area from 10 to 95%. In DS 941 Nov. 1958 is given the R_a values which may be expected for various production methods based on the triangular symbols.

Finland. B II 51 TES 565 — 28 May 1959.

B II 52 TES 566-28 and B II 53 TES 567-28 contain triangular symbols for use on drawings such as this:

▽	$R_z < 63\ \mu m$	▽	
▽▽	$R_z < 25\ \mu m$	▽▽	$R_z = 10$
$\overline{▽▽}$	$R_z < 16\ \mu m$	$\overline{▽▽}$	$R_z = 10$
▽▽▽	$R_z < 6.3\ \mu m$	▽▽▽	$R_{max} = 16$
▽▽▽▽	$R_z < 1.6\ \mu m$	▽▽▽▽	$R_z = 1.0$ - - 1.6

In B II 54 TES 568-28 are shown somewhat different symbols but also with triangles and an extended leg. In this case it may be written numerical values

for R_a, R_z or R_{max} together with the machining process. The sampling length can also be stated. Preferred values for the three measures are taken from the Renard Series R_a 5 going from 0.04 to 160 μm. The sampling length of 0.08, 0.25 - - - 25 mm is standard.
B II 55 TES 569-28 indicates where the triangular symbols are to be placed on the depicted object.
B II 56 TES 570-28 gives some general rules in the choice of surface roughness with respect to the operation and also more common rules for measuring.

France. Avant-projet 1961.

This proposal, published in September 1961, are based on the E-system, but it is said, that the definitions of the various roughness measures also are valid in the M-system.
The standard is divided into three parts, the first of which gives the fundamentals. The definition is kept close to the ISO recommendation and include the depth measures R_a, R_{max} and R_u (depth of smoothness) but not the R_z value. Another value R_v is the average depth of the valleys within the sampling length. A length measure is A_v which is the average distances between the crests within the sampling length. The two last values are also to be found in the swiss standard. The bearing length L_c is also defined.

Three proportion measures are given. $K_p = \frac{R_u}{R_{max}}$ ("Leerheitsgrad"), $K_h = \frac{R_m}{R_{max}} = 1 - K_p$ (filling out factor) and $T_c = \frac{L_c}{l}$ (the bearing factor).

Part two in the standard deals with the prescriptions for measurements and also gives recommendations for the different kind of instruments used.
Part three indicates what is to be taken as standard at present time to fullfill the requirements of the technical stage of to-days production. According to the recommendation in this part the R_a value is to be used as the only measure and besides this the production process must be indicated. It is mentioned that in some cases the R_a value can be replaced by the R_v or R_{max} value.
Preferred values for R_a is following the Renard Series R10 from 0.012 to 100 μm.

If possible the values are to be chosen from the coarser series $R\frac{10}{3}$ with the factor 2.
The sampling length is: 0.08, 0.25, 0.8, 2.5, 8 and 25 mm and the sampling length by which R_a is measured must be stated. Otherwise it is set forth that the sampling length is 0.8 mm.
The radius of the smaller rolling circle is chosen to 25 mm.

The symbol for use on drawing is $^{6.3}\surd$ or with max., min. values $^{6.3}_{3.2}\surd$

or $^{0.1}\surd\overline{\text{Process}}$

Germany.

DIN 4760, 4762 Blatt 1-3 contains the fundamentals.

DIN 4761 gives information on some macroscopic errors which occasionally can be found on a surface.

DIN 4763 contains a list of preferred values for the peak-to-valley value, R. The values are taken from the R 5 series with the factor 1.6 ranging from 0.040 to 2500 μm.

The levelling depth (depth of smoothness) R_u, is preferred to follow the same series from 0.010 to 630 μm and for the R_a value the preferred values run from 0.010 to 250 μm and also in the R5 series.

Preferred values for bearing length as well as for bearing area are from 10 to 95%, and the distance, c, is taken as 0.1, 0.25, 0.6 and 1.6 μm according to the value of the total irregularity height.

In DIN 4763 Beiblatt 1, Proposal, 1954 is listed the peak-to-valley values R, which can be expected in the various production processes and it also gives a means of relating it to triangular symbols.

DIN 4764, Proposal, 1953 gives some general information concerning the function of different surfaces.

DIN 3141, Tentative standard, 1960 contains the triangular symbols as follows:

	I	II	III	IV
▽	160	100	63	25
▽▽	40	25	16	10
▽▽▽	16	6.3	4	2.5
▽▽▽▽	—	1	1	0.4

The tabulated values in μm for the peak-to-valley value R is the greatest permissible and as will be seen there is distinguished between four ranges according to the type of production.

In DIN 3142 1960 is given another symbol $\sqrt{}$ where the R_a value, surface character, production method and other surface measures are written directly. No sampling length is standardized. The radius for the two rolling circles, which play a similar role in the E-system as the sampling length in the M-system, are given as 25 and 250 mm.

Great Britain. BS 1134 1961.

Preferred values for CLA also follow a Renard Series with the factor 2 going from 1 to 1000 μin and standard meter cut-off values of 0.003, 0.01, 0.03 --- 1 in. In a table are given the suitable meter cut-offs for various finishing processes.

The stylus tip radius is standardized to 0.0001″ and information concerning electrical integrating instruments is given, especially on the transmission characteristics.

BS 2634 Part 1 1960 gives information on ground, flat and cylindrical roughness comparison specimens.

BS 308 1953 explains the symbols used on drawings, these symbols is now abandoned in the new edition of BS 1134.

Hungary MSZ 4721-58.

This standard contains the fundamentals and is mainly based on the ISO Recommendation, but it also include many of the roughness measures which is mentioned in the previous survey. Although based on the M-system it also describe the E-system.

Very valuable in this standard as well as in other Hungarian standards is a list where the terms for the different roughness values are given in hungarian, russian, german, french and english.

MSZ 4722-58 contains a table of preferred values for R_a from 0.016 to 100 μm following a serie with the factor 1.25. Preferred values for R_z are taken from the same series and are going from 0.04 to 400 μm.

It is stated that:

$$R_z = 4.5\ R_a \text{ and } R_a \sim 0.9\ \text{RMS in the interval } 50 > R_a > 0.1\ \mu\text{m}.$$

No values for the sampling length is given.

There are different systems for symbols used on drawings, one of them using from one to four triangles with limits between. An open angles as $\overset{1.4}{\surd}$ or $\nabla\nabla\nabla^{\overline{0.4}}$ with written values can also be used.

In cases where max., min. values may be indicated the sign is $\overset{63}{\underset{32}{\surd}}$

If R_z values are to be used, the sign is $\sqrt{\vphantom{R}}^{\,R_z\ 50}$

In MSZ 4724-58R is given a table where the expected R_a values by various production methods is listed and MSZ 9654-58 gives the information concerning precision roughness comparison specimens.

Also of great interest is MSZ 9655-59R as it try to set up a connection between the R_a value, the IT grades and the dimensions according to the formula:

$$R_a = k \cdot T^n$$

where k and n is constant, n being 0,8 while k can be taken as one of three values between 0.025 and 0.100 according to the grade of the machining. For each of the three set of constants is given a table.

In MSZ 9656-60 is given the principles and prescribtions for measurements.

Italy. UNI 3963 September 1960.

Preferred values for R_a follow the Renard Series R 10 with the factor 1.25 from 0.025 to 25 μm. The sampling length is given as:

$$\begin{array}{llll} R_a & = 0 - 0.3\ \mu\text{m} & l = & 0.25\ \text{mm} \\ R_a & = 0.3 - 3\ \mu\text{m} & l = & 0.8\ \text{mm} \\ R_a & > 3\ \mu\text{m} & l = & 2.5\ \text{mm} \end{array}$$

In a table the expected R_a values obtained by various production methods are listed.

Of special interest in this standard is an attempt to give a relation between the ISO tolerances and the maximum permissible surface roughness:

ISO	Dimension mm				
	< 3	3–18	18–80	80–250	> 250
	R_a max. μm				
IT 6	0.2	0.3	0.5	0.8	1.2
IT 7	0.3	0.5	0.8	1.2	2
IT 8	0.5	0.8	1.2	2	3
IT 9	0.8	1.2	2	3	5
IT 10	1.2	2	3	5	8
IT 11	2	3	5	8	11
IT 12	3	5	8	12	20
IT 13	5	8	12	20	
IT 14	8	12	20		

For drawings triangular symbols are used as follows:

▽ $R_a \approx 12$ μm
▽▽ $R_a \approx 3$ μm
▽▽▽ $R_a \approx 0.8$ μm
▽▽▽▽ $R_a \approx 0.2$ μm

Japan. JIS B 0601 1955.

A standard is issued for the peak-to-valley value and preferred values going from 0.1 to 560 μm, divided into three groups. It is tabulated as follows:

Class	0.1–S	0.2–S	0.4–S	0.8–S	1.5–S	3–S	6–S	12–S	18–S	25–S
R μm<	0.1	0.2	0.4	0.8	1.5	3	6	12	18	25
Symbols	▽▽▽▽				▽▽▽			▽▽		
Standard area	0.3				1			3		

Class	35–S	50–S	70–S	100–S	140–S	200–S	280–S	400–S	560–S
R μm<	35	50	70	100	140	200	280	400	560
Symbols	▽								
Standard area	5					10			

From 0.1—12 μm the values follow the R $\frac{10}{3}$ series with a factor of 2. From 12—100 μm the series is R $\frac{20}{3}$ and the factor 1.5. From 100—560 μm the factor is 1.4.

The triangular symbols are also shown and to each group is given a "standard area in mm^2 of the basic surface" which in practice means the square of the sampling length.

JIS B 0651 1955 contains some information concerning stylus instruments e. g. such as stylus tip radius and load in relation to the roughness value R. Recommendations as to the electrical instrument and the recorder are also mentioned. JIS B 0652 1955 gives similar information for the measurement of surface roughness with light-wave interference instruments. Three other standards JIS B 0653 1957, B 0654 1957 and B 0655 1960 have been published but the author has no translation. Judging from the pictures and drawings in the standards it looks as though the first gives information on surface roughness measurements by the Schmaltz light-section method and the second deals with condenser measurements while the third cannot be understood as it only contains the Japanese text.

Netherlands. NEN 630 — I August 1958.

This standard, based on the M-system, is of interest as it is built up in a way somewhat different from the M-system in other countries. According to this standard the surface profile is considered as being composed of three separate profiles: the form profile; the wave profile and the roughness profile. The form profile is originated by the trajectory of the point of contact of a sliding circle of a given sliding radius with the surface profile. The errors of form are then the deviation between the ideal profile and the form profile.

The surface profile as related to the stretched-out form profile as a reference line is called the diagram profile. It gives the surface profile after the elimination of the errors of form and can be considered as being composed of the wave profile and the roughness profile.

The wave profile is originated by the trajectory of a mean line of given basic length, which travels through the diagram profile so that the enclosed surfaces on both sides are equal and minimum. The waviness is given as the deviation of this profile from the stretched-out profile.

The roughness profile is given by the trajectory of the point of contact of a tracing circle of a given tracer radius with the surface profile and related to the wave profile as the reference line. The roughness is then given by the deviation of this profile from the stretched-out wave profile.

In the system thus discussed the normal R_a value is defined and as unit is chosen 1 ru $\sim$ 1 μin.

From a theoretical point of wiev this system gives the same possibilities in distinguishing between errors of form, waves and roughness as does the E-system and in this respect it can be said to make an approach at the E-system.

Meanwhile, at the present no instrument is known which is capable of taking into account the various, imaginary and unknown stretched-out profiles.
NEN 630-II contains the following table for preferred values:

		5600 > 1400	1400 > 360	360 > 90	90 > 22	22 > 5.5	5.5 > 1.4	1.4 > 0.2
Ra	General series R10	3200 ---- ----1600	1250 ---- ----400	320 ---- ----100	80 ---- ----25	20 ---- ----6	5 ---- ----1.6	1.2 ---- ----0.25
ru	Normal series R5	4000 2500 1600	1000 630 400	250 160 100	63 40 25	16 10 6	4 3 2	1 0.5 0.25
Radius of sliding circle R mm		2000	1000	500	250	125	63	32
Basic length L mm		20 (25)[1]	10 (7.5)	5 (7.5)	2.5 (2.5)	1.2 (0.75)	0.6 (0.75)	0.3 (0.25)
Radius of tracer r μm		200	100	50	25	12.5	6	3

In NEN 630-III and 630-IV 1960 are given the rules for symbols on drawings. This is extremely complicated and consists of a system of black or white triangles or circles, one triangle and one circle symbol for each of the seven classes, see the table. In this standard the roughness is also set in relation to the dimensions, production methods and fitting according to the IT grades.

Poland. $\frac{PN}{M}$ *— 04250 1958.*

This standard gives the fundamentals.
No. 04251 1958 contains the preferred values for R_a and R_z both of them being divided into 14 classes. The R_a value is going from 0.008 to 100 μm following the R10 series with the factor of 1.25. The R_z value corresponding to the same series runs from 0.04 to 400 μm.
By comparison it will be found that
$R_z = 4R_a$ for $R_a > 2.5$ μm class 1-6
$R_z = 5R_a$ for $R_a < 2.5$ μm class 7-14
The sampling length is 0.08, 0.25, 0.8, 2.5, 8 and 25 mm.
In a table is listed preferred values for the sampling length in relation to the machining methods and the 14 roughness classes.
Standard No. 04252 1958 gives the symbols used on drawings which is a triangle with an extended leg. The roughness value is written directly together with the machining method and the lay for which special symbols are laid down.

1) According to the instrument used.

In standard No. 04254 1959 are given details for surface roughness comparison specimens.

Rumania. 5730 1957.

This standard is like the Polish, very similar to the ISO recommendation No. 221. Preferred values for R_a og R_z follow a Renard Series R10 with the factor 1.25, R_a going from 0.008-100 μm, and R_z from 0.04-400 μm.
The range is divided into groups each containing three values, the greatest of which is again chosen as the preferred value. In this way the real series for preferred values is $R \frac{10}{3}$ with the factor 2. By comparing the two tables for R_a and R_z it will be found that $R_z = 4R_a$.
The relation between sampling length, R_a and R_z are given as:

l_{max} mm	0.08	0.25	0.8	2.5	8	25
R_a μm	0–0.8	0.8 – 3.2	3.2 – 6.3	6.3 – 12.5	12.5 – 50	50 – 100
R_z μm	0–3.2	3.2 – 12.5	12.5 – 25	25 – 50	50 – 200	200 – 400

Spain. UNE 1037 1951.

R_a is standard and follows the R5 series with the factor 1.6 from 0.04 to 10 μm and the series $R\frac{5}{2}$, factor 2.5, from 10 to 63 μm.
It is stated that:
RMS $= 1.14\ R_a = 0.19\ R$ and
$R = 5.93\ R_a$.
Preferred values for wave height follows the series $R \frac{10}{2}$, factor 1.6, from 0.5 to 200 μm, and the series R5, factor 1.6, from 200 to 630 μm.
Symbols for the lay are equivalent to the U.S.A. symbols.
On drawing is used triangular symbols where:

$\triangledown$ $10 < R_a < 25$ μm
$\triangledown\triangledown$ $1.6 < R_a < 10$ μm
$\triangledown\triangledown\triangledown$ $0.16 < R_a < 1.6$ μm
$\triangledown\triangledown\triangledown\triangledown$ $0 < R_a < 0.16$ μm

By using triangles with an extended leg information such as R_a value, wave-height and wavelength, lay and roughness width can be written. A table gives the R_a values to be expected from various machining processes and the values are set in relation to the triangular symbols and the IT classes.

Sweden. SMS 671 December 1947.

Contains the fundamentals. Attention is drawn to the Swedish and Danish definition of peak-to-valley value (see earlier explanation and Fig. 1). Preferred

values for R range from 0.1 μm, and according to the R5 series with the factor 1.6.
Symbols for drawing are according to SMS 672 Dec. 1947.

$>\nabla$	R $>$ 100 μm	$\overline{\nabla\nabla}$	R $<$ 10 μm
∇	R $<$ 100 μm	$\nabla\nabla\nabla$	R $<$ 4 μm
$\overline{\nabla}$	R $<$ 25 μm	$\overline{\nabla\nabla\nabla}$	R $<$ 1.6 μm
$\nabla\nabla$	R $<$ 16 μm		

or $\nabla\overline{\ 10\ \mu}$ or with max/min. $\nabla\overline{\ 10\text{-}25\ \mu}$
The Swedish standards are at present being reviewed.

Switzerland. VSM 58300 November 1960.

This standard contains the fundamentals and is based on the E-system. Defini tions are given for most of the afore-mentioned roughness values, and it also includes some others which up to now have been very seldom used.
The standard VSM 10320 Bl. 1-7 contains triangular symbols for use on drawings.

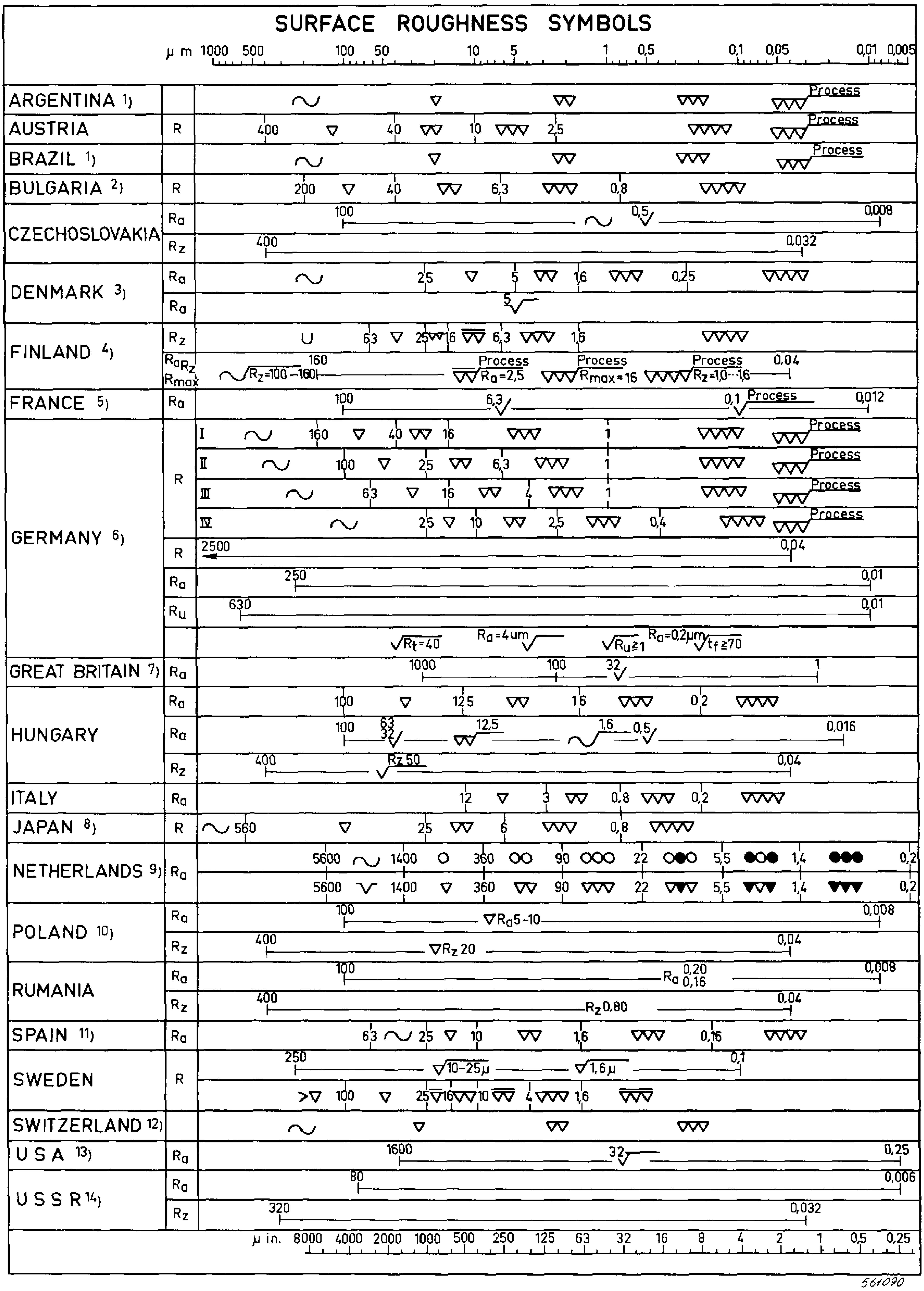
USA. ASA B 46.1 1955.

Recommended R_a values range from 0.25 to 1000 μin according to the R $\frac{10}{3}$ series, factor 2. By using some of the values in between, the preferred values will follow the series R10, factor 1.25.
For waviness height there is a similar series of preferred values from 0.00002 to 0.020 in.
The sampling length (roughness width cut-off) is 0.003, 0.010, 0.03, 0.100, 0.300 and 1.000 in.
Symbols for the lay are given and for specifying on drawings an open triangle is used with extended leg where the R_a value, roughness width, roughness width cut-off, waviness height, waviness width and lay can be written directly. There is also a table where expected R_a value for various production methods are listed.
Furthermore the standard contains recommendations concerning the stylus and tracer, transducer, amplifier and recorder, and precision reference specimens.

U.S.S.R. GOST 2789 1959.

This is also similar to ISO No. 221. The range of roughness is divided into 14 classes. R_a goes from 0.01 to 80 μm, R_z from 0.05 to 320 μm following the R $\frac{10}{3}$ serie. Class 6-14 contains three roughness values which form a series with the factor 1.25, the largest of which again relate to the above-mentioned range.
The relation between sampling length, R_a and R_z is:

Table 3.


SURFACE ROUGHNESS SYMBOLS
μ m 1000 500 100 50 10 5 1 0,5 0,1 0,05 0,01 0,005
ARGENTINA 1)
AUSTRIA
BRAZIL 1)
BULGARIA 2)
CZECHOSLOVAKIA
DENMARK 3)
FINLAND 4)
FRANCE 5)
GERMANY 6)
GREAT BRITAIN 7)
HUNGARY
ITALY
JAPAN 8)
NETHERLANDS 9)
POLAND 10)
RUMANIA
SPAIN 11)
SWEDEN
SWITZERLAND 12)
U S A 13)
U S S R 14)
Process
μ in. 8000 4000 2000 1000 500 250 125 63 32 16 8 4 2 1 0,5 0,25
561090

Remarks to Table 3

1) No limits between the different triangles are given. If necessary the production process can be added as shown to the right.

2) The roughness can also be indicated as:

∇ 3, ∇11b or $\overline{\nabla\ 2}$ Process, see explanation p. 18.

3) The symbol can be extended:

Wave height
Wave length
10 × 5 × 25 ← Reference length for waves
Machining process
Maximum R_a value → 0,10
Minimum R_a value → 0,04
Roughness width → 0,05
Polish × M ← Lay
70 % × 0,8 ← Sampling length
Bearing factor

4) On the horisontal extension can besides the production process also be indicated the traversing length and the sampling length.

5) If other measure than R_a are used it must clearly be indicated. In all cases the drawing must give information about the system used, the roughness measure, the sampling length, the unit and if needed the production process.

6) The full symbol is:

① R_a value with unit μm added.
② Surface character according to special symbols defined in DIN 4761. Production method.
③ Roughness measures according to DIN 4762 f.i. peak to valley value, bearing area etc. R_a is not written here, see ①

7) If needed the machining process, sampling length and lay can be written directly.

8) Above the triangles can be placed the roughness class, see p. 23, and on a horisontal extension the machining process due to special symbols, f. i.: 12–S $\nabla\nabla$ 50–w

In cases where it is wanted to indicate the waviness, the value is written under the extension and followed by a w as shown.

9) A sign as 40 $\surd$ can be used for indicating the R_a value by an arbitrary production process, 40 is used for surfaces without allowance for machining and 40 ∇ is used for surfaces with allowance for machining.

A sign as 40 16 $\surd$ is used for indicating maximum and minimum R_a value.

A sign as 40(5) $\surd$ is used when the sampling length differ from the standard value.

10) If needed the machining process or lay can be added as follows:

Process ∇ R_z1,25; × $\sqrt{\ }$ 9-10 (Process) according to special symbols for the lay.

11)

Waviness height
2 – 6 ← Waviness width
R_a value → 1,6 $\nabla\nabla\nabla$ = 0,13 ← Roughness width
Lay

12) No limit between triangles. An encircled letter indicates the production process according to special definition in VSM 10320 pag. 1-7.

13) The symbol can be extended:

Waviness height
0,002 – 2 ← Waviness width
Maximum R_a value → 63 0,010 ← Roughness width cut-off
Minimum R_a value → 32 ⊥ 0,005 ← Roughness width
Lay

14) On drawings is used a sign 500 $\surd$ For further details is referred to special standards.

1 mm	0.08	0.25	0.8	2.5	8
R_a μm	0.006–0.02	0.025–0.32	0.4–2.5	5–10	20–80
R_z μm	0.032–0.1	0.125–1.6	2.0–10	20–40	80–320

Symbols on drawings are an open triangle with the roughness values written directly.

ISO Draft recommendation No. 221 September 1958.

Preferred value for R_a range from 0.008 to 100 μm and for R_z from 0.040 to 400 μm corresponding to the R10 series with the factor 1.25. In national standards it is allowed to use $R\frac{10}{3}$, factor 2, or R 5, factor 1.6. The sampling length is 0.08, 0.25, 0.8, 2.5, 8 and 25 mm.

Summarizing Remarks.

In table 3 is listed the symbols used on drawings in the different national standards.

In most cases triangular symbols with or without fixed limits between the sign are used. Besides this many countries use triangular symbols with an extension from one of the anglesides where different information can be written either above or below the horizontal extension. Commonly the production process is stated in this way but the value of different roughness measures can also be written here.

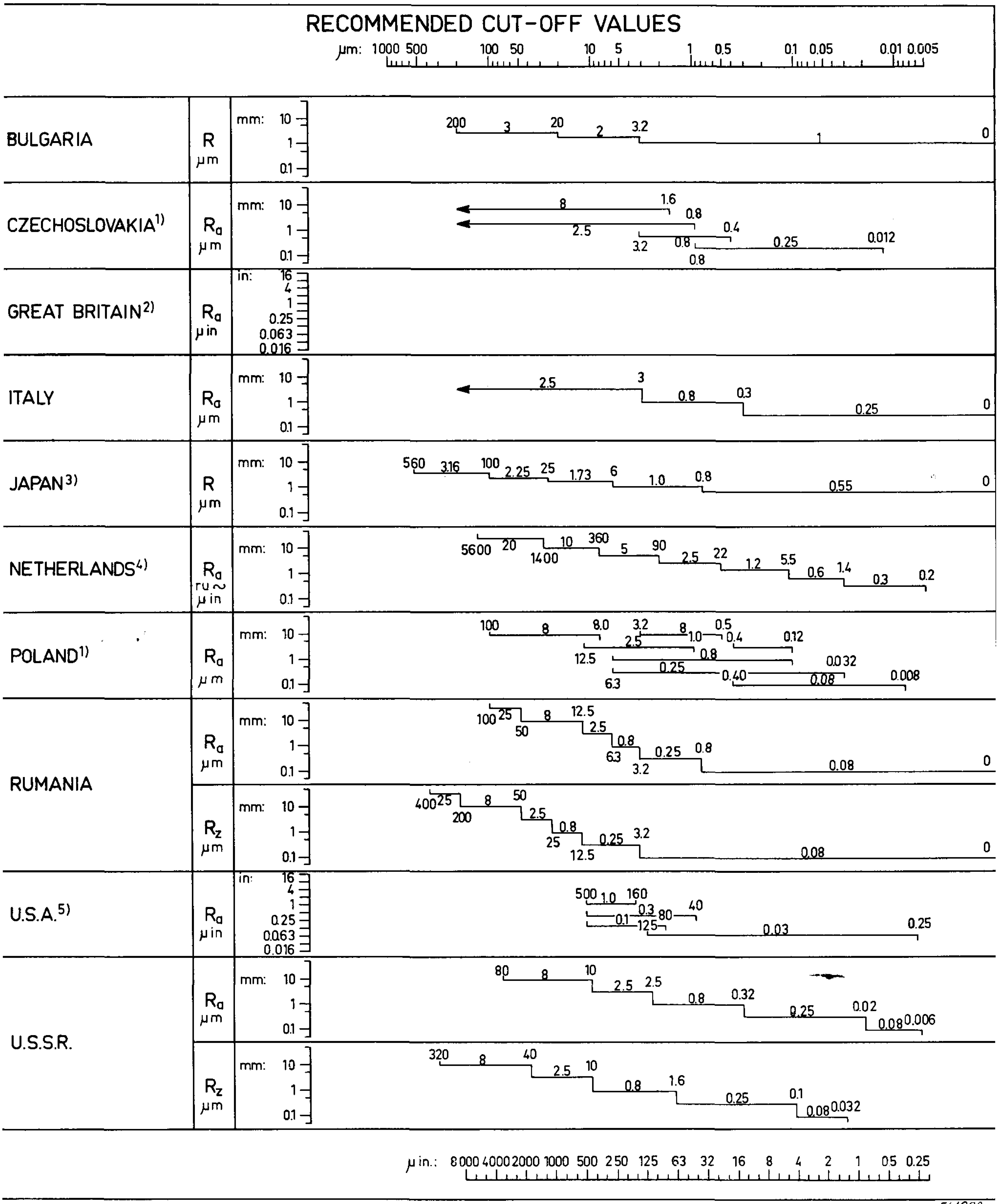
In newer standards there seem to be a tendency to change over from the "old" triangular symbols to a symbol like an open $\surd$ where all information concerning the surface is written. In the notes to the table are given examples of such symbols.*)

In most countries the sampling length (or cut-off values) are standardized. Most common is to use the values now recommended by ISO. In some national standards is also recommended a definite relation between cut-off values and the R_a, the R_z or the R value. In some countries the production process is also taken into consideration. The relationship between cut-off values and roughness values recommended in the national standards is shown in table 4.

As can be seen from this survey two basic measuring systems, the M- and the E-system are in use in various countries. Furthermore there is a large number of roughness values, all of them being used more or less, and perhaps measured at different cut-off value. Along with this has to be taken into account the different characteristics of the instruments used. There is thus a great risk to make mistakes in the measuring technique of surface roughness and it is therefore absolutely necessary that the people involved in this kind of work have a

*) An ISO committee ISO TC-10/SC1 is at present trying to develop an international symbol for use on drawings. This committee also tries to specify which measures ought to be indicated on the symbol and to decide where the various measures can be best stated.

Table 4.



1) The reason for the overlapping of the different cut-off intervals is that the cut-off values is set in relation not only to the R_a value but also to the production methods. This means, that within a given roughness class two or three different cut-off values can be used depending upon the machining process.

2) In BS 1134, 1961 is given a table over suitable meter cut-offs for various finishing processes.

3) The cut-off is taken as the square root of the "standard area of the basic surface".

4) The preferred cut-off values differ from the ISO recommendation. Normally the range given by the instrument used is allowed.

5) Cut-off values valid for physical specimens of surface roughness and lay. The reason for the overlapping of the cut-off intervals, see 1).

clear understanding of, and knowledge to, the many intricate problems which can turn up.*)
The advantage and disadvantage of the M- and the E-system has often been discussed and each have their supporters and their opponents. Notwithstanding the fact that no present-day instrument is able to measure according to the E-system calculation of roughness values, based on graphs laid out from the M- as well as the E-system seem to show that there is only a minor difference between the values calculated from the two systems. This difference is at least substantially smaller than the variation of the roughness values measured on different points on one and the same part. This is perhaps a worthwhile point to remember when discussion grows hot. The M-system has proved to be useful for about 20 years and a great number of instruments operating on this basis are in use all over the world, and it is now recommended by ISO. On the other hand, from a theoretical point of view, the E-system forms an exceedingly bountiful structure which perhaps in the future may become a parallel to the M-system, when all the difficulties have been overcome.
Amongst the countries which have reviewed their standard during the last few years there seems to be a tendency to follow the ISO recommendation. It is to be hoped that in the future the different national standards will become more homogeneous and that the number of roughness values used will be reduced, so that the confusion mentioned by Mr. Rubert is avoided.

*) See also: M. P. Rubert: Confusion in measuring surface roughness. Engineering. October 23, 1959 p. 393 and R. E. Reason: Orderly progress in surface measurement. ibid. 12. February 1960 p. 230.

Effective Profile Recording in conjunction with the B & K Roughness Meter Type 6102.

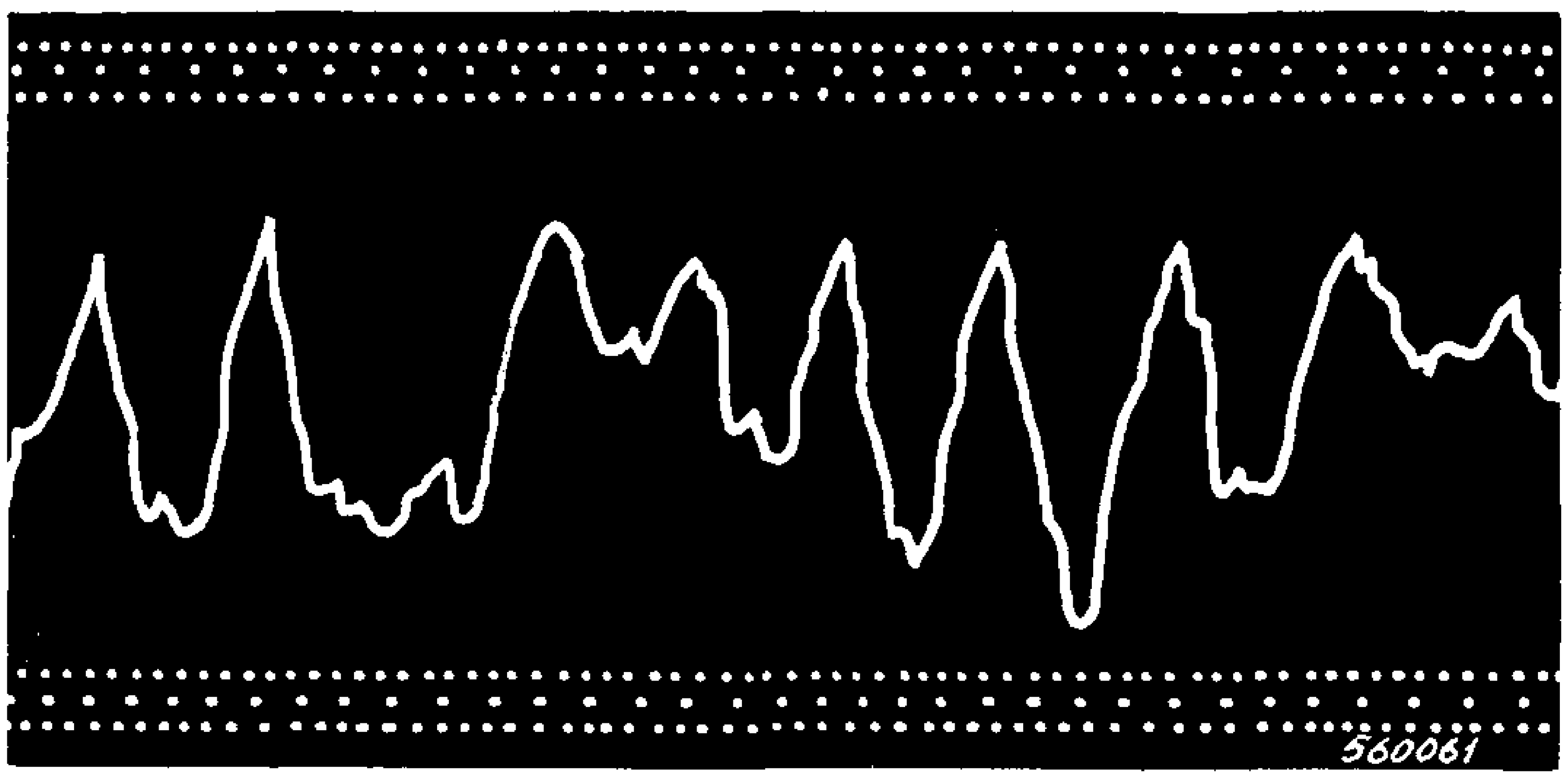
Whenever precise surface roughness investigations are required, reliable graphic representation of the effective profiles will be the best method for obtaining detailed information and for measuring accurately the different roughness values (R_{max}, R_z, A_r, bearing length B_b etc.) specified in the standards. Graphic recording of roughness profiles can be readily made by means of suitable electronic equipment and is briefly described in the following, in conjunction with the use of the Brüel & Kjær Roughness Meter Type 6102.

The Roughness Meter Type 6102, which is seen "in the field" on the cover photograph, consists mainly of a piezo-electric bender pick-up and an amplifier with meter providing direct reading of the R_a value in micrometers ($\mu m = 10^{-6} m$) or microinches. The instrument fulfils the requirements of the American Standard ASA B 46.1-1955. In addition, it can be employed for surface profile investigations, and a special pick-up has been designed for such applications. This pick-up, the Fine Surface Pick-up MP0001, is equipped with a diamond stylus presenting a tip radius of only 2.5 μm, which is applied on the surface with a force of less than 0.5 gramme. This stylus will follow the irregularities of machined surfaces much more closely than the 12.5 μm tip radius stylus of the standard pick-up, which is normally supplied with the instrument. The real profile is consequently transduced into an electrical signal with a much greater fidelity by the pick-up MP0001, while the meter indication (R_a value) will usually be the

Manufacture:	Type:	Frequency range:	Paper speed:	Method of writing	Writing-width:	Sensitivity:	Impe-dance:
Elena Schönander, Industrivägen 23, Stockholm	Mingograf 12	0-500 c/s	25, 50, 100 mm/sec.	ink paper	40 mm	15 mm/100 mV	
Philips	Oscilloscript PT 2002/00-01	0-300 c/s	25, 100 mm/sec.	stylus + carbonpaper	22 mm	max. 1 mm/6 mV	1 MΩ
Philips	Ocilloscript PT 2002/01-00	0-150 c/s	25, 100 mm/sec.	stylus + carbonpaper	44 mm	max. 1 mm/3 mV	1 MΩ
Fritz Schwartzer GmbH München-Pasing	Oscilloscript Single channel recorder	0-200 c/s	100 mm/sec. on request	stylus + carbonpaper	50 mm	—	
Hartmann & Braun A.G. Frankfurt a.M.	Lichtpunkt-Linienschreibe RLt-1 system HKKL 464	0-200 c/s	max. 20 mm/sec.	photopaper, immediately visible. Fixed for longer storage	30 mm	10 mm/3,2 mA 3/1 V	
Fritz Hellige & Co. GmbH. Freiburg 1.BR. v. Stephanstr. 4	Helcoscripter He-1	0-130 c/s 160 c/s-3 db	max. 100 mm/sec. + 30 mm/sec. on request	Pigment writing. Stylus + carbon roller	30 mm	10 mm/1 V	1 MΩ

(Prices of the order of £ 140 to 500)

same with the one or the other pick-up, since the omission of the finest irregularities is of little significance in an average measurement.
The Roughness Meter is provided with an output socket where the amplified electrical signal representing the effective profile is available with a peak-to-peak amplitude of up to 35 Volts. By connecting this output to a suitable recording instrument, a graphic representation of the profile may be obtained directly. Some oscillographic recorders which at the present time may be used for this purpose are listed at the bottom of p. 33.
These instruments have been selected principally because of their high writing speed, i.e. the extended frequency range of their writing system. It is an essential condition that the writing instrument is able to respond accurately to the totality of the frequency components which constitute the electrical signal representing the effective profile.*) Analyses carried out by means of the B & K Spectrum Recorder have shown that, when tracing typical machined surfaces at a constant speed of 3 mm/sec, most of the frequency components are comprised between 10-20 c/s and a few hundred c/s (i.e. roughness widths of 0.3 to 0.01 mm).
The Roughness Meter itself (pick-up + amplifier) is able to transmit, without appreciable distortion, any signal in the range 10 c/s to 1000 c/s. From the table is seen that no oscillographs are able to go as high up in frequency. The high frequency limit of the whole measuring chain, from the real profile to the recording paper, will thus be set by the writing system of the oscillograph employed. In general, however, it is possible by using a suitable tracing speed to transform most of the practically encountered profiles into signals contained within the frequency range 10 c/s to 200 c/s. Therefore, an oscillograph that is able to follow without distortion frequencies of up to around 200 c/s will suite in the great majority of cases. Below is shown an effective profile recorded under such conditions.



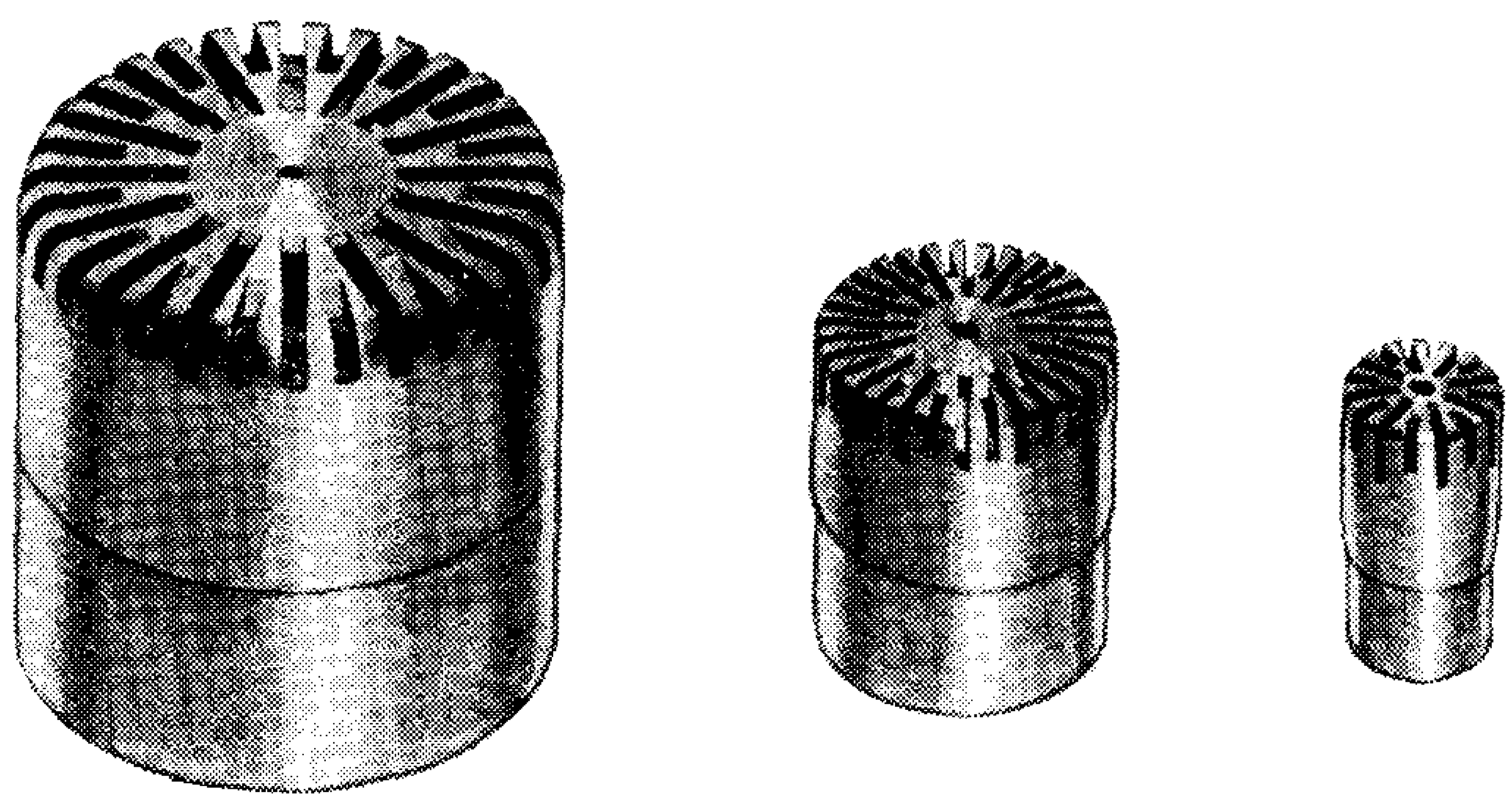
Photographic recording of the profile of a turned steel surface (R_a = 0.7 μm) obtained by means of Type 6102 plus an optical writing oscillograph with frequency range 0—200 c/s. (The vertical amplification is 150 times greater than the horizontal amplification).

*) To the large range of irregularities widths, or wavelengths, present on a profile corresponds an equally extended range of frequencies in the signal (frequency = tracing speed/roughness width). Refer also to Fourier analysis: any periodic function, no matter how complex, is made up of a sum of harmonically related sine wave components having definite amplitudes and phase relations to one another.

News from the Factory

¼ inch Condenser Microphones Type 4135 and 4136.

Two new Condenser Microphone Cartridges, the Types 4135 and 4136, with an external diameter of 6.3 mm (¼ inch) are now in production. The main improvements presented by the new cartridges with respect to their "one-inch" and "half-inch" counter parts are a better omnidirectivity and higher limits for the frequency and dynamic ranges. The "¼ inch" cartridges are designed with the same materials and according to the same principles which are the key of the performance of the other B & K microphones. Type 4135 is adjusted to give a flat free-field frequency characteristic at normal incidence, and Type 4136 is adjusted with a flat pressure response.



4131/4132 4133/4134 4135/4136

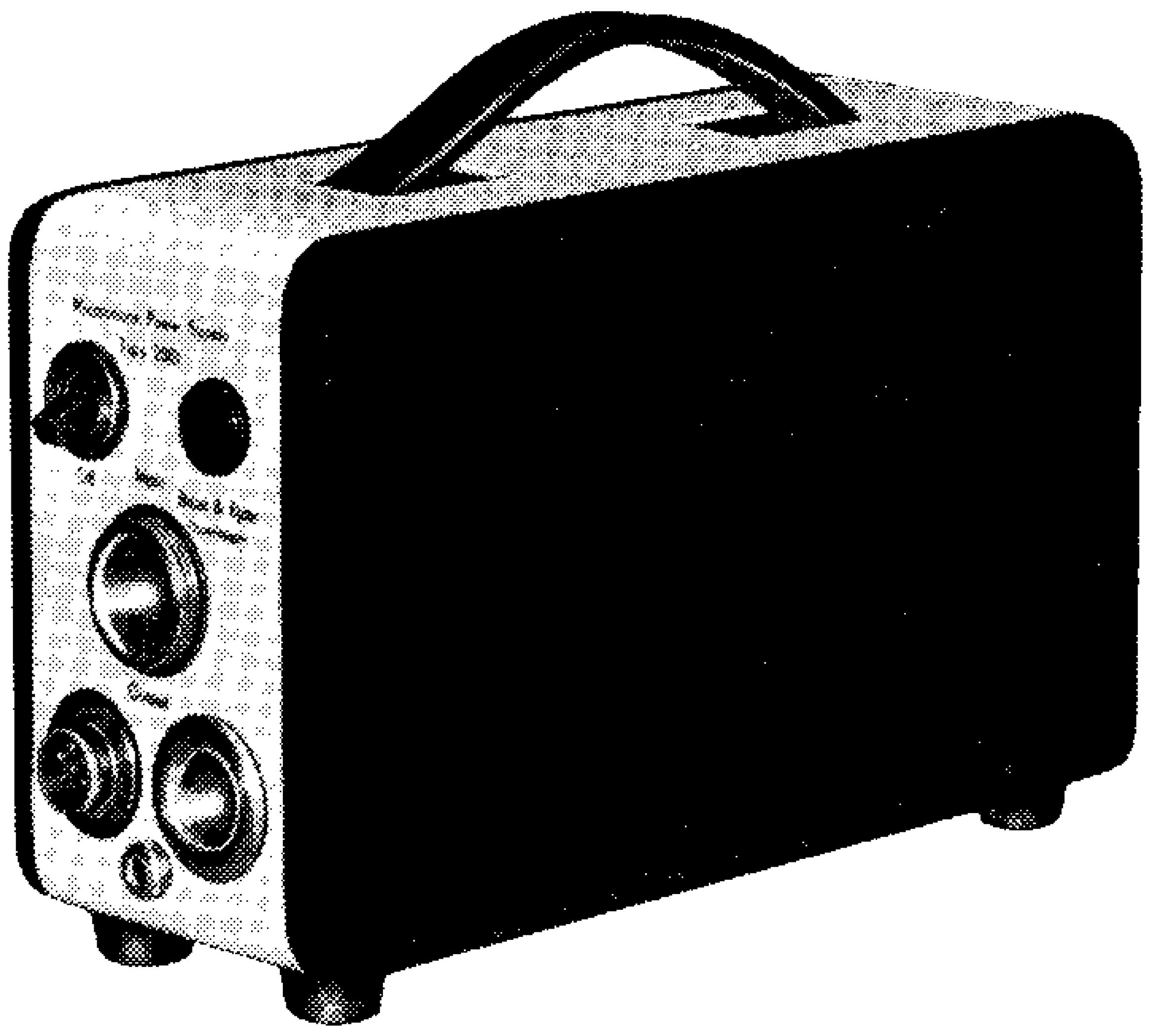
The new cartridges compared to the other B & K cartridges (scale 1/1).

The ¼ inch cartridges are intended to be mounted on the half-inch cathode-follower Type 2614-2615 by means of an adaptor Type UA 0035. This adaptor whose ¼ inch probe is 41 mm long (1⅝") features a low-capacity guardring arrangement between cartridge output and cathode-follower input. The overall characteristics of the ¼ inch Microphones Type 4135 + UA 0035 + 2614/15 and Type 4136 + UA 0035 + 2614/15 are the following:

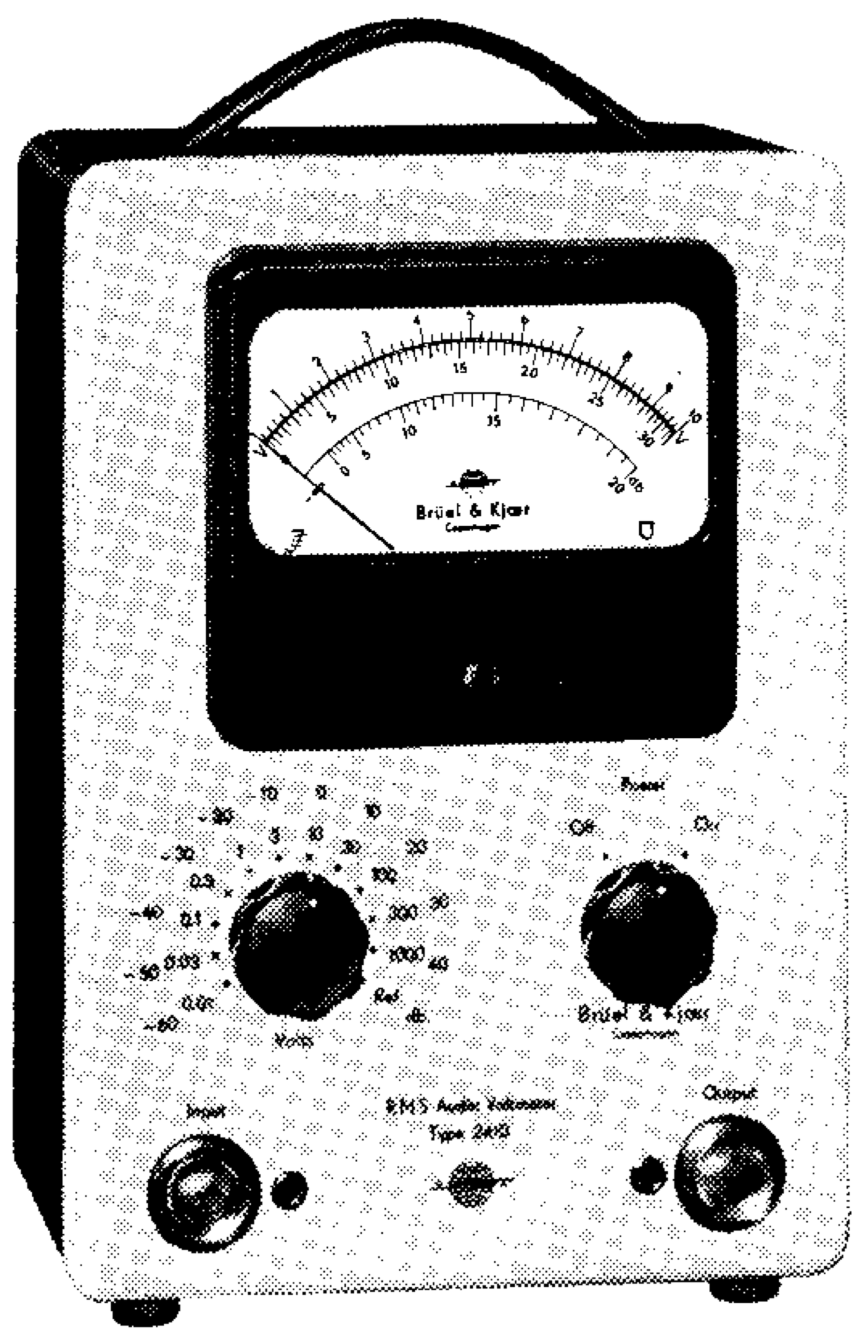
	Type 4135	*Type 4136*
Frequency range:	40 c/s — 100 kc/s	40 c/s — 80 kc/s
Sensitivity:	0.2 mV/μbar (— 74 db re.1V/μbar)	0.1 mV/μbar (— 80 db re.1V/μbar)
Dynamic range:	64 — 174 db	70 — 180 db
Omnidirectivity:	Better than ± 2 db up to 10 kc/s.	

The ¼ inch cartridges are delivered with detailed individual calibration chart including a frequency response curve going up to 200 kc/s.
Finally, it should be noted that the Pistonphone Type 4220 fits the ¼ inch cartridges. The Electrostatic Actuator UA 0033 can be used with the ¼ inch cartridge if the latter is mounted in an Adaptor DB 0264.

Microphone Power Supply Type 2801.
The Microphone Power Supply extends the use of the B & K Condenser Microphones into applications like phase shift and rise time measurement by oscilloscopes, triggering of oscilloscopes, multichannel tape recordings for later analysis, high quality studio reproduction, stationary noise monitoring stations etc.



Type 2801



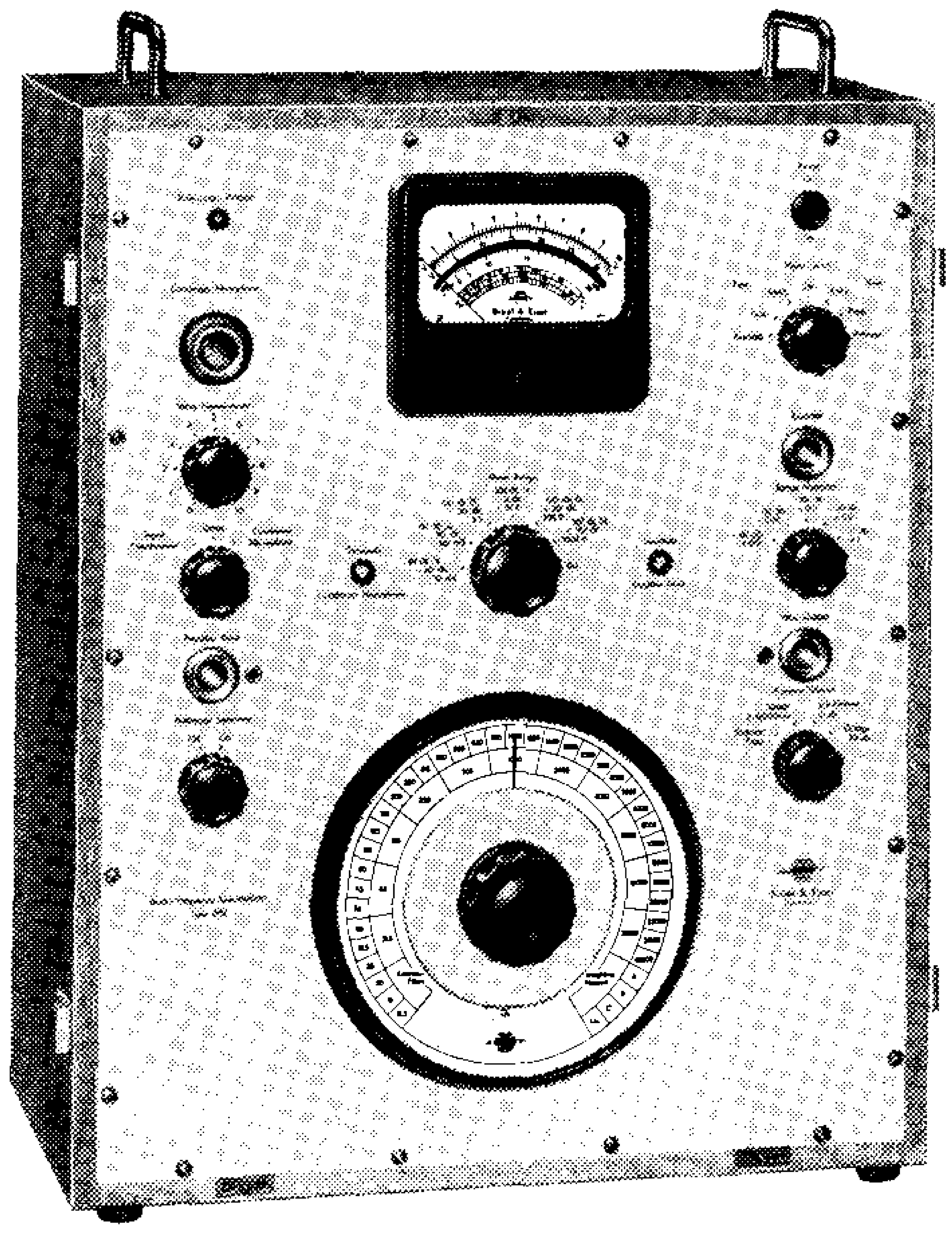
Type 2410

The power supply contains the necessary filament, anode and polarization voltage well filtered and supplied from a special line transformer featuring extremely low ground current and low magnetic stray fields. Besides a direct cathode follower output, a small transistorized output stage is incorporated the output impedance of which is 200 ohms, 200 ohms symmetrical or 50 ohms.

New R.M.S. Audio Voltmeter Type 2410.
The Voltmeter Type 2410 is a new design which supersedes the A.F. Voltmeter Type 2407.
The frequency range of Type 2410 is flat to less than 0.2 db between 20 c/s and 20000 c/s and to less than ± 0.5 db between 5 c/s and 50000 c/s. It contains a built-in square-wave reference signal and the dynamic range is approximately the same as for Type 2409. The input impedance is 1.5 MΩ parallel by 15-20 $\mu\mu$F. There is no built-in shunt resistor for a.c. current meas-

urements, but this type of measurement can be made by connecting an external shunt.

The rectifier circuit is of the "quasi-r.m.s." type and will measure the correct r.m.s. value of most A.F.signals. (Accuracy within ± 0.5 db for: 2 unharmonically related sine waves, white noise, and unsymmetrical pulses with crest factors up to 3 at full scale deflection).



Type 2112

Spectrometer Type 2112.

The new A.F. Spectrometer Type 2112 is a re-design of the Type 2111, by which following new features have been obtained:

a) The unit now contains 33 third octave filters in place of the original 30 and thereby now covers the frequency range 22 c/s to 45 kc/s. This has made available 11 one octave filters.

b) The center frequencies have been re-allocated to conform to the ISO preferred frequencies for acoustic measurements which demands that one of the octave filters appears with a center frequency of 1000 c/s.

c) The frequency charateristics of the filters at the lower frequencies have been altered so that they correspond to the shape of the filters at the higher frequencies.

d) The weighting networks have been re-designed to give a higher degree of stability and accuracy.

e) When used with a B & K Condenser Microphone Type 4131 or 4133 the unit covers all the requirements for Precision Sound Level Meters as inaugurated by the IEC in Helsinki, Finland in 1961.

The Spectrometer is available in the following versions:

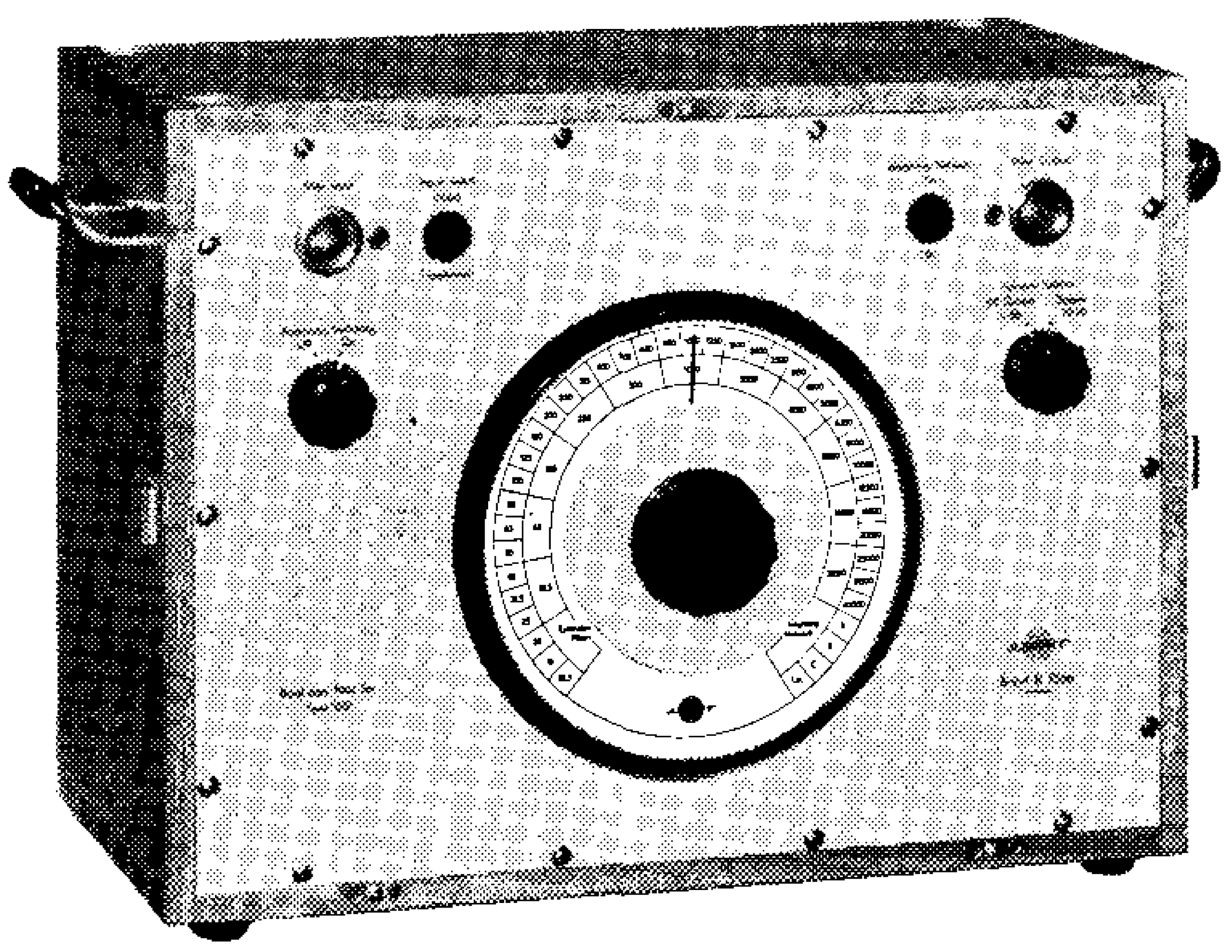
Type 2112 in a wooden cabinet with lids and handles for easy transportation.

Type 2142 in steel cabinet with flanges for mounting in 19″ racks.

Type 3313 Audio Frequency Spectrum Recorder. This version is a combination of the Spectrometer Type 2112 and the B & K High Speed Level Recorder Type 2305. It supersedes the Audio Frequency Spectrum Recorder Type 3312 and is mainly designed for the automatic recording of spectrograms, such as used in noise and vibration analysis.

Type 3326 A. F. Response and Spectrum Recorder. This version consists of a Spectrometer Type 2112 mechanically combined with a Beat Frequency Oscillator Type 1014 and a Level Recorder Type 2305. It supersedes the A. F. Response and Spectrum Recorder Type 3323 and allows the selective recording of frequency response characteristics of four-terminal networks as well as automatic continuous recording of harmonic distortion.

Band-pass Filter Set Type 1612.
This Set, which is intended for use with either the Microphone Amplifiers Type 2603 or 2604 or the Frequency Analyzer Type 2107 adapting these units for 1/3 or 1/1 octave analysis, replaces its forerunner the Type 1611. The latter has

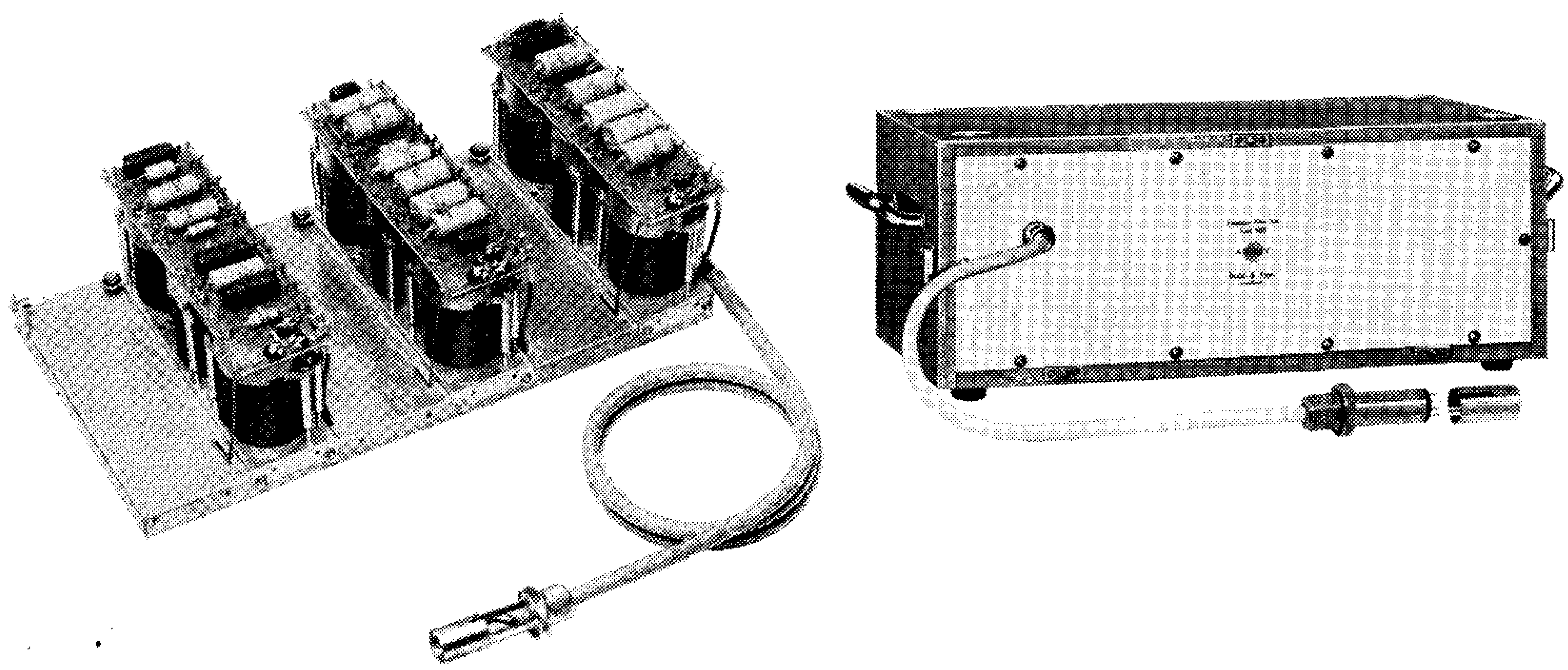


Type 1612

been reconstructed and modified to provide the features listed under the Spectrometer Type 2112, (a) to (d), but in addition it has a switch which enables the weighting networks A, B, C and the Linear position to be switched out of circuit. A useful advantage in handling random noise.

Extension Filter Sets.
In conjunction with the improvements in the Spectrometer as mentioned above, also new Extension Filter Sets have been developed. The Filter Sets have been re-designated as the Type 1620 (formerly 1619) and ZS 0146 (formerly ZS

0145) respectively. The latter unit is intended for use as a built-in component of the combined units Type 3313 and 3326 and is delivered on a chassis whereas Type 1620 is totally self-contained.
The new Extension Filter Set Type 1620 is comprised of three 1/3 octave filters with center frequencies of 12.5, 16 and 20 c/s, which can, by means of a switch, be combined into one 1/1 octave filter with a center frequency of 16 c/s. This allows selective measurements with the Spectrometer Type 2112 down to 11 c/s, the connection of the filter sets being readily accomplished by a cable terminated with a seven-poled plug.



Type 1620

Pre-Printed Recording Paper Alterations.

Due to the increase in the number of filters in the analysing units Type 1612 and 2112 it has been necessary to make alterations to the Level Recorder paper. The frequency calibrated paper, which corresponds to these equipments, has therefore been altered so that the frequency calibration now covers 10 c/s to 40 kc/s, yet still includes the calibrated portion for the weighting networks. (New paper Type QP 0123-0223-0323-1123). It is, however, possible to use these new papers with the old equipment as a calibration indication for this purpose is also printed, but note must be made that *old paper cannot be used with the new instruments.* Accordingly the photographic negative has been changed.

Random Noise Generator Type 1402.

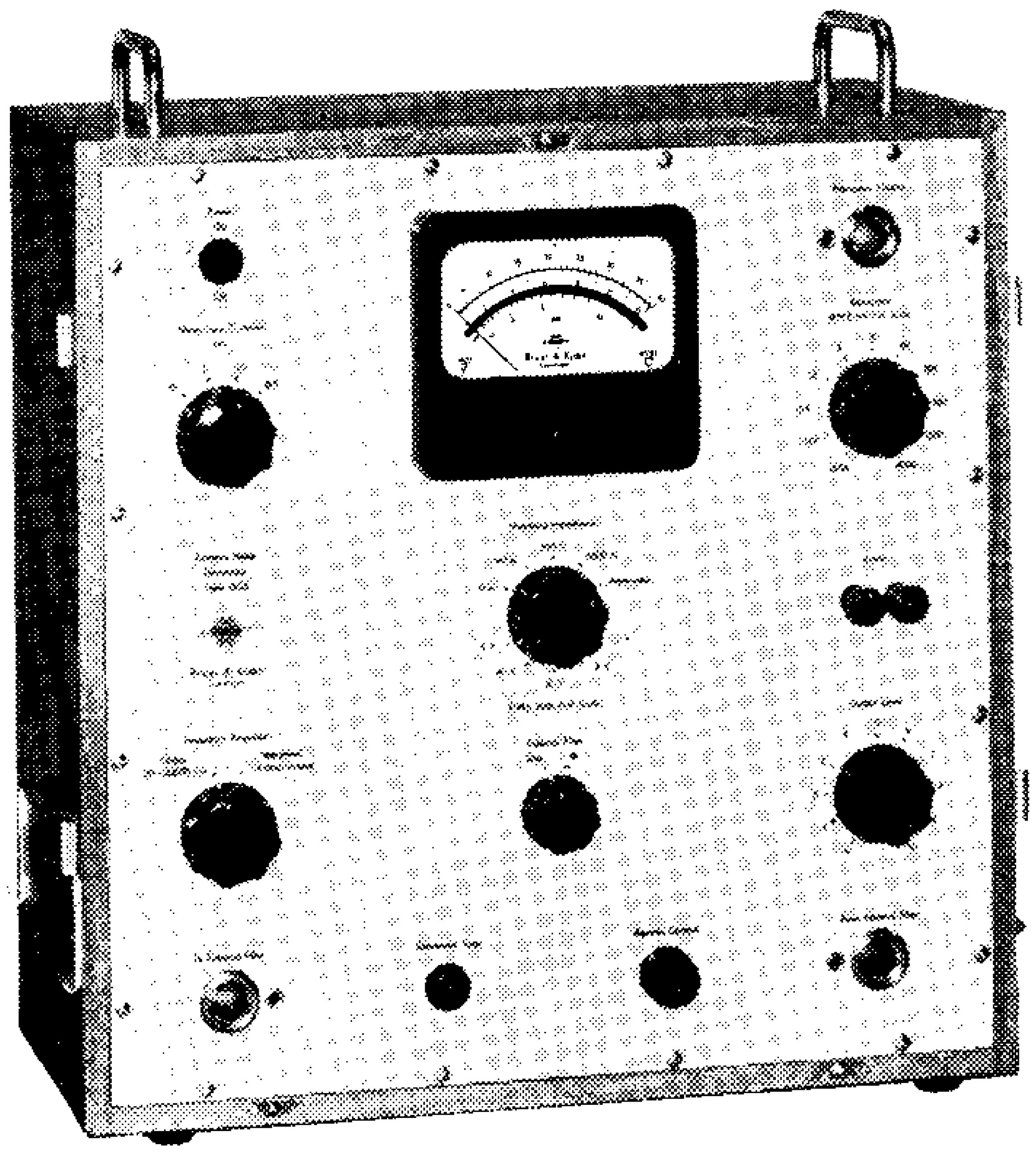
This Generator has been briefly described in "Technical Review" No. 2 this year, and in the following a summary of its main features will be repeated.

1) Type 1402 produces a flat frequency spectrum (equal energy per cycle bandwidth) to within ± 1 db from 20 c/s to 20000 c/s.

2) The distortion is less than 0.5 % unloaded at medium frequencies, and maximum available voltage peaks are 160 Volts (crest factor 4).

3) It has a symmetrical Gaussian distribution of amplitudes up to four times the RMS value ($4\,\sigma$).

4) The hum level is more than 55 db below the RMS level as measured in a 1/3 octave band centered at the mains frequency and better in all other 1/3 octave bands.



Type 1402

5) The Noise Generator includes a —3 db/octave filter for convenient analysis with constant percentage bandwidth filters.

6) Exact voltage and impedance matching conditions are included for insertion of the Band Pass Filter Set Type 1612 to produce 1/3 or 1/1 octave bands of noise.

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