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3D Surface Characterisation of Precision Finished Surfaces

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--ABSTRACT--

Frictional characteristics of the bearing and biomedical surfaces are known to be affected by surface texture. Therefore, detailed surface characterization is very important for predicting the tribological/functional response of the surface. Traditionally, only 2-D roughness parameters, which generally fail to capture the 3-D lay/surface geometrical characteristics, were used. There is a comprehensive set of 14 parameters developed by Dong et al. which capture the spatial and amplitude parameters. The paper deals with development of codes based on their work and characterizing precision and ultra-precision finished surfaces.

KEYWORDS : *surface, spatial, texture, topography*

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I. INTRODUCTION

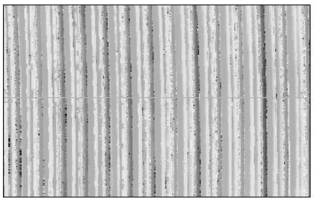
A set of 3D parameters are required to describe the properties of surface in effective way. Also the functional properties cannot be obtained by using 2D parameters. Various 3D parameters have been defined based on different properties like amplitude properties and spatial properties required for describing the surface [1]. These parameters have been successful in analysing various problems in industrial and research field, related to surface characterization. This data is acquired using stylus based contact methods or interferometry based optical methods. The computation of these parameters require considerable amount of calculations. Therefore a tool is required which can calculate these 3D parameters for various precision finished surfaces. This work presents 3-D surface amplitude and spatial parameters for different engineered surfaces. This work is focused on 3-D surface topographic analyses of four different classes of precision finished surfaces. The first category of surfaces is flat surfaces produced by super finishing methods used in bearing industry. The second category of surfaces is cylindrical surfaces used in bearing industry. The third category of surfaces is produced for specific tribological application. The fourth category of surfaces is machined sapphire surfaces and a super finished sapphire which has been created via a proprietary process developed at IIT Bombay.

II. ANALYSIS OF PRECISION FINISHED SURFACES

Flat Bearing Surfaces : Four precision finished bearing surfaces are analysed under this section: Grinding(GD), Honing (HN), Hard turning (HT), and Isotropic Finishing (IF). Typical topographies of the four surfaces produced in AISI 52100 steel (60-64 HRc) [5-6, 13]. The traditional 2-D analysis shows that IF has the lowest average surface roughness height (R_a) and GD the highest. The trend of the peak-to valley roughness height, R_t, is similar to R_a. R_{sq} is surface skewness, a measure of spiky features on the surface. A surface with predominant peaks is considered as 'positive skew' and a surface with predominant valleys is considered as 'negative skew'. 2-D surface parameters have been conventionally used to characterize surfaces. Some key 2-D parameter values for the four surfaces are given in TABLE 1.

Table 1, 2-D Surface parameters.

	GD	HN	HT	IF
R_a (□m)	0.51	0.24	0.29	0.05
R_t (□m)	3.81	1.72	2.37	0.32
Rsk	-0.66	-1.6	0.22	-1.5
$_q$ (^{o})	15.7	10.7	8.7	2.0



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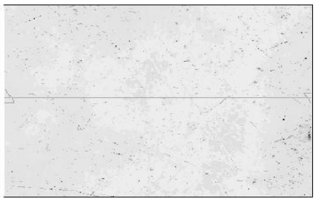

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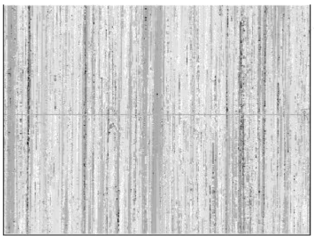

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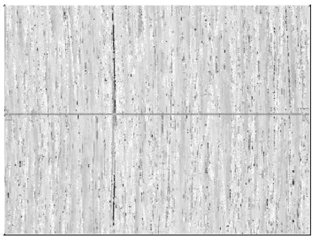

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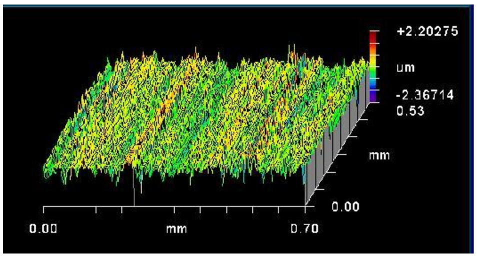

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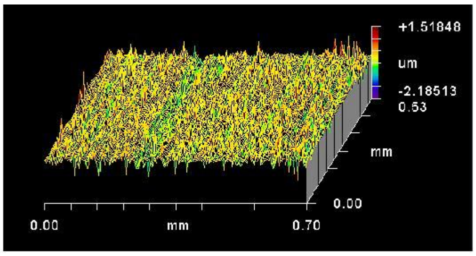

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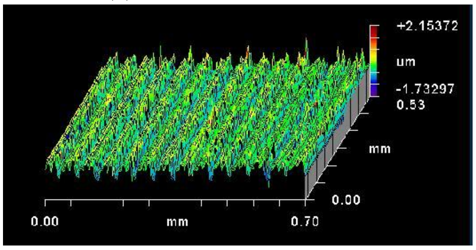

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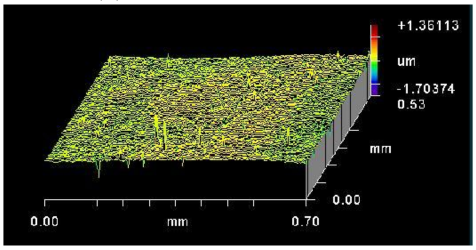


(d)

Figure 1, Gray scale images (top) and 3-D surface maps (bottom) of the: (a) GD, (b) HN, (c) HT and (d) IF surfaces

The differences in texture of the four surfaces are clearly evident in Figure 1. The GD surface is distinctly anisotropic. Contrary to expectation, the HN surface does not exhibit the distinct cross-hatched pattern typical of honed surfaces. This is attributed to the use of mild honing conditions (cross-hatch angle of 5 deg.) during surface preparation. The HT surface shows distinct peaks and valleys characteristic of the turning process. The IF surface does not exhibit a directional pattern and is an entirely random surface.

Amplitude Parameters : The mean values (from ten measurements) of S_q (RMS deviation) for the different surfaces are listed in Table 2. It can be seen that the IF surface has the lowest value while the GD surface has the highest.

Table 2, 3-D root mean square roughness height of surfaces

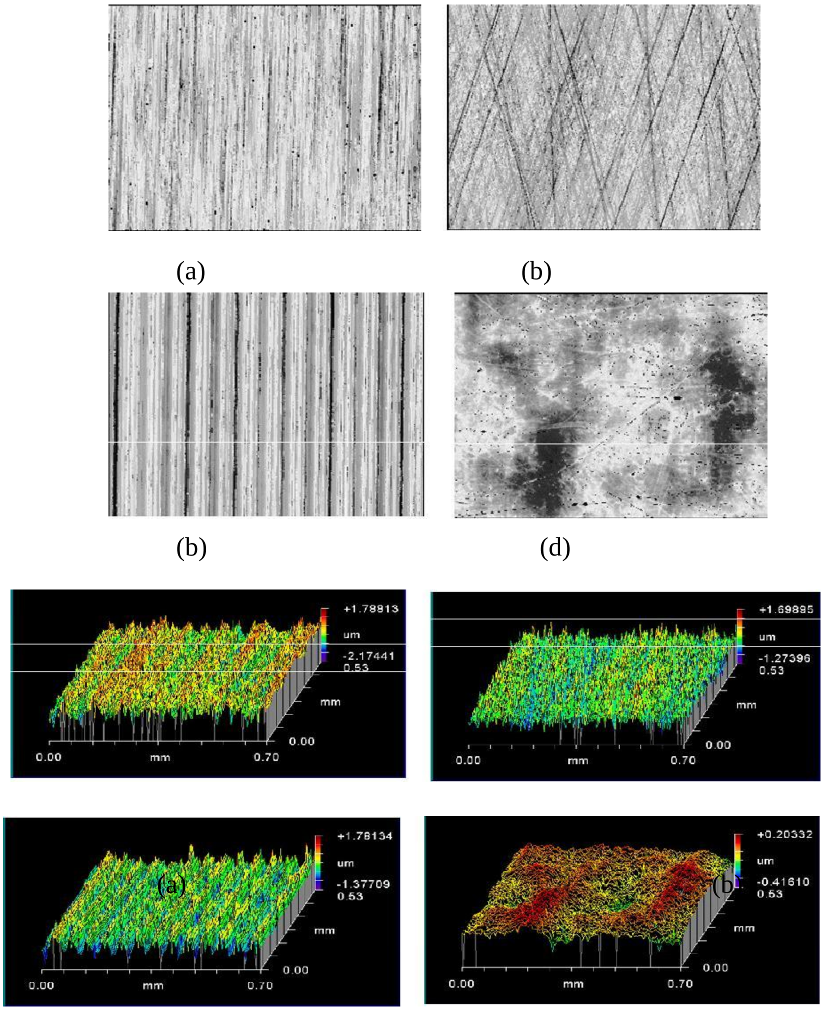
Surface	S_q (μm)
GD	0.424
HN	0.196
HT	0.331
IF	0.083

Spatial Parameters : 3-D spatial parameters can give information about texture. It can be seen from Table 3 that the S_{ds} (density of summits) value is lowest for the HT surface and highest for the GD surface. The HN surface has a high S_{ds} value. This is because the GD and HN surfaces have very high frequency components, meaning that their lay is very closely spaced and hence summits occur more often. Physically the S_{ds} parameter is assumed to provide a good estimate of the average number of asperities per unit area. The higher the number of asperities, larger is the real area of contact and therefore, greater adhesion, which directly influences the frictional response of the surface.

Table 3, 3-D spatial parameters

Surface	S_{al} (μ)	S_{ds} (/mm^2)
GD	5.50	5806.97
HN	6.59	3009.71
HT	48.51	61.11
IF	20.00	422.53

Cylindrical Bearing Surfaces : The cylindrical surface has been filtered to remove the form. The residual surfaces are shown in Figure 2. As shown in Figure 2, the textures of the four surfaces clearly differ like case of flat surfaces. For example, the GD surface is distinctly anisotropic while the HN surface exhibits a cross-hatched pattern (~300) typical of honing. The HT surface shows distinct peaks and valleys characteristic of the turning process. In contrast the IF surface exhibits a random pattern. Figure 3 shows the areal power spectral density (APSD). It captures the lay pattern or randomness of the surface. As shown in Figure 3, the spectral density captures the texture information. Especially, in Figures 3 (c) and 3 (d) it captures the hone angle of 30^0 and the repetitive nature of a hard turned surface.



(c) (d)

Figure 2, Gray scale images (top) and 3-D surface maps (bottom) of the: (a) GD, (b) HN, (c) HT and (d) IF surface.

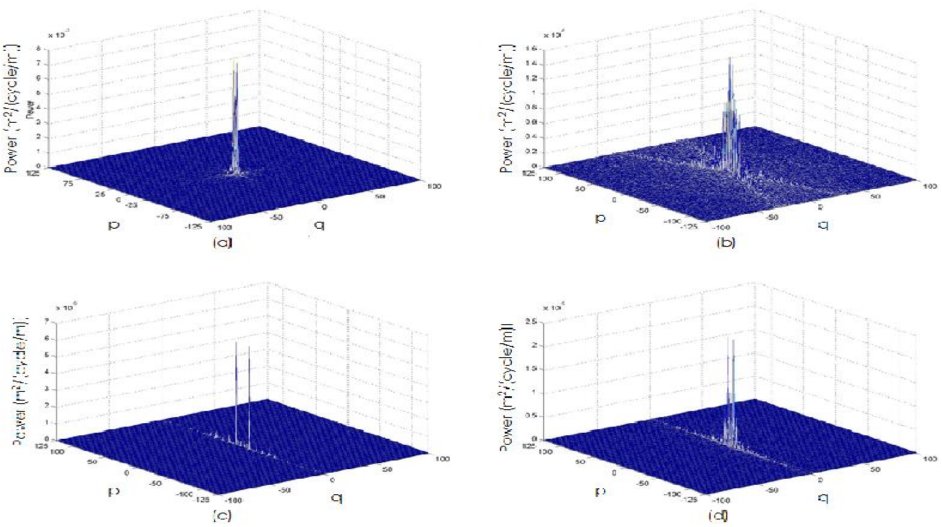


Figure 3, APSD Plot of filtered cylindrical surface

The spatial parameters: S_{al} (fastest decay autocorrelation length) and S_{ds} are derived from autocorrelation and texture direction is derived from the spectral density. Table 4 shows the amplitude parameter S_q and S_{sk} (skewness) and other spatial parameters. Note that the skewness is negative as seen previously in the 2-D parameters. The skewness is negative for the entire valley dominated surfaces obtained in a machined or abrasive polished surface. The S_{ds} provides an estimate of the average number of asperities per unit area. A large S_{ds} implies a large real area of contact (hence greater adhesion) and greater mechanical interlocking of asperities, which impacts friction. It can be seen from Table 4 that IF and HT have the lowest S_{ds} while HN and GD have significantly higher values. The texture aspect ratio captures the degree of isotropy; a higher value typically means isotropic or random whereas a lower value indicates anisotropy. The GD (ground) surface is anisotropic whereas polishing in a random vibratory setup results in an isotropic finished surface.

Table 4, 3-D surface parameters

	GD	HN	HT	IF
S_q (□m)	0.52	0.26	0.32	0.06
Ssk	-0.52	-0.06	0.29	-1.60
S_{al} (□m)	18.2	8.8	44.8	43.8
S_{ds} (□m^{-2})	636	2,130	92	73
S_{td} (deg)	90	-75/75	90	Random
Str	0.10	0.27	0.19	0.68

Tribological Surface : Unlike the previous two surfaces, the tribological surface reported here does not have a defined shape consequently, it is imperative to remove the second order surface to obtain the residual surface. The residual surfaces of all six surfaces are shown in Figures 4 through 8.

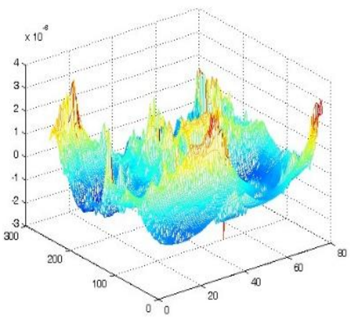


Figure 4, Residual surface of surface#1

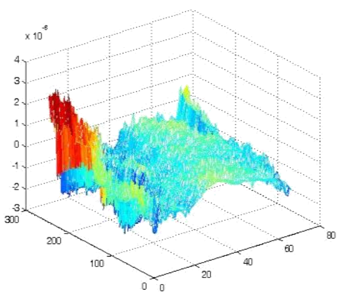


Figure 5, Residual surface of surface#2

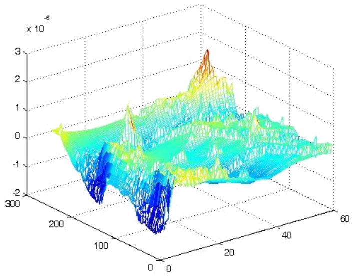


Figure 6, Residual surfaces of surface#3

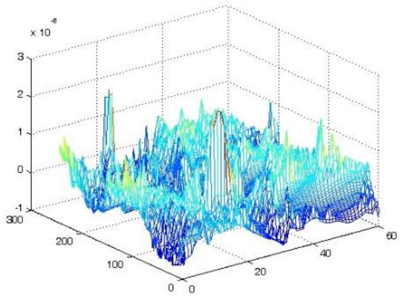


Figure 7, Residual surfaces of surface#4

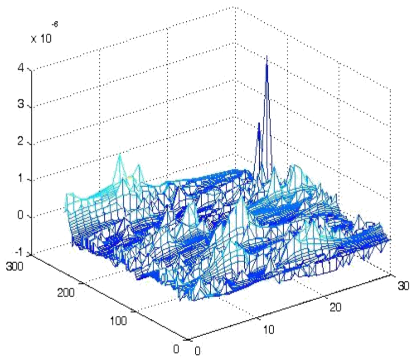


Figure 8, Residual surfaces of surface#5

Table 5 shows the amplitude and spatial parameters surface numbers 1 through 5. These surfaces are precision finished and skewness is positive this means that the surface is peak dominated as opposed to valley dominated. The slope of the surface is also large which indicated big drop in the heights of peaks and/or valleys.

Table 5, 3-D surface parameters of tribological surfaces

	Surface#1	Surface#2	Surface#3	Surface#4	Surface#5
S_q (□m)	0.70	0.56	0.33	0.37	0.21
Ssk	0.81	1.12	-0.07	0.71	1.54
S $_q$(rad)	0.12	0.20	0.09	0.11	0.10
S_{ds} (□m^{-2})	67	38.30	351.60	352	543.70

Sapphire Surface : The flat sapphire surface is face turned as shown in Figure 9. Note that the due to excessive tool wear in the machining phase which precedes polishing, the surface roughness varies significantly from one location to another even on the same face (see Figure 9).

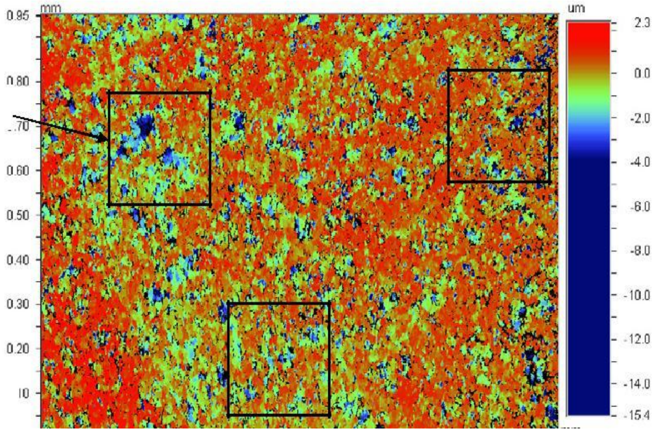


Figure: 9, Sapphire surface images before polishing

A proprietary polishing method developed at IIT Bombay has been utilized to polish the flat sapphire piece. Figure 10 shows the 3-D surface topography acquired via white light interferometer. There is clear evidence of pitting and surface cracks on the machined as well as polished surfaces. The relevant 3-D surface parameters that could capture the summits (high points) and craters will be density of summits (S_{ds}) and 3-D surface skewness (S_{sk}), respectively. From a

functional point of view, S_{sk} can indicate presence of troughs/spikes. Large negative skewness may be found in surfaces that have pits and troughs. S_{sk} and S_{ds} are given in Table 6.

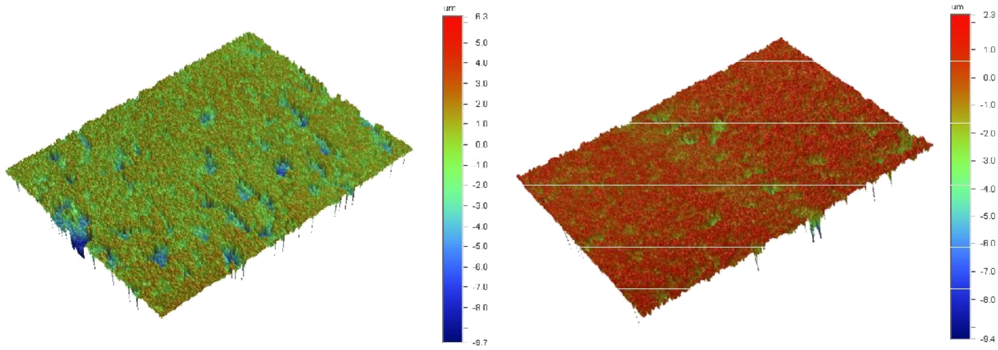


Figure:10, Surface topography(a)machined (b)polished

Table 6, 3-D parameters of sapphire

Surface	Sa (nm)	Sq (nm)	Ssk	Sds (/mm^2)
Machined	994.74	1410 .00	-2.04	856.99
Polished	602.00	860.6 0	-2.23	713.14

Table 6 lists the 3-D surface parameters before and after polishing. There is a decrease of 40% in S_a and S_q which shows that hydrodynamic polishing is reducing the peaks/summits. In addition, there is 17% reduction in the density of summits. This proves that polishing reduces the height and the number of the summits/peaks. On the other hand, surface skewness not only remains negative but exhibits a slight increase which reaffirms the trough/valley dominance of the surface due to pits induced by the machining process.

Consequently, it is important to minimize the pits prior to polishing. The machining and polishing is also carried out for sapphire cavity. Figure 11 shows the as machined surface without filtering and Figure 12 shows the machined surface post filtering.

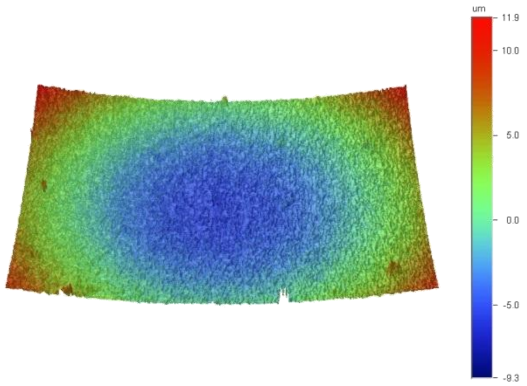


Figure 11, Polished sapphire surface with form

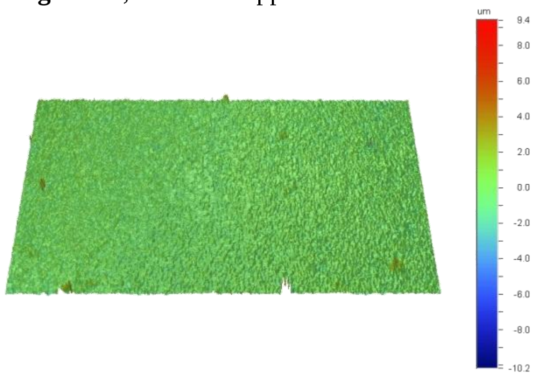


Figure 12, Polished sapphire surface without form

III. CONCLUSION

[1] The 3-D root mean square roughness height, S_q, and the density of summits, S_{ds}, can be used to quantify the influence of surface texture on functional response.

[2] The density of summits is higher when the surface is dominated by high frequency features or the surface features are spaced closely as opposed to turned surfaces where the feed marks are relatively far apart.

[3] AACF and APSD analyses can be effectively used for texture analysis.

[4] A large value of S_{al} indicates that the surface is dominated by low frequency components whereas a small value indicates otherwise.

[5] Turned surfaces have large values while ground and honed surfaces have smaller values of S_{al}.

[6] Surface skewness can be used for determining the peak or valley dominance. A positively skewed surface typically is peak or summit dominated whereas a negatively skewed surface is valley dominated.

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