SERBIATRIB '11

Serbian Tribology Society

12th International Conference on Tribology

Faculty of Mechanical Engineering in Kragujevac

Kragujevac, Serbia, 11 – 13 May 2011

THE INFLUENCE OF THE RELATIVE SLIDING ON THE SURFACE QUALITY

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Abstract: *This paper presents a study on the surface quality pointing out the influence of relative sliding on the topography parameters. Traditional roughness parameters as Ra and Rq, deal only with relative high of the asperities to the mean line and they give no information on shape, slope and asperities magnitude, on their appearance frequency on the profile length. The authors analysed a set of 3D parameters including the amplitude ones (Sa, Sku, Ssk and St) and functional parameters as Svk, Sk and Spk as calculated with a dedicated soft from the bearing area. Tests were done on roller-roller tribotester lubricated with the grease grade UM185Li2EP (general purpose grease for rolling bearings), the temperature of the environment being kept at 80°C. There was studied the influence of relative sliding speed on the skewness and the kurtosis of the surface topography, but also on common parameters as Sa and St. Such a study may be used for selecting a suitable surface quality and to evaluate the surface topography degradation in time, after tests under severe conditions, very close to the actual ones.*

Keywords: *roller-roller tribotester, relative sliding, profilometry, functional 3D parameters.*

1. INTRODUCTION

Traditional roughness parameters as *Ra* and *Rq*, deal only with relative high of asperities to the mean line and they give no information on shape, slope and asperities magnitude, on their appearance frequency on the profile length.

3D profilometry offers the opportunity for a deeper and more accurate analysis of the surface quality [3-5].

Multiple measurements in different areas on the sample can produce results within a large range, due to variations of the surface texture across the sample surface. Consequently, the results of any single measurement may not be representative of the overall surface quality [3, 4] and specialists recommend methods to be applied for a more accurate characterisation of the surface, more often for manufactured parts, and rarely for evaluating how the surface quality evolved in actual exploitation.

The parameters involved in this study are briefly described below. The analysed amplitude parameters are: the roughness average, *Sa* [μm], the root mean square *Sq* [μm], the surface skewness, *Ssk* [-], the surface kurtosis, *Sku* [-], the peak-peak height, *St* [μm].

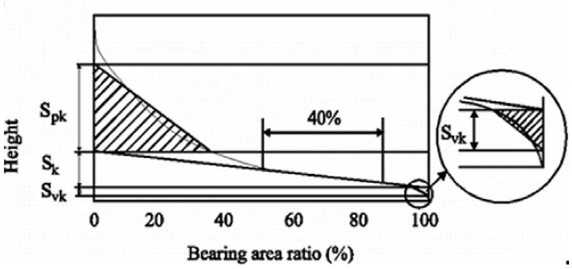


Figure 1. Bearing curve illustrating the calculation of *Spk*, *Sk* and *Svk* [6]

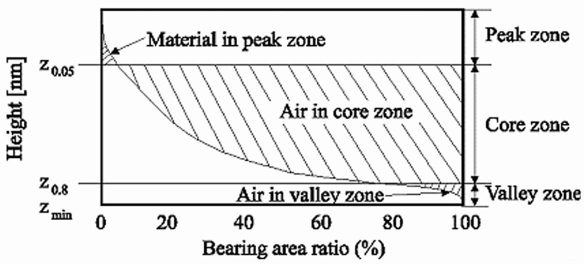


Figure 2. Bearing curve illustrating the calculation of *Sbi*, *Sci* and *Svi* [6]

The functional parameters are described graphically in Figures 1 and 2.

The surface bearing index, Sbi [μm], is defined as:

$$Sbi = \frac{Sq}{Z_{0.05}} \quad (1)$$

where $Z_{0.05}$ is the distance from the top of the surface to the height at 5% bearing area.

The core fluid retention index, Sci [μm], is defined as:

$$Sci = \frac{\dfrac{V_v(h_{0.05}) - V_v(h_{0.080})}{(M-1)(N-1)\delta x \cdot \delta y}}{Sq} \quad (2)$$

where $Vv(Z_x)$, is the void area over the bearing area ratio curve and under the horizontal line Z_x.

The valley fluid retention index, Svi [μm], is defined as:

$$Svi = \frac{V_v(h_{0.80})}{(M-1)(N-1)\delta x \cdot \delta y} \quad (3)$$

For relations (1)…(3), M is the number of lines of the investigated area and N are the number of points on each line.

The reduced summit height, *Spk,* is the height of the upper left triangle [6]. The core roughness depth, *Sk,* is the height difference between the intersection points of the found least mean square line. The reduced valley depth, *Svk,* is the height of the triangle drawn at 100% (Figure 1).

2. TESTING METHODOLOGY

Tests were done on a roller-roller tribotester (Fig. 1) [2]. The test conditions were: normal load Q=1.0 kN, enclosure temperature θ=80°C, rolling speed (for ξ=0%) v=1.09 m/s, testing period t=240 minutes, lubricant: grease grade UM185Li2EP (general purpose grease for rolling bearings), diameter of rollers for pure rolling D=42.0 mm, contact width B=10 mm ($B_{Roller1}$=10 mm, $B_{Roller2}$=12 mm)

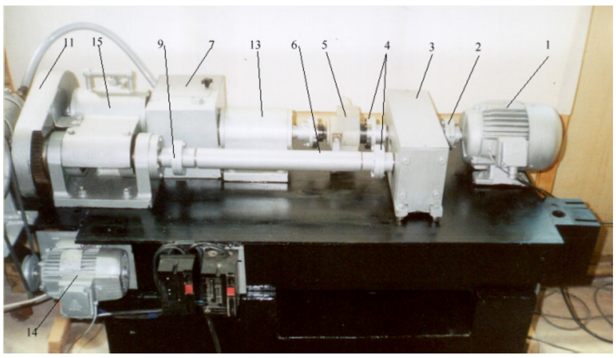


Figure 3. The testing machine 1– driving electric engine; 2, 4, 9– rigid coupling; 3– gear transmission; 5– torque transducer; 6– intermediate shaft; 7– thermoisolant box; 8 – tested rollers (in box 7); 10– force transducer; 11– reducing gear box.

The relative sliding between rollers was pointed out by the sliding coefficient, calculated as:

$$\xi = \frac{2(v_1 - v_2)}{v_1 + v_2} \cdot 100\ [\%] \quad (4)$$

v_1 and v_2 being the peripheral speeds for the roller 1 and 2, respectively. ξ=0 is for pure rolling.

The roller geometry allows running the test with three values for the relative sliding: ξ=0% (pure rolling), ξ=16.3% and ξ=33.5%.

Rollers were made of heat-treated high-quality carbon steel. All rollers were grinded and the topography parameters are given in all figures as for unworn surfaces. The rollers 3A, 5C, 1E and 4A are made of steel grade OLC25 (0.25% C) and the rollers 3B, 5D, 1F are made of steel grade OLC45 (0.45% C). The investigated pairs of rollers are: 3A-3B, 5C-5D, 1E-1F and 4A-4B.

There were investigated square areas of 500μm x 500μm, in the central zone of the wear track with the help of a CETR contact profilometer. The vertical range was set up to 500 μm as wear tracks had visible traces in the sliding direction and the scan speed was set at 35 μm/s. This research was done for 200 points per line and the step between lines was selected at 5 μm. All parameters are calculated from the raw profiles that "rebuild" the actual surface [6]. The stylus equivalent loading force was set at 28 mg for all measurements.

A single 3D measurement is usually insufficient for the grading of a surface, if a specific parameter value is desired. It is recommended a standard number of five sampling length for 2D parameters [7, 8] and the number of line samples are 100 for all three measurements on each wear track, but someone could say these are too "concentrated" in a small area of the surface of interest. It was found that it is often necessary to perform at least 5 measurements to obtain a stable mean value for many roughness parameters while others need a larger number as there is often one or few measurements diverging from the expected normally distributed result [1, 4, 8].

For worn surfaces the number of measurements will be established depending on surfaces to be investigated. Here the authors did 3 measurements for each roller and there were calculated the average values of the 3D amplitude parameters and several functional parameters as obtained from raw (non-filtered) (examples are given in table 1 and Figure 9). $As\%(S_x)$ is the percentage of up-deviation from the calculated average value:

$$As\%(S_x) = \frac{Max(S_x) - Average(S_x)}{Average(S_x)} 100 = \frac{As(S_x)}{Average(S_x)}\ [\%] \quad (4)$$

Ai%(S_x) is the percentage of the inferior deviation from the calculated average value:

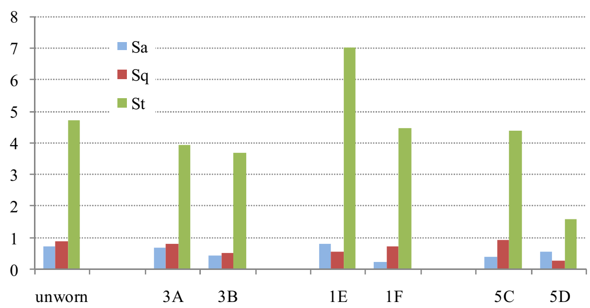
$$Ai(S_x)=\frac{Min(S_x)-Average(S_x)}{Average(S_x)}100=\frac{Ai}{Average(S_x)}[\%] \quad (5)$$

In relationships (4) and (5), S_x is one of the parameters *Sa*, *Sq*, *St*, *Sku*, *Ssk*, *Sbi*, *Sci*, *Svi*, *Sk*, *Spk*, *Svk*. *Max*(S_x) is the maximum value of all measurements for parameter S_x, *Min*(S_x) is the minimum value of all measurements for parameter S_x and *Average*(S_x) is the average value of all measurements for parameter the same S_x.

Filtered profiles could disturb the values [3, 4], especially for high peaks and deep valleys that are important to be pointed out on worn surfaces.

3. CONCLUSION

Figure 4 presents the amplitude parameters *Sa*, *Sq* and *St*. As mentioned in [1, 3, 4] *Sa* is not a reliable parameter for assessing the surface quality, especially for worn surfaces. For all investigated surfaces *Sa* is lower than the value obtained for grinded (unworn) surfaces and even *Sq* seems to have the same tendency and both ones could be considered less sensitive to relative sliding. *St* has a clear trend to be reduced for both rollers under pure rolling, but at ξ=16.3%, there were recorded the highest values meaning that this value could generate the highest peaks. These are dangerous especially for lubricated contacts because they incapacitate for generating a continuous film of lubricant and increase the probability of direct contacts among asperities.



ξ=0% ξ=16.3% ξ=33.6%

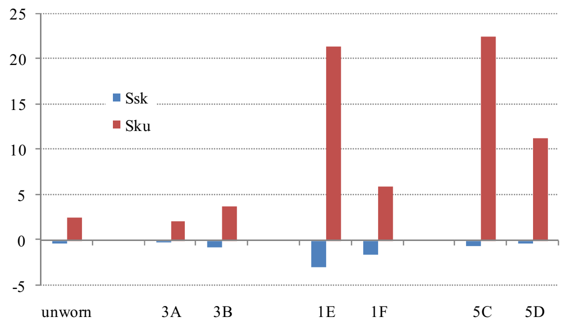
Figure 4. Amplitude parameters *Sa*, *Sq* and *St* for the tested rollers

Sku increases for all tested surfaces, but especially for rollers with relative sliding, meaning that the relative sliding could generate a distribution with rare but narrow peaks. The values are much lower for the steel grade OLC45 and for this steel grade the influence of relative sliding seems to be almost linear under the test conditions. For the steel grade OLC 25 both values of relative sliding have generated close values for this parameter. *Sku* has the largest spread range, about 8...9 times greater than the initial value. Figure 8 presents images of the worn surfaces as being rebuilt based on the measured coordinates and these images reveal isolated deep valleys.

The negative values for *Ssk* point out there are holes in the surface topography, deeper for ξ=16.3% and for this test, for the roller made of steel grade OLC25.

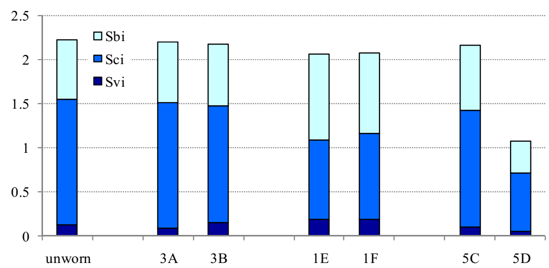
Ssk has a similar trend for the highest relative slide (ξ=33.5%). Due to this value the asperities are "micro-grinded" and *Ssk* is similar to the initial ones. High relative changes of these two parameters (*Ssk* and *Sku*) for the worn surfaces are also reported by Krzyzak in [5].

If one analyses only the average parameter *Sa*, he will notice that it remains close to the initial value, or even lower, but the conclusion that surface become smother is a "false friend" and additional information is necessary for describing it. For instance, *St* – the maximum peak-to-valley value on the investigated areas, increases for roller tested under relative sliding, but for the rollers under pure rolling, the parameters like *Sa*, *Sk* and *St* are smaller with 20...25%. Even *Sa* for all tested rollers remains in a range considered good for further exploitation, the higher values for *St* offers the motivation of harder damages on rollers 5C-5D and 1E-1F.



ξ=0% ξ=16.3% ξ=33.6%

Figure 5. Amplitude parameters *Ssk* and *Sku* for the tested rollers



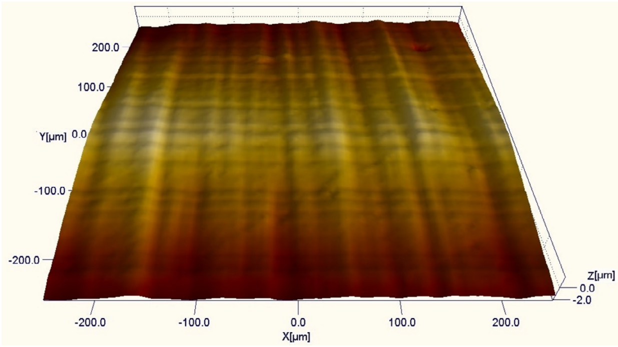
ξ=0% ξ=16.3% ξ=33.6%

Figure 6. Functional parameters *Sbi*, *Sci* and *Svi* for the tested rollers

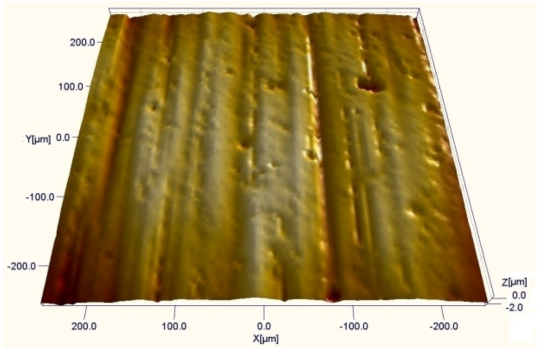
Table 1. Example of data for the roller 5C.

3D parameter	Sample 5C_1	Sample 5C_2	Sample 5C_3	Average	MAX	MIN	As	Ai	As (%)	Ai (%)
Sa	0.371	0.376	0.373	**0.373**	0.376	0.371	0.003	-0.002	0.68	-0.59
Sq	0.489	0.601	0.537	**0.542**	0.601	0.489	0.058	-0.053	10.787	-9.74
Ssk	-0.676	1.770	-2.939	**-0.615**	1.770	-2.939	2.385	-2.324	-387.84	377.92
Sku	7.188	39.160	21.375	**22.574**	39.160	7.188	16.586	-15.386	73.47	-68.15
St	6.268	13.290	7.030	**8.863**	13.290	6.268	4.428	-2.595	49.95	-29.27
Spk	0.634	4.367	0.135	**1.712**	4.367	0.135	2.655	-1.577	155.09	-92.10
Sk	1.099	0.829	0.804	**0.910**	1.099	0.804	0.189	-0.107	20.72	-11.74
Svk	0.618	0.685	0.919	**0.741**	0.919	0.618	0.178	-0.123	24.08	-16.59

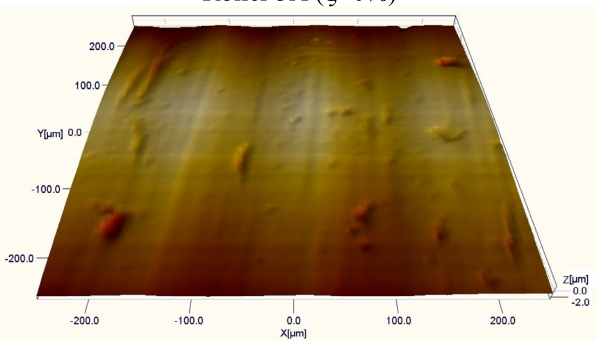
Table 1 contains the results with 3 digits after point for easy reading, all operations being done with 5 digits after point.



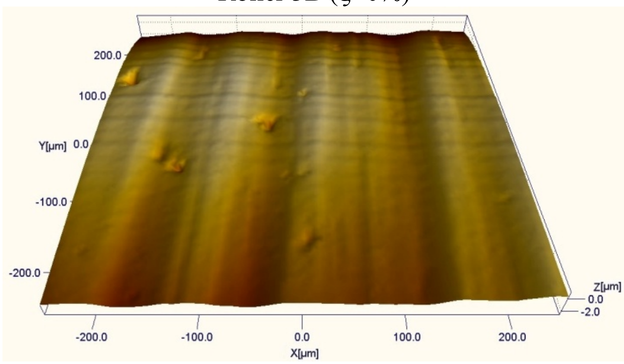
Roller 3A (ξ=0%)



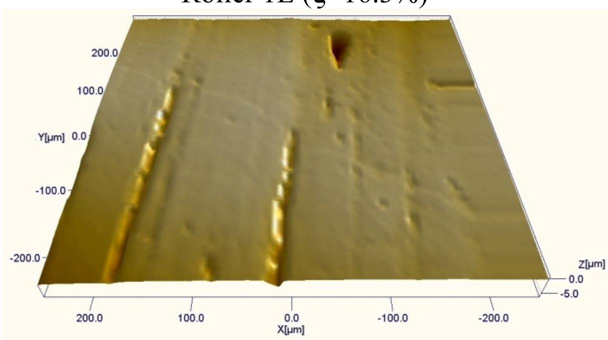
Roller 3B (ξ=0%)



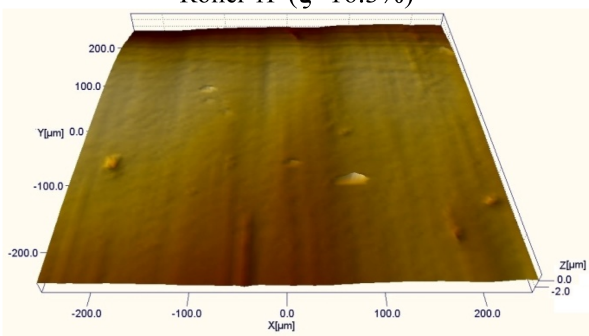
Roller 1E (ξ=16.3%)



Roller 1F (ξ=16.3%)



Roller 5C (ξ=33.5%)



Roller 5D (ξ=33.5%)

Figure 8. Virtual images of the investigated surfaces

Large *Sbi* indicates a good bearing property. Only for the higher relative sliding there was noticed a decrease of *Sbi* and *Sci*. Large values of *Sci* indicate that the void volume in the core zone is large. For the tests with pure rolling the change of these parameters and their sum value are insignificant, but for ξ=33.5% the sum is slightly reduced and *Sbi* increases. Small values of *Svi* indicate small void volumes in the valley zone (correlate Figure 6 to virtual images in Figure 8).

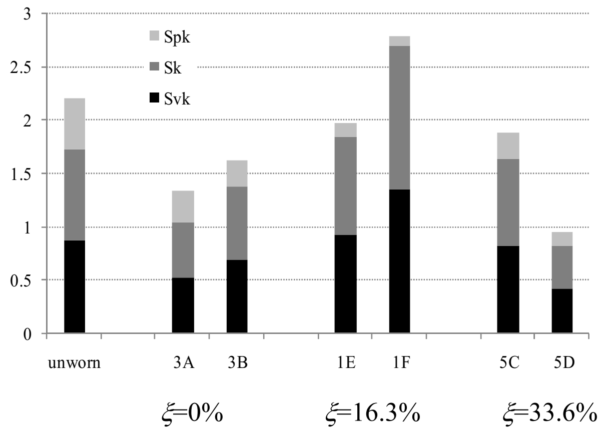


Figure 7. Functional parameters *Spk*, *Sk* and *Svk* for the tested rollers

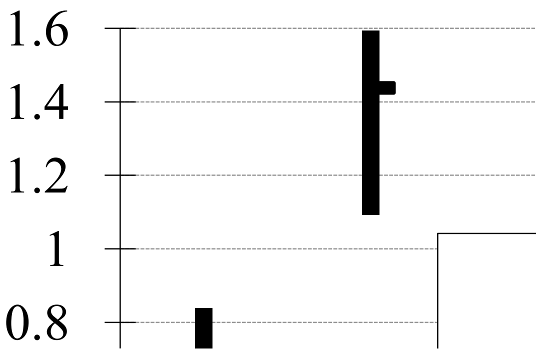


Figure 9. The spread range for functional parameters for roller 5C (three measurements on 500 x 500 μm each)

For ξ=0% and ξ=33.6% the functional parameters *Svk*, *Sk* and *Spk* are reduced as compared to the initial surface, but for ξ=16.3% the sum of these parameters is higher, *Svk* and *Sk* being much higher as compared to the unworn surface (Figure 7).

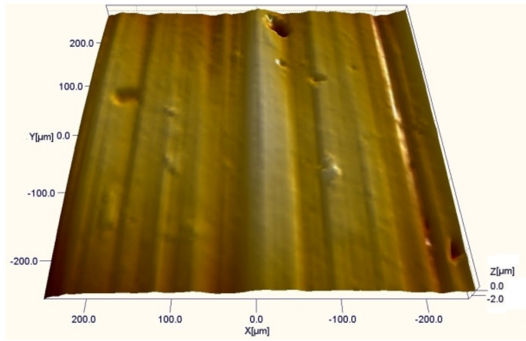
A comparative study of the surface topography, obtained by changing a single parameter during the tests, may reveal at least a qualitative influence of this parameter that could be useful for practicians.

There could be noticed two groups of parameters:

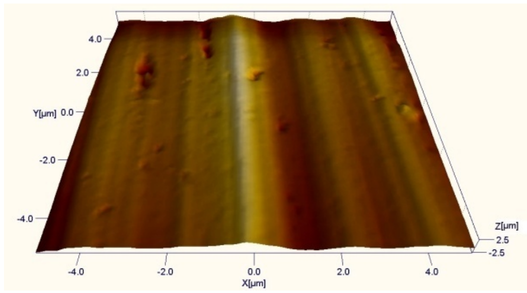
- parameters less influenced by the relative sliding, including *Sa*, *Sq*,

- parameters bearing a greater influence, these being *Ssk* and *Sku* and the functional parameters.

Taking into account the ranging of the calculated parameters, one may notice that *Sa*, *Sq*, *Svk* and *Sk* have a narrow spreading range, a second group may include parameters with a range similar to the parameter value (50…100%), e.g. *St* and *Sku*. A special attention has to be paid to *Ssk* that could have the spreading range much greater as compared to the average value.

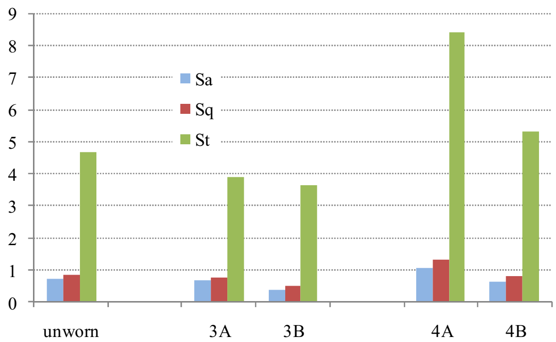


Roller 4A



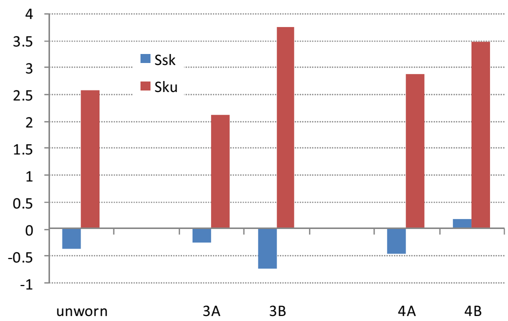
Roller 4B

Figure 10. Virtual rebuilding of the tested surfaces for Q=0.7 kN, pure rolling



Q=1.0 kN Q=0.7 kN

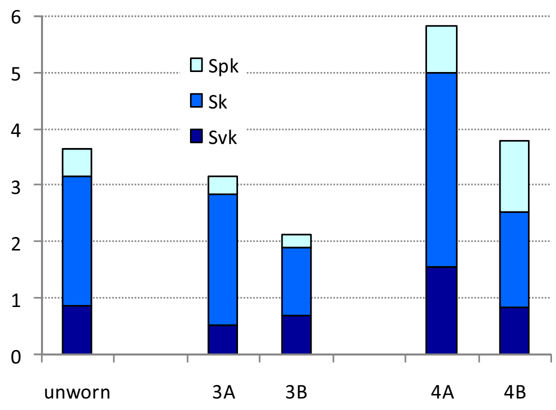
Figure 11. Amplitude parameters *Sa, Sq* and *St* for the roller surfaces under pure rolling



Q=1.0 kN Q=0.7 kN

Figure 12. Amplitude parameters *Ssk* and *Sku* for the roller surfaces under pure rolling

For pure rolling an increase of the normal load from 0.7 kN to 1.0 kN modifies the functional parameters as given in Figures 11-13, reducing the sum of these parameters as compared to the value obtained on unworn surface and that of tested at Q=0.7 kN.



Q=1.0 kN *Q*=0.7 kN

Figure 13. Functional parameters *Sk*, *Spk* and *Svk* for roller surfaces under pure rolling

Comparing images from Figure 8 (rollers 3A and 3B) and Figure 10 (rollers 4A and 4B), one may notice that the damaging processes of the surface are similar, but more intense for the rollers bearing *Q*=1.0 kN. The higher load reduced the amplitude parameters like *Sa*, *Sk* and *St* (Figure 11). *Ssk* remains in the negative range for *Q*=1.0 kN, but for *Q*=0.7 kN there were recorded values giving a positive average (Figure 12). Under this load and pure rolling, the higher isolated peaks may be less damaged as compared to those under a rolling-sliding motion. It could also be the consequence of adhesive wear (isolated high peaks above the surface could be seen in Figure 10, suggesting wear debris adhered on the roller surface).

Taking into account the surface quality, steel grade OLC45 is more appropriate for application with similar conditions as those involved in these tests as compared to the steel grade OLC 25, because many of the surface parameters have only a small increase, meaning the surfaces could continue to work under those conditions. A similar qualitative evaluation was obtained by analysing the virtual images of the tested surfaces as given by a dedicated soft of the 3D profilometer.

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