Paper 23

WORKSHOP REQUIREMENTS OF SURFACE MEASUREMENT

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INTRODUCTION

THE GROWING INTEREST in more sophisticated parameters of surface topography than the simple c.l.a. index, the long overdue move towards taking a balanced interest in both physical and topographic parameters, and the attempts being made to express performance in terms involving both, will lead to further consideration of the workshop point of view and of what industry may ultimately require for effective and, at the same time, economic control of performance.

It is probably legitimate to start from the premise that it is the whole process of manufacture (in all its stages) that finally imparts to every surface every one of its physical and topographic characteristics. This premise provided the basis of the normal industrial system in which the degree of roughness produced by each specified process was kept under control generally by sight and touch. A considerable advance was made by the introduction of the stylus instrument, which represented in effect a defined thumb-nail with numerical read-out. The c.l.a. or pseudo-r.m.s. index that was indicated was, however, regarded not as a measure of performance, but simply as a comparative index for control of process, which, it was hoped, would serve as a stepping stone towards something better (1)†. In practice it appears to have been more useful than was originally thought possible.

The system of specification by process (in sufficient detail) combined with a controlling index, if fully applied, often involves the construction of models and test rigs with which to optimize the methods chosen for manufacturing the surfaces, which have then only to be reproduced. Although lacking in exactitude, the system is basically sound and practical, for it has the concealed virtue of covering, at least by implication, many important physical characteristics such as surface structure and crystalline deformation, and also many topographic characteristics such as the periodicity, randomness, and general shape of the profile.

The system, however, gives no direct information about the functional behaviour of the surfaces involved; it may inhibit the substitution of new and possibly better processes, and it may sometimes militate against optimum loading of available production plant. From this has sprung a natural desire to specify requirements in terms independent of process.

THE CURRENT POSITION

The most widely used parameter has been the c.l.a. or approximate r.m.s. value, although on the Continent the peak-to-valley height is often used, not because it is necessarily better, but because there the art started on that basis, from simple measurement of profile graphs instead of from meter readings.

Workshops have had to interpret these measures in relation to their products in much the same way as hardness numbers, i.e. through practical experience. They have generally found it possible to apply them without interfering too much with the normal flow of piece-part production, and the benefits in more uniform performance of components which have resulted have seemed to justify the cost of production control.

Occasionally, however, reports are received of applications for which the c.l.a. index appears to give inadequate control. These reports can frequently be traced to an imperfect use of the instrument; for example, an unsuitable datum or meter cut-off or traverse length. Other cases have been encountered where differences in performance were traced to differences in the physical state of the surfaces, and had little to do with the topographic aspect. In some instances, however, it seems evident that more information has been required than could be

The MS. of this paper was received at the Institution on 28th January 1968.
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† *References are given in Appendix 23.1.*

conveyed by the c.l.a. index alone, even in association with process: these have been prominent in the control of the textures required on rolled steel strip to be used for deep drawing and subsequent painting, where the shortcoming was not so much with the parameter used for measuring the height (the c.l.a. value) as with the lack of one operative *along* the surface, for example the crest spacing. In this context crest spacing is now being expressed in terms of the number of crests per unit length. Already, however, two systems of counting have been envisaged, namely peak and high-spot, and as yet neither has been sufficiently developed to come within the ambit of formal standardization (**2**).

Instruments have become available in great variety, from costly equipments applicable to a wide variety of surface textures and parts, to comparatively simple instruments properly applicable to a much smaller range of textures though sometimes to an even greater range of parts. Unfortunately the proper use of these instruments is sometimes marred by lack of appreciation of the topographic characteristics of the surfaces to be measured, and the importance of relating to them the operative characteristics of the instrument to be used.

A significant distinction can be drawn between the range of textures and the range of workpieces for which an instrument is serviceable. It is possible to design an instrument with a great range of datum devices (skids, shoes, optical flats, etc.) and a wide range of meter cut-offs, which can be considered to be reasonably universal with respect to the range of textures it can measure, but which is, nevertheless, restricted in the range of workpieces because the requirement of a high standard of measurement may set stringent requirements in the design and rigidity of its mounting. On the other hand, a simple instrument may be designed with rather rough but very adaptable mounting arrangements, together with a compact pick-up which can readily be positioned on a very wide range of parts of awkward size and shape, but which is suitable for a comparatively small range of textures, with the result that while the instrument may be 'universal' with regard to workpieces it is far from universal with respect to the range of textures it can handle.

Another cause of indifferent measurement can result from thinking that a simple instrument, although perhaps not very accurate, may nevertheless serve as a good comparator. In reality it will do so only if the irregularities to be compared come within the appropriate range of its datum device (generally a skid) and transmission characteristic. For example, if the irregularities to be compared have the same height and shape but different crest spacings, it is quite possible that skid effects may result in a high c.l.a. reading for one and a low c.l.a. reading for the other, leading to an even greater percentage error in the comparison than in the value of either surface by itself. Again, if the crest spacings on one specimen come inside the meter cut-off and on the other come outside this cut-off, the comparison will also be invalidated—in this case as much for the sophisticated as for the simple instrument.

FURTHER DEVELOPMENT OF MEASUREMENT TECHNIQUES

It is probable that from the workshop point of view the objective of most of the research that is done will be to enable surfaces to be described and specified adequately for their functional purposes better than they can be now, but still with a *minimum* number of physical and topographic parameters. Each additional specified parameter, adding something to the problems and cost of piece-part production, must eventually justify itself in ultimate economies in assembly and/or performance.

It is not impossible that after a period of interest in sophisticated parameters (during which much may be learned) there will be a swing back to recognition of the process which, after all, says a great deal in a practical way that is comprehensible to most workshop people.

A vitally important consideration underlying the value of the information conveyed by many of the parameters in course of investigation, both known and new, is the quality of the reference line from which they are measured.

The characteristics of the centre line (one parallel to the general direction of the profile), of the least squares mean line, and of the mean lines found by electrical and mechanical filtering have all been described and found lacking in some respect. They are compared in Fig. 23.1, with respect to nominally straight profiles exhibiting (*a*) repetitive and (*b*) random irregularities:

(*a*) The centre-line (Fig. 23.1*a*) is completely satisfactory as defined in B.S. 1134 for repetitive profiles, but for irregular profiles its inclination may require an element of human judgement. Despite this possible criticism, it has always had a strong practical appeal.

(*b*) The least squares line calculated through a finite length of sample (Fig. 23.1*b*) can acquire an unrealistic inclination for the repetitive profile (depending in amount on the starting point in the cycle and the number of cycles included) although the effect is generally negligible for irregular profiles (**3**).

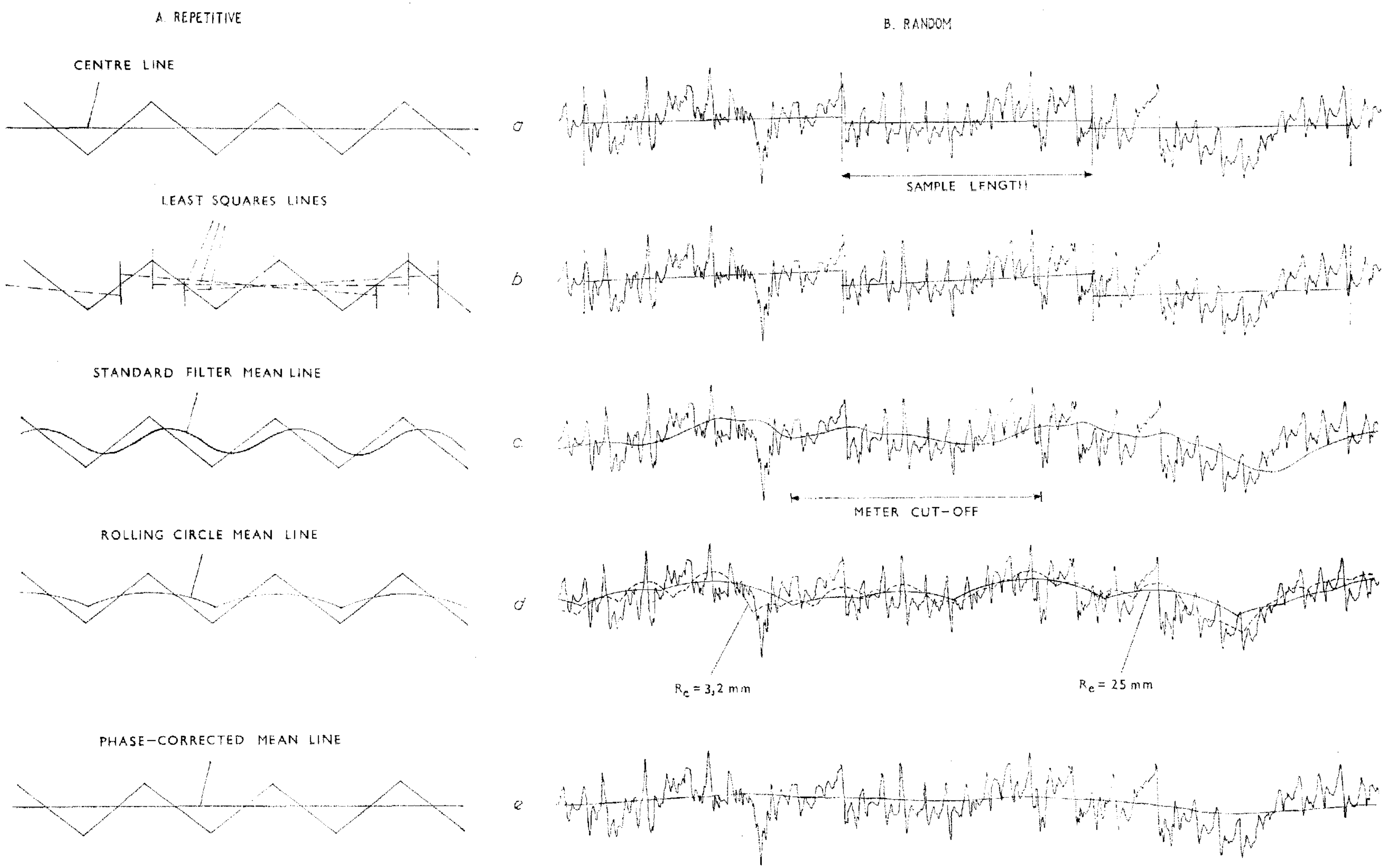
(*c*) The mean line found by the standard two-stage capacitor/resistor filter (Fig. 23.1*c*) may undulate within the pass-band for repetitive and for irregular profiles unless the cut-off can be made considerably greater than the crest spacing.

(*d*) The rolling-circle mean line (Fig. 23.1*d*) found by mechanical filtering, which is formed by the displaced envelope line, also tends to undulate for both types of profile unless the radius used for the rolling circle can be made very long (which may be impracticable).

Since there are parameters which cannot properly be referred to a filtered reference line which undulates as shown in the Figs 23.1*a–d*, it seemed clear that further work on the reference line would have to be done.

THE DEVELOPMENT OF THE ELECTRICAL WAVE FILTER

The difficulty with the standard filter, and all filters of its kind, is that the required attenuation is accompanied by a



A. REPETITIVE
B. RANDOM
CENTRE LINE
a
SAMPLE LENGTH
LEAST SQUARES LINES
b
STANDARD FILTER MEAN LINE
c
METER CUT-OFF
ROLLING CIRCLE MEAN LINE
d
R_c = 3,2 mm
R_e = 25 mm
PHASE-CORRECTED MEAN LINE
e

Fig. 23.1

shift of phase of the high frequencies relative to the low, which distorts the waveform and hence the mean line.

Continuing the work done on the equation of the mean line of the standard wave filter (4), Whitehouse proceeded to examine, initially by computer methods, the behaviour of an imaginary filter postulated to have a flat transmission characteristic right up to the cut-off (followed by fairly rapid attenuation) and which did not shift relative to each other the phases of the component signals flowing through it. This work confirmed an expectation that the mean line found by such a filter would correspond with the centre-line definition of B.S. 1134 for repetitive profiles, and it seemed to accord with the definition in a mechanically realistic way for irregular profiles.

In another paper for this Conference, Mr Whitehouse shows that a filter system free from phase distortion can be realized by feeding into it, for each position along the profile, information regarding the profile lying ahead of as well as behind that time. Having achieved a filter without phase distortion, the provision of the required transmission characteristic becomes a matter of practicable design. Such a filter can be realized in various ways.

The best rate of attenuation has still to be investigated, because it has been noticed that the residual amplitude of the mean line is sometimes affected by it.

While it is a normal property of filters transmitting the shorter wavelengths (i.e. the roughness) that the part of the original signal rejected by the filter forms the mean line of the part transmitted, it has hitherto not been possible to suggest that the mean line found by the standard filter should be defined as waviness because its shape and phase relation has been mechanically unrealistic. A phase-corrected filter with the required transmission characteristic avoids the difficulty, so that if the transmitted part of the signal is accepted as the roughness, then waviness can be defined as the mean line of the roughness isolated by such a filter (Fig. 23.1*e*).

The question of whether a given undulation should be regarded as waviness or roughness will, of course, still depend on accepted convention (for example, depending on what caused it, as indicated in B.S. 1134:1961) and the appropriate cut-off will still have to be stated. It is from this point onwards that the representation of the waviness will be determined by the filter.

There can be little doubt that the concept of the phase-corrected filter will help considerably in solving the problems of waviness.

In general, it can be said that phase distortion will have little or no effect on parameters such as the true r.m.s. value, auto-correlation coefficients, and power spectra which involve the r.m.s. value. It will affect most other parameters such as peak values and their distributions, amplitude density curves, bearing areas, first and second derivatives from which slopes of flanks and curvature of crests can be derived, c.l.a. to some extent, and cross-correlation techniques.

In standardization too, the phase-corrected filter with a flat transmission characteristic right up to the cut-off, would close the gap which can sometimes be found between the results of evaluation from the geometrical and standard two-stage capacitor/resistor (CR) mean lines.

Further progress on the topographic front will probably be towards three-dimensional representation of surface irregularities of all kinds, including both texture and errors of form.

SOME PARAMETERS CONSIDERED IN RELATION TO FUNCTION

From a functional point of view, an important consideration is whether the surface will operate as an entity as in fatigue, corrosion, plating, painting, etc., or in association with another surface as for example in bearings, slideways, deep drawing, and sliding or static electrical contacts. While the shape of the reference line may not be of primary importance for the former group, it could obviously be significant for the latter.

Consideration of bearing area

While the Abbott–Firestone 'Bearing Area' curve (generally discussed with reference to a straight reference line) is often accepted as the basic representation of the rate of wear, its significance involves a number of points, and the following may be put forward:

(1) The bearing curve as normally determined applies only to a small sample of the surface, so that in the presence of waviness or error of form the real area of contact over the whole surface may be very much less than that suggested by the bearing curve.

Furthermore, the bearing area is generally considered in relation to a mating surface assumed to be without imperfection, whereas in practice the mating surface will also have its bearing characteristics, resulting in an even greater divergence between the real and indicated bearing area.

(2) When derived from a profile graph traced with respect to a true datum, the curve expresses strictly the rate of increase of the bearing *length* fraction $\Sigma l/L$. This fraction can be related to the bearing *area* fraction $\Sigma a/A$ only if certain conditions are fulfilled.

For the general case, the bearing fraction $\Sigma a/A$ of an area A can be determined by taking through it a sufficient number of equidistant cross-sections and measuring the bearing length Σl for each cross-section in a defined reference surface intersecting the cross-sections.

In the normal use of an instrument, the successive sections are likely to be of constant length and scan a substantially rectangular area. Then

$$\frac{\Sigma a}{A} = \frac{b_1 + b_2 + \ldots + b_n}{n}$$

where b_1, b_2, $\ldots$, b_n are the successive bearing length fractions referred to the desired reference surface.

In some cases it may be found that the bearing area fraction can be determined acceptably from a very few cross-sections, in other words that the bearing length fraction will be substantially the same for all parallel cross-sections.

Such a case occurs for ruled surfaces, where the profiles of all cross-sections taken across the lay are similar and corresponding points on each are equidistant from a smooth reference surface relative to which the bearing area is to be described. Other common cases occur for irregular textures such as those often produced by sand blasting and by grinding, for which a few representative sections will generally suffice, the sections for the latter process being taken preferably across the lay.

(3) If the bearing fraction is determined by a meter operating on the profile after it has been modified by a filter which introduces phase distortion, the bearing fraction will be determined with respect to a reference line which undulates through the original profile, and may have little connection with the way in which wear or compression will actually develop.

The significance of the shape of the reference line used for evaluating $\Sigma l/L$ is shown in Fig. 23.2 where *aa* is the mean line found by the standard two-stage CR filter. It will be appreciated that meter evaluations of $\Sigma l/L$ will refer to equal offsets from this line, regardless of whether the offset is expressed from the mean line or as a distance below the crests. The line *aa* is evidently not the one relative to which wear or compression is likely to occur. A similar difficulty arises with the rolling circle envelope line of the E-System, because this reference line, being represented by a succession of arcs as shown by the line *bb*, also undulates. To minimize the effect, the meter cut-off or the radius of the rolling circle should be as large as practicable.

The most useful reference line for studying the relationship between two surfaces in contact would clearly be a line that could be common to both. This would be a line or surface representing the nominal shape of the two parts or the direction of motion, e.g. a straight line such as *cc* for nominally flat surfaces. The degree of approximation to it found by the phase-corrected filter for the surface in question is shown by the line *dd*.

(4) Most surfaces in contact work under load, but measurements from profile graphs refer only to unloaded surfaces.

In Fig. 23.3*a*, a rough surface with a slight error of form makes contact with an assumed perfect flat. At first there is engagement only in the centre, but after a small amount of wear or compression of the crests, there is some degree of contact all over, as shown by Fig. 23.3*b*.

Now consider a much smoother surface having the same error of form, shown initially in contact in Fig. 23.3*c*, and then in Fig. 23.3*d* after the central texture has been reduced in the same proportion as in Fig. 23.3*b*. In Fig. 23.3*d* there is still no contact at the ends of the surface, and contact all over will not be secured until there has been wear or compression of solid material in the centre; this may take a long time, or very high loading, to reach.

Estimation of the overall bearing area will involve measurement relative to a datum extending over the whole

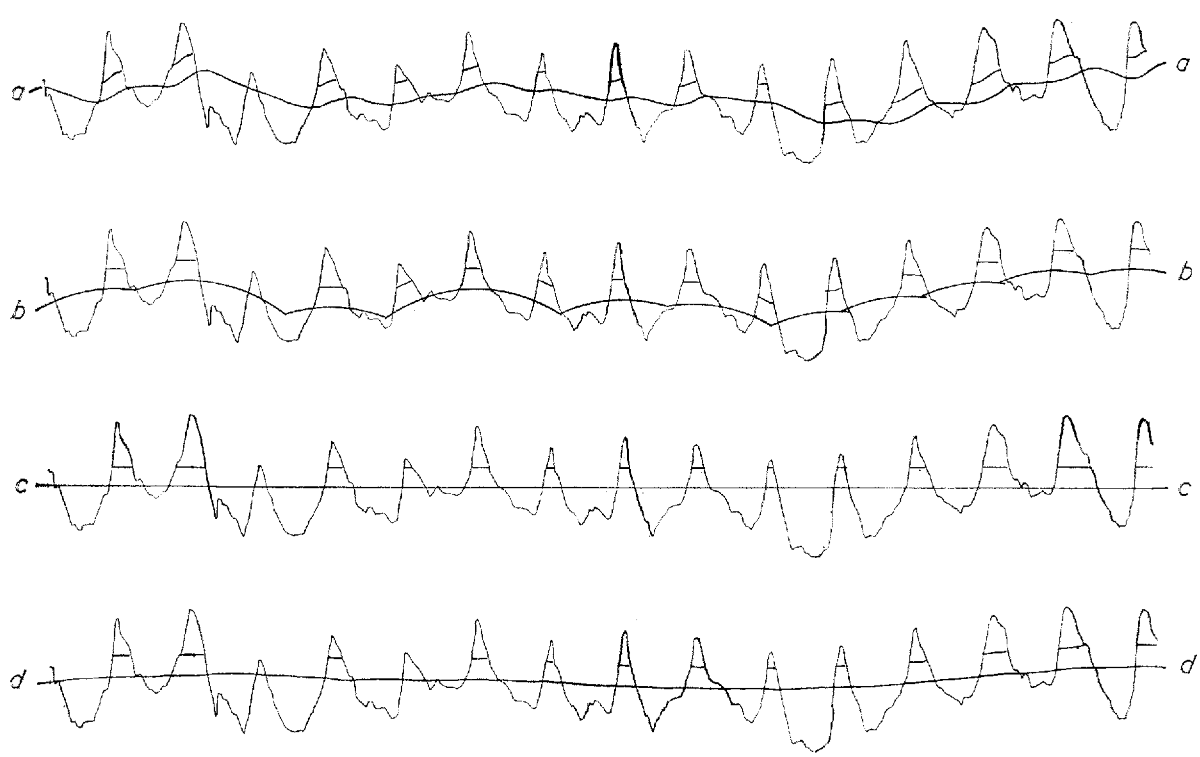


Fig. 23.2

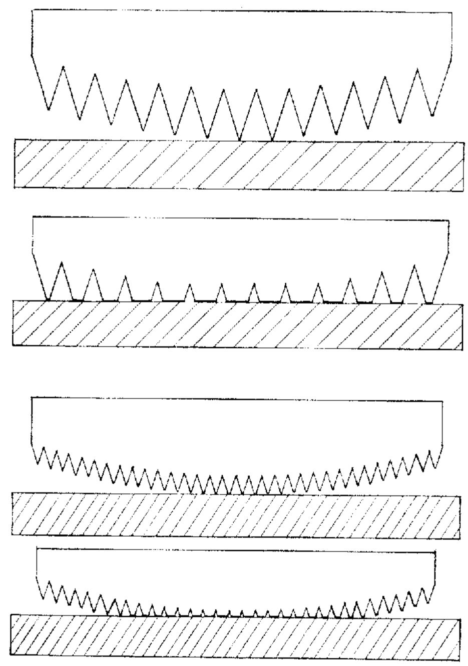


Fig. 23.3

surface, and the stiffness and flexure of the members as a whole will also have to be considered. For example, the bolts holding two flanges together may suffice to pull out a certain amount of error of form and even of waviness, apart from compressing the crests of the roughness.

It is possible that relationships could be established between permissible amounts of roughness, waviness, error of form, and stiffness, for different applications.

A relevant consideration is that when fine textures are called for, particularly if ground or turned, a known requirement is to use a machine in good condition and to pay full attention to refinements of technique. This, in turn, will tend to minimize waviness and often errors of form, and it may be that in some cases the smoothness called for, perhaps at considerable production cost, is but the means to this end.

A full understanding of the behaviour of surfaces in contact will, however, involve their physical characteristics, and more information is required about the behaviour of the roughness texture, particularly with regard to how the crests compress, flow, and wear.

Consideration of peak heights and curvatures

Although the methods by which the phase-shifting filter can distort profiles coming within the pass-band have already been demonstrated, repetition of the profiles shown in Fig. 23.4 may be permissible in order to emphasize that assessments of peak heights or their distributions or curvatures based on the filtered profile may be quite misleading unless a sufficiently long meter cut-off can be used.

CHOICE OF REFERENCE LINES

For any kind of experimental investigation of performance in relation to parameters that are sensitive to the quality of the reference line, the one chosen should be mechanically as realistic as possible, as there would be little benefit from making elaborate experiments involving the wear and shape of peaks based on representations which made worn flats appear to slope or peaks to have materially incorrect levels or curvatures.

The centre-line as normally defined, and expressed through the medium of the phase-corrected filter, appears to possess most of the desired characteristics. Even if an instrument with a phase-corrected filter and the convenience of meter readings referred to its mean line is somewhat costly, no problem need arise in applying the concept of a phase-corrected filter when working from digitally recorded profiles, as is already being done, because it is as easy to compute the phase-corrected mean line as the phase-distorted mean line of the standard two-stage CR filter. Tables of weighting factors similar to those

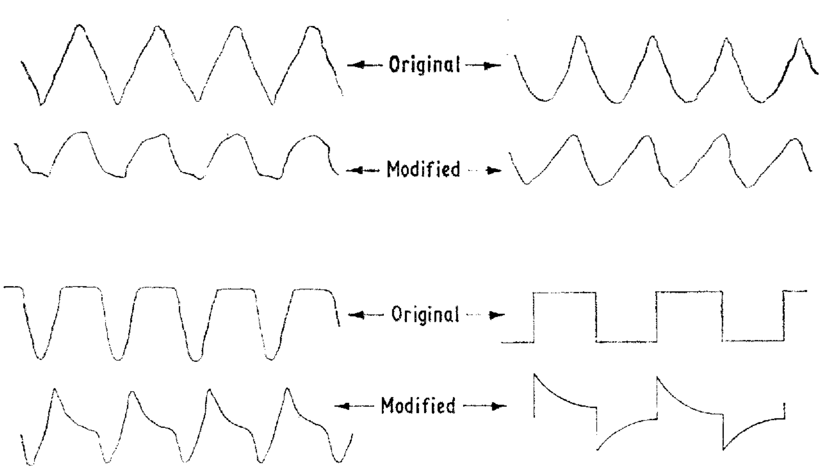


Fig. 23.4. Distortion of waveforms produced by the standard filter just inside the cut-off

previously published for the standard filter (4) have already been prepared and will presently be made available.

In the workshop, for as long as the simpler parameters will suffice, the widely used standard two-stage CR filter seems likely to find continued use, a relevant consideration being that in the simpler types of instrument which must form a desirable objective for use by machine operators, the transducer itself often forms part of the filter circuit.

A DISTINCTION BETWEEN MEASUREMENT AND SPECIFICATION OF WORKPIECES

A quite important point of concern to national standards is that a distinction should be made between the requirements for uniform measurement of surfaces as they are encountered, and the requirements for specifying surfaces that have yet to be made. The former does not automatically provide for the latter.

Parts already made exhibit hills and valleys which have functional significance and can be surveyed and described in various ways, as can the mountains on the earth. For this purpose, the first requirement is simply to ensure that the instrument used for surveying the topography measures over a base length appropriate to the spacing of the crests.

For the purpose of specification, however, the indication on the drawing is generally limited to the permissible roughness height (generally indicated by the c.l.a. value), in combination with a statement of the sampling length over which measurement is to be made (generally in terms of the meter cut-off) and no formal provisions have so far been made for indicating the range of crest spacings that the process may produce. If the measurement of the manufactured workpiece is to have its intended meaning, either the process must yield crest spacings shorter than the meter cut-off prescribed on the drawing, or the inspector must use his discretion to increase the meter cut-off sufficiently to embrace what the process has produced (which, of course, will again provide a valid assessment of the c.l.a.). One remedy is obvious: it could be clearly stated in the standards that when roughness texture is specified in terms of a parameter (such as c.l.a.) to be measured with a prescribed sampling length or meter cut-off, the prescribed sampling length or meter cut-off *must* be taken as an upper limit to the crest spacing that the manufacturing process may produce. This would not only help to ensure rational measurement without putting the inspector in a quandary, but would also represent an additional control over the process, the occasional need for which is reflected in the current use of peak or high-spot counting.

APPENDIX 23.1

REFERENCES

(1) Reason, R. E. 'Surface finish and its measurement', *Instn Prod. Engrs J.* 1944 (October).

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