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The use of areal surface texture parameters for determining machining parameters in precision grinding

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The use of areal surface texture parameters for determining machining parameters in precision grinding

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ABSTRACT

The surface texture of a manufactured part is influenced by the manufacturing processes used to produce the part. Changes in these processes will result in changes in the surface texture of the part. In order to characterise and optimise the machining process variables that will affect the functionality of crankshafts, the surface texture of crankshaft samples, subjected to different manufacturing techniques, has been investigated. A focus variation microscope and a contact stylus instrument were used for the measurements. The selection of filters in evaluating areal surface texture parameters, and a comparison between the optical and stylus instruments is discussed. The response of areal surface texture parameters to changes in machining process variables is also highlighted.

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Approved on behalf of NPLML by Dr Andrew Lewis, Assistant Knowledge Leader.

CONTENTS

FIGURES

TABLES

1 INTRODUCTION

Modern manufacturing uses surface functionalization to change or to improve the physical behaviour of a part. To control this process a 3D or areal characterisation of the surface is required. As a part of the NMS Engineering and Flow Metrology Programme, ‘Measurement and characterisation for areal surfaces’ project, NPL has been involved in the development of measurement strategies for areal surface texture that are best suited to characterise industrial surfaces. Cranfield Precision, a division of Cinetic Landis Ltd, part of the Fives Group was one of the industrial partners in this project and contributed with crankshaft samples subjected to various manufacturing processes. Topography measuring techniques and areal surface texture parameters that can be used as a tool to optimise the machining process variables for improved surface texture of crankshafts are presented in this report.

The content of this report focuses on the effect of the change in machining process variables on the surface texture of crankshaft samples. The machining process variables that are under investigation are:

- in-feed axis configuration;
- grinding process; and
- type of grinding wheel.

The current measurement protocol at Cranfield Precision is to measure surface roughness parameters (*Ra*, *Rsk*, *Rq* and *Rt*) on crankshaft components.

A cosmetic issue with the surface texture of crankshaft components produced at Cranfield Precision is the appearance of a rope-like pattern on the surface of the crankshaft. This pattern is visible to the naked eye and is affected by the dressing parameters. Existence of the rope pattern on crankshaft components after the grinding process does not cause a significant effect in meeting Cranfield Precision specifications, but it causes customers to complain. The presence of the rope pattern is not picked up by the above profile parameters [1]. In order to resolve this issue with the rope pattern it is necessary to understand the surfaces and the effect of machining process variables.

The scope of this case study is listed below.

- To investigate how measurement values of areal parameters change as machining process variables are altered.
- To make recommendations regarding the surface texture parameters that are sensitive to changes in machining process variables.
- To assess the viability of using areal surface measurement to measure the rope pattern on crankshaft components.
- To determine the capability of the surface produced by different manufacturing techniques to be a good bearing surface.

The aim of case study is as follows.

- To determine the most suitable surface texture parameters that represent change in machining process variables.
- To explore the areal texture parameters that would indicate the presence of the rope pattern on crankshaft components.

The samples under test and machining process variables used to machine crankshaft samples are described in section 2. Measurements were made on the crankshaft samples using a focus variation microscope (FVM) and a profile measuring contact stylus instrument (CS). The instrument and instrument setup used for the measurements are given in section 3. Section 4 describes the measurement and analysis of surface texture, including selection of appropriate filters. Results obtained from the instruments are given in section 5. Section 6 presents a discussion of the results. As specified by the customer, the areal surface texture parameters that may be useful to determine the capability of the surface to be a good bearing surface are *Ssk*, *Sku*, *Sds*, *Sal*, *Sfd* and *Smr*. The variation of these specific areal surface texture parameters with change in machining process variables is also included in section 6. Section 7 presents summary and conclusions.

2 SAMPLES UNDER TEST

Four samples honed by four different machining techniques were supplied to NPL for investigation. The machining techniques are used, or proposed to be used, by Cranfield Precision to process crankshafts. An image of a representative sample placed in a vee-block is shown in figure 1. Each sample has five cylindrical sections, all five sections are subjected to the same machining technique and hence, are assumed to have similar characteristics. The samples characteristics are:

Material:	Steel 42CroMo
Surface Treatment:	Induction hardened to 52 Rc
Dimensions:	Length - 120 mm Diameter of shoulder - 30 mm Diameter of bar - 20 mm

Figure 1. Photograph of crankshaft sample 1

Although the five sections on all four samples are subjected to the same machining technique, sample 4 has a clear rope pattern on one part of all five sections. Currently the rope pattern is only considered to be a cosmetic defect.

Table 1 lists the operations, processes and machine configurations used to machine crankshaft samples. The crankshaft samples under investigation are subjected to similar hardening and surface treatment processes so that the samples are representatives of real life components.

Table 1. Machining process configuration used to machine crankshaft samples used for case study [1]

Sample	Process
Sample 1	• Experimental in-feed axis configuration • Standard plunge grind cycle • Grinding wheel 1
Sample 2	• Standard in-feed axis configuration • Standard plunge grind cycle • Grinding wheel 1
Sample 3	• Standard in-feed axis configuration • Experimental grinding process • Grinding wheel 1
Sample 4	• Standard in-feed axis configuration • Standard plunge grind cycle • Cubic Boron Nitride (CBN) grinding wheel 2

3 INSTRUMENTATION AND INSTRUMENT SETUP

The instruments used for the surface measurement of the crankshaft samples are listed below.

Measurements were made on the crankshaft samples using a FVM [2] and a CS [3].The instrument set up for the FVM and CS are given below.

- FVM manufactured by Alicona - InfiniteFocus Microscope

  Magnification objective lens: 20×
  Field of view: 715 µm × 544 µm
  Numerical aperture: 0.4
  x-spacing: 0.438 µm
  y-spacing: 0.438 µm

- CS manufactured by Taylor Hobson - PGI 1000

  Stylus: conisphere
  Stylus tip radius: 2 µm
  Traverse speed: 0.5 mm s^{-1}
  Length of profile: 6 mm

The software used for the analysis is MountainMap version 5.1.

The instruments are maintained in a clean environment with the humidity controlled to 45 % ± 5 % and the temperature controlled to:

- FVM - 20 °C ± 0.1 °C
- CS - 20 °C ± 0.5 °C

4 MEASUREMENTS AND ANALYSIS

In the majority of cases measurements were made on the crankshaft samples using the FVM. The reason for using an optical instrument is the shorter measurement time than the CS [2]. A CS was also used for some measurements to allow a comparison of the performance of the FVM with the CS. In this section measurement and analysis for filter selection, for comparing the performance of FVM against the CS and for surface roughness are presented.

4.1 FILTER SELECTION

To understand the performance of the FVM and to optimize the spatial bandwidth of the filters for the analysis of the surface of the samples, a series of measurements were carried out on the test sample using both the CS and the FVM.

Initially, measurements were made on the five sections (C1 to C5) of crankshaft sample 1 at five positions (D0, D1, D2, D3, D4), as shown in the figure 2, using 100× and 20× magnification lenses.

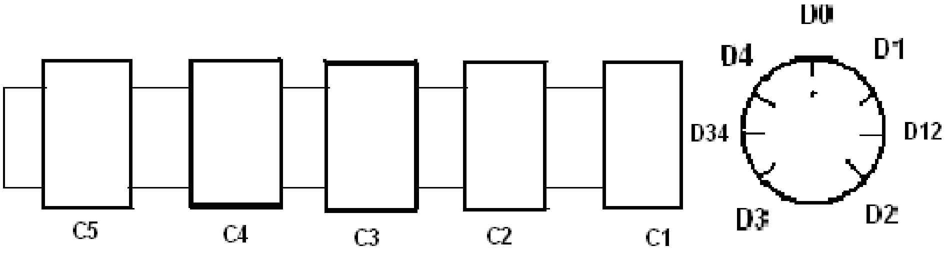


Figure 2. Schematic diagram of crankshaft sample

To avoid the effect of variations in the surface due to variability in fabrication, the same parts of the sections were measured. This allowed measurement techniques and areal parameters to be compared [4].

A set of S- and L-filter nesting indexes (the S-filter nesting index is similar to the λs cut-off filter which isolates the roughness from shorter wavelength components and the L-filter nesting index is similar to λc cut-off filter, which isolates waviness from roughness components) was investigated to determine the spatial bandwidth that can be used for the analysis of the roughness of crankshaft samples. In the selection of the appropriate nesting index filters, the analysis was based on the significant variation of areal parameters with respect to changes in the machining process variables at different spatial bandwidths. Based on the spacing of data in the *x*-axis, an initial set of filters of 2.5 µm (S-filter) and 0.8 mm (L-filter) were used for the analysis. Four iterative changes (see table 2) were made to these filter values to obtain an optimum measurement bandwidth. The analysis showed that the appropriate combination of S- and L-filter nesting indexes, which showed significant variation of areal parameters with respect to changes in the machining process variables are 8 µm and 0.5 mm respectively.

Table 2. Filters used for testing

Bandwidth	**S-filter nesting index/µm**	**L-filter nesting index/mm**
1	2.5	0.8
2	5.0	0.8
3	2.5	0.5
4	8.0	0.5

4.2 MEASUREMENTS

Comparison of the performance of a FVM with a CS

To compare the performance of a FVM with a CS, measurements were made on all five sections at one position on all four samples.

Variation of areal parameters with machining process variables

For the measurement of surface texture and to investigate variation of areal parameters with change in machining process variables, measurements were made using the FVM on the five sections at five positions (as shown in figure 2) on sample 1, 2 and 3. On sample 4, measurements were made at two places on the five sections, one with no rope pattern and one with a rope pattern, at three angular positions (D0, D12, D34) see figure 2. Insufficient time prevented more measurements being made on sample 4.

4.3 ANALYSIS

Comparison of the performance of FVM with CS

The following is a list of steps followed for the analysis of the data obtained from the FVM and CS. These steps were chosen to allow easy comparison of the results in order to check the performance of the FVM with the CS.

FVM:

- Zoom: 0.5 mm × 0.5 mm.
- Morphological filter that simulates the smoothing effect of a 2 μm ball radius.
- Level the surface using a least square mean plane.
- Five parallel profiles extracted.
- λs cut-off of 8 μm (Gaussian filter) on each profile.
- λc cut-off of 0.5 mm (Gaussian filter) on each profile.
- Evaluate parameters from each primary profile.
- Primary amplitude parameters: *Pq, Psk, Pku, Pp, Pv, Pz, Pa*, *Pc* and *Pt*.
- Roughness amplitude parameters were calculated by taking the mean of five values.

CS:

- Data from the CS were re-sampled to match with the spacing of the data from the FVM.
- Profile from re-sampled data.
- Zoom: 2.5 mm.
- Level the profile using a least square line.
- λs cut-off of 8 μm (Gaussian filter).
- λc cut-off of 0.5 mm (Gaussian filter).
- Evaluate profile parameters.
- Roughness amplitude parameters: *Rq, Rsk, Rku, Rp, Rv, Rz, Ra*, *Rc* and *Rt*.

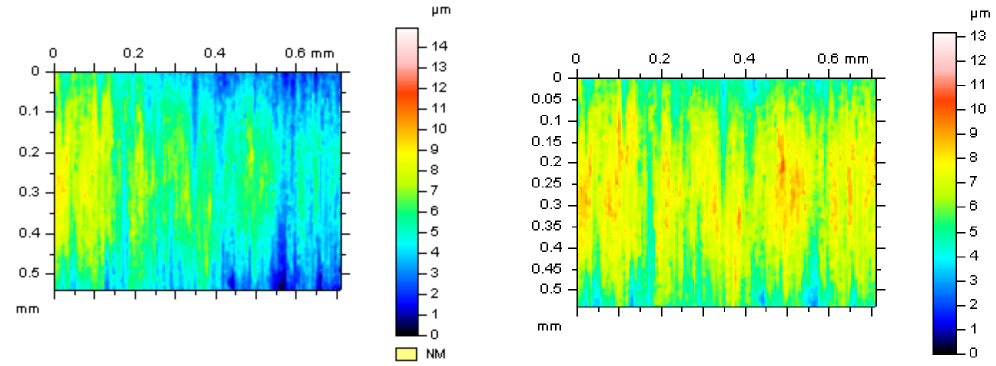
Variation of areal parameters with change in machining process variables

The steps that were followed to evaluate the variation in areal parameters with change in machining process variables were as follows.

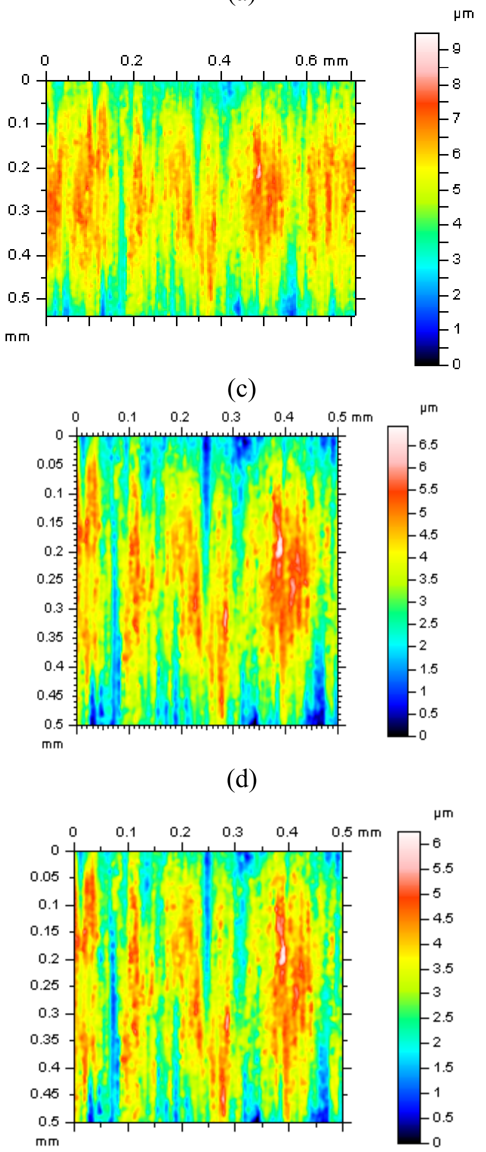
- Level the surface using a least square mean plane.
- Fill non-measured points.
- S-filter nesting index of 8 μm (Gaussian filter).

- L-filter nesting index of 0.5 mm (Gaussian filter).
- Evaluate areal roughness parameters.
- Height Parameters: *Sq, Ssk, Sku, Sp, Sv, Sz* and *Sa.*
- Functional Parameters: *Smr, Smc* and *Sxp.*
- Spatial Parameters: *Sal, St* and*, Std.*
- Hybrid Parameters: *Sdq* and *Sdr.*
- Volume Parameters: *Vm, Vv, Vmp, Vmc, Vvc* and *Vvv.*

An example of the software analysis of the surface of sample 1 at position D0, section C1 is shown in figure 3.



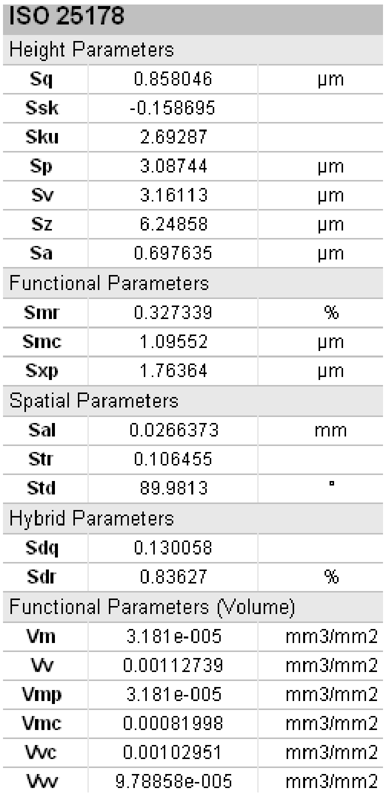
(a) (b)



(c)

(d)

(e)



ISO 25178		
Height Parameters		
Sq	0.858046	µm
Ssk	-0.158695	
Sku	2.69287	
Sp	3.08744	µm
Sv	3.16113	µm
Sz	6.24858	µm
Sa	0.697635	µm
Functional Parameters		
Smr	0.327339	%
Smc	1.09552	µm
Sxp	1.76364	µm
Spatial Parameters		
Sal	0.0266373	mm
Str	0.106455	
Std	89.9813	°
Hybrid Parameters		
Sdq	0.130058	
Sdr	0.83627	%
Functional Parameters (Volume)		
Vm	3.181e-005	mm3/mm2
Vv	0.00112739	mm3/mm2
Vmp	3.181e-005	mm3/mm2
Vmc	0.00081998	mm3/mm2
Vvc	0.00102951	mm3/mm2
Vvv	9.78858e-005	mm3/mm2

Figure 3. Example of software analysis of sample 1 (a) surface, (b) levelled and filled non measured points, (c) 8 µm S-filter nesting index applied, (d) zoomed (0.5 mm × 0.5 mm), (e) 0.5 mm L-filter nesting index applied. On the right hand side is a parameter table (FVM data)

5 RESULTS

5.1 COMPARISON OF THE PERFORMANCE OF FVM AND CS

The FVM and CS measurement results are given in table 3 and table 4. The values in table 3 are the mean parameter values based on five sets of measurements. The standard deviations given in table 3 are the standard deviations of the mean parameter values. Data in table 4 are the mean parameter values of five traces and the standard deviations are the standard deviations of mean parameter values.

Table 3. Profile data from the FVM

Parameter Type	Parameter	Units	Sample 1	Stdev	Sample 2	Stdev	Sample 3	Stdev	Sample 4	Stdev
Amplitude	***Rp***	µm	1.86	0.08	1.61	0.11	1.85	0.09	1.10	0.04
	Rv	µm	2.00	0.06	1.70	0.04	2.07	0.14	1.14	0.06
	Rz	µm	3.86	0.11	3.32	0.12	3.92	0.15	2.24	0.09
	Rc	µm	1.85	0.08	1.51	0.06	1.72	0.05	1.00	0.04
	Rt	µm	3.86	0.11	3.32	0.12	3.92	0.15	2.24	0.09
	Ra	µm	0.60	0.02	0.50	0.01	0.55	0.01	0.33	0.01
	Rq	µm	0.74	0.03	0.62	0.02	0.71	0.01	0.42	0.01
	Rsk	-	-0.14	0.04	-0.03	0.08	-0.10	0.09	-0.04	0.04
	Rku	-	2.97	0.12	2.97	0.12	3.50	0.18	2.96	0.04

Table 4. Profile data from the CS

Parameter Type	Parameter	Units	Sample 1	Stdev	Sample 2	Stdev	Sample 3	Stdev	Sample 4	Stdev
Amplitude	***Rp***	µm	1.63	0.10	1.11	0.12	1.57	0.13	0.56	0.05
	Rv	µm	1.60	0.04	1.18	0.07	1.87	0.10	0.54	0.05
	Rz	µm	3.23	0.13	2.29	0.16	3.44	0.19	1.10	0.07
	Rc	µm	1.37	0.05	0.94	0.07	1.35	0.04	0.43	0.03
	Rt	µm	3.81	0.10	2.66	0.21	4.24	0.32	1.46	0.13
	Ra	µm	0.51	0.02	0.34	0.03	0.49	0.02	0.15	0.01
	Rq	µm	0.63	0.02	0.43	0.03	0.62	0.02	0.19	0.02
	Rsk	-	-0.01	0.08	-0.10	0.17	-0.11	0.15	0.07	0.17
	Rku	-	2.98	0.21	3.49	0.25	3.76	0.46	3.92	0.09

5.2 VARIATION OF AREAL PARAMETERS WITH CHANGE IN MACHINING PROCESS VARIABLES

Data obtained from the FVM for evaluating the variation in areal parameters with machining process variables are summarised in table 5. In table 5, the parameter values of sample 1 to sample 3 are the mean parameter values based on the twenty-five sets of measurements. The standard deviation is the standard deviation of the mean. The parameter values of sample 4 and sample 4 rope patterns are the mean parameter values of fifteen sets of measurements and the standard deviation is the standard deviation of the mean.

The definition of the parameters listed in the following tables are defined in international standard ISO 25178-2 [5]. The parameters with '*' in table 5 are defined in document EUR 15178N [6].

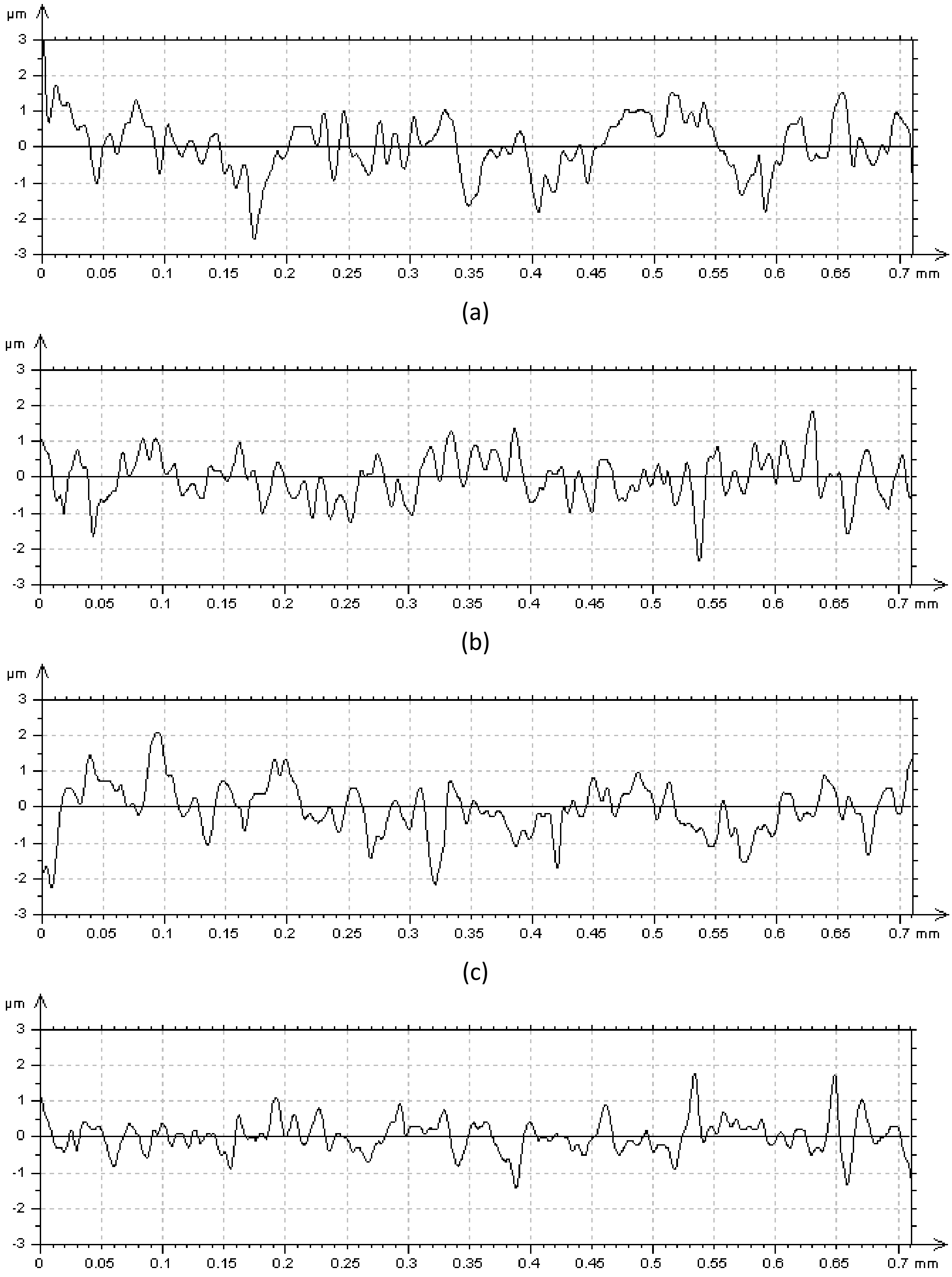
Table 5. Surface parameters - data are from the FVM

Parameter Type	Parameter	Units	Sample 1	Stdev	Sample 2	Stdev	Sample 3	Stdev	Sample 4	Stdev	Sample 4 Rope Pattern	Stdev
Amplitude	***Sq***	µm	0.79	0.01	0.69	0.01	0.77	0.01	0.54	0.01	0.52	0.02
	Ssk	-	-0.22	0.03	-0.09	0.09	-0.15	0.07	-0.23	0.04	-0.36	0.05
	Sku	-	3.07	0.05	4.07	0.91	3.95	0.28	3.36	0.13	3.31	0.08
	Sp	µm	2.72	0.07	3.05	0.38	5.12	0.28	2.43	0.29	2.27	0.15
	Sv	µm	3.17	0.06	2.92	0.06	4.38	0.28	2.27	0.06	2.24	0.10
	Sz	µm	5.88	0.10	5.96	0.38	9.50	0.52	4.71	0.29	4.51	0.20
	Sa	µm	0.63	0.01	0.54	0.01	0.61	0.01	0.43	0.00	0.41	0.01
Functional	***Smr***	%	1.61	0.40	1.07	0.26	0.11	0.05	2.74	0.70	1.52	0.42
	Smc	µm	1.00	0.01	0.86	0.01	0.94	0.02	0.66	0.01	0.62	0.02
	Sxp	µm	1.66	0.03	1.42	0.02	1.62	0.01	1.18	0.01	1.16	0.04
Spatial	***Sal***	mm	0.026	0.001	0.039	0.003	0.036	0.002	0.062	0.002	0.062	0.004
	Str	-	0.161	0.011	0.299	0.026	0.248	0.018	0.243	0.006	0.251	0.009
	Std	°	89.995	0.002	89.992	0.002	89.859	0.133	89.994	0.003	89.996	0.004
Hybrid	***Sdq***	-	0.13	0.00	0.13	0.00	0.13	0.00	0.10	0.00	0.10	0.00
	Sdr	%	0.80	0.02	0.83	0.02	0.83	0.04	0.51	0.02	0.47	0.02
	**** Sds***	µm^{-1}	2.950	0.017	3.061	0.027	3.007	0.026	3.447	0.030	3.448	0.032
	**** Sfd***	-	2.481	0.003	2.512	0.003	2.443	0.003	2.527	0.004	2.525	0.005
Volume	***Vm***	µm^3 µm^{-2}	0.032	0.001	0.030	0.001	0.035	0.002	0.024	0.001	0.021	0.001
	Vv	µm^3 µm^{-2}	1.027	0.015	0.888	0.010	0.975	0.018	0.686	0.008	0.639	0.020
	Vmp	µm^3 µm^{-2}	0.032	0.001	0.030	0.001	0.035	0.002	0.024	0.001	0.021	0.001
	Vmc	µm^3 µm^{-2}	0.710	0.009	0.612	0.006	0.685	0.008	0.489	0.006	0.467	0.016
	Vvc	µm^3 µm^{-2}	0.930	0.015	0.804	0.010	0.879	0.019	0.615	0.008	0.569	0.019
	Vvv	µm^3 µm^{-2}	0.098	0.002	0.084	0.001	0.096	0.001	0.070	0.001	0.070	0.003

6 DISCUSSION

6.1 COMPARISON OF THE PERFORMANCE OF THE FVM AND THE CS

The profile obtained from the CS can be compared to the profile extracted from the surfaces obtained from the FVM (see figure 4 and figure 5).



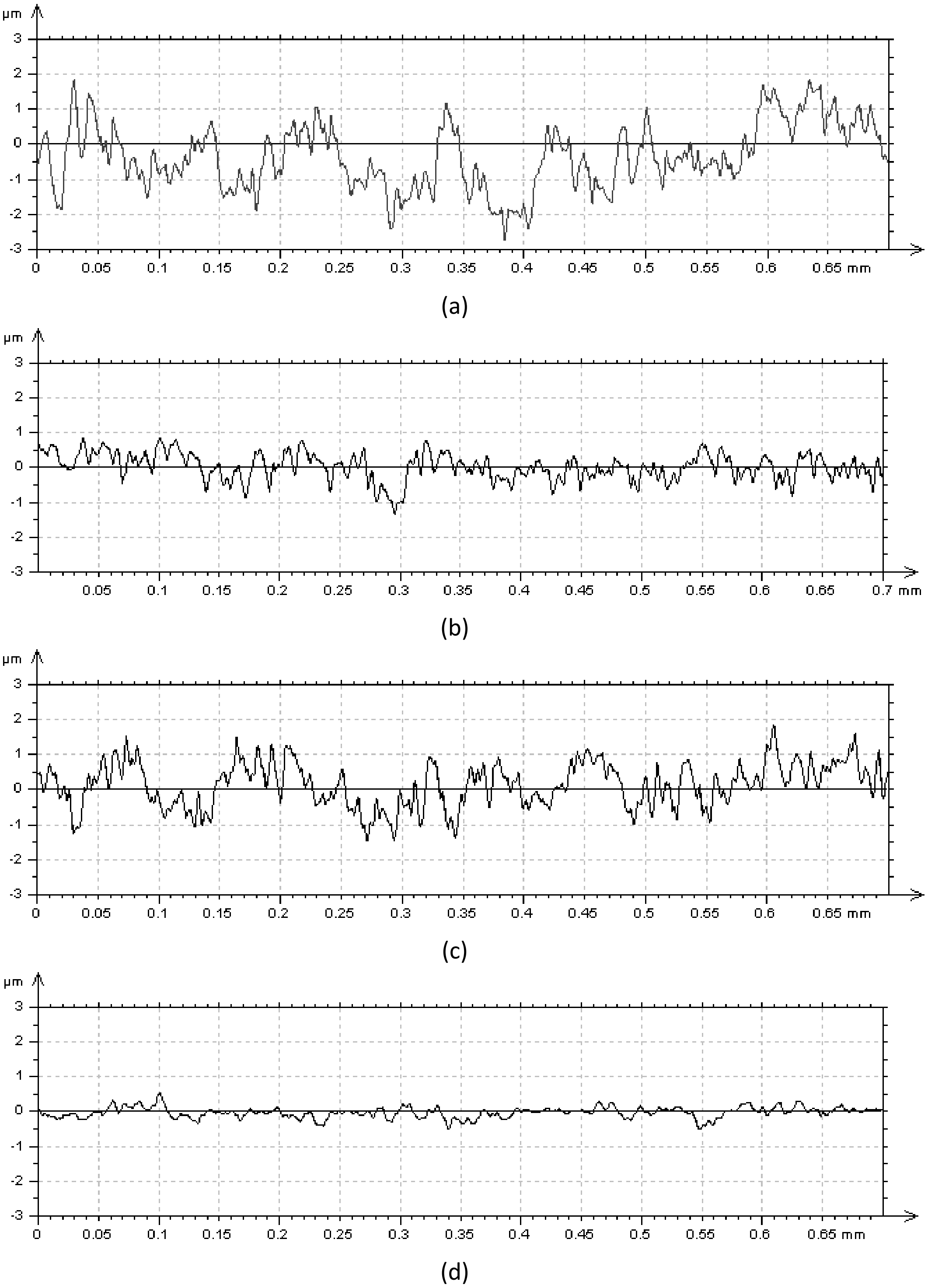
(a)

(b)

(c)

(d)

Figure 4. Profiles from (a) sample 1, (b) sample 2, (c) sample 3, (d) sample 4 (data from the FVM)



(a) (b) (c) (d)

Figure 5. Profiles from (a) sample 1, (b) sample 2, (c) sample 3, (d) sample 4 (data from the CS)

The parameters that can be compared between the CS and the FVM measurements are *Ra, Rq* and *Rz* [4]. Figure 6, figure 7 and figure 8 show the comparison of the *Ra*, *Rq* and *Rz* values obtained from the FVM and the CS. The error bars represent the standard deviation of the mean.

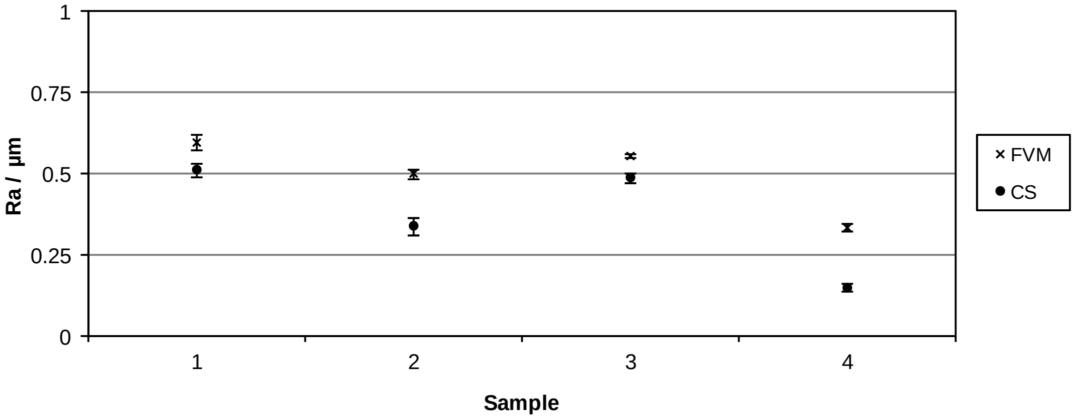


Figure 6. Comparison of amplitude parameter (*Ra*) of the samples from measurements made with the FVM and CS (error bars are for $k = 1$)

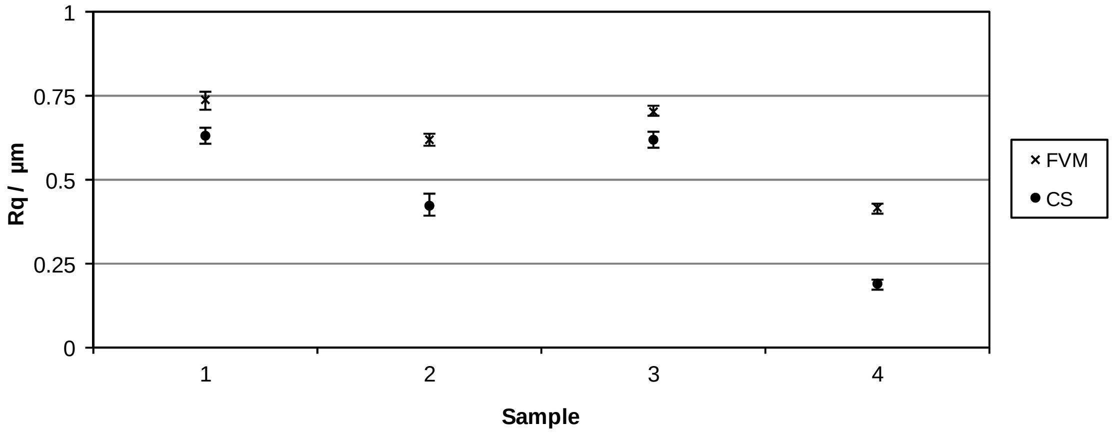


Figure 7. Comparison of amplitude parameter (*Rq*) of the samples from measurements made with the FVM and CS (error bars are for $k = 1$)

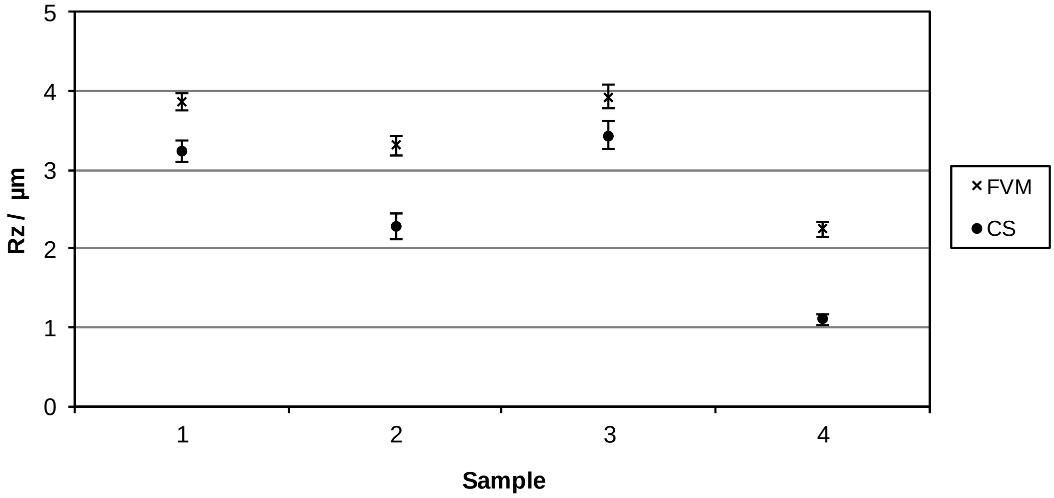


Figure 8. Comparison of amplitude parameter (*Rz*) of the samples from measurements made with the FVM and CS (error bars are for $k = 1$)

Figure 6, figure 7 and figure 8 show that *Ra*, *Rq* and *Rz* of all the samples show similar trends. The parameter values obtained from the FVM are higher than those from the CS. The reason for this difference between the CS and FVM data is not fully understood. Since the variation in the data obtained from the CS and the FVM are systematic; the FVM can still be used to measure the correlation of the areal parameters with change in machining process variables.

6.2 VARIATION OF AREAL SURFACE PARAMETERS WITH MACHINING PROCESS VARIABLES

Table 5 shows the surface parameter data obtained from the FVM. The data are intended to show that the surface has modified with change in machining process variables: in-feed axis configuration, grinding process and grinding wheel. Sample 2 was produced using a conventional manner for manufacturing a crankshaft component with standard in-feed axis configuration, standard plunge grind cycle and using a standard grinding wheel. The variation of the *Sa* and *Sq* values with changes is machining process variables is shown in the figure 9 and figure 10.

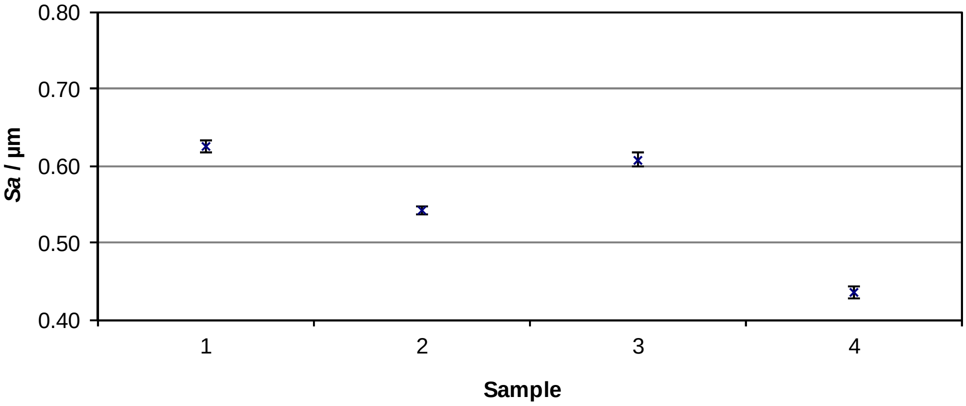


Figure 9. Variation of *Sa* with machining process variables (data from the FVM, error bars are for k = 1)

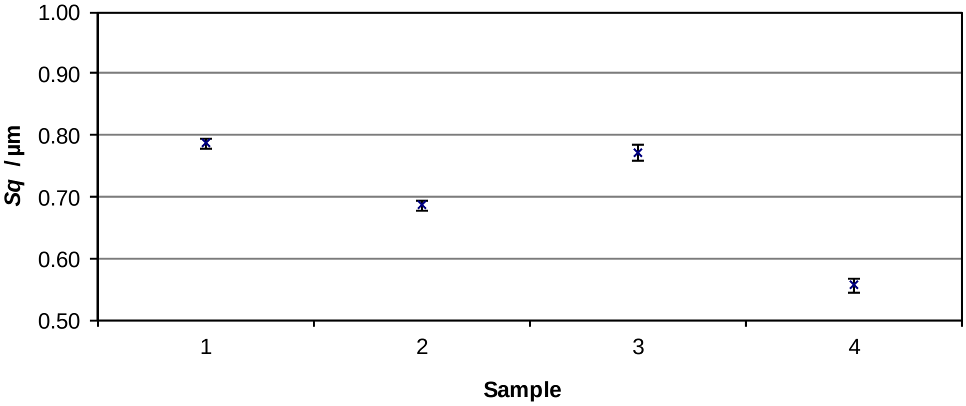


Figure 10. Variation of *Sq* with machining process variables (data from the FVM, error bars are for k = 1)

From figure 9 and figure 10 it is apparent that the trend of *Sa* is similar to that for *Sq*. From figure 10 it can be seen that the *Sq* of sample 1 is greater than the *Sq* of sample 2 implying that change in in-feed axis configuration has an effect on the *Sq* parameter result. But, with the change in grinding process, the roughness of sample has increased and this is shown with the higher *Sq* of sample 3. Usage of a CBN grinding wheel has drastically reduced the *Sq* value by approximately 45 % (see figure 10). This change in *Sq* shows that the choice of the grinding wheel has an effect on the surface texture of the sample.

Other than *Sa* and *Sq*, the areal parameters that show variation with change in machining process variables can be identified by a variation factor (σ_{ij}), which is the combined standard deviation of the mean of the areal parameter divided by the difference in the mean parameter values. The equation that was used to calculate the variation factor is

$$\sigma_{ij} = \frac{\sqrt{\sigma_i^2 + \sigma_j^2}}{\left| M_i - M_j \right|} \times 100 \qquad (1)$$

where $\sigma_{i\,j}$ is the variation factor, σ_i and σ_j are standard deviation of the means of two samples *i* and *j*, and M_i and M_j are the mean of parameter values of two samples.

In **table 6**, $\sigma_{1\;2}$ is the variation factor based on the difference in the mean of parameter values of samples 1 and 2.

Table 6. Variation in factor of surface parameters with respect to machining process variables (FVM data)

Parameter Type	Parameter	$\sigma_{1\,2}$ %	$\sigma_{2\,3}$ %	$\sigma_{3\,4}$ %	$\sigma_{4\,\text{4-rope}}$ %
Amplitude	***Sq***	12	18	6	60
	Ssk	70	198	104	48
	Sku	92	794	53	309
	Sp	119	23	15	202
	Sv	33	19	13	345
	Sz	494	18	12	178
	Sa	11	16	6	63
Functional	***Smr***	89	28	27	67
	Smc	13	23	7	48
	Sxp	13	10	4	232
Spatial	***Sal***	25	103	9	14562
	Str	20	62	361	119
	Std	100	100	98	169
Hybrid	***Sdq***	73	1019	12	76
	Sdr	76	1735	13	80
	**** Sds***	29	71	9	2805
	**** Sfd***	13	6	6	543
Volume	***Vm***	69	55	22	39
	Vv	13	24	7	46
	Vmp	69	55	22	39
	Vmc	11	14	5	79
	Vvc	15	28	8	44
	Vvv	16	15	6	433

A value below 100% of $\sigma_{i\,j}$ indicates correlation between change in machining process variables and surface texture parameters. The smaller the value of $\sigma_{i\,j}$, the stronger the correlation between the surface texture parameter and change in machining process variable.

The parameters that showed measureable variation between sample 1 and sample 2 are *Sa, Sq, Vmc, Sxp* and *Smc*, between sample 2 and sample 3 are *Sxp*, *Vmc*, *Sa*, *Sq* and *Smc*, and between sample 3 and sample 4 are *Sxp*, *Vmc*, *Smc*, *Sa* and *Sq* from this it is clear that the parameters that show measurable change with change in machining process variables are amplitude parameters, functional parameters and volume parameters. Other than *Sa* and *Sq*, the common areal parameters that showed significant variation with change in machining process variables with all the four samples are *Vmc*, *Smc* and *Sxp.* The variation of these common parameters is shown in figure 11 to figure 13.

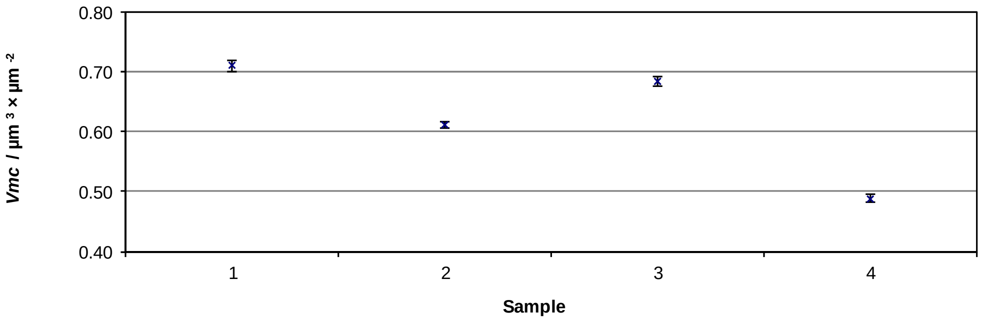


Figure 11. Variation of *Vmc* with machining process variables (data from the FVM, error bars are for $k = 1$)

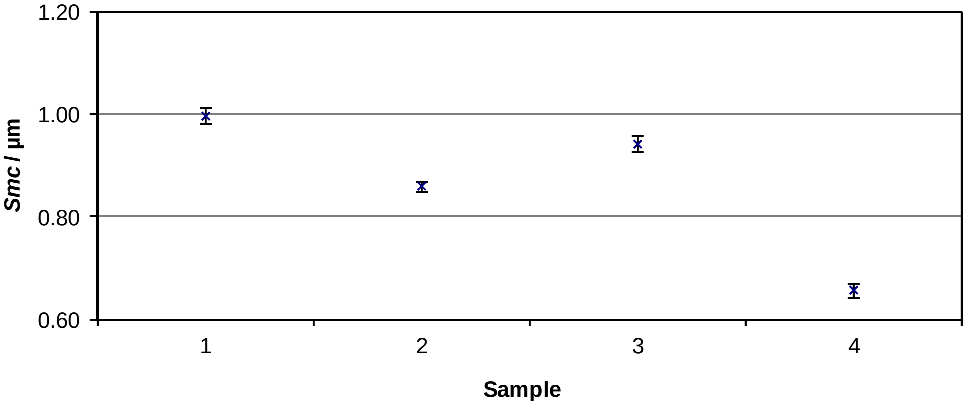


Figure 12. Variation of *Smc* with machining process variables (data from the FVM, error bars are for $k = 1$)

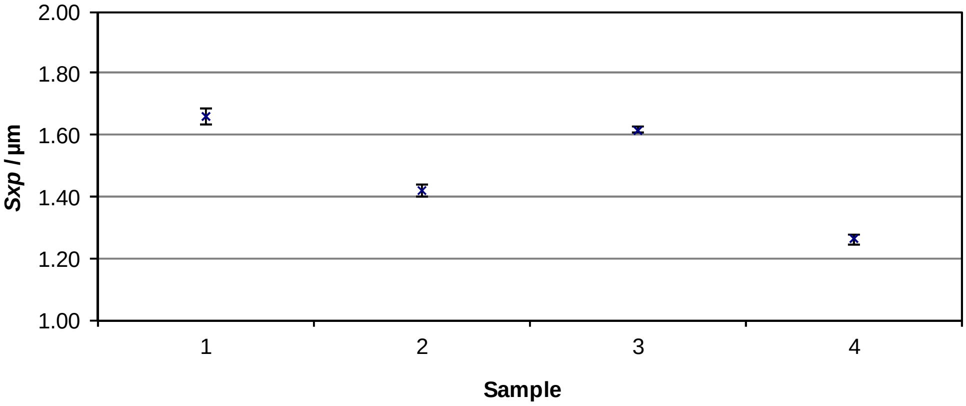


Figure 13. Variation of *Sxp* with machining process variables (data from the FVM, error bars are for $k = 1$)

From figure 11 to figure 13 it is apparent that all three parameters, *Vmc*, *Smc* and *Sxp*, show similar trends. It was noticed that there is a decrease in parameter value when using CBN grinding wheel 2 (sample 4) when compared to the conventional method of manufacturing crankshafts (sample 2), which implies that there is a significant effect of the type of grinding wheel on the surface texture.

Changes in in-feed axis configuration and grinding process also have an effect on surface texture but of smaller magnitude when compare with the effect of change in grinding wheel.

6.3 ROPE PATTERN

Table 5 shows the surface parameter values obtained from the FVM on sample 4 rope pattern. It is evident from the parameter values in table 5 that the areal parameter values obtained from sample 4 rope pattern surface are not significantly different to most of the parameter values obtained from the non-rope patterned surface. From **table 6** it can be seen that some of the volume parameters such as *Ssk*, *Vm*, *Vv*, and *Vvc* may be useful to measure the presence of a rope pattern on the surface of sample 4. The variation of *Vm*, *Vv*, *Vvc* and *Ssk* with the presence of a rope pattern can be seen in figure 14 to figure 18.

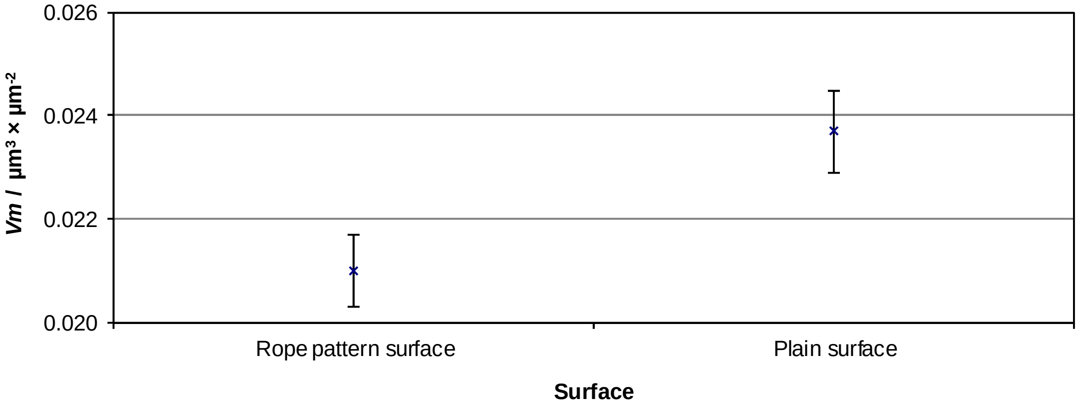


Figure 14. Variation of *Vm* with presence of rope pattern on sample 4 (data from FVM, error bars are for $k = 1$)

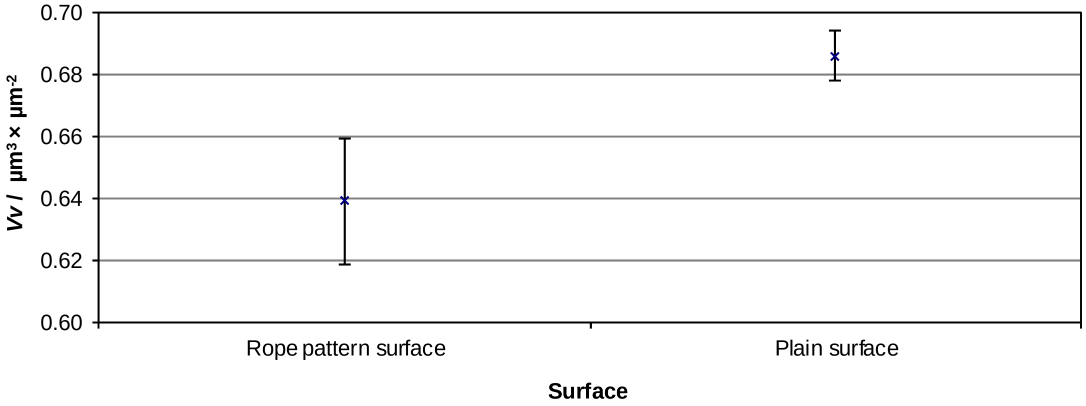


Figure 15. Variation of *Vv* with presence of rope pattern on sample 4 (data from the FVM, error bars are for $k = 1$)

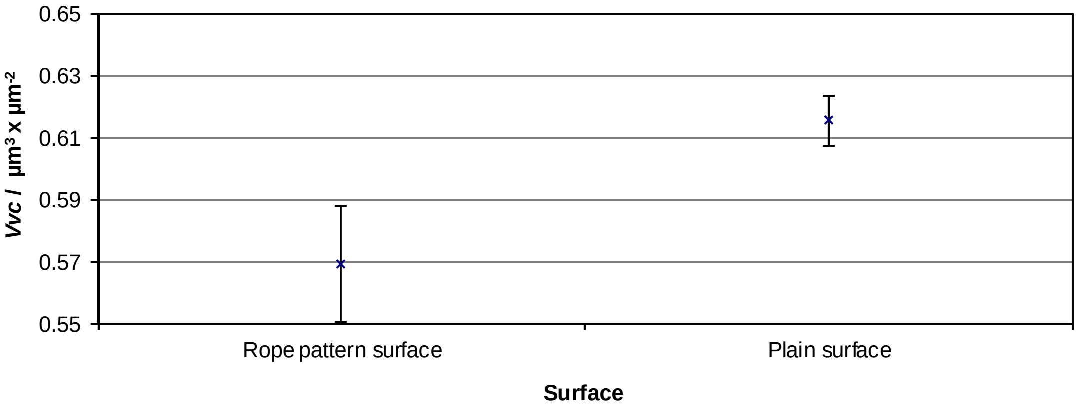


Figure 16. Variation of *Vvc* with presence of rope pattern on sample 4 (data from the FVM, error bars are for *k* = 1)

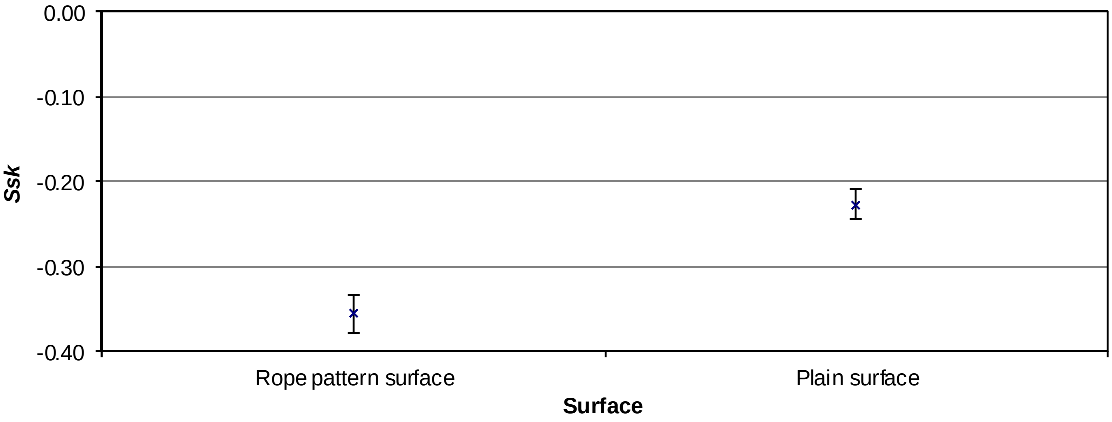


Figure 17. Variation of *Ssk* with presence of rope pattern on sample 4 (data from the FVM, error bars are for *k* = 1)

From figure 14 to figure 16, it can be seen that the volume parameters on rope pattern surfaces shows lower values than on the non-rope pattern surface. The presence of a rope pattern increases the void volume, which effects, for example, oil retention capacity. The *Ssk* value obtained from the rope pattern surface has a more negative skew than the non-rope pattern surface, which is one of the requirements for a good bearing surface. From the results it is clear that the presence of a rope pattern on the surface of a crankshaft component may not negatively effect the performance of the component although it has an effect on the visual appearance.

6.4 BEARING SURFACE

The areal surface texture parameters used in industry to monitor the quality of a bearing surface are *Ssk*, *Sku*, *Sds*, *Sal*, *Sfd* and *Smr*.

Ssk

A good bearing surface should possess negative skew. A surface with positive skew is likely to have poor oil retention capability. The variation of the *Ssk* value with machining process variables is shown in figure 18.

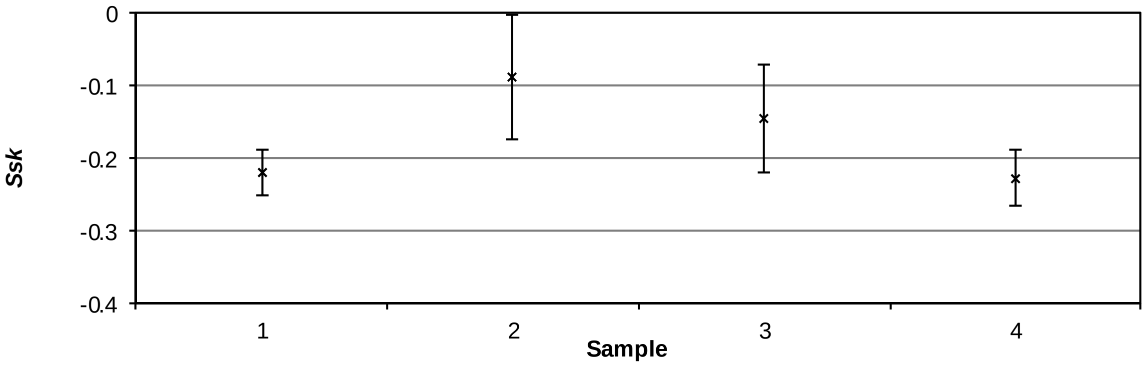


Figure 18. Variation of *Ssk* with machining process variables (data from the FVM, error bars are for $k = 1$)

Comparing the *Ssk* values of samples 1, 3, 4 with sample 2, it is clear that sample 1 and sample 4 possess similar *Ssk* parameter values with overlapping standard deviations implying that change in in-feed axis configuration (sample 1) and using BNC grinding wheel (sample 4) has similar effect on *Ssk* parameter.

Sku

The *Sku* value for a good bearing surface should be low. A spiky surface will have a high kurtosis value and a bumpy surface will have low kurtosis value. The variation of *Sku* value with machining process variables is shown in figure 19. It is clear from figure 19 that the standard deviation of the *Sku* parameter of each sample overlaps and hence it is difficult to say that there is a significant variation in *Sku* value with change in machining process variables.

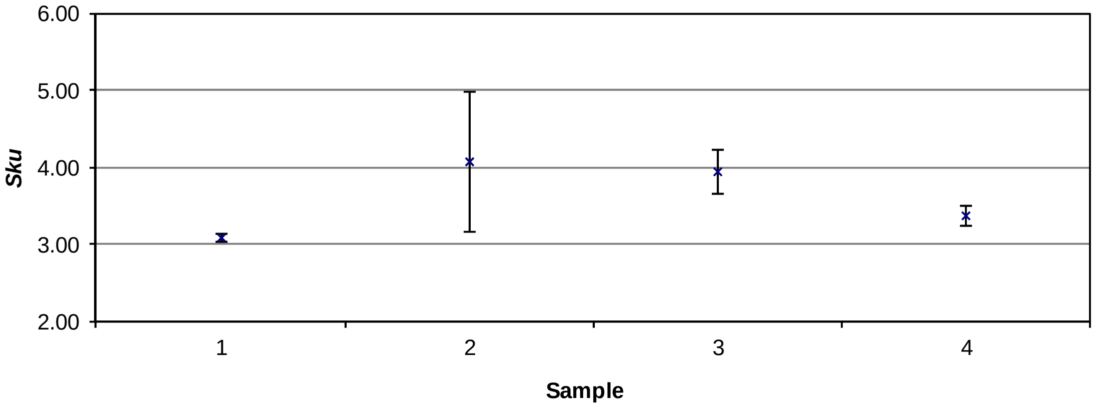


Figure 19. Variation of *Sku* with machining process variables (data from the FVM, error bars are for $k = 1$)

Sds

The density of summits indicates the “running in” potential be a surface. Figure 20 shows the variation of machining process variables on the *Sds* parameter. It can determined from figure 20 that the number of peaks has increased for sample 4 when compared to the other samples.

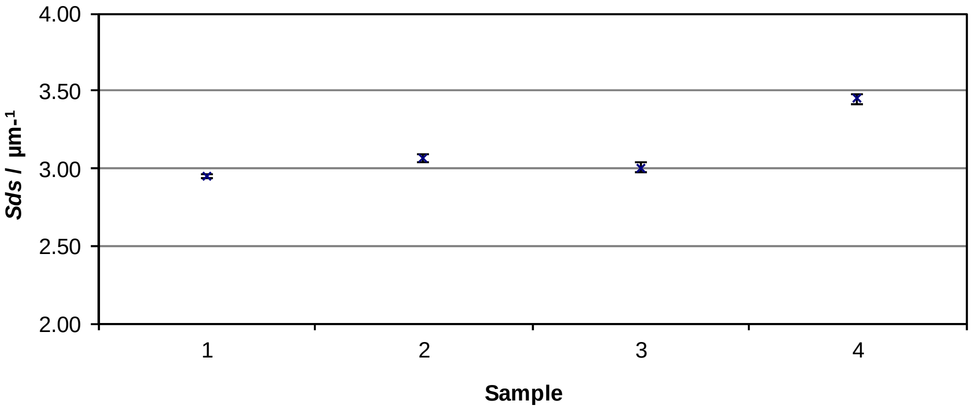


Figure 20. Variation of *Sds* with machining process variables (data from the FVM, error bars are for $k = 1$)

Sal

Sal is an indication of spatial frequency components of the surface. The *Sal* value for a good bearing surface should be high. Figure 21 shows the effect of the variation of machining process variables on the *Sal* parameter.

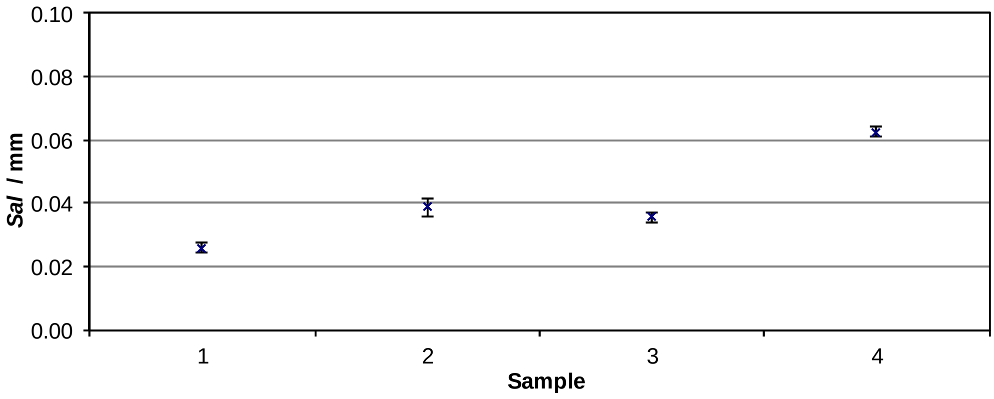


Figure 21. Variation of *Sal* with machining process variables (data from the FVM, error bars are for $k = 1$)

Figure 21 shows that the change in in-feed axis configuration (sample 1) and the change in grinding process (sample 3) have similar effects on the *Sal* parameter. Change in grinding wheel (sample 4) has a significant effect on the *Sal* parameter. Using CBN grinding wheel 2, the *Sal* parameter value has drastically increase by 60 % when compare to sample 2. This increase is a good indication that a surface is a good bearing surface.

Sfd

The *Sfd* parameter gives an indication of perceived roughness from a visual perspective. Figure 22 shows the effect of the variation of machining process variables on the *Sfd* parameter. From figure 22 it is clear that the change in machining process variables has a small effect on the *Sfd* areal parameter.

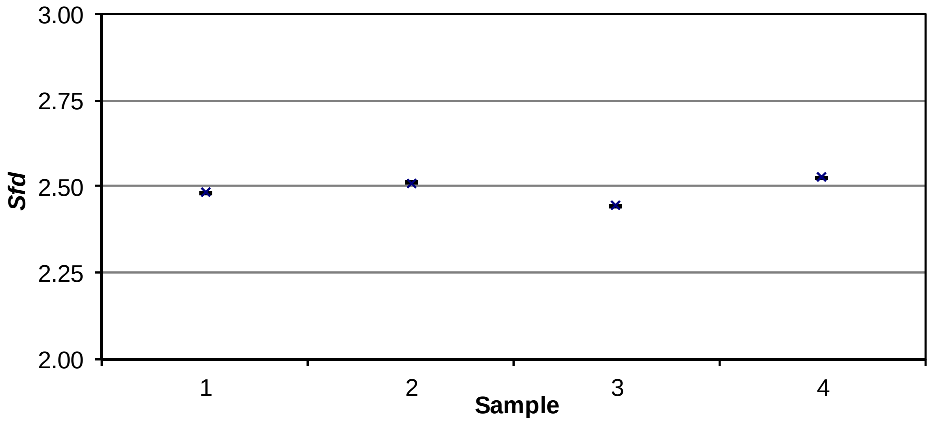


Figure 22. Variation of *Sfd* with machining process variables (data from the FVM, error bars are for k = 1)

Smr2

Smr is defined as the area material ratio of the scale limited surface. It determines the load carrying capacity of a component. The *Smr* value for a good bearing surface should be high. Figure 23 shows the effect of variation of machining process variables on the *Smr* parameter.

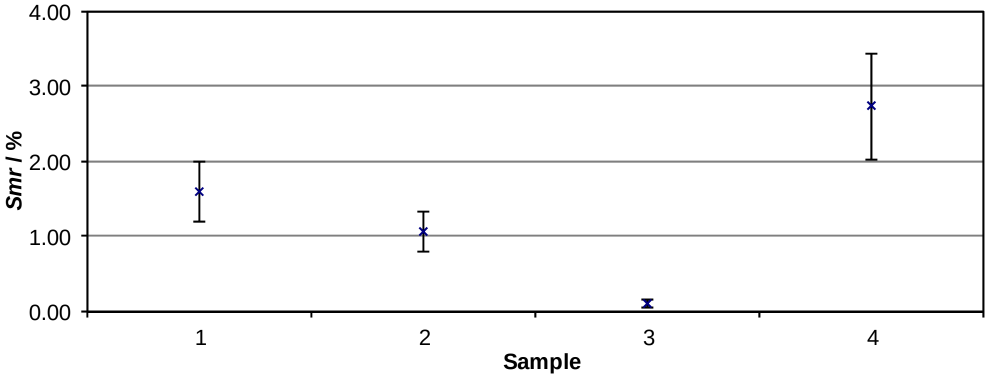


Figure 23. Variation of S*mr* with machining process variables (data from FVM, error bars are for k = 1)

It can be seen from figure 23 that the change in processing variables has a significant effect on the material ratio. With change in in-feed axis configuration (sample 1) the *Smr* value has increased by 60 % when compared to sample 2. With change in the grinding process (sample 3) the *Smr* value has decreased by 80 % and with change in grinding wheel (sample 4), the *Smr* value has increased by more than 100 % when compared to sample 2.

7 SUMMARY AND CONCLUSIONS

Changes in machining processes result in changes in the measured surface texture. NPL has investigated the surface texture of crankshaft samples from Cranfield Precision, subjected to different manufacturing techniques in order to characterise and optimise the machining process variables that will affect the functionality of the crankshafts. The machining process variables that were investigated are: in-feed axis configuration; grinding process; and type of grinding wheel.

The conclusion is that surface texture parameter values do show variation with changes in machining process variables and recommendations can be made regarding the surface texture parameters that are sensitive to changes in machining process variables.

The viability of using areal surface measurement to measure the cosmetic defect such as rope pattern on crankshaft components is also presented.

Optical instruments can be compared with stylus instrument when the spatial bandwidth of the instrument and filters used for the analysis are matched. Selection of filters is highly important when evaluating surface texture parameters. Poor selection of filters may lead to parameters with values that are not functionally significant, or are not representative of the real surface.

The variation of surface parameters with change in manufacturing process variables should be measured by calculating the relative standard deviation in percentage based on the difference in mean parameter values ($\sigma_{i\,j}$). The smaller the value of $\sigma_{i\,j}$, the stronger the correlation between the surface texture parameter and change in machining process variable.

The parameters that showed measureable variation with change in machining process variables are

- in-feed axis configuration (sample 1 and sample 2) are *Sa, Sq, Vmc, Sxp* and *Smc*;
- grinding process (sample 2 and sample 3) are *Sxp*, *Vmc*, *Sa*, *Sq* and *Smc*; and
- grinding wheel (sample 3 and sample 4) are *Sxp*, *Vmc*, *Smc*, *Sa* and *Sq*.

The areal parameters values obtained from rope pattern surface of sample 4 are not significantly different to most of the parameter values obtained from non-rope pattern surface. The parameters that may be useful to show measurable variation between the non-rope pattern surface on sample 4 and the rope pattern surface on sample 4 are *Vm*, *Vv*, *Vvc* and *Ssk.*

8 ACKNOWLEDGEMENTS

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