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Surface roughness: the measurement of spark erosion reference standards

A. PRAKASH†, K. STRUIK‡ and J. KONING‡

The paper describes the surface roughness measurement of spark erosion reference standards by means of digital technique, enabling a comprehensive assessment of roughness parameters. Using digital and Fourier analysis, parameters have been evaluated in terms of density and slope distribution, Abbott curve, power spectrum, auto-correlation functions, etc. The commonly used Ra, Rms and Rt have been calculated as per the ISO standard on the mean line (M) system. The effects of standard ISO-double RC and the suggested phase-corrected filters on the roughness parameters, waviness in particular, have also been discussed.

Introduction

More definitive methods are needed to augment the rather limited existing quantitative parameters used for the assessment of surfaces. In the absence of such an assessment it is difficult to decide which of the roughness parameters need to be controlled precisely to achieve the desired functional requirement of a system. From an industrial point of view any surface roughness assessment is incomplete if it cannot lead to predicting the performance of surface under operating conditions. The reliability of a system cannot be forecasted satisfactorily without establishing the relationship between surface characteristics and surface functions of the components constituting the system.

On the other hand basic research in diverse fields such as wear, corrosion, lubrication, dynamic response of machine tools, etc., cannot be satisfactorily conducted without a knowledge of the quality and functional behaviour of surfaces involved. The basic purpose of this study is to define surface characteristics in such parameters which are sufficiently representative of surface functional behaviour. Surfaces produced by spark erosion process providing relatively random configuration are ideal for such an investigation.

Notation

The terminology used is in accordance with the ISO recommendations on surface roughness measurement by the mean line (M) system§. The surfaces investigated were from the spark erosion reference standards, which are made according to the German 'VDI 3400' specifications for electro-erosion

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§ ISO recommendations on surface roughness measurement, ISO/R 468–1966 [E], ISO/R 1878–1970 [E], ISO/R 1880–1970 [E], ISO/TC 57 (Secretariat 86) 175 E.

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machining. These standards (Fig. 1) are recommended for comparison purposes by the physical and chemical machining group of the C.I.R.P.

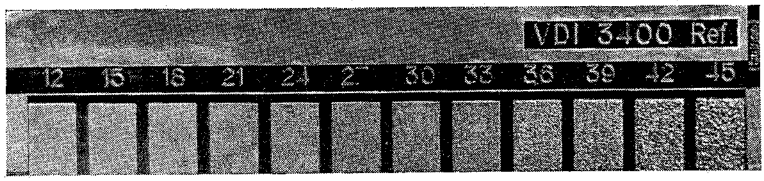

Figure 1.

Specifications of the other standard equipments used are: stylus—type FT 250 with a datum attachment, radius 3 μm, force 0·8 mN, maximum range 250 μm, manufactured by Perthen, West Germany. Measuring Bridge—type KWS/3S–5, carrier frequency 5 kHz, manufactured by Hotttinger Baldwin Messtechnic, West Germany. Digital Voltmeter—model DPM–1E1V, voltage full scale 1·999 V, manufactured by Analog Devices, Cambridge, Massachusettes U.S.A.

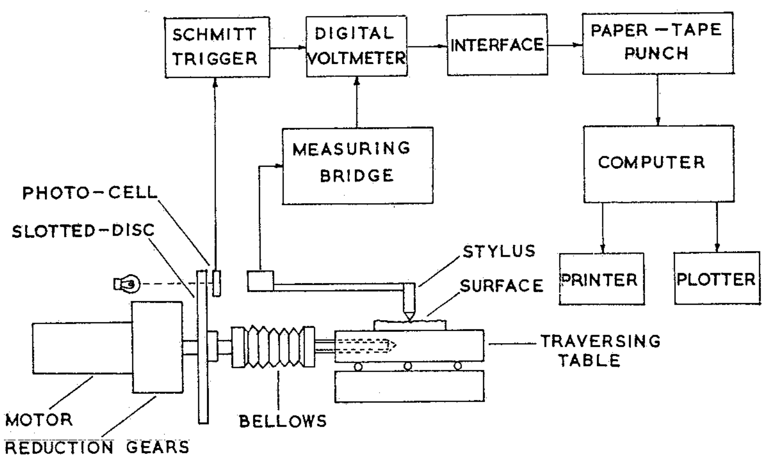

Figure 2. Schematic diagram of the digitized surface roughness measuring apparatus.

The apparatus

The apparatus used, shown diagrammatically in Fig. 2, is based on the principle of stylus-type roughness measuring instruments with provision for digitizing of the surface profile ordinates. It consists of traversing table, stylus-pivot, slotted disc and photo diode mechanism and electronic circuitry and instruments such as measuring bridge, digital voltmeter, interface, etc.

The process of digitizing consists of converting continuous data into discrete numbers. Analogue signals originating from the stylus traversing over the surface to be measured are converted into discrete digital signals by the digital voltmeter. The slotted disc and photo diode mechanism triggers these signals so as to be recorded at distances of 2·5 μm only. These digitized signals having values proportional to departures of the profile from a reference level are punched on a paper tape. A special code (Compact) used reduces punching time by a factor of 2·5.

Accuracy of measurement

It is important to have a sufficient number of profile ordinates to describe properly the significant information in the high frequencies. On the other hand sampling at points which are too close together will yield correlated and highly redundant data and increase greatly both the labour and cost of calculations. Recording profile ordinates at points closer than 2·5 μm leads to no greater accuracy when the minimum stylus tip radius recommended is 2 μm.

The stylus used was fitted with a new tip and well adjusted for linearity. The apparatus was calibrated with a lever specially made for the calibration of stylus type instruments (Rank Taylor Hobson, England). The calibration, carried out at various magnifications, was within $\pm 0{\cdot}5\%$. The zero level of the apparatus, determined by traversing over an optical flat of known accuracy, was of the order of 0·003 μm (Ra) and therefore not taken into account. Errors due to dynamics of a moving stylus were found insignificant for the present set-up of the apparatus and traverse speed used.

Calculation of roughness parameters

A standard cut-off length (c.o.) of 0·8 mm and a traverse length of 4 mm with a step of 2·5 μm between two ordinates was used. Computer programme (courtesy Mr. P. Vanherck, University of Leuven, Belgium) first determines the position of a mean line (line of least squares) through the profile. New ordinates having zero mean are used for plotting surface profiles and in calculating standard parameters as Ra, Rms, Rt, etc.

Total depth of the profile is divided by lines drawn parallel to the straight reference line at equal distances. The percentage of ordinates lying between two lines (class-width) divided by the class-width gives normalized ordinate density function. The shape of the density curve is described by the two parameters skewness and kurtosis (Peklenik 1967–68). Skewness is zero if the density function is symmetrical around the mean value. It is positive or negative if more ordinates are present at the top or bottom of the profile respectively. Kurtosis is equal to three for a Gaussian curve. It is greater than three for a sharp rising curve and less than three for a flatter curve. Abbott curve also known as bearing area curve, gives cumulative ordinate density function and represents the length of material intercepts at various depths as a percentage of the total length. The percentage of tangents with the slope-value concerned lying in the corresponding class-width divided by the class-width gives normalized slope distribution function. Root mean square value of the slope has been used to calculate average wavelength introduced by Spragg and Whitehouse (1970-71).

Roughness parameters based on the mean line found by ISO-double RC and phase-corrected filters as suggested by Whitehouse and Reason (1967–68, 1965) have also been calculated. Transmission characteristics of both the filters are given in Fig. 3.

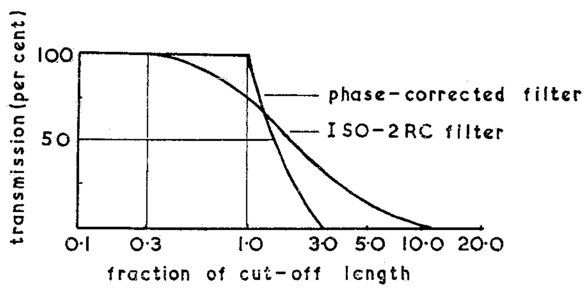

Figure 3.

The Fourier transformation is a useful tool for determining the frequency content of a time varying signal. The power spectrum which is obtained by applying Fourier transformation to the profile ordinates and conjugate multiplication, gives frequency composition in the frequency domain. The auto-correlation function, obtained by applying inverse Fourier transformation to the Power spectrum, furnishes similar information in the time domain. In order to implement Fourier transformation digitally, the continuous input signals are sampled (measured) at fixed intervals of distance (Δl) instead of time. For digitized signals, the formal Fourier parameters—the frequency step (Δf), also referred to as frequency resolution, and the bandwidth (f-max)—are calculated by the formulae $\Delta f = 1/N \,.\, \Delta l$, $f\text{-max} = \Delta f \,.\, N/2$, where N is the total number of digitized signals referred to as profile ordinates and Δl is the distance between two profile ordinates. In the present case the values of the frequency step and the bandwidth are 0·195 and 200 cycles/mm. respectively. For normalization power has been divided by the bandwidth giving its value in μm^3. The auto-correlation function has also been normalized by dividing its value at zero shift (auto-corr (0)). To avoid ‘ aliasing errors ’ and reduce computing time cosine window and Fast Fourier transformation have actually been used (Dens, 1971, Otnes and Enochson 1972).

Details of calculations are available in a draft recommendation to CIRP TC ‘ Surfaces ’ meeting, February 1973, by Mr. W. de Bruin, University of Twente, Netherlands and Mr. P. Vanherck.

Table 1 summarizes the Ra, Rms and Rt values calculated for fine (15, 18), medium (27, 30) and rough (36, 42) classes (surfaces) of the four standards. The range, which is standard deviation for the 5 c.o. lengths of a sampled length, specified for ISO-R468 is also approximately applicable to the ISO-2RC and phase-corrected filters. Tables 2 and 3 show specimen computer outputs. For the sake of comparison the Ra values calculated for various standards have been plotted in Figs. 4 and 5. Figures 6 and 7 show specimen computer plottings of surface profiles and the various functions for classes 27 and 36 standard 1. The length traversed by the stylus being long, only one measurement has been taken on each surface. The term Rt used is the mean of independent Rt values of the five successive sampling lengths.

Analysis of results

Ra : values measured by ISO-R468 and both the filters fall within the specified range for medium class only (27). They are lower or higher for fine

Standard No.	VDI-Class No.→	15			18			27		
	Specifications	RA	RMS	RT	RA	RMS	RT	RA	RMS	RT
1	ISO-R468	0·34	0·41	2·07	0·62	0·74	3·62	1·98	2·40	10·85
		±0·03	±0·03	±1·00	±0·05	±0·05	±1·05	±0·50	±0·60	±2·45
	ISO-2RC Filter	0·56	0·68	2·87	0·71	0·90	5·07	2·13	2·62	15·06
	Phase-corrected	0·34	0·41	2·96	0·62	0·75	5·07	2·03	2·48	14·14
2	ISO-R468	0·43	0·54	2·78	0·72	0·90	4·67	2·10	2·55	11·40
		±0·05	±0·07	±0·45	±0·02	±0·05	±1·15	±0·45	±0·50	±3·60
	ISO-2RC Filter	0·57	0·72	3·50	0·90	1·18	4·82	2·28	2·80	13·55
	Phase-corrected	0·43	0·54	3·20	0·73	0·90	5·24	2·18	2·67	13·50
3	ISO-R468	0·40	0·50	2·50	0·68	0·85	4·50	2·25	2·80	12·54
		±0·05	±0·05		±0·07	±0·07	±1·20	±0·75	±0·80	±4·00
	ISO-2RC Filter	0·40	0·50	2·62	0·71	0·91	4·92	2·45	3·02	15·00
	Phase-corrected	0·40	0·49	2·86	0·68	0·84	5·32	2·37	2·90	15·14
4	ISO-R468	0·39	0·48	2·83	0·67	0·81	4·13	2·20	2·70	12·50
		±0·04	±0·05	±1·45	±0·06	±0·05	±0·40	±0·65	±0·75	±3·65
	ISO-2RC Filter	0·89	1·04	3·42	0·76	0·94	4·63	2·30	2·87	14·30
	Phase-corrected	0·39	0·48	4·05	0·67	0·81	4·38	2·23	2·76	14·40
	Specified values	0·56 0·53–0·60			0·80 0·75–0·85			2·24 2·12–2·36		

(*continued*)

Standard No.	VDI-Class No.→	30			36			42		
	Specifications	RA	RMS	RT	RA	RMS	RT	RA	RMS	RT
1	ISO-R468	2·95	3·73	26·00	7·07	8·60	33·70	19·30	23·00	82·40
		±0·90	±0·90	±16·00	±3·00	±3·10	10·50	±6·80	±7·50	±29·50
	ISO-2RC Filter	9·62	11·67	37·40	8·47	10·80	53·80	21·40	27·80	104·0
	Phase-corrected	2·82	3·57	44·20	7·47	9·30	46·40	18·80	22·60	103·0
2	ISO-R468	2·67	3·33	14·80	6·65	8·25	35·10	19·45	23·10	88·00
		±1·20	±1·6	±9·00	±3·30	±4·00	13·40	±10·20	±12·10	±50·00
	ISO-2RC Filter	8·78	10·06	28·50	9·33	11·44	54·80	29·10	34·70	158·7
	Phase-corrected	2·67	3·40	21·30	7·28	9·22	46·20	21·65	25·80	112·5
3	ISO-R468	2·95	3·65	16·90	7·55	9·50	41·30	14·10	17·40	71·7
		±1·00	±1·30	±4·00	±1·60	±1·60	11·10	±12·50	±15·40	±57·0
	ISO-2RC Filter	9·25	10·65	28·30	9·45	11·8	57·80	17·70	22·40	122·0
	Phase-corrected	3·03	3·80	20·60	7·82	9·98	52·70	14·90	19·50	121·3
4	ISO-R468	2·35	2·95	16·20	7·47	8·95	34·60	14·50	18·00	73·7
		±0·80	±1·10	±11·20	5·10	±5·70	±16·40	±6·00	±7·00	±27·0
	ISO-2RC Filter	10·65	12·03	32·70	8·58	11·12	55·30	17·30	20·75	90·6
	Phase-corrected	2·41	3·05	24·30	7·47	9·40	47·70	14·30	17·90	83·70
	Specified values	3·15 3·0–3·35			6·30 6·0–6·7			12·50 11·8–13·2		

Table 1. Values in micrometre.

Line of least squares length 6·478 mm

RT = 18·2839
RA = 2·1909
RMS = 2·7075
SKEW = +0·1227
KURT = 3·0358
SLOPE RMS = 0·19556

Average wave length (AVWL) = 86·9896

ISO R468 C. O. = 0·8 mm

RA (mean)	RMS (mean)	RT (max)	R (min)	RP_3
$+0{\cdot}1979_{10}+1$	$+0{\cdot}2410_{10}+1$	$+0{\cdot}1305_{10}+2$	$-0{\cdot}6160_{10}+1$	$+0{\cdot}6890_{10}+1$

Per C. O. length :

RA	RMS	RT	R (min)	RP
$+0{\cdot}1995_{10}+1$	$+0{\cdot}2455_{10}+1$	$+0{\cdot}1135_{10}+2$	$-0{\cdot}5040_{10}+1$	$+0{\cdot}6307_{10}+1$
$+0{\cdot}1749_{10}+1$	$+0{\cdot}2134_{10}+1$	$+0{\cdot}9912_{10}+1$	$-0{\cdot}5422_{10}+1$	$+0{\cdot}4490_{10}+1$
$+0{\cdot}2311_{10}+1$	$+0{\cdot}2763_{10}+1$	$+0{\cdot}1136_{10}+2$	$-0{\cdot}6160_{10}+1$	$+0{\cdot}5199_{10}+1$
$+0{\cdot}2127_{10}+1$	$+0{\cdot}2631_{10}+1$	$+0{\cdot}1236_{10}+2$	$-0{\cdot}5471_{10}+1$	$+0{\cdot}6890_{10}+1$
$+0{\cdot}1712_{10}+1$	$+0{\cdot}2067_{10}+1$	$+0{\cdot}9318_{10}+1$	$-0{\cdot}3688_{10}+1$	$+0{\cdot}5630_{10}+1$

Standard deviation :			RT (mean)
$+0{\cdot}2531_{10}+0$	$+0{\cdot}3039_{10}+0$	$+0{\cdot}1227_{10}+1$	$+0{\cdot}1086_{10}+2$

ISO filter C. O. = 0·8 mm

RA = 2·1376
RMS = 2·6246
RP = 6·4917
RT = 15·0642

Phase corrected filter C. O. = 0·8 mm

RA = 2·0335
RMS = 2·4886
RP = 7·1130
RT = 14·1485

Table 2. VDI-Normal No. 27, Spark erosion reference standard 1. Unspecified values in micrometre.

and rough surfaces respectively. Double RC filter gives about 30% higher values compared to those given by ISO-R468 and the phase-corrected filter which are close to each other. It is noteworthy that in the case of class 30 which showed excessive waviness, phase-corrected filter gave better results (Fig. 5).

Rms : values follow a trend similar to RA values only that double RC filter gives about 40% higher values compared to those given by phase-corrected filter and ISO-R468 which are close to each other. The ratio Ra : Rms is about 1 : 1·3.

Rt : both filters give near equal values which are about 50% higher to those given by ISO-R468. This is so as the values given for ISO-R468 in Table 1 are means of individual Rt values of 5 c.o. lengths and thus greatly eliminating waviness.

Line of least squares length 6·488 mm

RT = 73·5250
RA = 8·1158
RMS = 10·8003
SKEW = +0·4106
KURT = 4·4292
SLOPE RMS = 0·26675

Average wave length (AVWL) = 254·3942

ISO R468 C. O. = 0·8 mm

RA (mean)	RMS (mean)	RT (max)	R (min)	RP
$+0{\cdot}7076_{10}+1$	$+0{\cdot}8602_{10}+1$	$+0{\cdot}4156_{10}+2$	$-0{\cdot}1665_{10}+2$	$+0{\cdot}2491_{10}+2$

Per C. O. length:

RA	RMS	RT	R (min)	RP
$+0{\cdot}6400_{10}+1$	$+0{\cdot}8359_{10}+1$	$+0{\cdot}3751_{10}+2$	$+0{\cdot}1591_{10}+2$	$+0{\cdot}2160_{10}+2$
$+0{\cdot}6908_{10}+1$	$+0{\cdot}8277_{10}+1$	$+0{\cdot}3089_{10}+2$	$-0{\cdot}1665_{10}+2$	$+0{\cdot}1425_{10}+2$
$+0{\cdot}7362_{10}+1$	$+0{\cdot}9250_{10}+1$	$+0{\cdot}3888_{10}+2$	$-0{\cdot}1397_{10}+2$	$+0{\cdot}2491_{10}+2$
$+0{\cdot}5283_{10}+1$	$+0{\cdot}6399_{10}+1$	$+0{\cdot}2570_{10}+2$	$-0{\cdot}1213_{10}+2$	$+0{\cdot}1357_{10}+2$
$+0{\cdot}9426_{10}+1$	$+0{\cdot}1073_{10}+2$	$+0{\cdot}3556_{10}+2$	$-0{\cdot}1611_{10}+2$	$+0{\cdot}1945_{10}+2$

Standard deviation:			RT (mean)
$+0{\cdot}1525_{10}+1$	$+0{\cdot}1577_{10}+1$	$+0{\cdot}5401_{10}+1$	$+0{\cdot}3371_{10}+2$

ISO filter C. O. = 0·8 mm

RA = 8·4718
RMS = 10·8037
RP = 24·3822
RT = 53·7815

Phase corrected filter C. O. = 0·8 mm

RA = 7·4763
RMS = 9·3133
RP = 23·0658
RT = 46·3612

Table 3. VDI-Normal No. 36, Spark erosion reference standard 1. Unspecified values in micrometre.

Various functions shown in Figs. 6 and 7 give comprehensive information about the functional behaviour of surfaces. Density and Abbott curves, skew and kurtosis values tell about the distribution pattern of peaks and valleys and are suggestive of friction, wear resistance and load supporting characteristics. Surfaces with wide plateaus will well support the total load compared to surfaces with protruding peaks which are prone to collapse under load, yet they may have identical Ra and Rt values. Slope curves suggestive of directional changes of the profile curves, are of significance where the component is subsequently treated for improving its surface properties.

Rt value which measures only the total depth of surface irregularities is by no means a complete definition of the roughness as no account is taken of the frequency of the surface irregularities. *Power spectrum* establishes the frequency which, in turn, bears important relationships to the basic characteristics

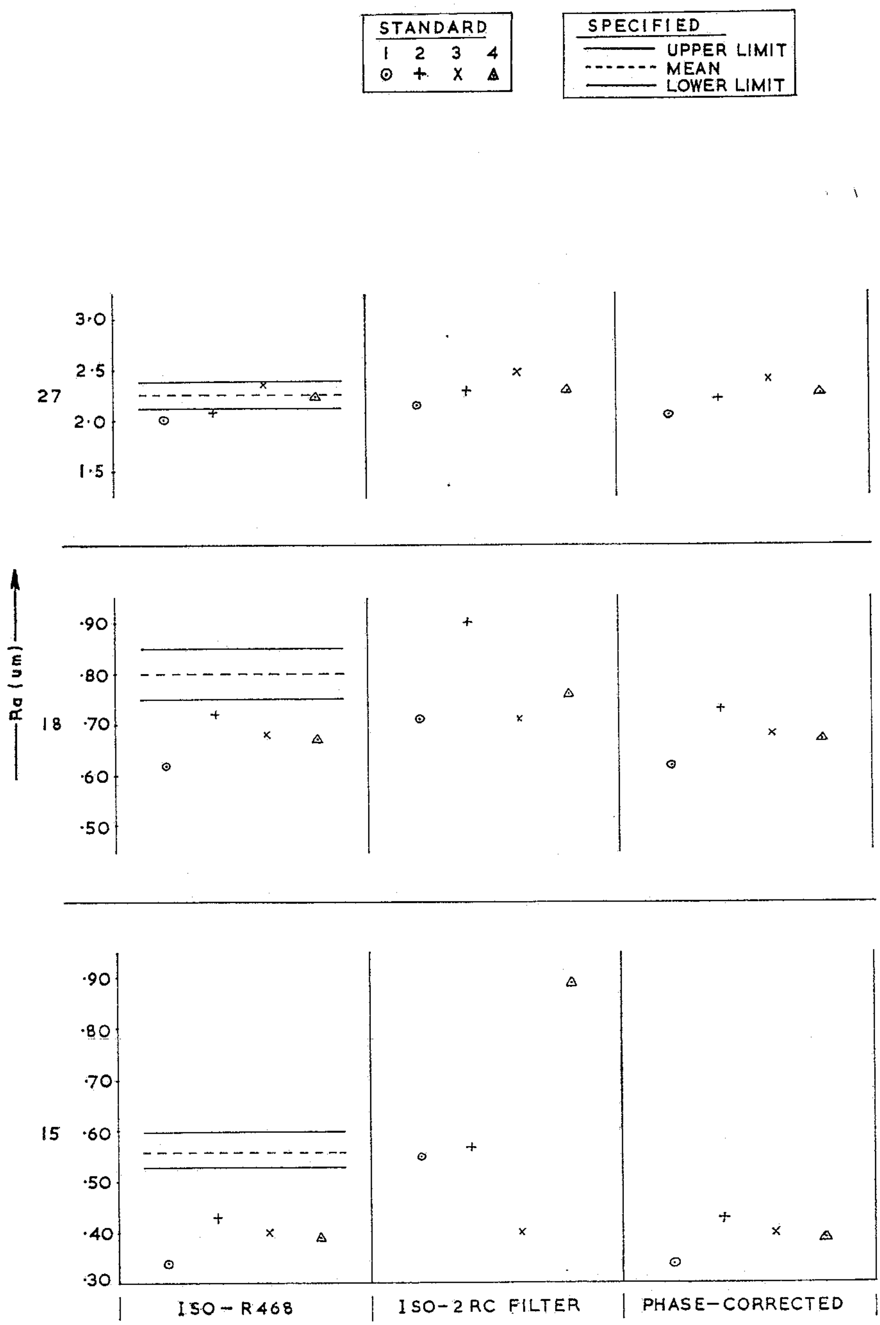
STANDARD
1 2 3 4
SPECIFIED
UPPER LIMIT
MEAN
LOWER LIMIT
Ra (um)
27
3·0
2·5
2·0
1·5
18
·90
·80
·70
·60
·50
15
·90
·80
·70
·60
·50
·40
·30
ISO – R468
ISO – 2 RC FILTER
PHASE – CORRECTED

Figure 4.

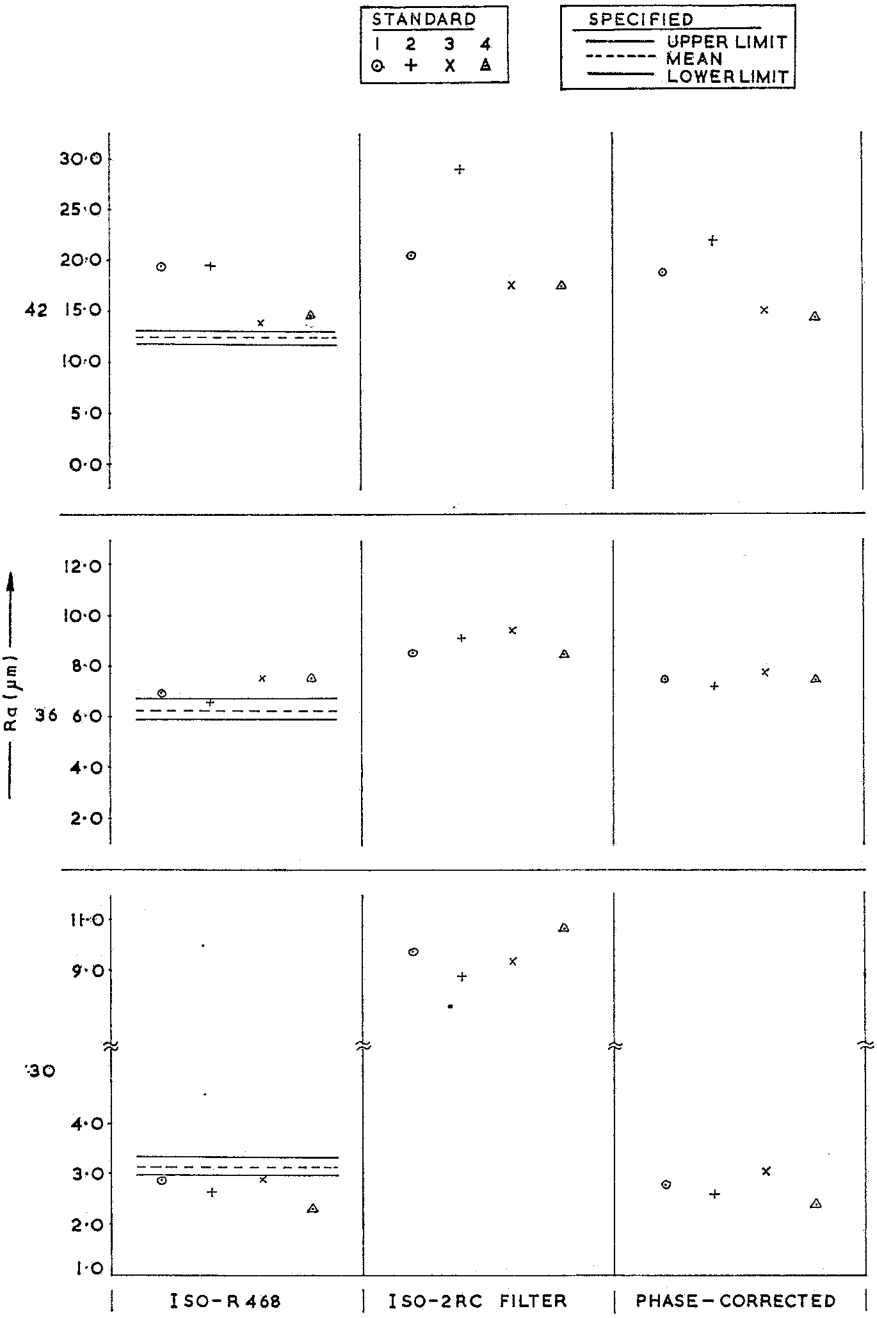
STANDARD
1 2 3 4
SPECIFIED
UPPER LIMIT
MEAN
LOWER LIMIT
30·0
25·0
20·0
42 15·0
10·0
5·0
0·0
12·0
10·0
8·0
36 6·0
4·0
2·0
Ra (μm)
11·0
9·0
30
4·0
3·0
2·0
1·0
ISO-R 468
ISO-2RC FILTER
PHASE-CORRECTED

Figure 5.

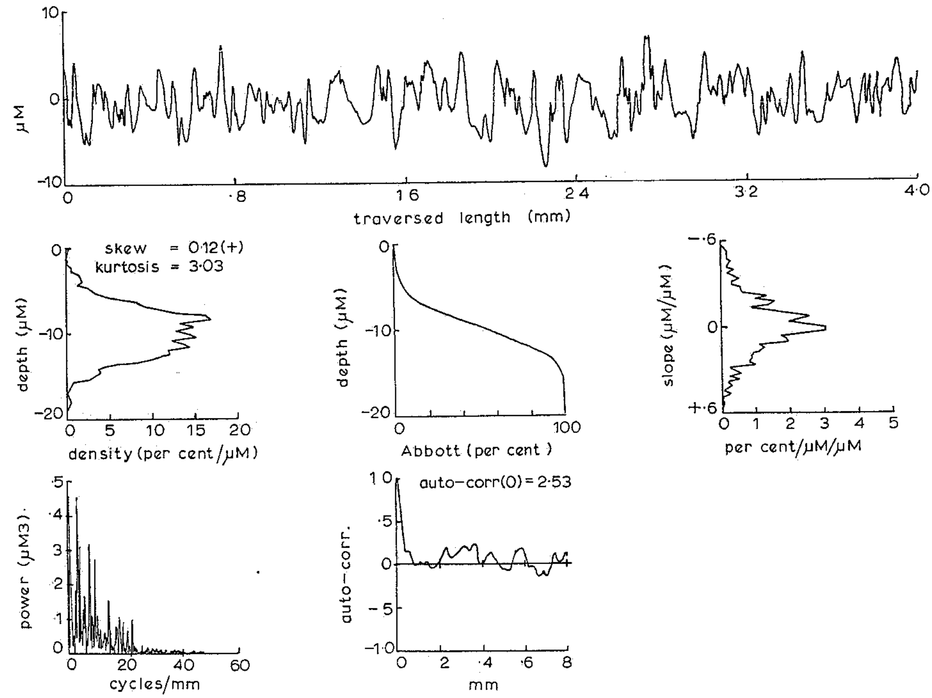

Figure 6. Spark erosion reference standard 1, VDI-class No. 27. Main frequency =0·19 cycles/mm ; maximum frequency =53·32 cycles/mm.

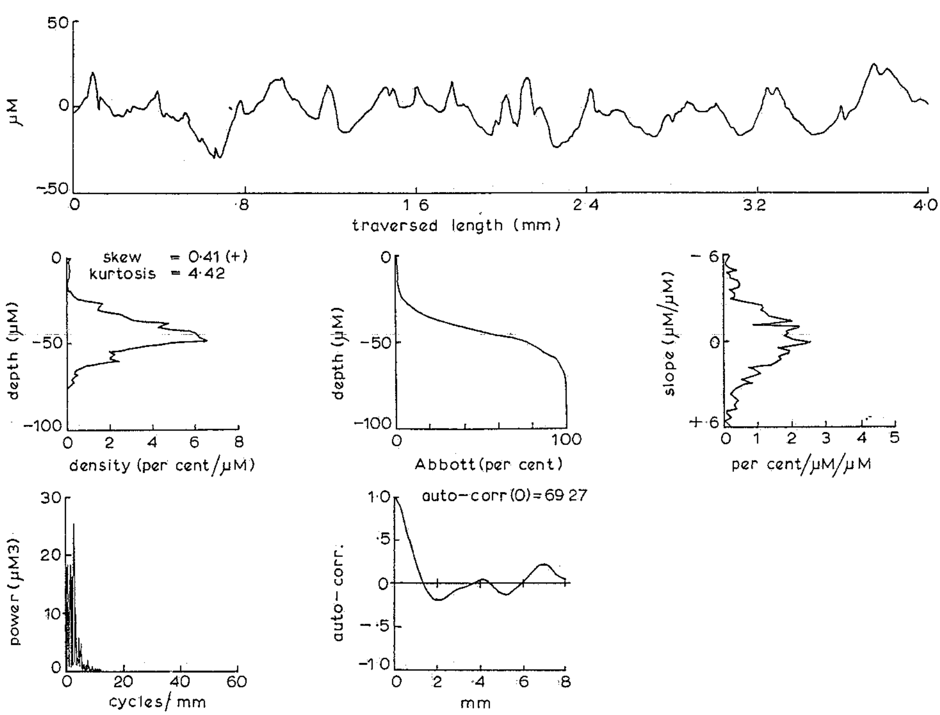

Figure 7. Spark erosion reference standard 1, VDI-class No. 36. Main frequency =2·54 cycles/mm ; maximum frequency =11·91 cycles/mm.

of the physical systems involved. *Auto-correlation* function describes the general dependence of the surface irregularities at one time on the irregularities at another time. It shows where the irregularities are similar to each other along the sampled length ; similarity is indicated by a peak in the auto-correlation function. It provides a powerful tool for detecting deterministic structure which might be masked in a random background.

As expected of a fully random surface the density distribution function is a near Gaussian curve; power spectrum shows many frequencies and auto-correlation function quickly falls to zero (Figs. 6, 7).

Conclusions

In general, results indicate that for the same class, the four standards do not give identical roughness values. Measured values of all the standards differ appreciably from those specified. Only class 27 gives roughness values which are close to the specified range. Ra and Rms give identical information and no relationship exists between Ra and Rt values of the surface.

The study also brings to light :

(a) That an assessment or comparison of the surfaces based entirely on their Ra, Rms and Rt values can lead to incorrect conclusions, specially when surfaces with random configurations are involved. In such cases functions such as density and slope distribution, power spectrum, auto-correlation, skewness, kurtosis, etc., of the surface give realistic and comparable information about its characteristics.

(*b*) The superiority of the phase-corrected filter (not yet incorporated in commercial instruments) over the standard ISO double RC filter in dealing with waviness. For Ra and Rms values the phase-corrected filter compares favourably with the ISO-R468 standard.

It should be of interest to investigate the possibility of a relationship that may exist between the power, auto-correlation functions and Ra, Rt values of the surface.

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Cet article décrit la mesure de la rugosité de la surface d'érosion électrique de référence standart au moyen de techniques digitales, permettant une évaluation compréhensive des paramètres de rugosité. Utilisant les analyses digitales et de Fourier, les paramètres ont été exprimé en terme de distribution de densité, distribution de pente, courbe d'Abbott, spectre de puissance, fonctions d'autocorrélation etc. Ra, Rms et Rt ont été calculé en norme I.S.O. sur le système de ligne moyenne (M). Les effets des filtres I.S.O.-double RC et correcteur de phase suggéré par Whitehouse, sur les paramètres de rugosité, en particulier l'ondulation, ont été discuté.

Die vorliegende Arbeit berichtet über die Messung der Rauheit der für die elektroerosive Bearbeitung vorgeschlagene Referenzoberfläche mit Hilfe einer digitalen Methode. Mittels digitaler Auswertung und Fourieranalyse werden Kenngröszen ermittelt für die Haüfigkeitsverteilungen der Amplituden und der Neigung, der Abbott Kurve, des Wellenlängenspektrums und der Autokorrellation. Die herkömmlichen Gröszen Ra, Rt, Rs werden berechnet in Übereinstimmung mit ISO R 468 für das M-system. Der Einfluss des standadisierten ISO-doppelt-RC Filters und des von Whitehouse vorgeschlagenen Phasenkorrigierten Filters auf die Messwerte, insbesondere auf die Welligkeit, wird diskutiert.

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