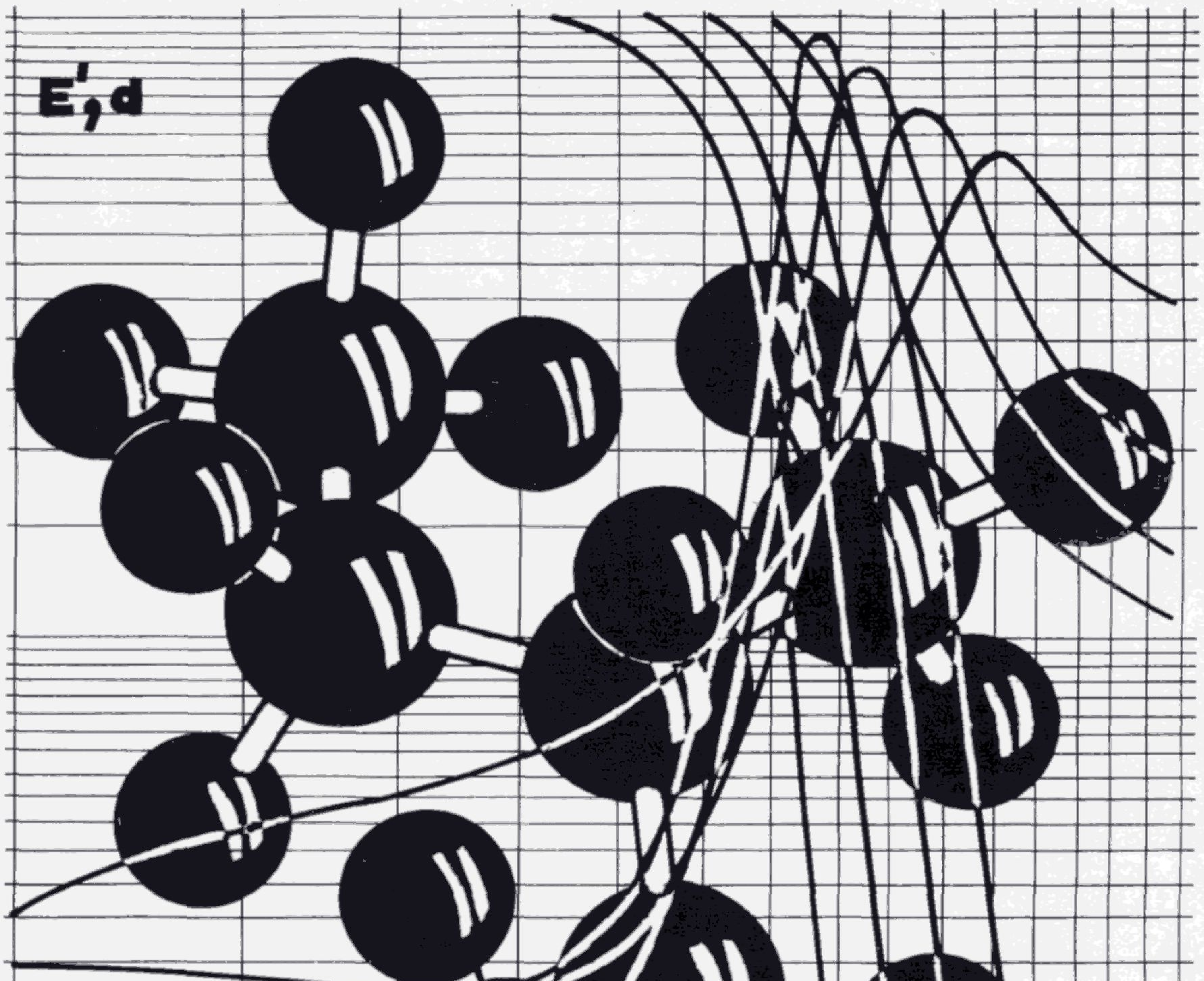
Brüel & Kjær

Technical Review

Teletechnical, Acoustical and Vibrational Research



COMPLEX MODULUS OF ELASTICITY

No. 4

October 1957

Acknowledgment to
Reg.-Rat a.M. Dr. Herman Oberst.

We are indebted to Dr. H. Oberst who is known all over the world as the pioneer in respect of measuring methods for the determination of the dynamic qualities of plastic materials and for the development of vibration-damping coatings on metal surfaces. We have attended the pioneer work of Dr. Oberst at close quarters, and it is, as a result of this that the following article is written.

Reprint: October 1960

Measurements of Modulus of Elasticity and Loss Factor for Solid Materials

by

A. Schlägel

INTRODUCTION

In the modern production of automobiles, aircraft, railway material, air conditioning units, home-appliances, and many other things, the war against noise and vibrations is rapidly becoming intensified. A very important means of reducing the noise and vibrations from mechanical constructions is to cover the different metallic parts with damping materials. In most cases lacquers or layers of high polymer materials are chosen.

Owing to this development there is an increasing demand for objective measuring methods for determination of the damping-effect.

This article endeavours to show some of the basic definitions and constants which are necessary for comparing the different materials. Also the line of action of these measurements is described in detail.

A special effort is made to describe the methods which already have been used successfully for measuring the necessary constants of the metals employed as well as the coating materials.

ZUSAMMENFASSUNG

In der modernen Industrie gewinnt der Kampf gegen Geräusch und Körperschall bei der Herstellung von Straßen- und Schienenfahrzeugen, Flugzeugen, Klimaanlagen, Haushaltgeräten u. s. w. immer mehr Bedeutung.

Schwingende Konstruktionselemente mit dämpfenden Material zu überziehen hat sich als ein wirksames Mittel hierfür erwiesen, wobei meist Lacke oder Schichten hochpolymerer Kunststoffe angewendet werden.

Im Zuge dieser Entwicklung ist auch die Forderung nach Meßmethoden zur objektiven Untersuchung des Dämpfungseffekts stärker hervorgetreten.

Im folgende Artikel werden einige Grunddefinitionen und Konstanten angegeben, die bei dem Vergleich der verschiedenen Dämmstoffe eine Rolle spielen, ferner werden die Meßverfahren näher beschrieben.

Insbesondere werden diejenigen Meßverfahren behandelt, welche bereits im größeren Umfang für die Untersuchung der gebräuchlichen Träger und Schichten angewendet wurden.

INTRODUCTION

La lutte contre le bruit et les vibrations s'intensifie rapidement dans les industries productrices d'automobiles, d'avions, de matériel roulant pour chemins de fer, d'appareillage pour le conditionment d'air et pour les applications ménagères.

Un moyen très important pour réduire le bruit et les vibrations des engins mécaniques consiste à en recouvrir de matériaux absorbant les différentes parties qui sont le siège de vibrations. Le plus souvent on choisit des laques et couches de matériaux hautement polymérisés.

Vu ce développement, se manifeste une demande croissante pour des méthodes de mesures objectives permettant de déterminer l'effet d'amortissement obtenu.

Le but de cet article est de faire connaître quelques définitions fondamentales et constantes qui sont nécessaires dans la comparaison des différents matériaux. La succession de ces mesures est également décrite en détail.

L'article traite en outre tout spécialement des méthodes qui sont utilisées avec succès pour la mesure des constantes des métaux et des matériaux de revêtement désirées.

General.

The modulus of elasticity E is defined by the equation

$$E = \frac{\sigma}{\varepsilon} \qquad \text{I}$$

where σ is the stress and ε is the relative elongation.

By plotting σ as the ordinate versus ε as the abscissa in a rectilineal coordinate system the well known stress-strain diagram is obtained. Due to the gradually subversion of the internal stresses, the stress σ of high polymeer materials, strictly spoken, is not only a function of the strain ε but also of the time.

This dependence of time which is more or less pronounced is left out of account in this article.

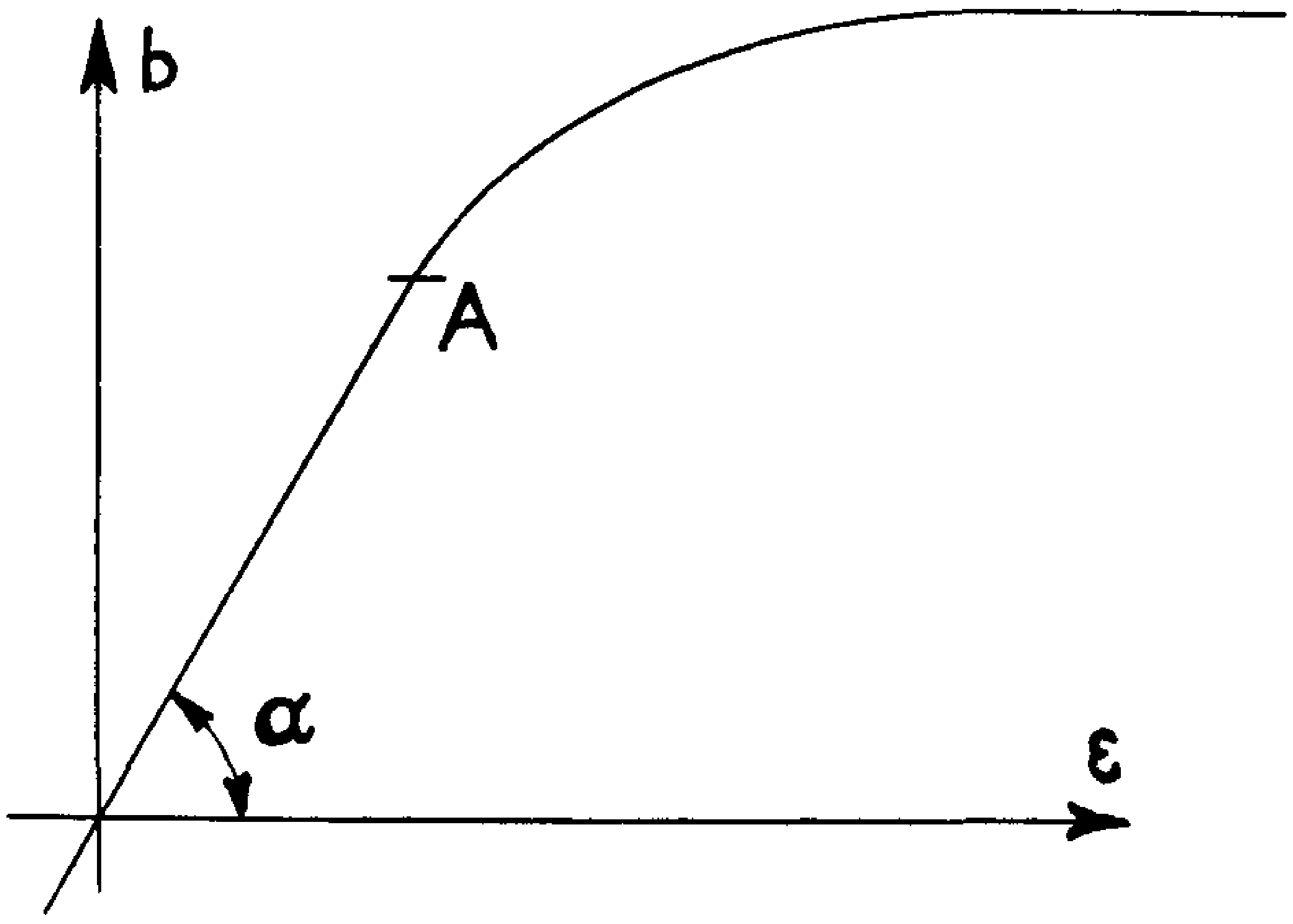


Fig. 1. Stress-Strain diagram.

The stress-strain diagram is illustrated in fig. 1. A indicates the proportional limit, i. e. the point to which there is still linear relationship between σ and ε. E can thus be determined from the angle α as:

$$\operatorname{tg}\alpha = \frac{\sigma}{\varepsilon} = E$$

Corresponding to this definition the dynamic modulus of elasticity E* is defined as:

$$E^* = \frac{d\sigma}{d\varepsilon} \qquad \text{II}$$

where ε is varied periodically within the limits of proportionality.

Due to the internal friction there will be a phase-shift between the total force and the strain. This effect leaves E* complex and as such it can be represented as a vector resolvable in two components, one along the real axis and one along the imaginary. See fig. 2.

The dynamic modulus of elasticity can now be written:

$$E^* = E' + E'' = E' \, (1 + jd). \qquad \text{III}$$

d is called the loss factor, and is defined as

$$d = \operatorname{tg}\delta = \frac{E''}{E'} \qquad \text{IV}$$

Thus it is possible to determine E* by measuring the real part E' and the loss factor d.

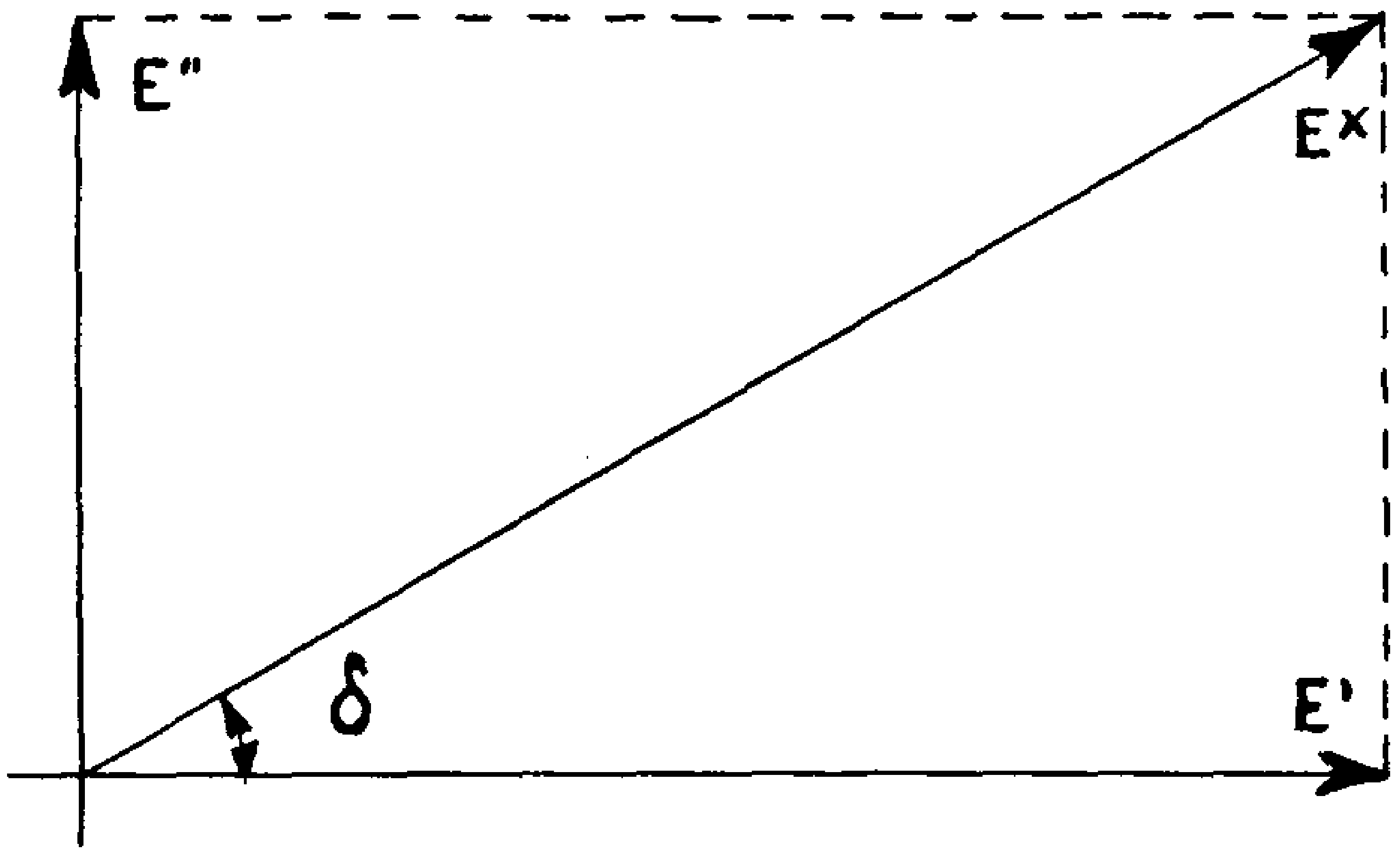


Fig. 2. Complex modulus of elasticity E resolved in its real and imaginary parts.*

Measuring Methods.

The measuring methods can be divided into Resonant Methods and Non-Resonant Methods, depending on whether the measuring frequency is determined by the dimensions of the sample or is chosen arbitrarily.

Of the methods mentioned in this article, the Frequency Response Method and the Reverberation Method are Resonance Methods whereas the Progressive Wave Method and the Standing Wave Method are Non-Resonant Methods.

The Frequency Response Method.

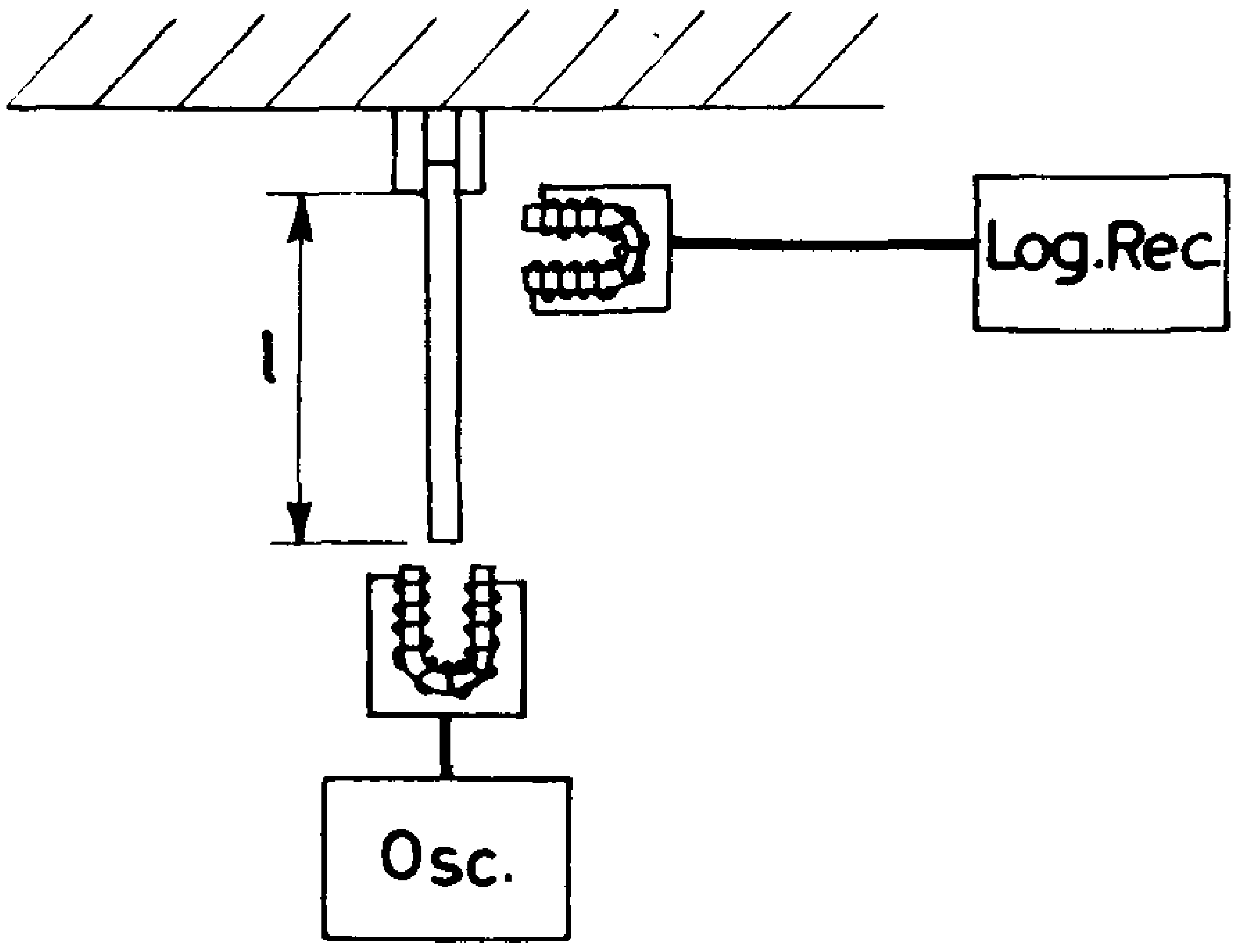
As shown in fig. 3 a bar shaped sample is suspended at its nodal points. From an external source it is forced into flexural vibrations, the amplitude of which are measured by a displacement sensitive Pick-up.

The frequency of the external force is varied and the amplitude of the vibrations versus the frequency is plotted as illustrated in fig. 4.

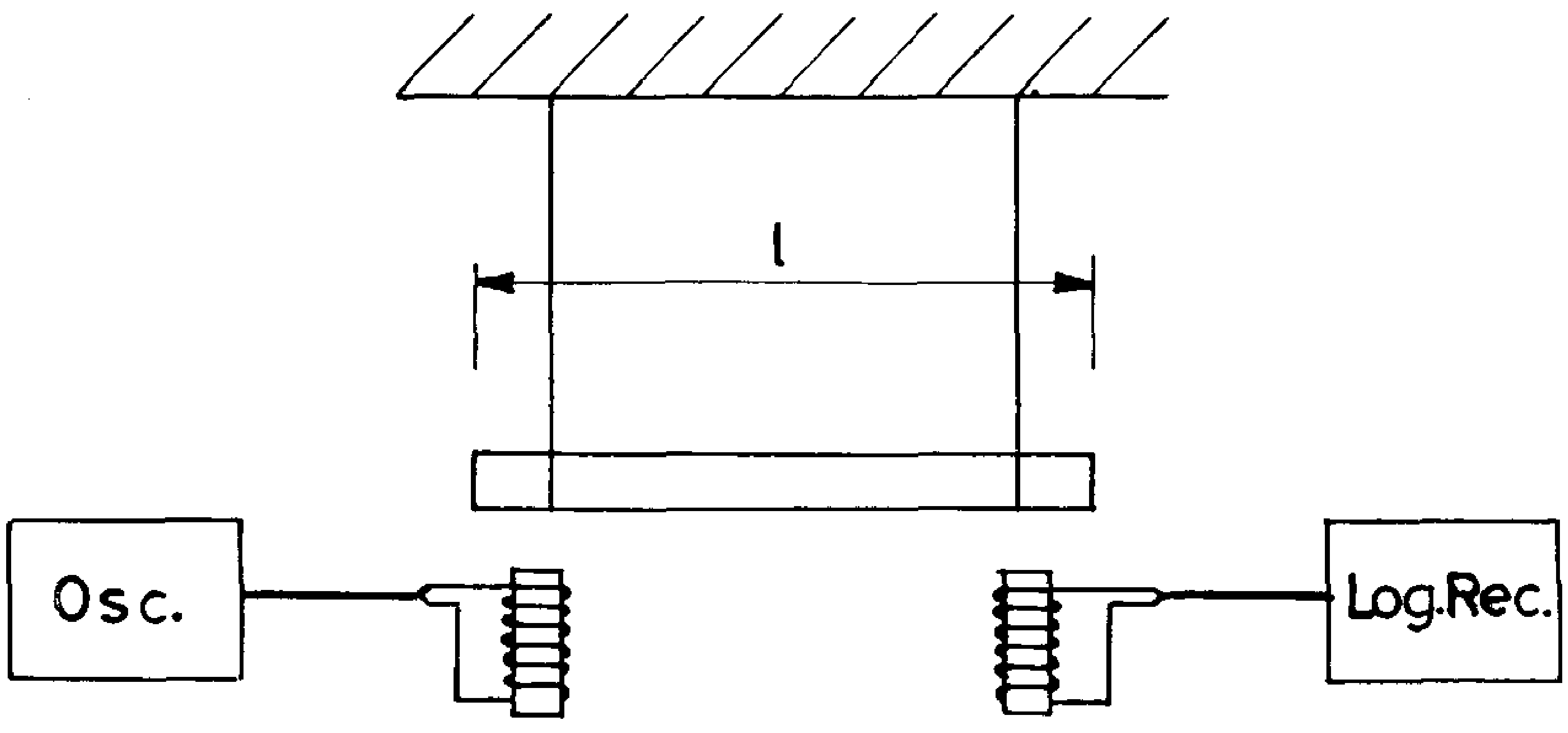
From such a curve the loss factor d can be calculated as:

$$d = \frac{\Delta f_n}{f_n} \qquad \text{V}$$

Δf_n (c/s) being the bandwidth of the resonance peak and f_n (c/s) the resonance frequency. The index which is a whole number indicates the order of the



"Clamped-free"



" free-free "

Fig. 3. Suspension possibilities for the Frequency Response Method.

resonance frequency determined by the position of the suspension points. The real part E′ of the dynamic modulus of elasticity can be found from the resonance frequency as the mechanical dimensions of the bar are known: 2)

$$E' = \left(\frac{f_n}{\beta_n^2}\right)^2 \left(\frac{l^2}{q} 4 \pi \sqrt{3}\, \varrho\right)^2 \text{ dyne/cm}^2 \qquad \text{VI}$$

f_n (c/s) is the resonance frequency, l (cm) the active length of the sample, q (cm) the thickness, and ϱ (g/cm^3) the material density.
β_n is a function depending on the boundary conditions of the bar.

When both ends of the sample are either free or clamped:

$$\beta_1 = 4.73 \quad \beta_2 = 7.853 \quad \beta_3 = 10.996$$
$$\beta_n = (n + {}^1/_2)\,\pi \text{ for } n > 3$$

and when one is free and the other clamped

$$\beta_1 = 1.875 \quad \beta_2 = 4.694 \quad \beta_3 = 7.855$$
$$\beta_n = (n - {}^1/_2)\,\pi \text{ for } n > 3$$

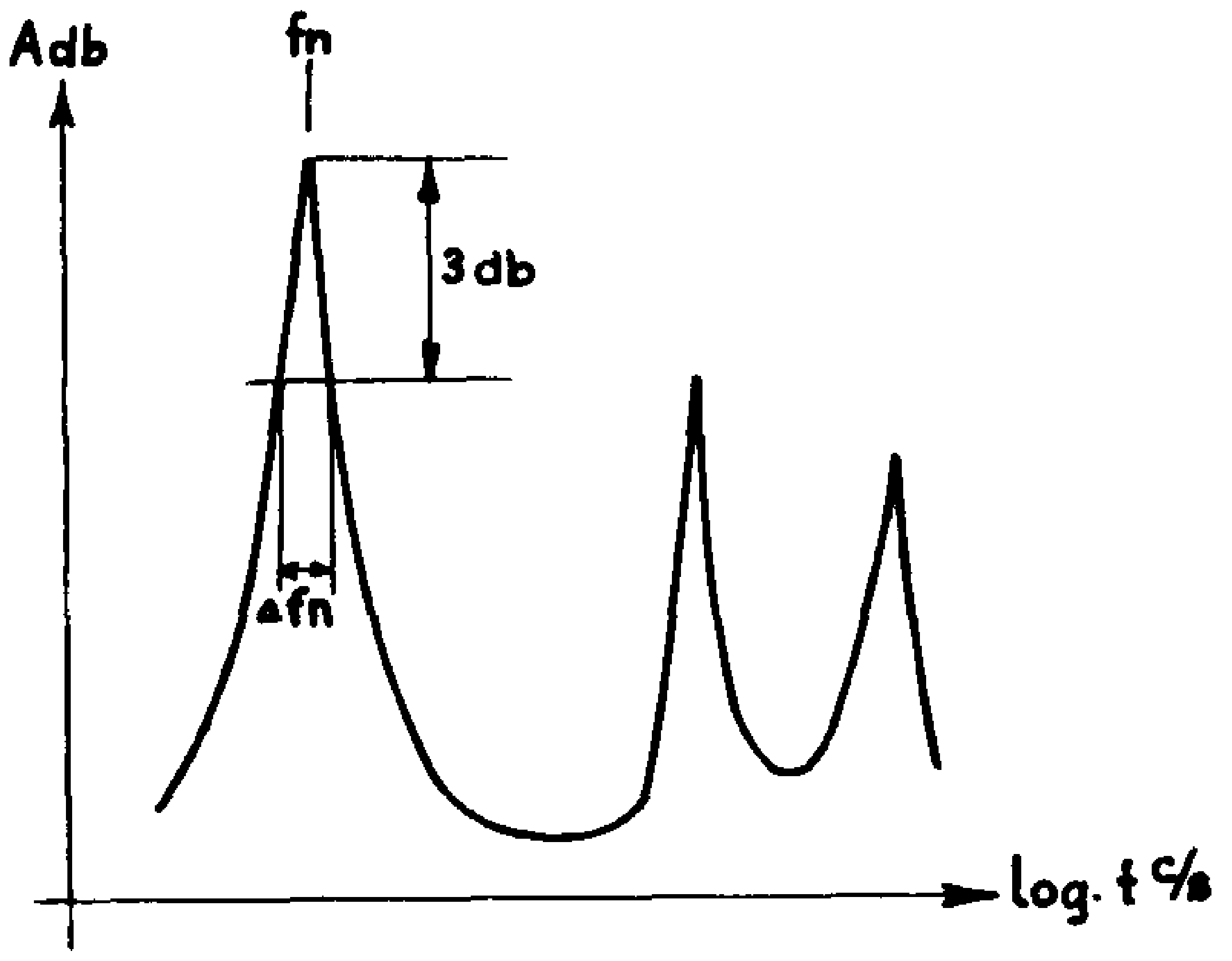


Fig. 4. Frequency Response Curve of a sample. f_n indicates the resonance frequency of the n'th harmonic and Δf_n the bandwidth.

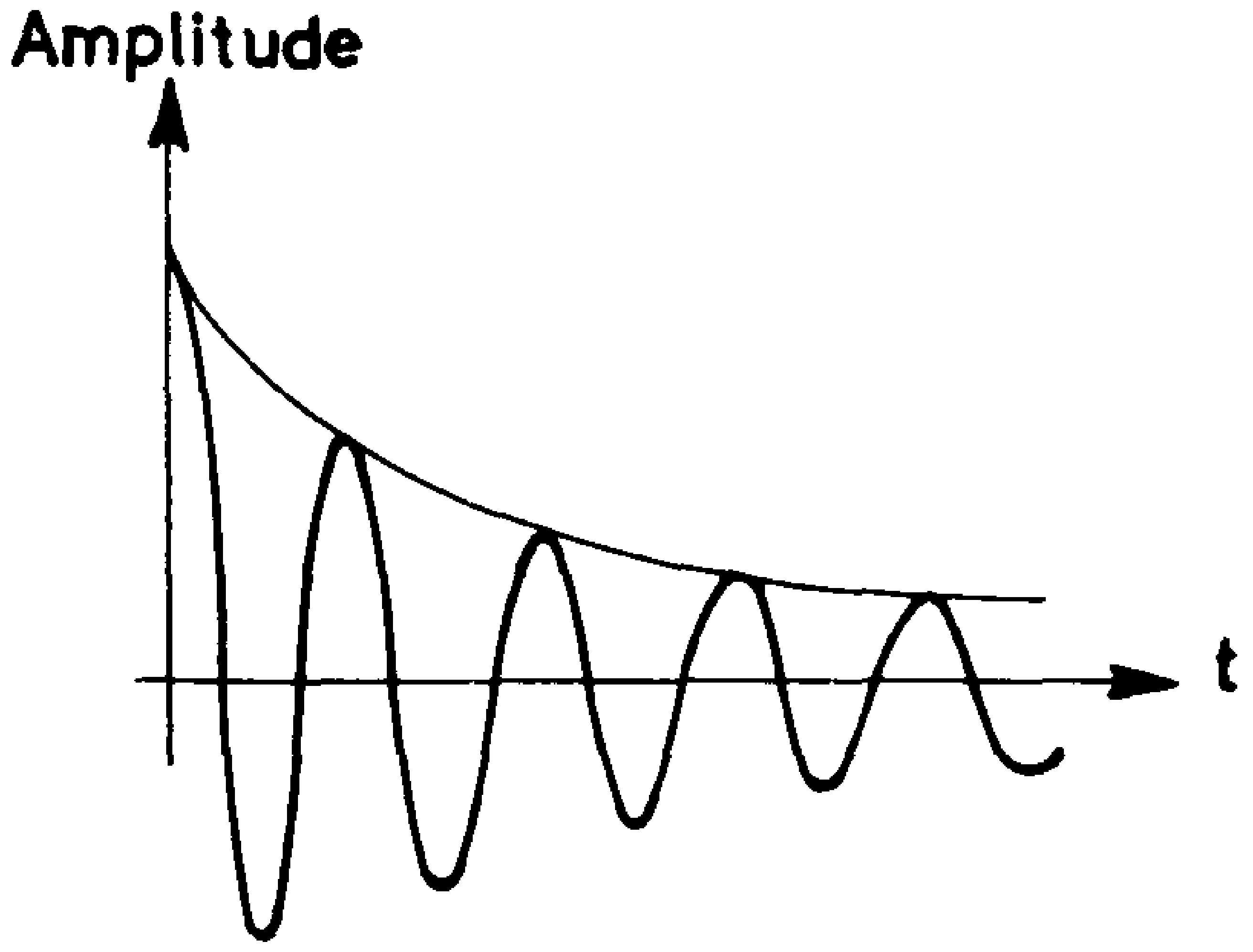


Fig. 5. Decay of a damped oscillation as a function of time.

This measuring method can be used for values of d between approx. 0.6 and 0.001.

When the loss factor is too big it will be impossible to measure the amplitude because no standing waves will be present, and if it is too small the resonance peaks will be too narrow to allow the bandwidth to be measured with reasonable accuracy.

The Reverberation Method.

The same mechanical set-up as mentioned above can be used for this method. The external source is tuned to the resonance frequency of the sample, which will start a forced oscillation with a steady amplitude. When the external force is suddenly removed the amplitude of the vibration will decrease exponentially as illustrated in fig. 5.

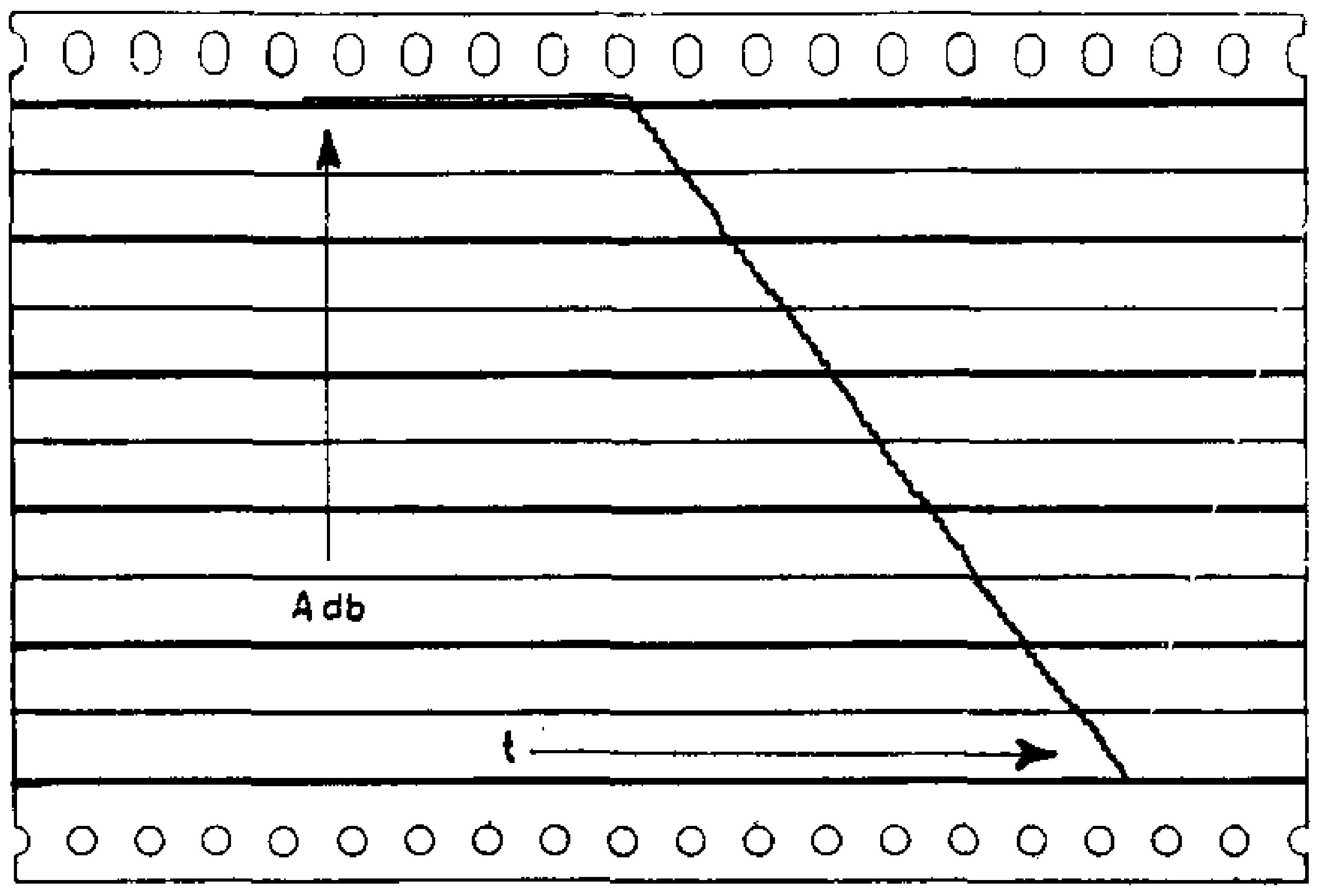


Fig. 6. Decay of a damped oscillation recorded on a logarithmic recorder.

If the voltage from the pick-up, proportional to this decreasing amplitude, is fed to a logarithmic recorder with a constant paper speed the curve will be recorded as a straight line (see fig. 6) and from this curve the loss factor d is calculated.

$$d = \frac{2.2}{T \times f_n}$$

T (sec.) is the reverberation time and is defined as the time it takes the amplitude to drop 60 db, and f_n the resonance frequency.
The real part E′ of the dynamic modulus of elasticity is found from equation VI page 7.
By this method the upper limit for measuring the loss factor is set by the measuring instruments. There is no lower limit as $d = 0$, $T = \infty$ will give a horizontal "decay curve".

The Progressive Wave Method.
By this method the sample is clamped at one end and forced into flexural vibrations by means of an external source at the other end.
The amplitude of the vibrations can now be measured as a function of the distance from the vibrating source by passing an amplitude sensitive pick-up along the bar. The signal from the pick-up will be found to decay after an exponential curve as illustrated in fig. 7. When measurements are carried out on pliant materials (as f. inst. soft elastic synthetic materials) the reproducibility of the method is a little doubtful. This problem may be solved by using a fixed pick-up and moveable vibrating source. 4)
By feeding this signal to a logarithmic recorder where the paper speed is synchronized with the pick-up movement, this exponential curve is recorded as a straight line, from which the damping can be measured in db per cm. See fig. 8.

$$D(\text{db/cm}) = \frac{a}{b}$$

In this case the wavelength λ must be measured separately. This can be done by looking at the signal from the pick-up on a Cathode Ray Oscilloscope. λ will

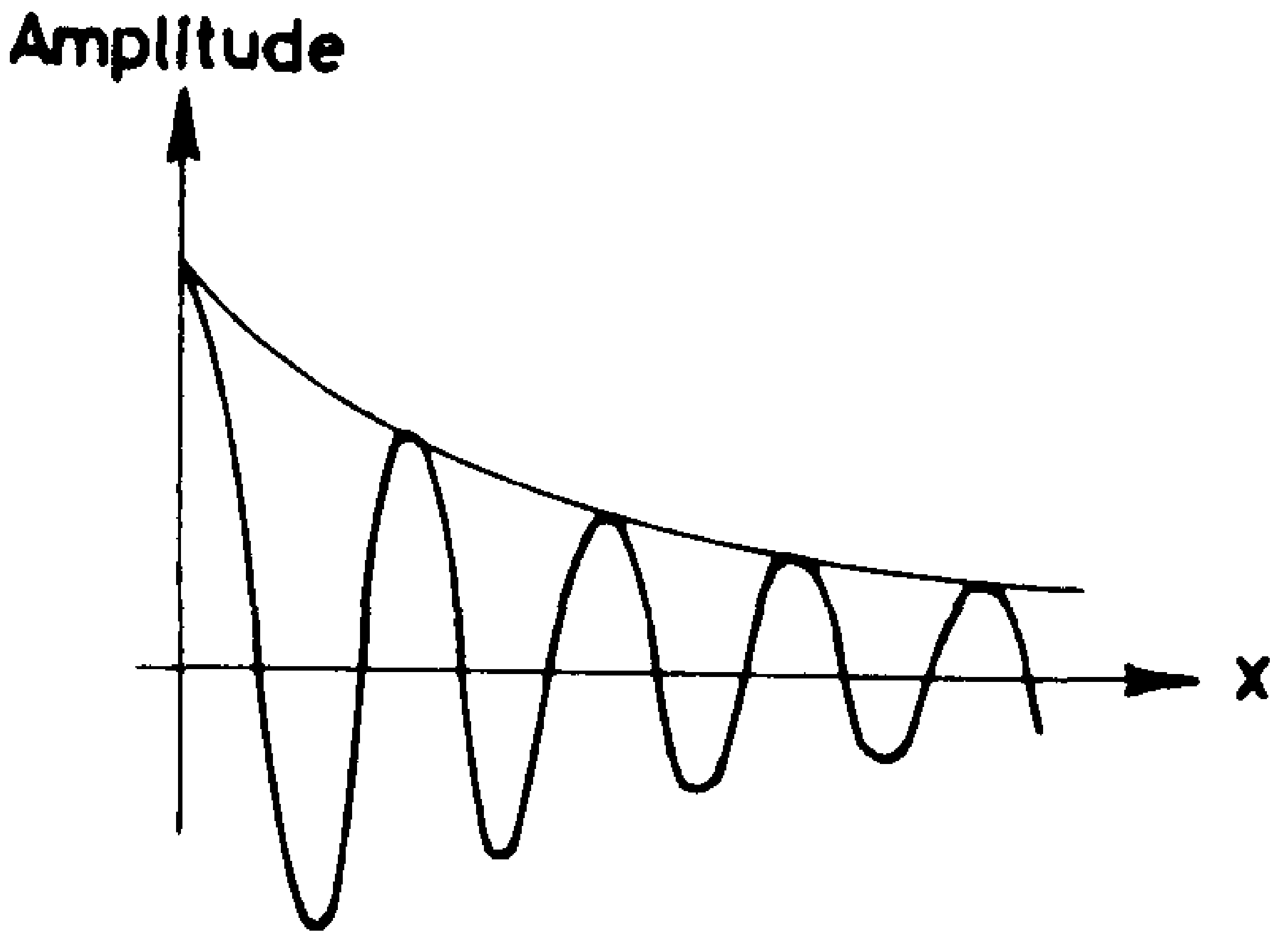


Fig. 7. Decay of a progressive wave with respect to the distance from the exciting source.

now be equal to the length the pick-up has to be moved along the sample to shift the signal on the oscilloscope 360°.

From the measured values of D (db/cm) and λ (cm), E′ and d are calculated from the equations: 2)

$$E'_t = \frac{3}{\pi^2} (f \times \lambda^2)^2 \frac{\varrho}{q^2} \text{dyne/cm}^2 \qquad \text{VIII}$$

$$d = \frac{D \times \lambda}{13.6} \qquad \text{IX}$$

f (c/s) is the frequency, q (cm) the sample thickness and ϱ (g/cm^3) the material density.

As the measuring method is based upon a damped progressive wave train, it can only be used where the loss factor is so high that no standing wave can be obtained.

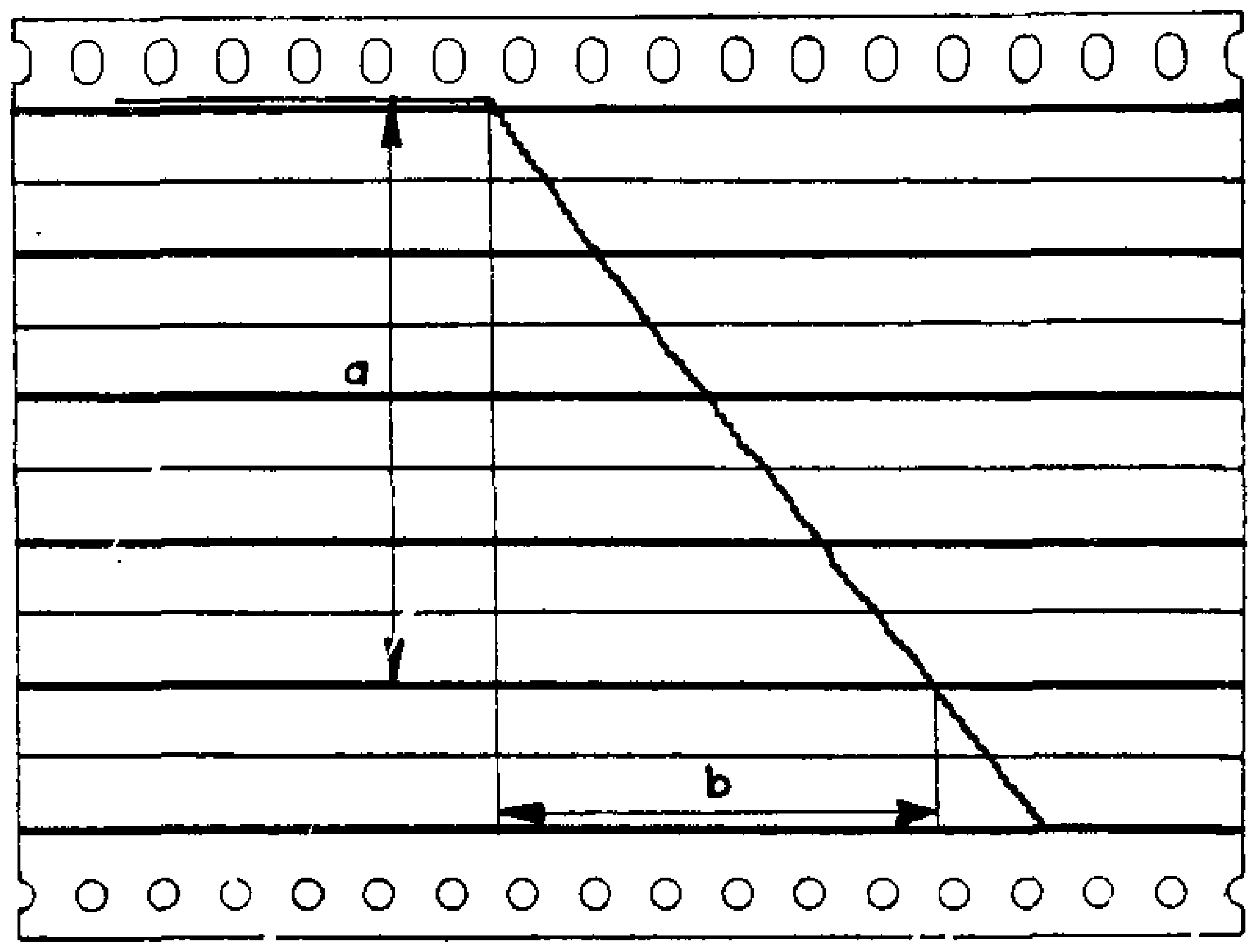


Fig. 8. Same as fig. 7 but recorded on a logarithmic recorder.

The Standing Wave Method.

It is readily seen that if the loss factor of the material is too small a standing wave pattern will be obtained instead of a damped wave pattern.

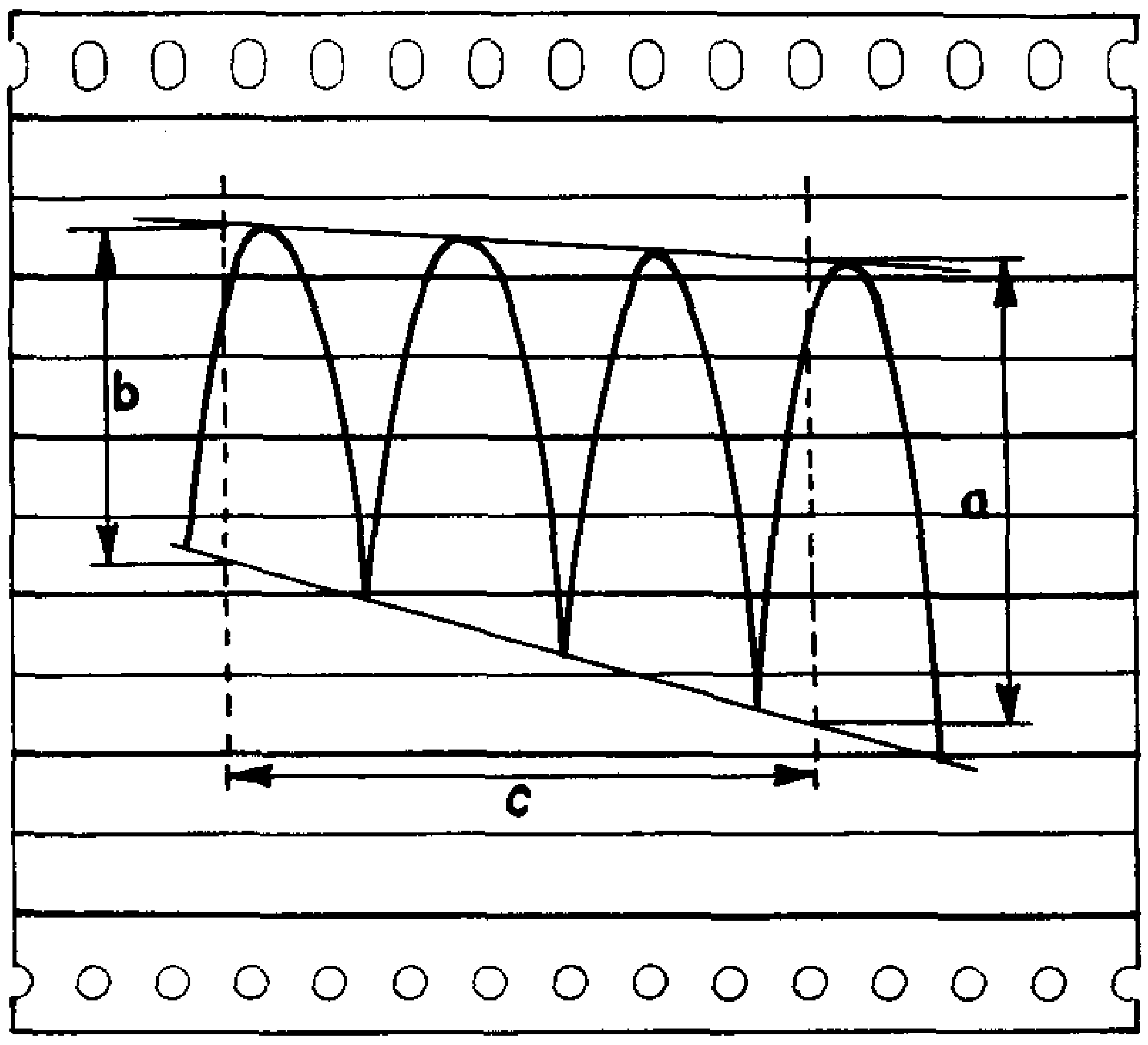


Fig. 9. Standing wave pattern of a sample recorded on a logarithmic recorder

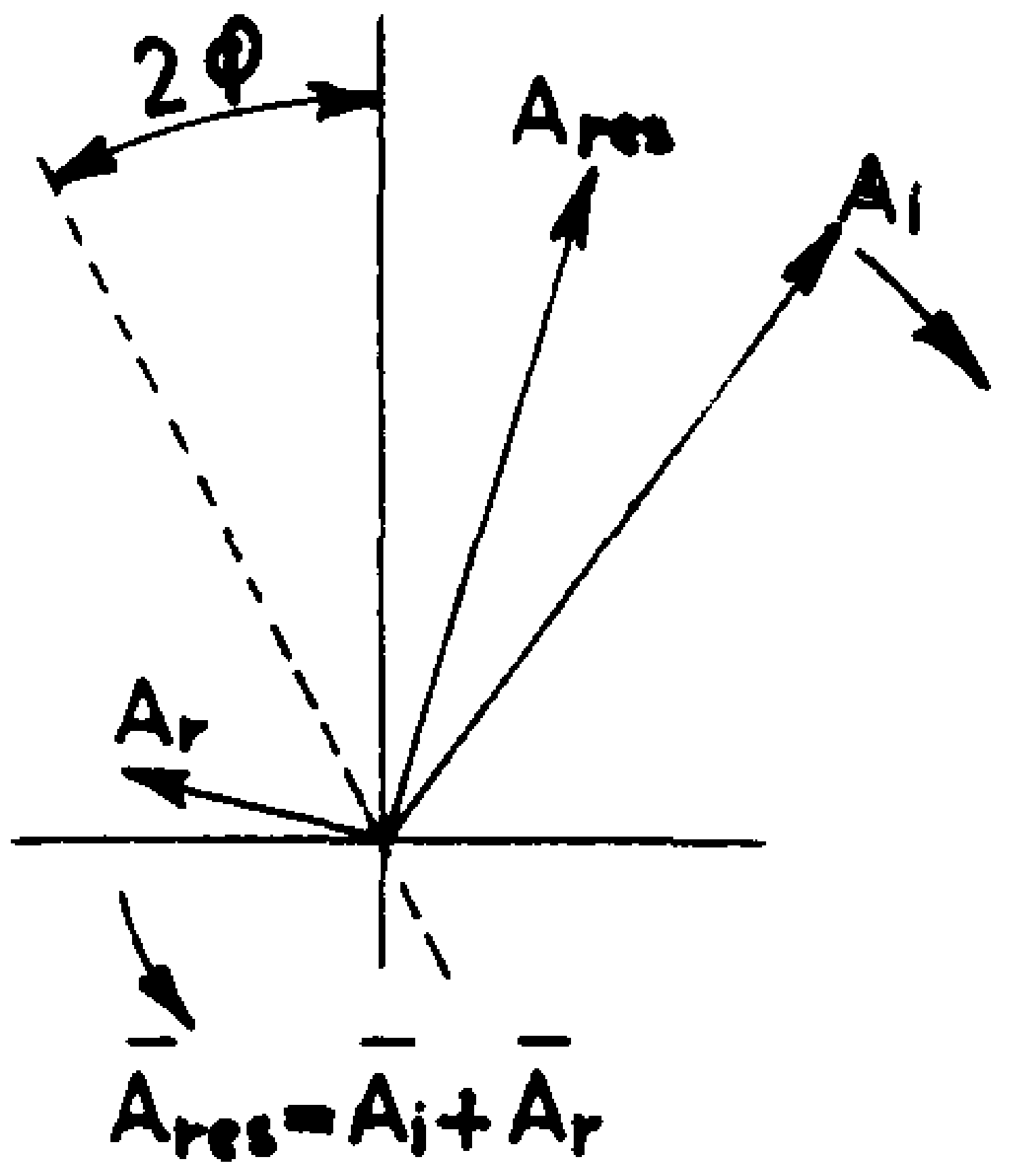


Fig. 10. The incident, the reflected and the resultant wave as vectors.

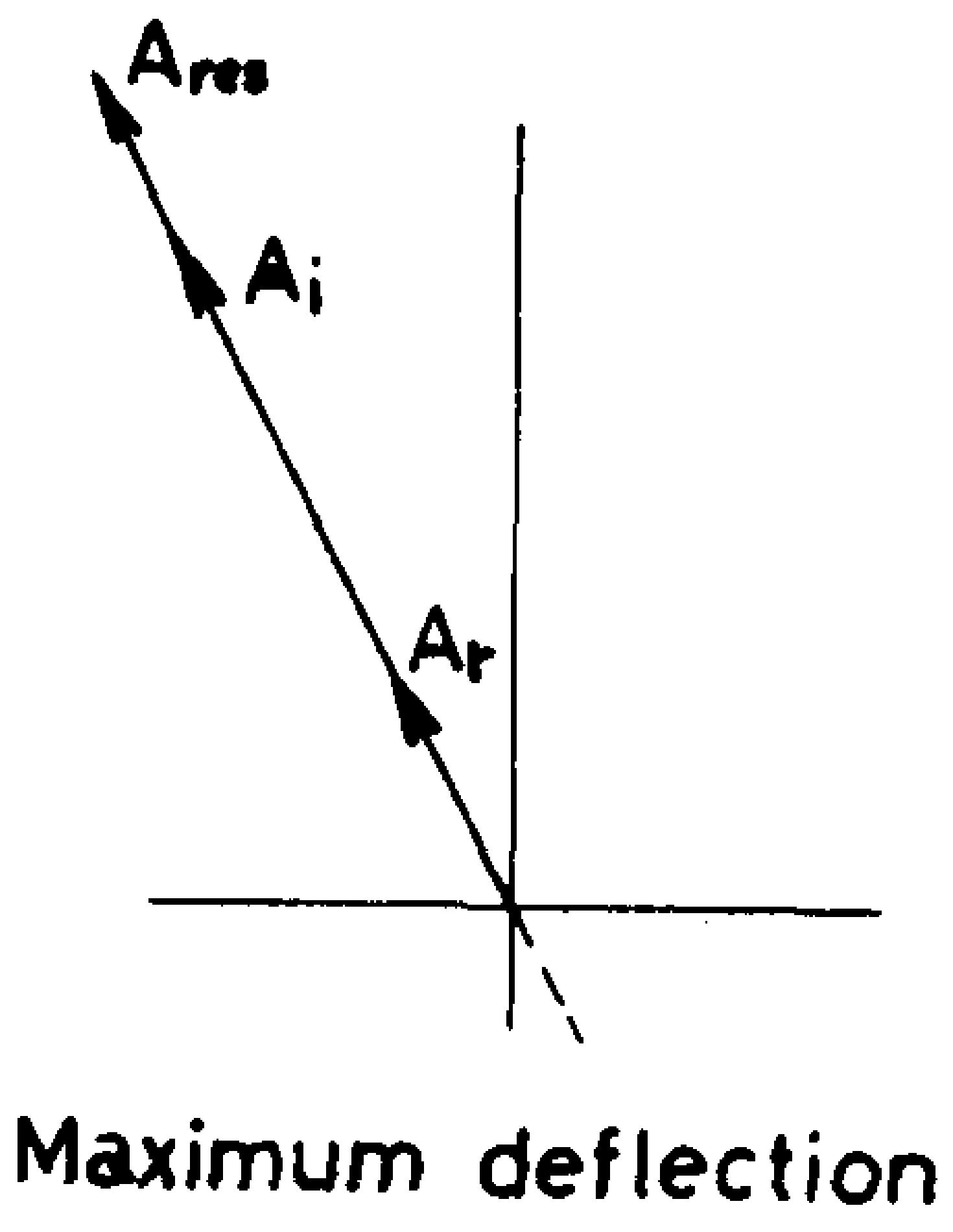


Fig. 11. The vectors in fig. 10 in the "maximum" position.

As the pick-up travels along the sample, the curve recorded on a logarithmic recorder will be as illustrated in fig. 9.

This pattern is built up of two wave components, an incident wave $A_i\ e^{-kx}$ travelling from the excited end of the sample towards the clamping point, and a reflected $A_r\ e^{kx}$ wave travelling in the opposite direction (k is complex). These wave components can be represented by two vectors rotating with the same angular velocity, but in opposite directions. 5) This is illustrated in fig. 10. From fig. 11 and 12 it can be seen that the maxima represent the sum of the two components and the minima the difference.

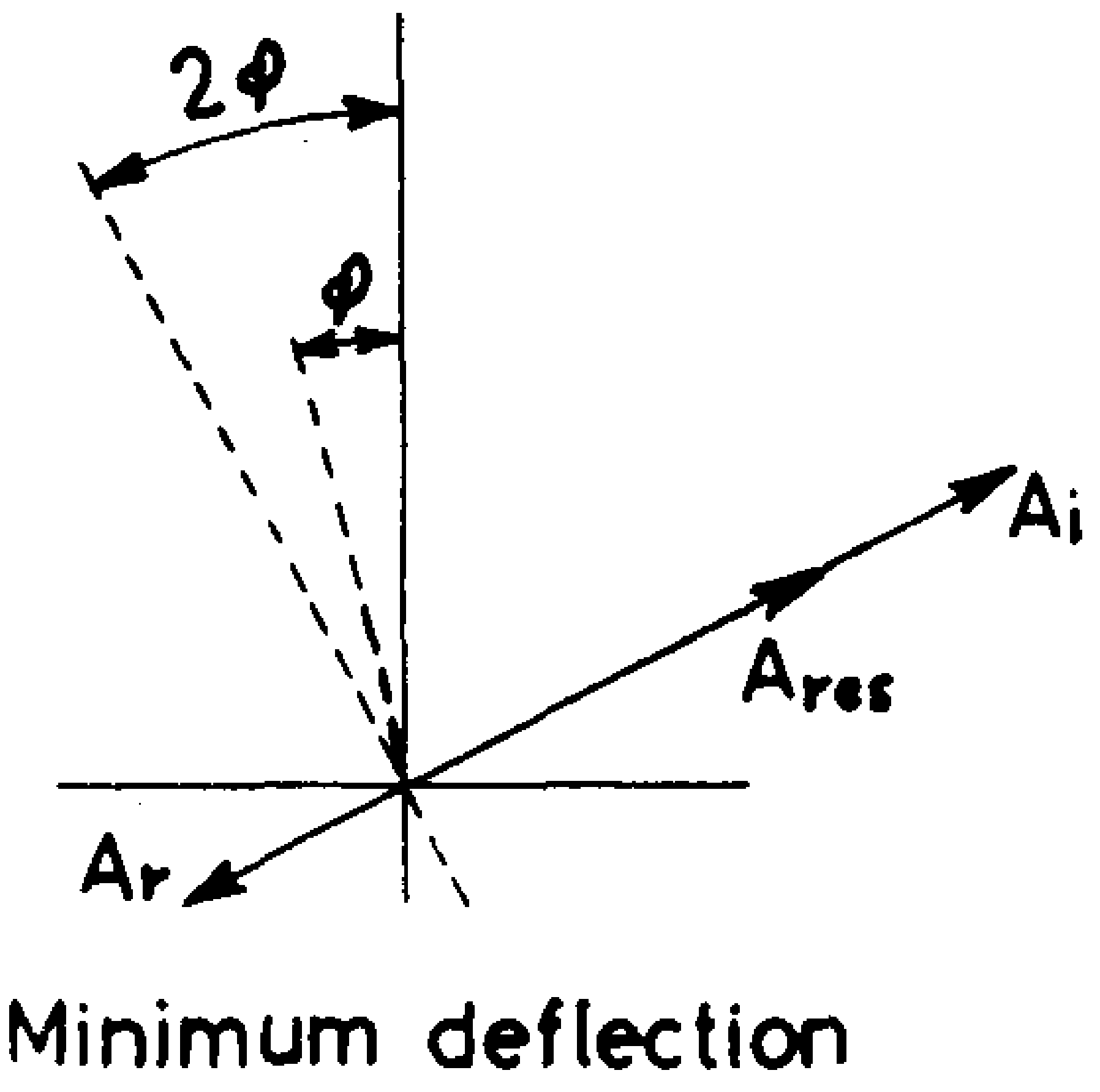


Fig. 12. The vectors in fig. 10 in the "minimum" position.

The curve through the maxima must consequently be $|A_i e^{-kx}| + |A_r e^{kx}| = A_i e^{-\alpha x} + A_r e^{\alpha x}$ and through the minima $|A_i e^{-kx}| - |A_r e^{kx}| = A_i e^{-\alpha x} - A_r e^{\alpha x}$ where α is the damping in Neper. For $D = 8.7 \times \alpha$ it is seen that the damping D in db per cm is found as shown in fig. 9 by subtracting b from a and dividing the result by 2 c.

$$D = \frac{a - b}{2c} \cdot \text{db/sec.}$$

(See further Brüel & Kjær Technical Review No. 1 1958).

The wave length λ is easily measured on the recording as the distance between two consecutive minima.
The loss factor and the real part of E* can then be calculated from equations VIII and IX.

Instruments.
The electronic equipment used for the measuring methods mentioned in this article is, besides different electro-magnetic and electro-mechanical transducers, the Audio Frequency Response and Spectrum Recorder Type 3321 (Fig. 13). This unit consists of a Beat Frequency Oscillator Type 1014, an Audio Frequency Spectrometer Type 2109 and a Level Recorder 2304.
The B.F.O. covers the frequency range from 20 to 20,000 c/s with a logarithmic scale of an accuracy better than 1 % ± 1 c/s.
The Audio Frequency Spectrometer involves 27 $^1/_3$ octave filters covering the

range from 36 c/s to 18,600 c/s. This range, however, can on special request, be extended to cover the range from 15 c/s to 36,000 c/s.
The Level Recorder is a high speed instrument for recording level variation of signals within the frequency range 20—200,000 c/s.
The advantage which can be derived from the Audio Frequency Response and Spectrum Recorder is that both the B.F.O. and the A.F. Spectrometer can easily be synchronized with the recording paper on the Level Recorder.

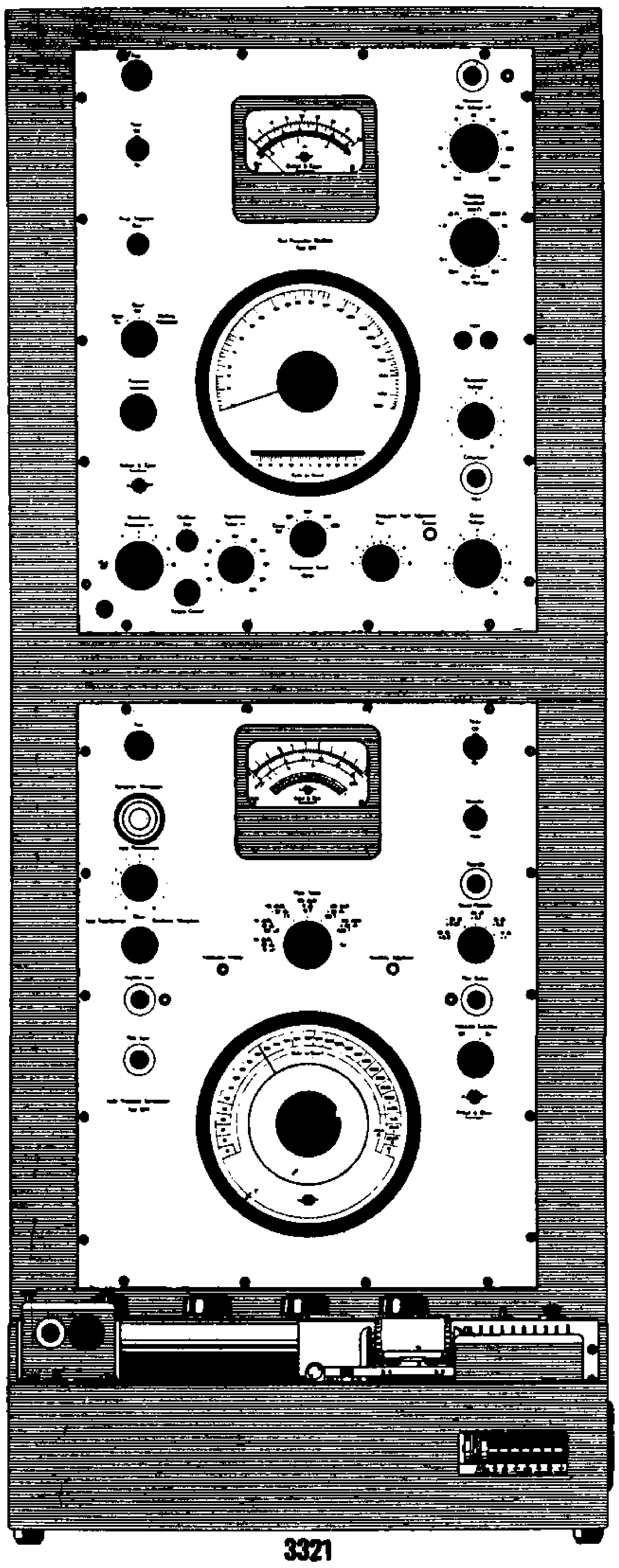


Fig. 13. Drawing of the Audio Frequency Response and Spectrum Recorder Type 3321.

Frequency Sweep:

The speed of the frequency sweep of the Oscillator and the Spectrometer can be varied in 8 steps. The desired speed is chosen with the aid of a moveable wheel mounted in the gear box of the Level Recorder. The wheel can be moved along an axle, and is locked in the positions marked A, B, C, D, E, F, G, and H by means of a spring. Each position corresponds to a certain paper-speed, and the time for scanning the frequency range of the instrument can be found from the table given below:

Paper speed:	10	3	1	0.3	0.1	0.03	0.01	0.003	mm/sec.
Wheel:	A	B	C	D	E	F	G	H	min.
Time for complete rev. 20-20,000 c/s (Osc.)	0.24	0.8	2.4	8	24	80	240	800	min.
Time for scanning 40-16,000 c/s (Spectr.)	0.21	0.7	2.1	7	21	70	210	700	min.
Time for complete rev. of scale pointer	0.4	1.33	4	13.3	40	133	400	1333	min.

For production control a high speed is of interest. However, to be able to get a frequency response curve of a sample of a material with a low loss factor the low speeds are essential.

Practical Measurements.

To investigate the applicability of the Audio Frequency Response and Spectrum Recorder Type 3321 for the different measuring methods, some measurements have been carried out at our laboratories.

The line of action of these will be described and the results and a short theoretical explanation will be given in the next number of Technical Review.

LITERATURE

1. *Morse:* Sound & Vibrations.
2. *G. W. Becker:* Mechanische Relaxationserscheinungen in nicht weichgemachten hochpolymeren Kunststoffen.
3. *H. Oberst:* Werkstoffe mit extrem hoher innere Dämpfung.
4. *G. W. Becker:* Koll. Zeitschr. 140, 1 (1955|.
5. *Per V. Brüel:* Sound Insulation and Room Acoustics.

Surface Roughness Measurements.

by *Jens T. Broch,* Dipl. ing. E.T.H.

It has been known for a long time that the surface roughness of machine parts plays an important role in mechanical engineering and design. Whenever a drawing of an essential part of a machine is made, not only the manufacturing tolerances, but also the surface finish requirements of the part should be specified on the drawing. This is natural because the surface roughness of the part is closely related to factors such as wear, friction, lubrication and fatigue of the material.

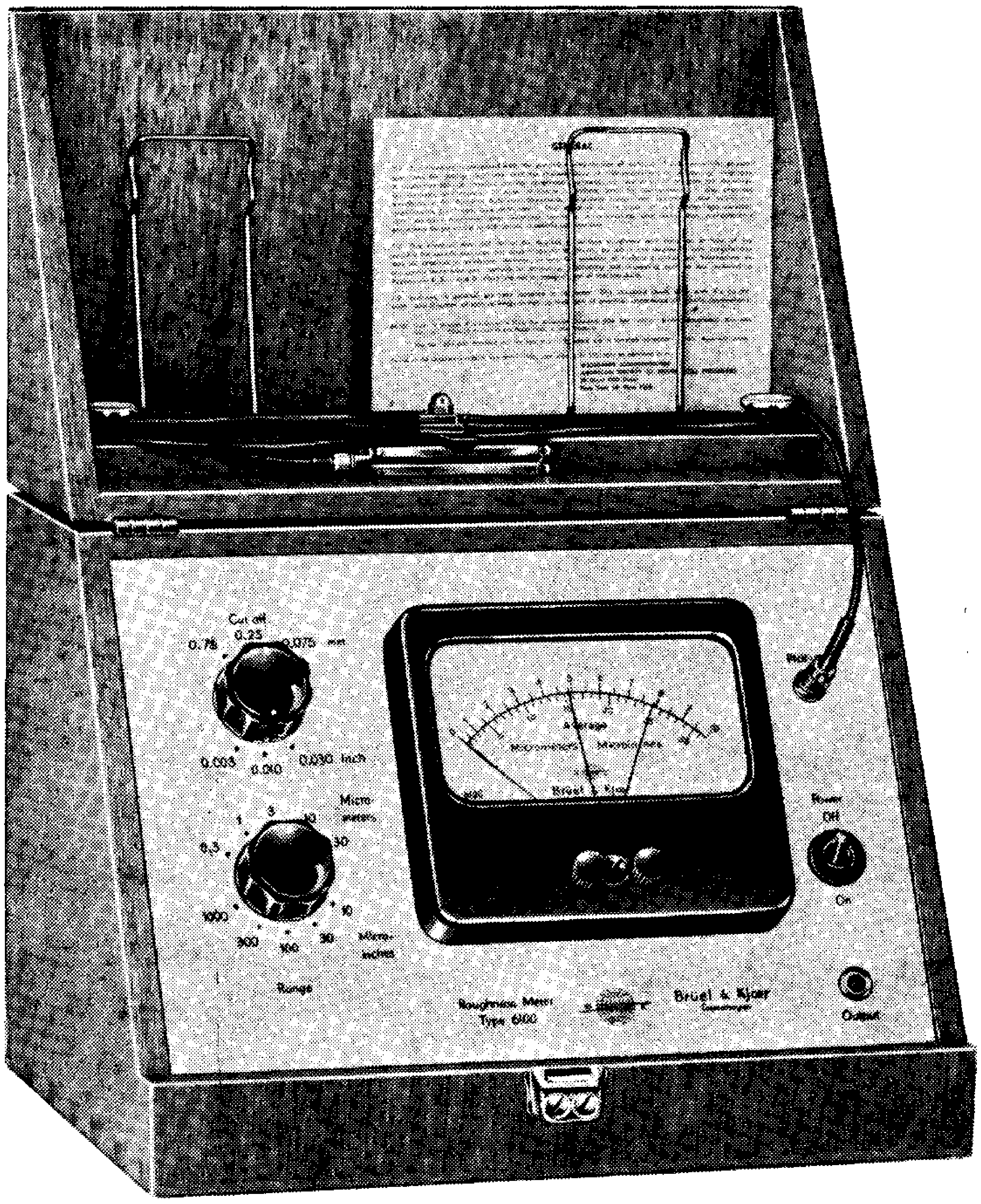


Photo of the Roughness Meter.

In the case of an ordinary screw-connection or other simple static couplings the requirements to be met with regard to the surface finish are not very strict. However, wherever fast moving parts such as rotating axles, pistons running at high speeds etc. are involved great care must be taken to obtain the correct finish.

In former days, where convenient surface roughness measuring equipment was not available a common method used in the manufacturing process of more critical machine parts was just to produce the part with the smoothest obtainable surface.

This method is still being used by many manufacturers. However, a careful study of the "efficiency" of different machine parts as a function of their surface finish will in most cases result in the conclusion that producing a surface smoother than a certain "limit value" determined by the functioning of the part in question is actually a waste of time and costly production machinery.

When small quantities of the critical part are being produced this "waste" will normally not be of great importance. On the other hand, if greater quantities are to be produced, or the part is being "mass-produced" any waste of time or production machinery is extremely important.

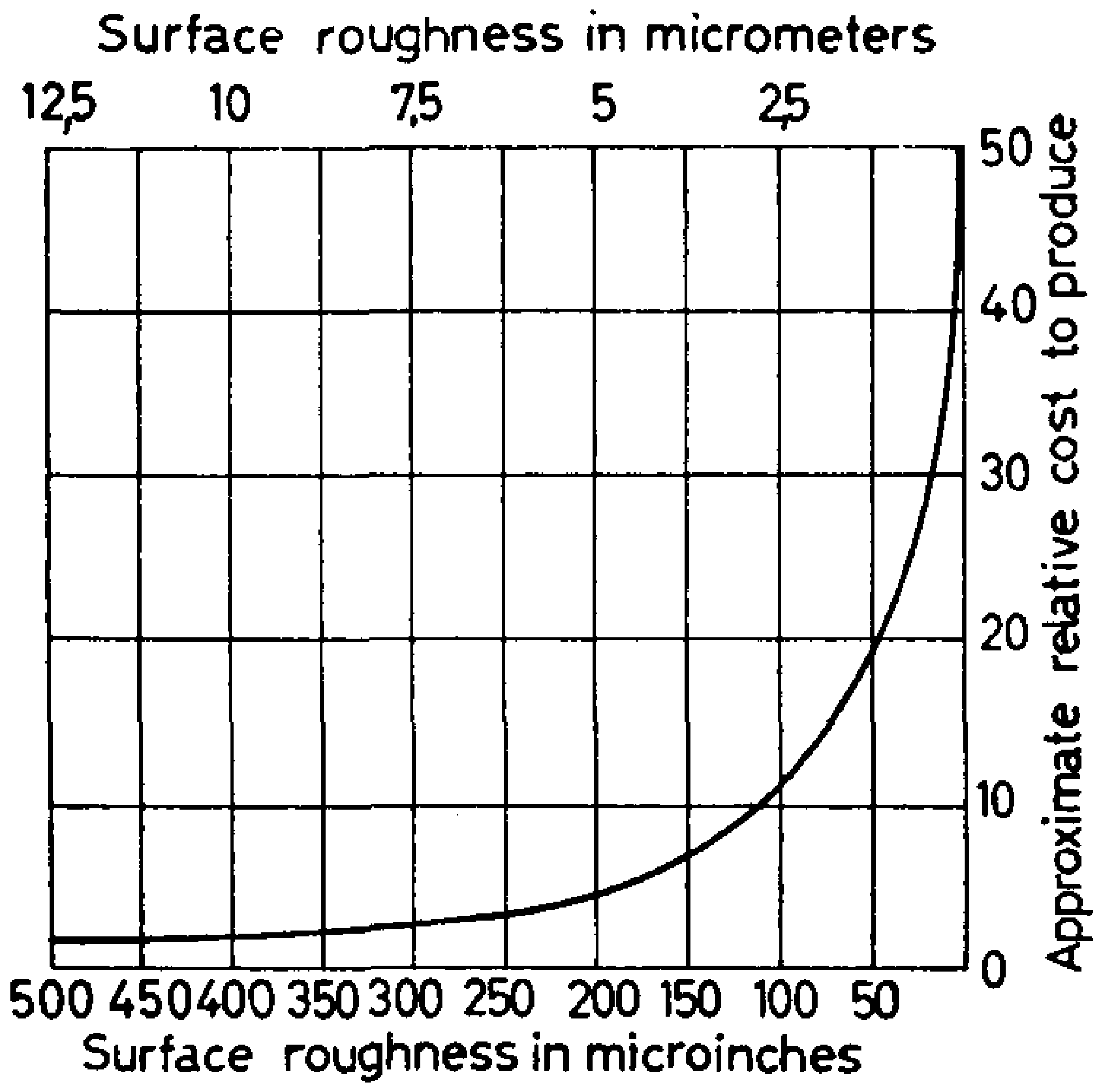


Fig. 1. Curve showing a rough average relationship between production cost and surface roughness of the finished product.

To obtain a clearer picture of the amount of "waste" to be expected in such cases, a curve based on investigations made in the United States is shown in fig. 1. From the curve can be seen that especially in cases where the surface finish is critical, i. e. for surfaces having a roughness value (AA, C.L.A.) smaller than 2.5 μmeter (100 μinches) the relative production cost increases rapidly with the required surface finish.

To be able to determine the most economical methods of tooling, machine set-ups, speeds and feeds to produce the surface quality required for the machine part in question, actual surface roughness measurements must be taken. The measurements necessary to be carried out in this case are more or less a laboratory job.

However, during production the tool wear and differences in uniformity of the material used might cause the surface roughness of the final products to deviate from the original requirements. It is therefore necessary, during the production of precision machine parts to be able to check each specimen before it leaves the production line. This will no more be a laboratory job, and requires a measuring set-up which is easy to operate and by means of which the measuring process itself requires a minimum of time.

Different, more or less convenient and accurate measuring methods are now available and eliminating the extremely inaccurate methods based fully upon "human judgement", e. g. comparing the sample and the prototype by looking at it or "feeling" the surface roughness by means of the fingers, three basic groups of measuring equipment remain:

1) Measuring methods based on optical investigations and photographing the result.
2) Measuring arrangements equipped with mechanical pick-up and indicating instrument.
3) Measuring arrangements equipped with mechanical-electrical pick-up and electronic amplifier and indicating instrument.

Optical measuring equipment is best suited for laboratory development work and the relatively slow way in which such an equipment operates makes it inconvenient for use in production control systems. Also the use of purely mechanical measuring methods in such systems is inconvenient because they normally require a permanent measuring set-up and specially cut samples.

Mechanical-electrical measuring arrangements, on the other hand, are well suited for production control of surface roughness. Here the surface can be investigated with the aid of a motor-driven or hand-held type of pick-up, connected to the indicating instrument by means of a screened cable only. This instrumentation is flexible and can be conveniently used almost anywhere in a workshop or factory.

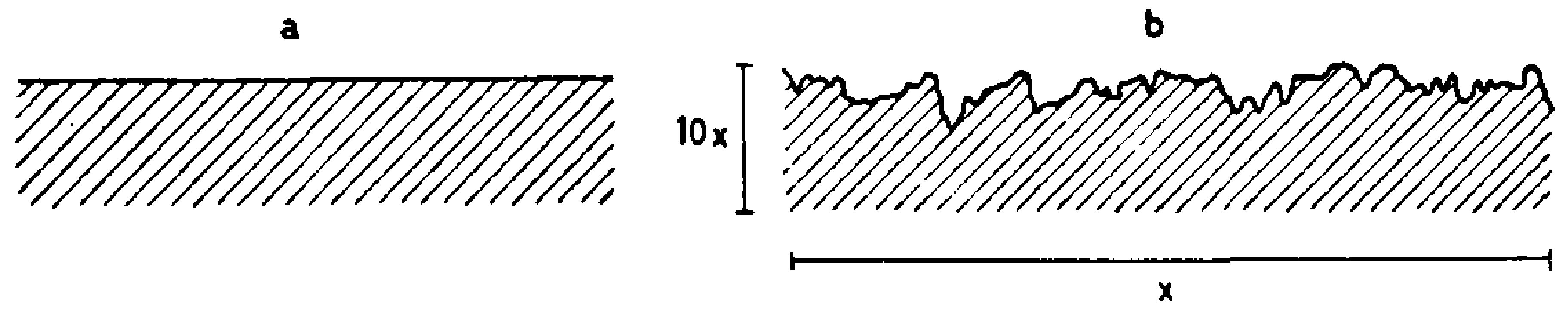


Fig. 2. a) Theoretical surface.
b) Actual surface.

Before describing a typical measuring arrangement using a mechanical-electrical type of instrumentation some important surface characteristics should be reviewed. Fig. 2 shows the difference between a theoretical (ideal) surface and an actual surface. To characterize practically obtainable surfaces, which differ greatly from each other depending upon the production method employed, it has been found necessary to introduce certain standard definitions, some of which will be given in the following:

μmeter (micrometer). One millionth of a meter. (1 μm $= 10^{-6}$ m $= 10^{-3}$ mm).

μinch. One millionth of an inch. (μinch $= 10^{-6}$ inch).

Surface. The surface of an object is the boundary which separates that object from another object or substance.

Surface irregularities. Deviations from a theoretical surface, including roughness and waviness.

Roughness. Relatively finely spaced surface irregularities, the height, width, and direction of which establish the predominant surface pattern. Irregulaities produced by cutting edges and machine tool feed may be considered roughness. The height is rated in μmeters (or μinches) arithmetical average deviation from the mean line; the symbol AA (arithmetic average) or C.L.A. (center line average) being used as descriptive abbreviations.

Waviness. Irregularities of the surface which are of greater spacing than roughness. These irregularities may result from such factors as machine or work deflections, vibration, heat treatment, or warping strains. The height is rated in mm (or inches) at the peak-to valley distance. The width is rated in mm (or inches) as the spacing of adjacent waves.

Roughness Width Cut-off. The maximum width in mm (or inches) of surface irregularities to be included in the measurement of roughness height. Roughness may be considered as superposed on a wavy surface.

Lay. The direction of the predominant surface pattern, produced by tool marks or grains of the surface ordinarily determined by the production method used.

Flaw. Irregularities which occur at one place, or at relatively infrequent intervals in the surface, e. g. a scratch, ridge, hole, peak, or check.

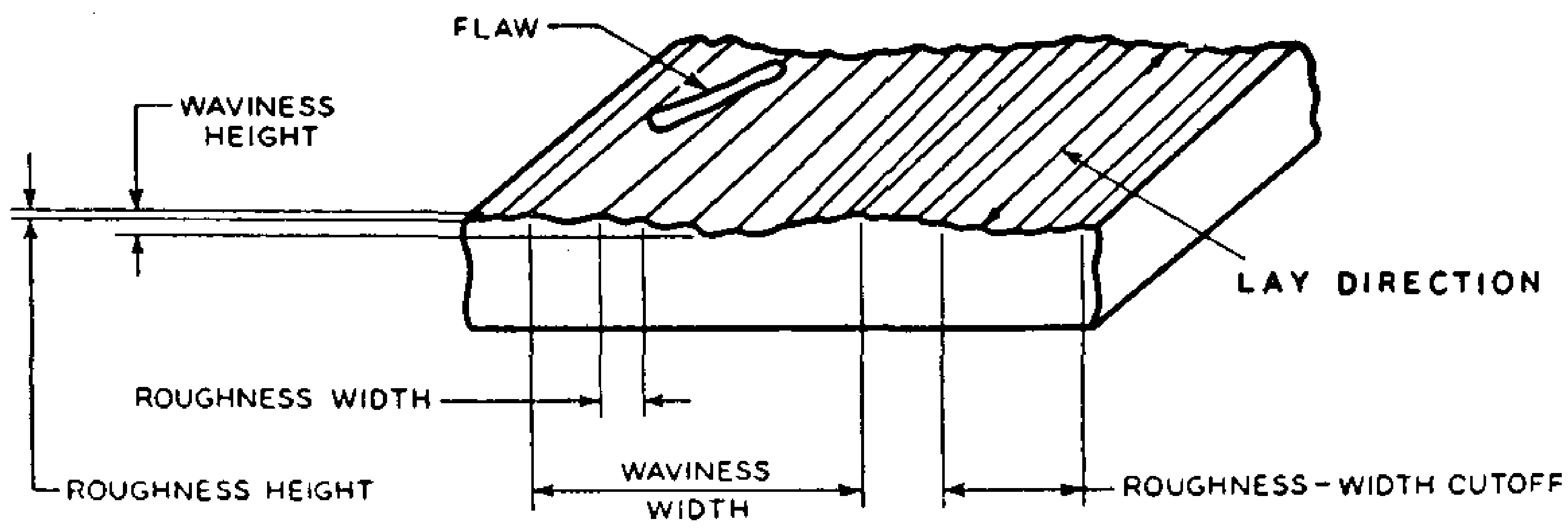


Fig. 3. Drawing illustrating the meaning of the Standard definitions (from A.S.A. B 46. 1-1955, fig. 11, p. 8).

Fig. 3 and 4 illustrate the meaning of the above definitions with regard to an actual surface.

From fig. 3 is seen that when measurements are taken it is of the utmost importance to be able to clearly define which property of the surface is actually being measured, and the accuracy of the measured result.

A convenient, practical and reliable measuring arrangement for the measurement and control of surface roughness of machined work pieces is shown in fig. 5. The figure shows the Roughness Meter Type 6100 which functions as follows:

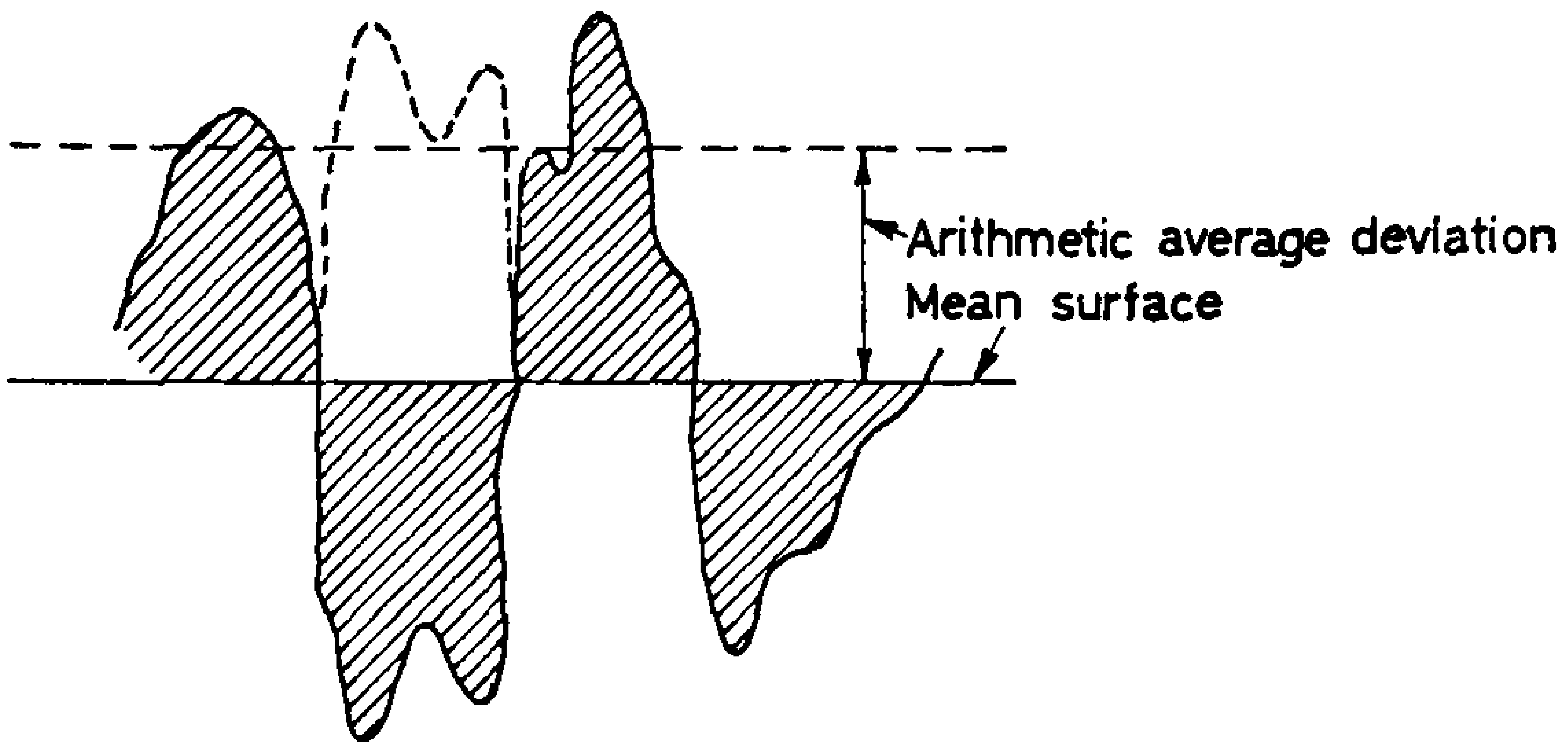


Fig. 4. Example of a "practical" surface with indication of the mean surface and average deviation. The magnification in the vertical direction is approx. 50 times that in the horizontal direction.

A small stylus-type displacement pick-up is moved at a speed within 3 mm/sec. (1/8 inch/sec.) and 10 mm/sec. (3/8 inch/sec.) along the surface being checked. During the traverse the pick-up stylus will follow the finely spaced surface irregularities and its up and down movements are converted into an a. c. voltage by means of a piezo-electric transducing element.

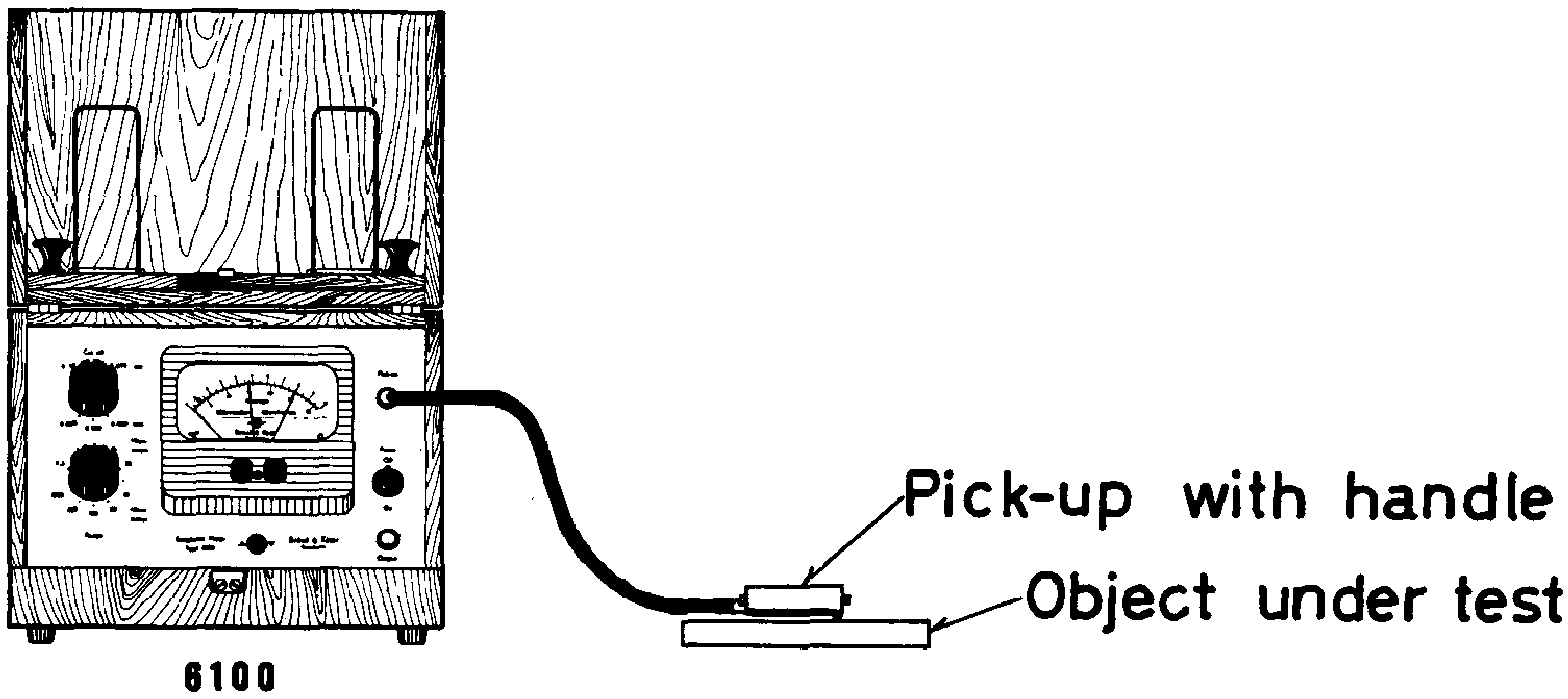


Fig. 5. Measuring arrangement suitable for laboratory as well as production control measurements of surface roughness.

The output voltage from the pick-up is fed to the input of an electronic amplifier, and the average value of the surface irregularities can then be read off the calibrated meter scale directly in μmeter (or μinches).

The accuracy of the measured surface roughness value will depend mainly upon the following factors:

1) The pick-up skid radius.
2) The tip radius of the stylus.
3) The stylus pressure.
4) The hardness of the surface being checked.
5) The setting of the "Roughness Width Cut-off" switch of the instrument.

The importance of these factors will be evident from the brief discussion given below.

To provide a reference surface for the pick-up the pick-up housing must be supplied with one or more skids, the radius of which should be chosen relative to the highest roughness width to be included in the measurements. This is readily seen because when the pick-up is moved along the surface being investigated only the up and down movement of the stylus with respect to the pick-up housing is measured. The skid radius of the pick-up of Type 6100 is 10 mm, which is approx. 13 times greater than the highest roughness width cut-off value available in the instrument. The inaccuracies in the measured result caused by vertical movements of the pick-up head itself are thus minimized.

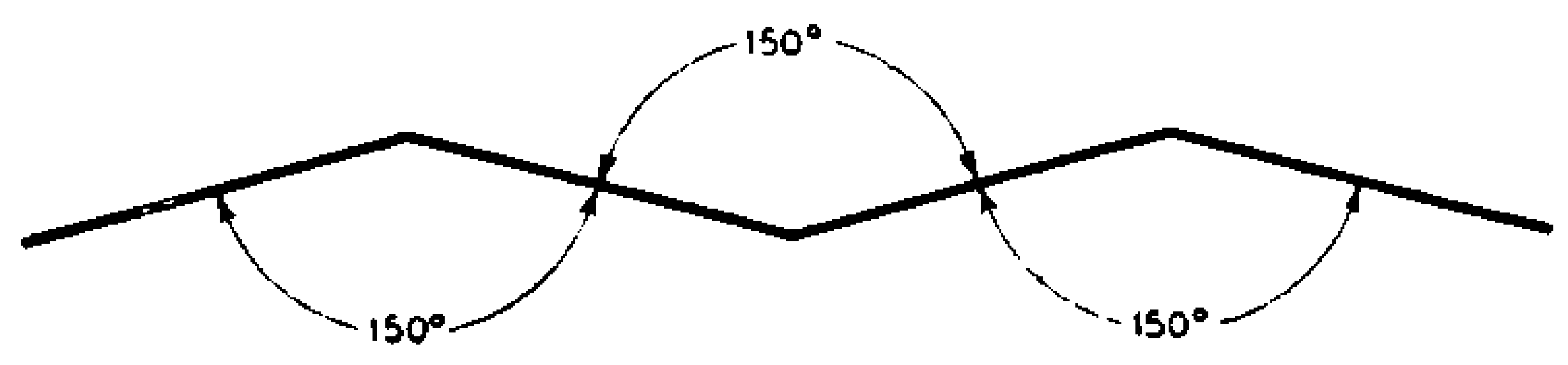


Fig. 6. Profile of the Precision Reference Specimens (from A.S.A. B 46. 1-1955, fig. 12, p. 10).

The stylus tip radius is chosen to compromise the necessary mechanical strength of the stylus with its ability to follow even finely spaced surface irregularities. The stylus used on the pick-up of the Roughness Meter has a tip radius of 12 μmetres (500 μinches) and the material chosen for the stylus tip is diamond whereby great mechanical strength is obtained and practically no wear takes place. However, a set of Precision Reference Specimens MA 0011 is available by means of which the condition of the stylus can be checked from time to time.

To illustrate the effect of the stylus tip radius upon the accuracy of the measured result two surfaces of the type shown in fig. 6 will be considered. The actual surface roughness values (arithmetic average, C.L.A.) of the surfaces are 3.12 μmetres (125 μinches) and 0.5 μmetres (20 μinches) respectively. Fig. 7 indicates clearly how an inaccuracy in the measured surface roughness is introduced. In the case of the "3.12 μmetres surface" the Roughness Meter Type 6100 will measure the surface roughness with practically no error

(error $\simeq$ 0.35 %). When the "0.5 μmetres surface" is checked, however, the instrument will indicate a surface roughness value approx. 12 % lower than the actual surface roughness.

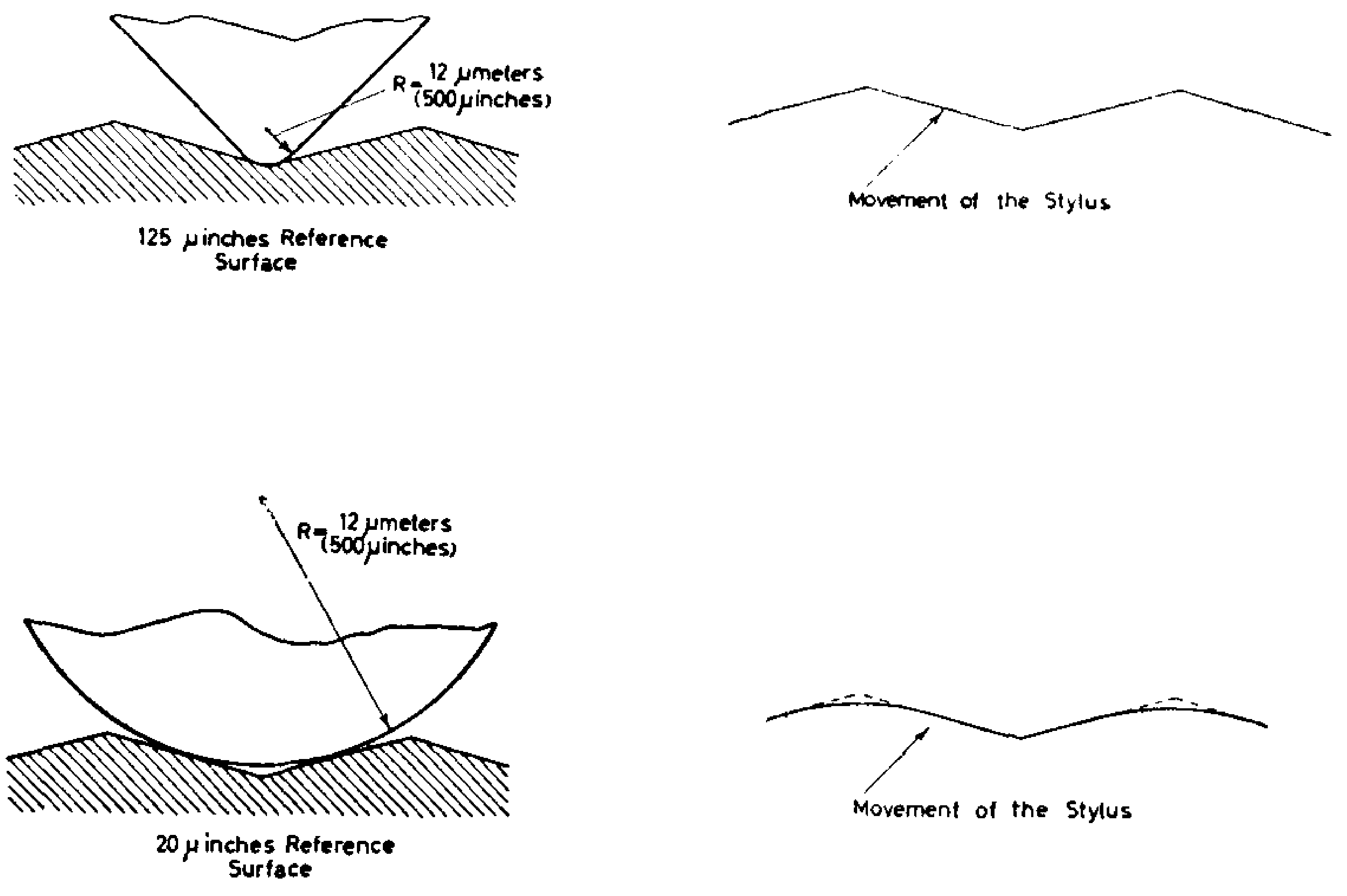


Fig. 7. Sketch showing measurements on the Reference Specimens by means of a stylus with finite tip radius.

Fig. 8 shows an error curve, based on the type of surface shown in fig. 6, and valid for different values of stylus tip radii. Because the type of surfaces

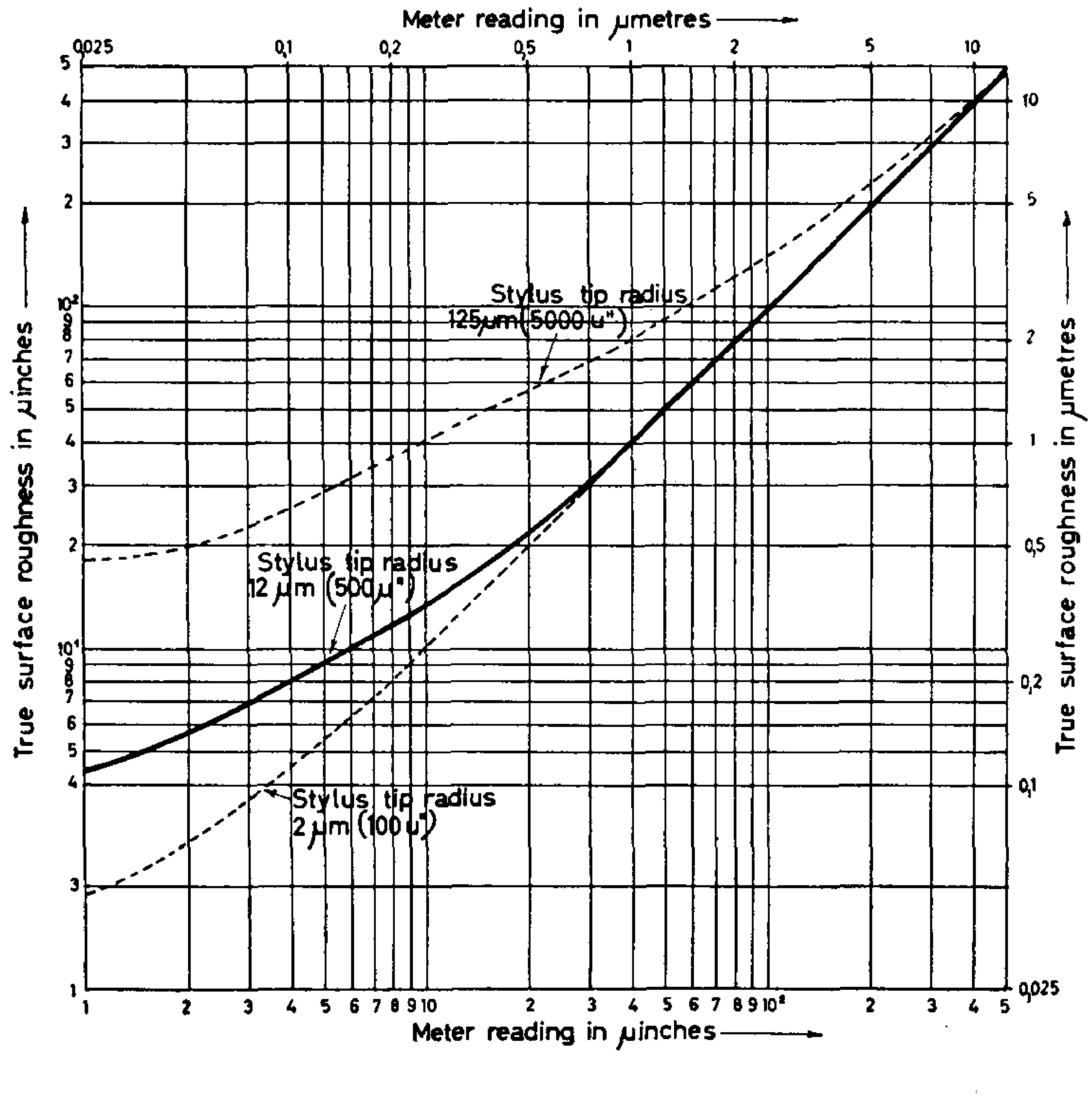


Fig. 8. Correction Curve for stylus type measurements. Valid for the type of surface shown in fig. 6.

normally met with in practice differ greatly from the one shown in fig. 6 this curve should only be taken as an illustrative example.

The static stylus pressure is chosen such as to obtain suffiently high acceleration of the pick-up stylus to make it penetrate into the bottom of the surface "valleys". The pressure should, on the other hand, not be so great that the stylus cuts the "peaks" of the surface thereby causing inaccuracies in the measured result and "scratching" the surface. The cutting of the surface peaks and the resulting inaccuracy in the measurements, as well as the "scratching" of the surface will also depend on the hardness of the surface being checked. A stylus pressure of approx. 1 gramme has been chosen for the pick-up of Type 6100, and a series of experiments have shown that the "scratching" of the surface as well as the measurement errors are negligible when metal surfaces are being investigated.

An important feature is the variable "Roughness Width Cut-off" switch by means of which it is possible to estimate the influence of surface waviness upon the measured result. See also the definitions of surface roughness, waviness and roughness width cut-off, page 18.

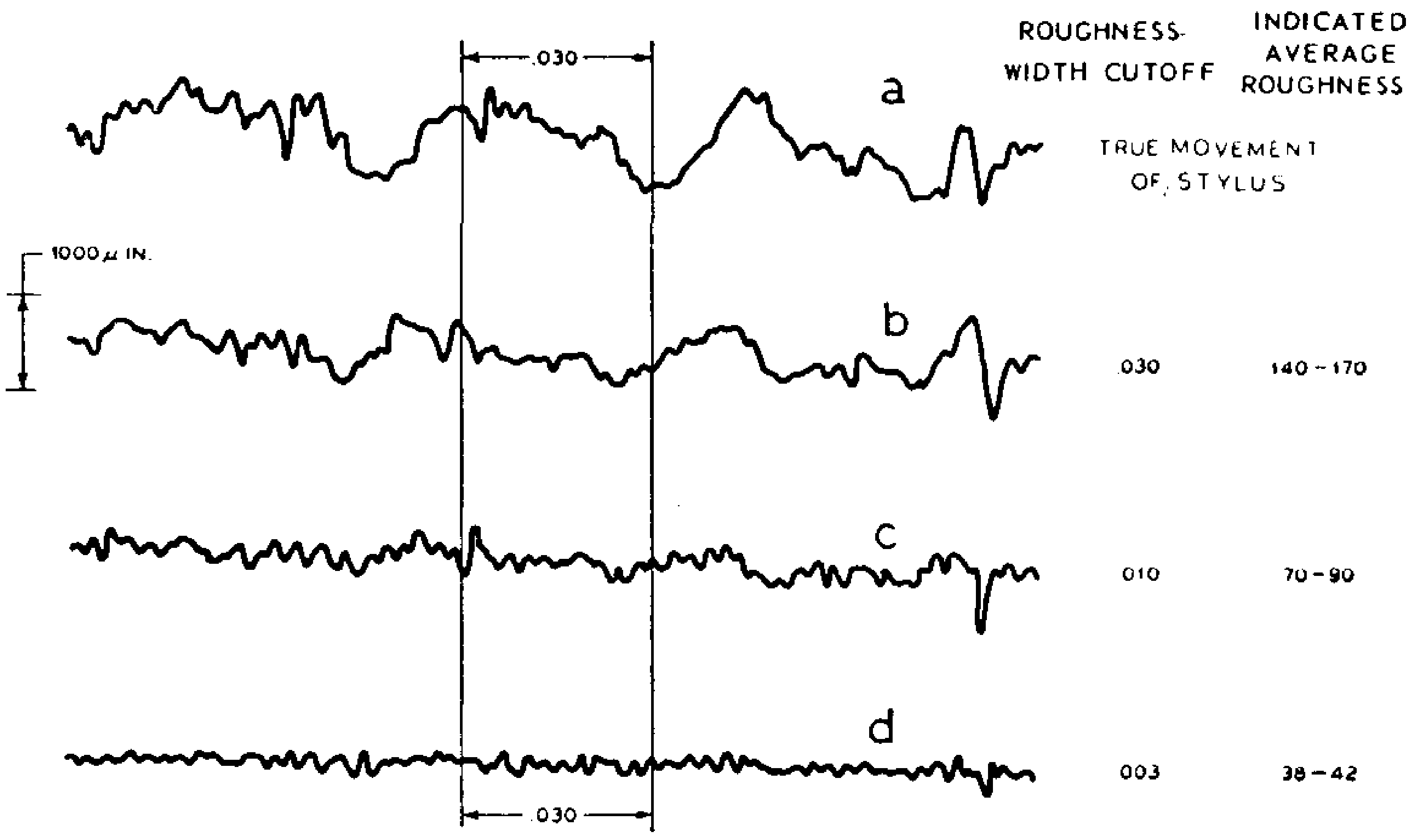


Fig. 9. Sketch showing the effect of different settings of the Roughness Width Cut-off switch. (From A.S.A. B 46. 1-1955, fig. 17, p. 17).

Fig. 9 a shows a practical surface and figs. 9 b, c and d illustrate the effect upon the measured result when different settings of the "Roughness Width Cut-off" switch are used. The importance of this switch when the absolute value of the surface roughness has to be measured is clearly noticed.

The discussion of the measurement accuracy given above is of special importance when the Roughness Meter is used in development laboratories. When used on the production line, most of the measurements required will be relative measurements, i. e. comparing a sample to an already approved prototype. These types of measurements are extremely easy to carry out, making use of a further feature of the instrument, the adjustable tolerance pointers on the instrument meter.

Fig. 10 shows a close-up view of the meter, and by means of the tolerance pointers preset limits for approval of the workpiece can be set directly on the meter scale. The only operations necessary to check the surface roughness of

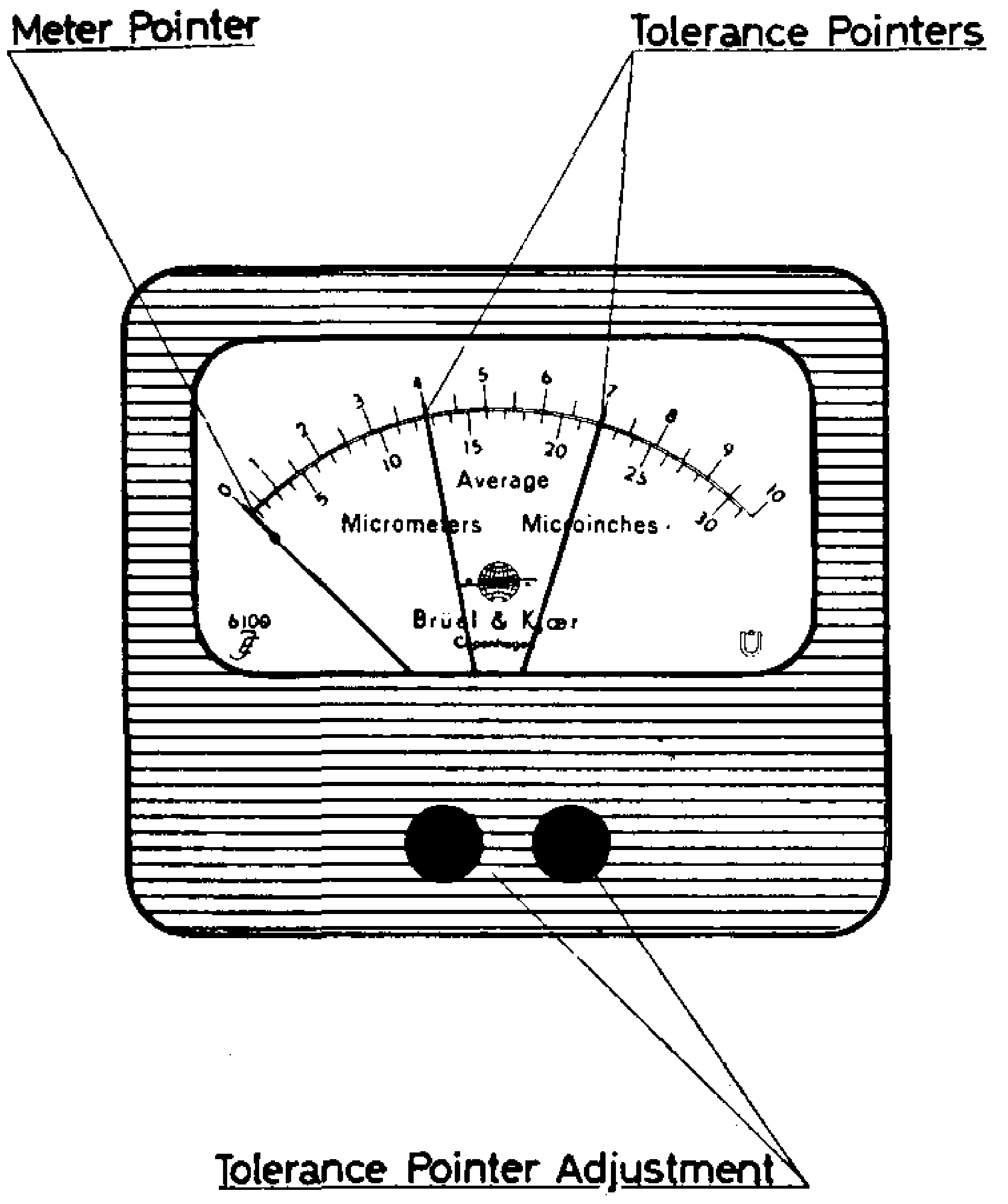


Fig. 10. Close-up of the instrument meter of 6100 showing the adjustable tolerance pointers.

the sample are then to place the sample conveniently, and see if the meter deflection is within the preset tolerance limits.

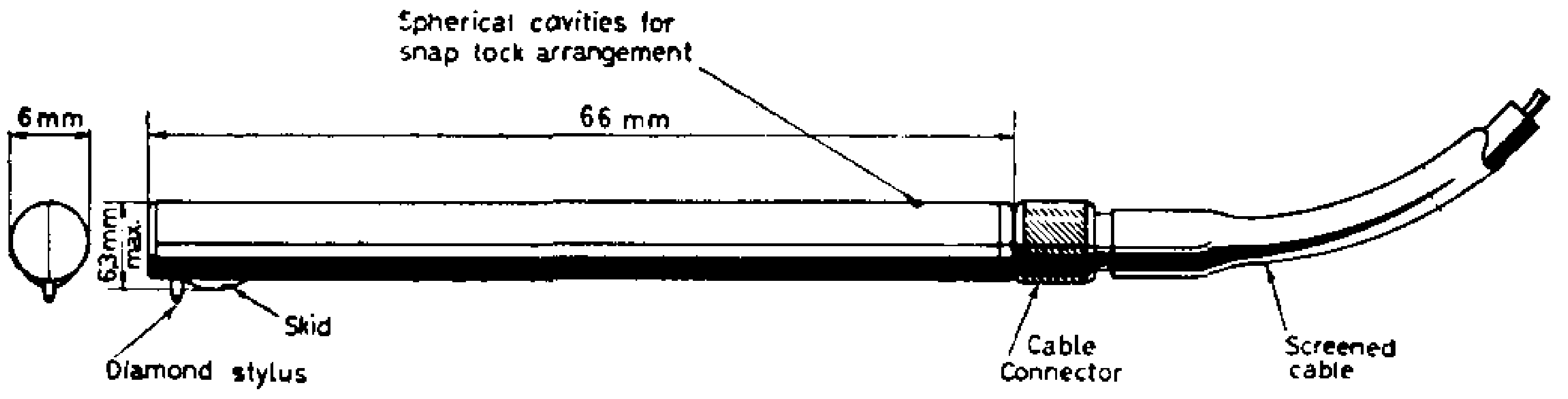


Fig. 11. Drawing of the pick-up of Type 6100.

Fig. 11 shows a dimensional drawing of the pick-up, and by means of the standard accessories supplied with the Roughness Meter measurements in *bores with inner diameters as small as 6.35 mm (¼″) and depths of up to 50 mm (2″), as well as on rods or wires with outer diameters down to 0.5 mm (0.02″)* are possible. Further information as to the specifications and use of the instrument is found in the instruction manual for Type 6100.

The importance of surface roughness measurements and of establishing practically useful roughness standards are generally recognised by most mechanical engineers. In the United States the American Standards Association (ASA) has published certain standard requirements for the type of measuring equipment to be used, and the Roughness Meter Type 6100 has been designed in accordance with this standards requirements (ASA B 46.1-1955). It also confirms with the British Standard 1134:1953.

Other countries are at present introducing somewhat similar standards (based on the measurement of AA (C.L.A.) roughness values), and a great amount of investigation work has been devoted to surface roughness problems.

The introduction of inexpensive, readily operated, flexible and accurate measuring equipment is a great help in solving these problems, and enables furthermore the production of critical machine parts to be more economic and accurate than was possible only a few years ago

News from the Factory

New Instruments

Hearing Aid Test Box Type 4212.

The Hearing Aid Test Box Type 4212 is designed primarily for the acoustical and electro-acoustical testing of all types of hearing aids and small microphones.

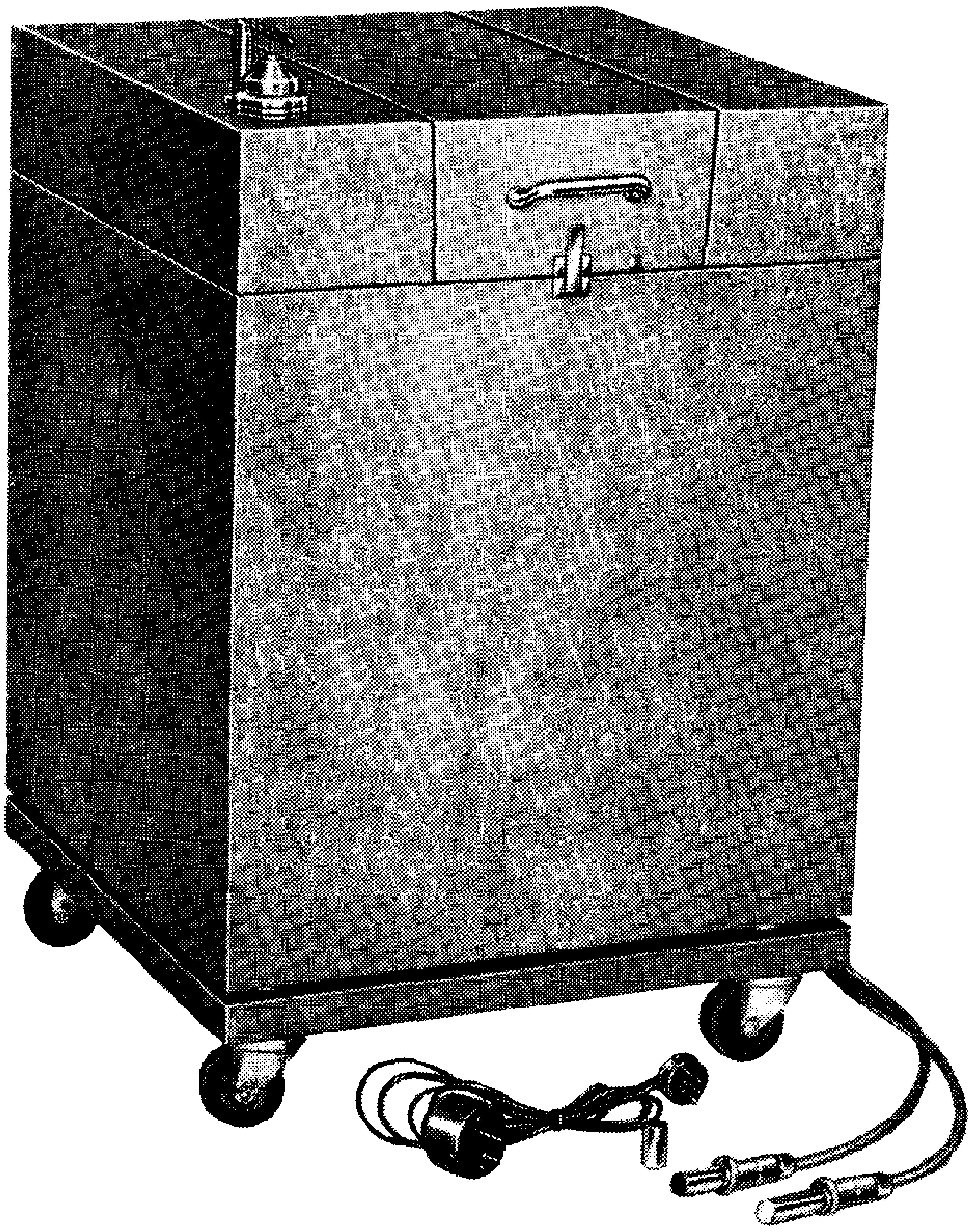


Photo of Hearing Aid Test Box Type 4212.

It consists basically of a small anechoic chamber with built-in loudspeaker and regulating precision microphone, high pass filters, and an artificial ear. The anechoic chamber itself enables practical free-field measurements of small objects to be taken in a frequency range from approx. 150 c/s to 5,000 c/s, and is effectively insulated against air-borne noise as well as impact sound.

A Condenser Microphone is used to keep a constant reference sound level. To be able to carry out complete acoustical tests on hearing aids an artifical ear, consisting of a second Condenser Microphone and a 2 cc coupler for insert types of earphones is mounted on the outside of the Test Box. A mechanical load system supplies the necessary mechanical pressure to the earphone when placed in the coupler.

Furthermore, a 2 cc coupler, specially designed for use on hearing aids with built-in earphones (e.g. hearing aid spectacles), is also included in Type 4212.

Beat Frequency Oscillator Type 1013.

A new Beat Frequency Oscillator covering the frequency range 200 c/s to

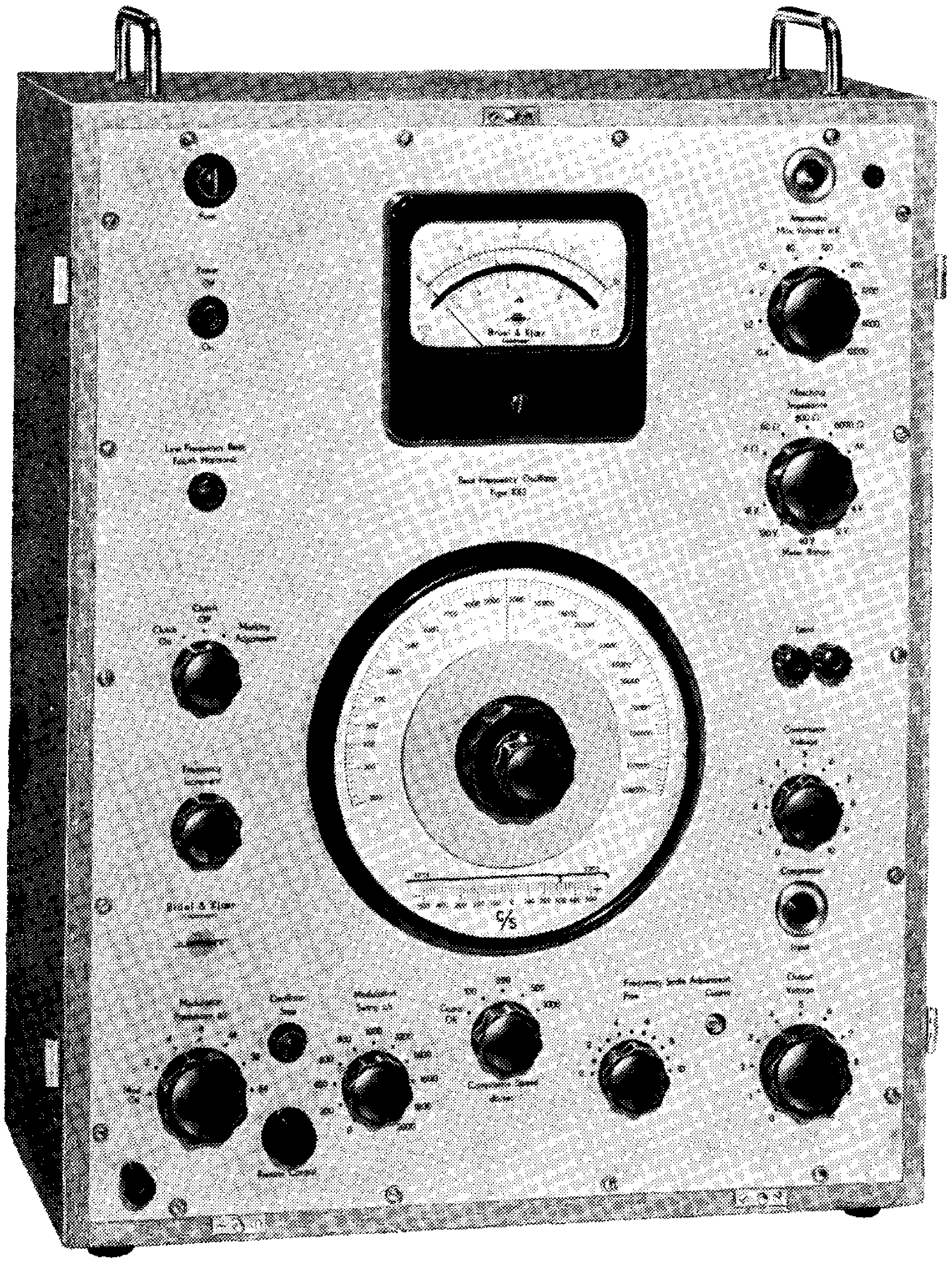


Photo of Beat Frequency Oscillator Type 1013.

200,000 c/s with a voltage accuracy better than ± 1 db is now in production. Its illuminated scale is logarithmic from 200 c/s to 200 kc/s and an "Incremental Scale" allows exact frequency selection in the range — 500 to + 500 c/s. A switch enables the output impedance to match 6, 60, 600, and 6,000 Ω with a maximum output voltage of 120 V and an output power of approx. 3 Watts and 1.5 Watt for 6,000 Ω and 6 Ω respectively. On an attenuator output terminal the maximum output voltage is variable in steps of 10 db from 0.4 mV to 12 Volts and is continuously variable within each attenuator range by means of a potentiometer. The typical distortion is 0.2 % and the overall distortion better than 0.5 % for an output power of 0.5 Watt.

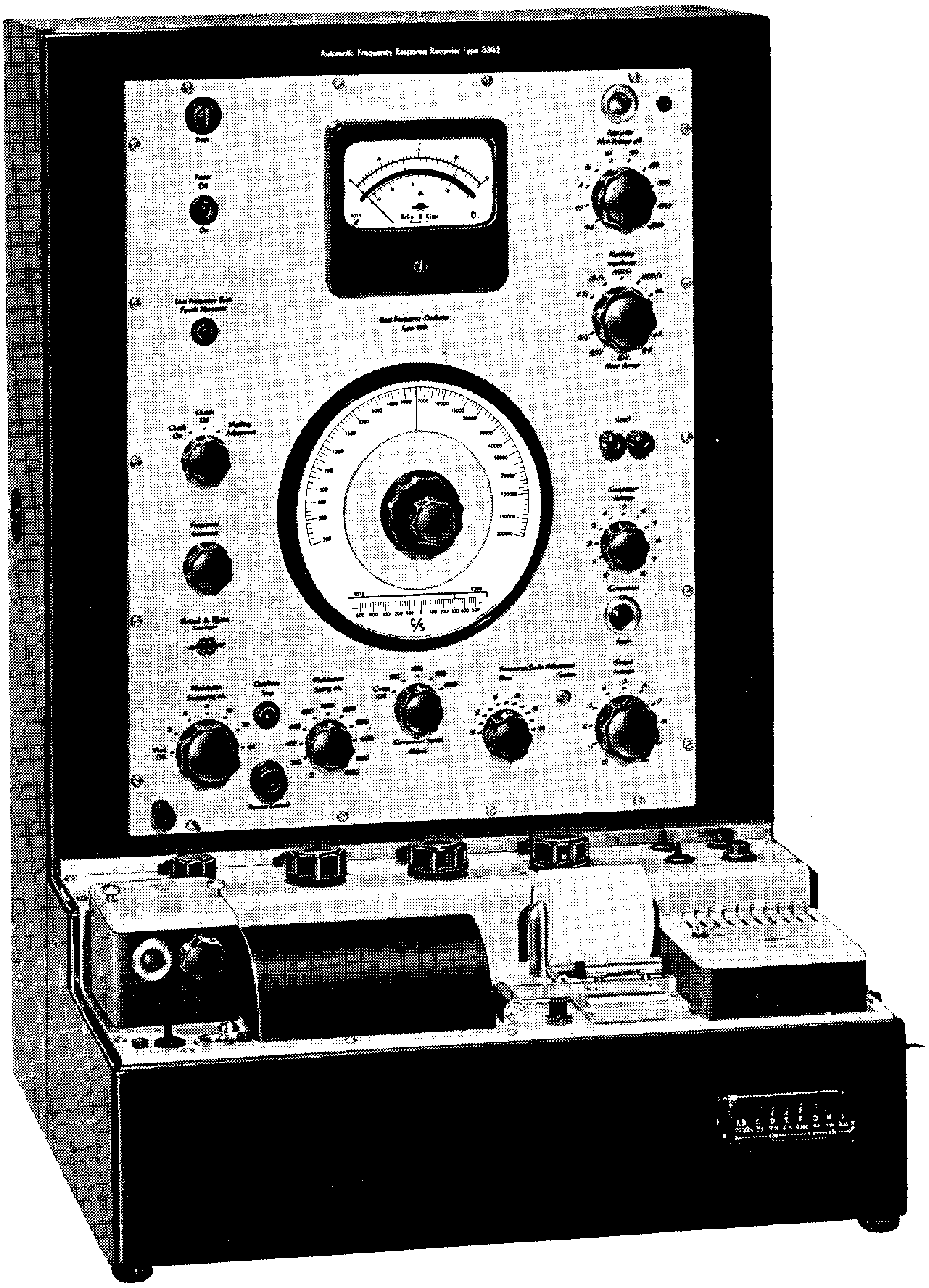


Photo of Automatic Frequency Response Recorder Type 3301.

As for the Beat Frequency Oscillator Type 1014, the Type 1013 is provided with a worm gear for automatic frequency scanning, and with a regulating amplifier maintaining a constant voltage, current or sound pressure to within 1 or 2 db for a level variation of 45 db. The speed of regulation is variable in steps: 100 — 200 — 500 and 1,000 db/sec. Furthermore, a built-in saw-tooth oscillator enables a stepwise variable frequency modulation of 2 — 4 — 8 — 16 — 32 or 64 c/s with a continuously variable modulation swing from 0 to ± 2,000 c/s to be made. A line voltage of 115 — 127 — 150 — 220, and 240 Volt of a frequency within 40—400 c/s can be used for operating the instrument.

In the figure is shown the Automatic Frequency Response Recorder Type 3301. It consists of the Beat Frequency Oscillator Type 1013 and the Level Recorder Type 2304.

UB 0005.

The connection piece UB 0005 i designed for the coupling of two flexible shafts UB 3003. It is made of nickel-plated brass and its maximum length is 43 mm.

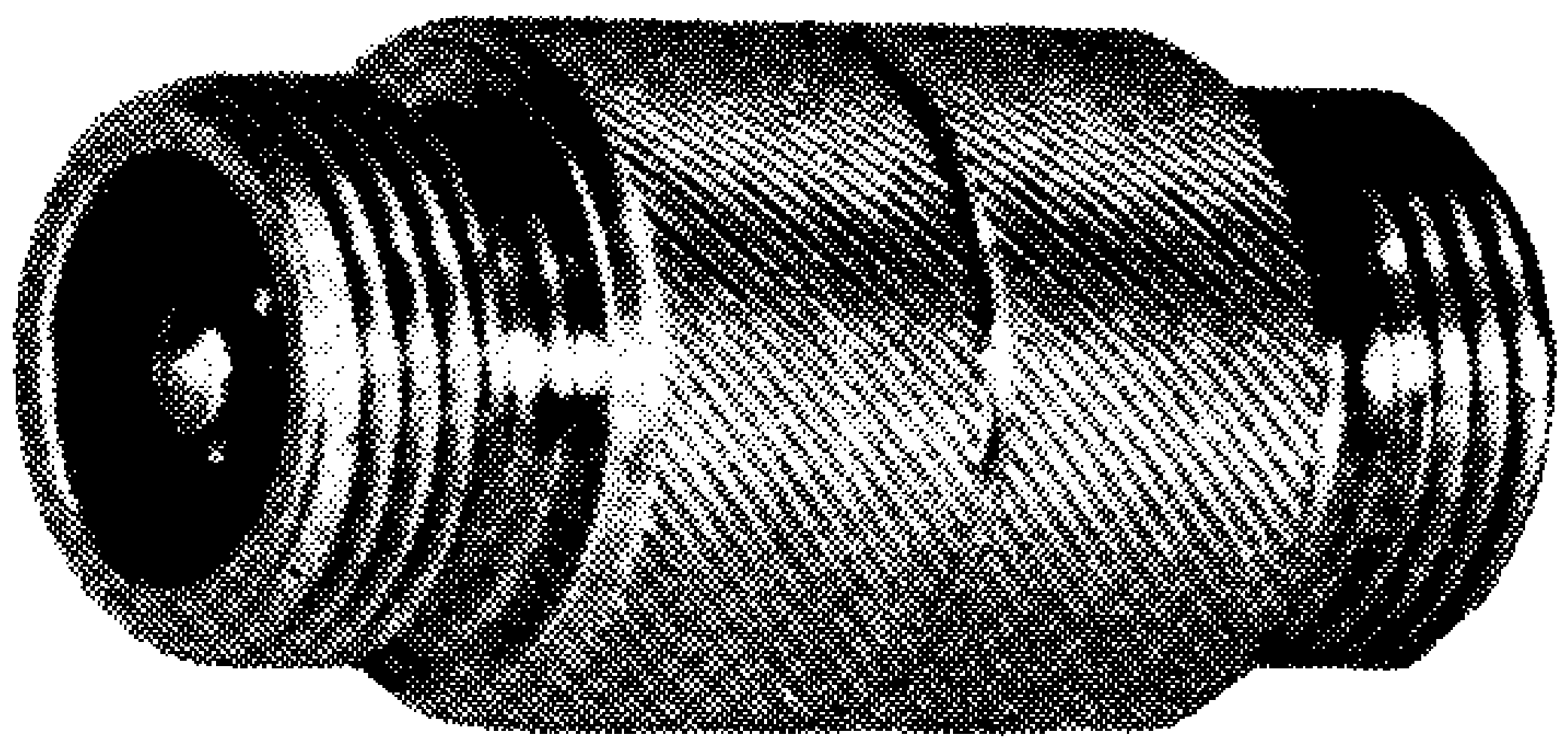


Photo of UB 0005.

Price Reduction.

Constant Sound Pressure Source Type 4211. Laboratory Trolley Type 3112.

On account of increased demand we are now able to tender the Constant Sound Pressure Source Type 4211 and the Laboratory Trolley Type 3112 to a much lower price than before. For further information we refer to your Brüel & Kjær representative.

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