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Surface characterization of spline coupling teeth subjected to fretting wear

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Abstract

Splined couplings are mechanical components subjected to fretting phenomena above all when they are working in misalignment conditions and so the teeth surface morphology may change according to the corresponding working parameters (misalignment amplitude, presence of lubrication, etc). Aim of this work is to use the surface roughness to identify the fretting wear damage on spline coupling teeth. Experimental tests have been performed by means of a dedicated test rig, using steel made specimens. Teeth roughness has been measured before and after tests. In order to emphasize the different surfaces status, the measured roughness values have been processed considering both traditional and sophisticated parameters as kurtosis and skewness. The effect of transmitted torque and angular misalignment have been investigated. Preliminary results show that roughness values may change according to the working conditions.

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1. Introduction

Fretting is a phenomenon affecting components subjected to contact stress and relative displacements. Fretting occurs commonly in clamped connections and demountable couplings and involves surfaces in contact subjected to cyclic small amplitude relative displacements [1]. The role of debris is critical in fretting wear; generally, once debris accumulates on the contacting surfaces, it forms compacted oxide beds and the wear rate is reduced

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significantly [2, 3] but, if debris remains inside the contact region, it forms with the lubricant a kind of abrasive paste which speeds up the wear phenomenon. The debris oxidizing forms very small abrasive particles (order of microns), which are deposited and cause the worsening of wear process. The resulting damage may consist in a simple surfaces discoloration, in the formation of surface craters (the most common case) or in the removal of a considerable amount of material. The oscillating movement causes the surface layers erosion, exposing new areas to the phenomena of welding and breaking parts.

Fretting strength varies strongly because of the materials in contact and the lubricant characteristics: lubricants characterized by low viscosity tend to reduce the intensity of fretting maintaining the oxygen away from the area of interface and generally they carry away the debris created by wear; on the contrary lubricants that have an high viscosity tend to increase the fretting wear damage.

Fretting is currently an interesting field of research, also considering that there is not a consistent standard giving a best practice about both fretting design and testing [2].

Researchers aim to identify the surface aspect being different according to the fretting wear mode [3].

A common goal is to characterize a damaged surface by means of a suitable parameter, as an example the roughness. Surface roughness evaluation is very important for many fundamental problems such as friction, contact deformation, heat and electric current conduction, tightness of contact joints and positional accuracy [4].

Regarding the analysis of fretting phenomena, some authors utilized the variation of roughness parameters. As an example, Kucharski et al. investigated the evolution of the contact zone, by means of both wear scar depth and surface roughness in the contact zone [3]. Kubiak et al. presented an experimental study about the influence of the finishing surface and the machining process on the fretting damage arising in both partial and full sliding regimes [5].

Aim of this work is to use some surface roughness parameters to identify the fretting wear damage in a real engineering application like spline coupling teeth [6]. Splined couplings are mechanical components used to connect two rotating shafts; these components find applications in many industrial sector and in particularly in the aerospace field. One of the main cause splined couplings failure is the fretting wear caused by the relative motion between engaging teeth; as a matter of fact, these components are subjected to fretting phenomena above all when they work in misaligned conditions [7] and so the teeth surface morphology may change according to the corresponding working parameters (misalignment amplitude, presence of lubrication, etc). Experimental tests have been performed by means of a dedicated test rig [10,11]; specimens are steel made splined couplings (see Figure 1a).

The main feature of this test rig is to apply and to monitor a specific angular misalignment between shaft and hub and it is able to reproduce the real operating conditions to which the component is subjected.

In this work some roughness parameters available in literature [4] have been chosen to identify the teeth surface topography variation due to the wear phenomena. Particular attention has been paid in using not only traditional [4] roughness parameters, but also the more sophisticated ones as kurtosis and skewness [10]; parameters have been measured before and after each tests. The effect of both transmitted torque and angular misalignment on the surface damage aspect have been investigated.

2. Experimental set up and data processing techniques

The test bench used in this work has a mechanical power recirculation scheme [8], since the external power to be applied offsets only the power dissipated in friction [8]. Splined couplings specimens are steel made (42CrMo4) nitrogen-hardened; they have crowned tooth profile and the main characteristics are: 26 teeth, 1.27mm modulus, 30° pressure angle, 200 mm crowing radius and 12 mm face width. The surface of all teeth of each specimen has been analyzed before and after the wear tests with a Alpha SM RT-70 profilometer; the roughness trend of the teeth surface has then been obtained. To guarantee the correspondence of the same profile measurement before and after each tests, a dedicated device has been realized (see Figure 1b); in this way a perfect parallelism of the specimen axis has been obtained respect to the support plane of the profilometer touch probe.

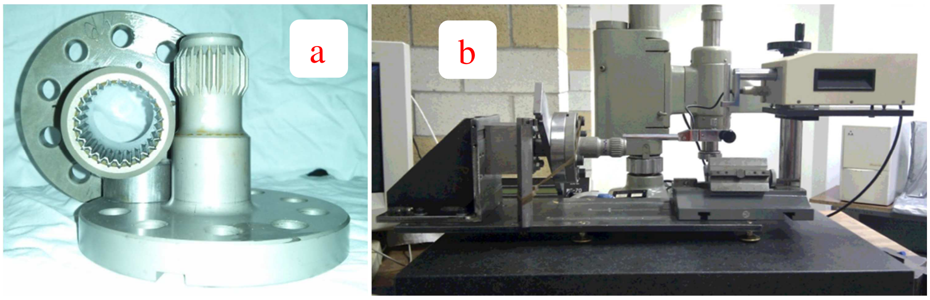

Fig. 1. spline coupling specimen (a), positioning of the specimen before a roughness acquisitions (b).

Test parameters considered in this work are resumed in Table 1, all tests have been performed with lubrication active. Each test duration is 10M cycles and lasts in five days, totally all tests presented in this work were performed in about 2.5 months.

Table 1. tests parameters.

Test	Torque [Nm]	Speed [rpm]	Misalign. [‘]	N° of cycles
MB1	700	1500	0	10M
MB2	700	1500	5	10M
MB3	700	1500	10	10M
MB4	1000	1500	0	10M
MB5	1000	1500	5	10M
MB6	1000	1500	10	10M
MB7	1300	1500	0	10M
MB8	1300	1500	5	10M
MB9	1300	1500	10	10M

Three different roughness parameters groups (amplitude, spacing and hybrid parameters) have been considered to process experimental signals provided from the profilometer. Amplitude parameters are the most important ones to characterize the surface topography. They are generally used to measure the vertical characteristics of the surface deviations [4]. Spacing parameters may measure the horizontal characteristics of the surface deviations [4]. Hybrid property is a combination of amplitude and spacing. Any changes, which occur in either amplitude or spacing, may have effects on the hybrid property [4].

In this work the most representative parameters of these three groups have been chosen to analyze the variation of the surface topography with the aim to determine which parameter best emphasizes the presence of wear on the teeth surface. According to [4] and [11], seven amplitude parameters, R_a, $R_{z(ISO)}$, R_{tm}, R_v, R_p, R_{sk} and R_{ku}, one spacing parameter P_c and one hybrid parameter Δa have been considered (see Figure 2). Parameter R_a is defined as the average absolute deviation of the roughness irregularities from the mean line over one sampling length [4]. Parameter $R_{z(ISO)}$ is defined by the International UNI EN ISO [12] as the sum of height of the largest profile peak height and the largest profile valley depth within a sampling length. Parameter R_{tm} is defined as the mean of all maximum peak to valley heights obtained within the assessment length of the profile [12], parameter R_v as the maximum depth of the profile below the mean line within the assessment length [4] parameter R_p as the maximum height of the profile above the mean line within the assessment length [4], parameter R_{sk} is the third central moment of profile amplitude probability density function, measured over the assessment length and used to measure the symmetry of the profile about the mean line. It is sensitive to occasional deep valleys or high peaks; a symmetrical height distribution, i.e. with as many peaks as valleys, has zero skewness. Profiles with peaks removed or deep scratches have negative skewness. Profiles with valleys filled in or high peaks have positive skewness [4]. Parameter R_{ku} is the fourth central moment of profile amplitude probability density function, measured over the assessment length. It describes the sharpness of the probability density of the profile. If Rku < 3, the distribution curve is said to be platykurtoic and has relatively few high peaks and low valleys; if Rku > 3, the distribution curve is said to be leptokurtoic and has relatively many high peaks and low valleys [4]. Parameter P_c is defined as the number of local peaks, which is projected through a selectable band located above and below the mean line by the same distance. The number of peak count is determined along the assessment length and the result is given in peaks per centimeter [4]. Parameter Δ_a is defined as the mean absolute profile slope over the assessment length [4].

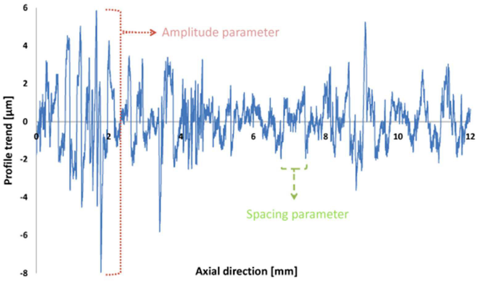

Fig. 2. profile trend of a crowned tooth.

3. Results and discussion

To compare the roughness values before and after each test, all roughness parameters have been represented by a polar graph. The quadrant of the graph has been divided into 26 parts corresponding to each tooth of the specimen; the roughness parameter values before (pre test) and after (post test) wear tests may be seen on the corresponding radius. In the following, for sake of brevity, only the most representative parameter between the above considered parameter are considered. In particular R_a, R_{tm}, R_{sk}, and P_c have been chosen to represent the wear damage because they shown the most significant variation before and after the tests.

As an example of tooth surface after a test, a zoomed damage area is shown in Figure 3.

Figures 4-7 show R_a, R_{tm}, R_{sk} and P_c in polar graphs together with the corresponding specimen image respectively for tests MB1 and MB2 (Figure 4), MB3 and MB5 (Figure 5), MB6 and MB7 (Figure 6), MB8 and MB9 (Figure 7).

To better emphasize how the roughness parameters may vary after a test and also to point out the influence of both torque and misalignment angle, the percent difference of the sub-area of the curve representing the trend of each roughness parameter related to the 26 teeth has been considered.

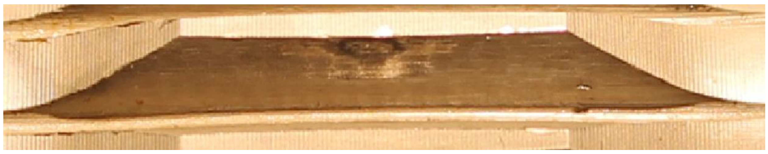

Fig. 3. zoom of a tooth of MB9 test.

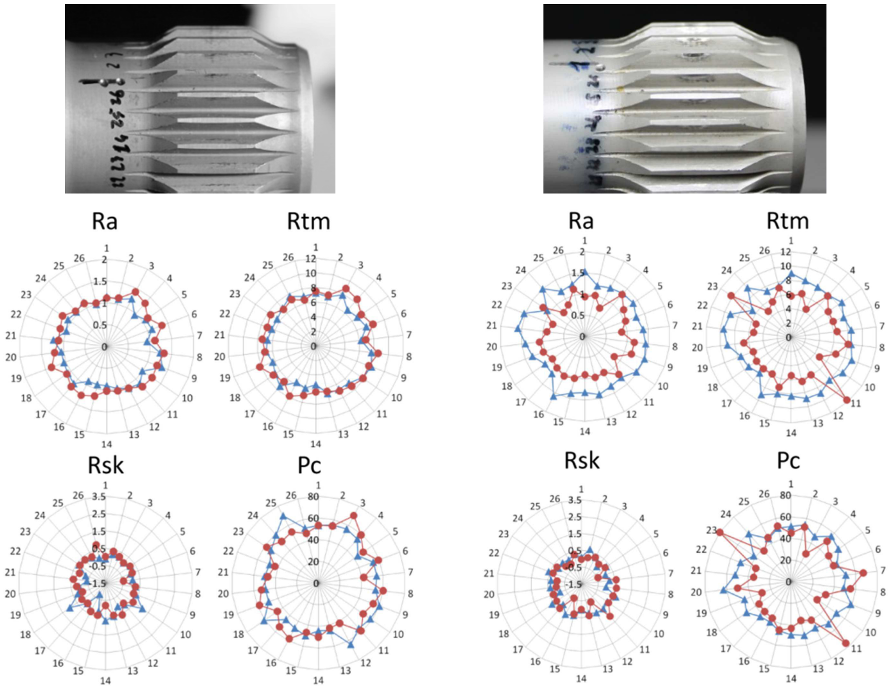

Fig. 4. roughness parameters (R_a, R_{tm}, R_{sk}, P_c) for test MB1 (left) and MB2 (right).

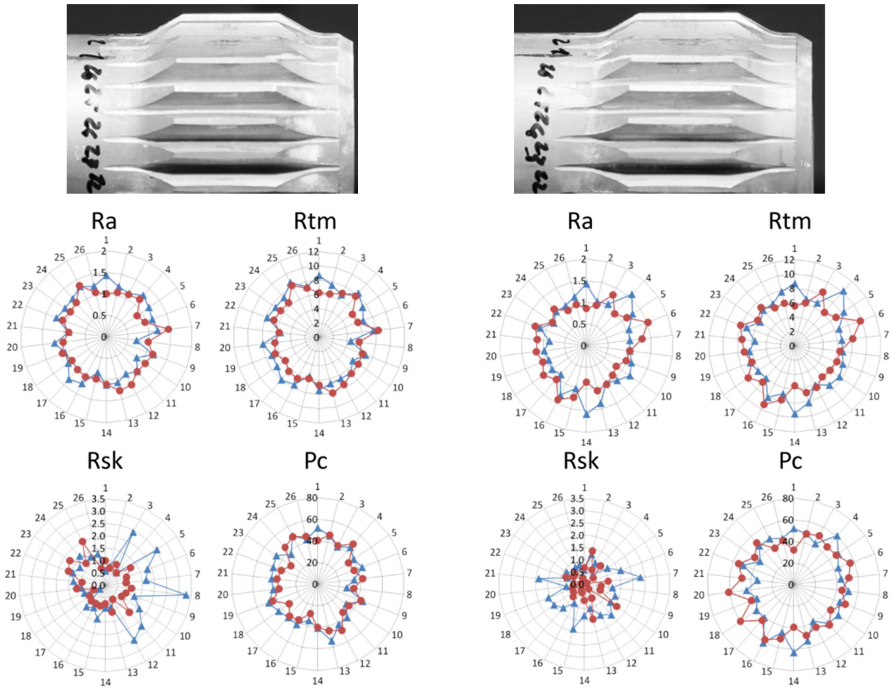

Fig. 5. roughness parameters (R_a, R_{tm}, R_{sk}, P_c) for test MB3 (left) and MB5 (right).

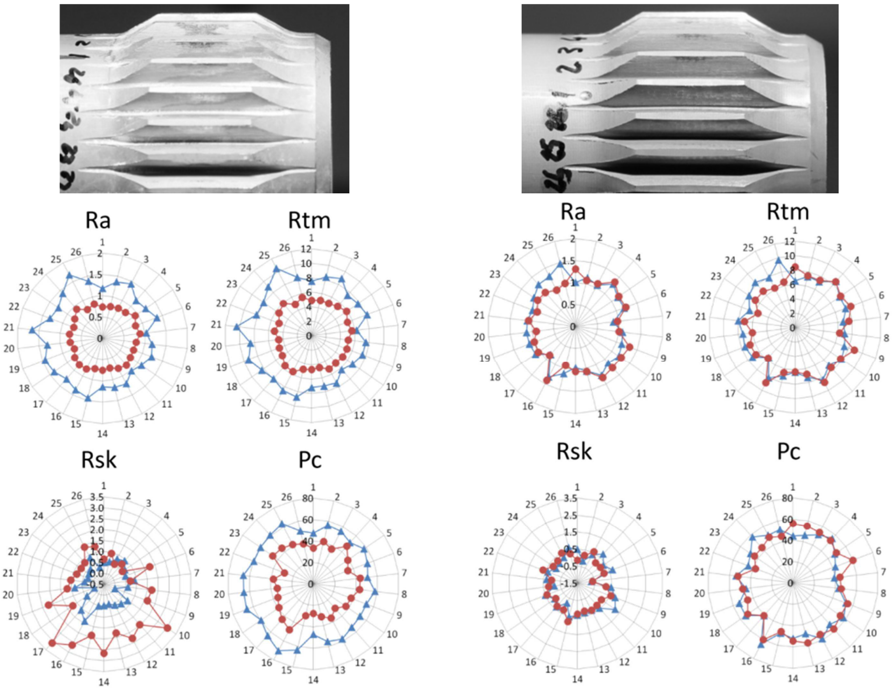

Fig. 6. roughness parameters (R_a, R_{tm}, R_{sk}, P_c) for test MB6 (left) and MB7 (right).

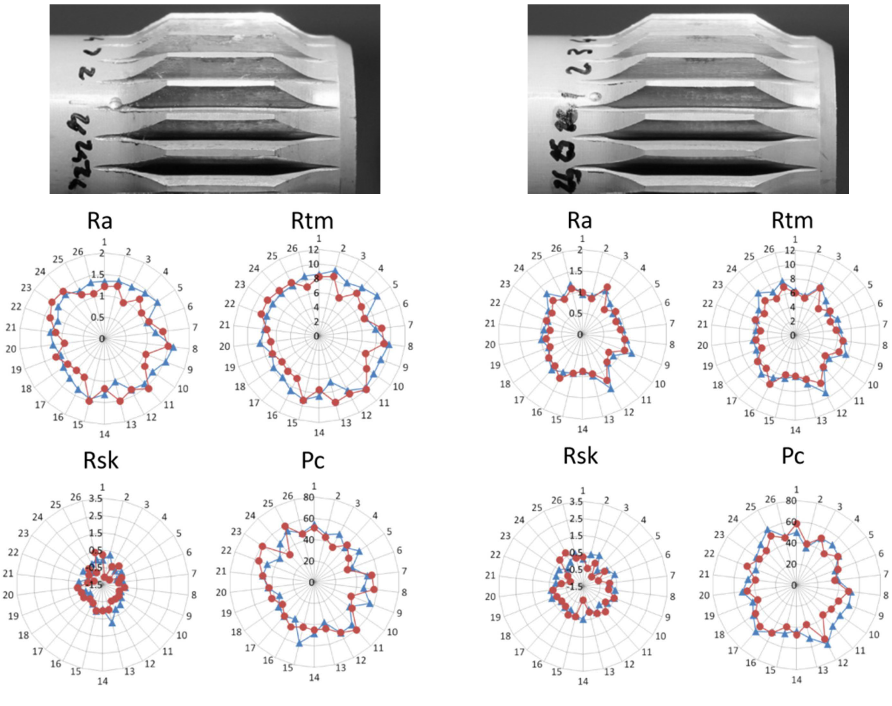

Fig. 7. roughness parameters (R_a, R_{tm}, R_{sk}, P_c) for test MB8 (left) and MB9 (right).

Figure 8 represents the trend of the roughness parameters for varying both misalignment angle and applied torque.

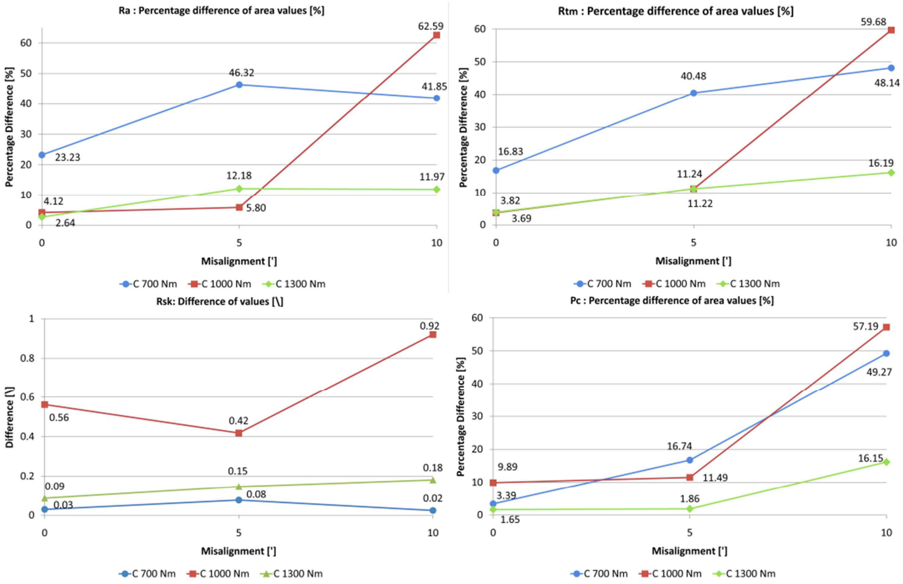

Fig. 8. effect of the applied torque on mean roughness area variation (α = 0’, 5’ and 10’).

In particular, diagrams of Figure 8 show that all the chosen roughness parameters are able to emphasize the fretting damage phenomenon, above all on the basis of the different testing conditions, although to a different amount.

Particularly, the most relevant surface damage is shown in the tests where the maximum misalignment angle (corresponding to the maximum surfaces sliding) and 1000Nm torque have been applied.

On the contrary, the tests performed with the maximum torque value (1300Nm) show a roughness difference variation significantly lower respect to the others.

This unexpected phenomenon related to the tests done with 1300Nm is due to the fact that, for this torque value, the splined couplings material exceeds its upper yield point; in this condition the number of peaks decreases due to the high stresses of the teeth in contact.

The R_{sk} representation is different from the others (the other trends are represented with the percentage difference of polar graphs area values); this choice is due as a significant variation of this parameter corresponds to an unit variation of its value and only with this representation it is possible to emphasize this peculiarity. As a matter of fact, in the case of test MB6 (1000Nm and 10') the value difference is close to the unit (0.92).

The above quoted trend of the analyzed roughness parameters is probably due to the nature of the fretting phenomenon; so, like previously described, being fretting an adhesive wear phenomenon, due to the greater sliding (proportional in this case to the misalignment increasing), a higher number of "cold welding" may be created, producing new high peaks when they break. At the same time, being the fretting also an abrasive wear phenomenon, due to the presence of the debris mixed with the pressurized oil, new deep valleys may be produced.

4. Conclusions

In the present paper the characterization of the surface topography in a real component has been performed by means of roughness parameters.

In particular, splined couplings teeth (crowned) subjected to fretting damaging have been analyzed in different working conditions.

Tests have been performed for varying both angular misalignment between shaft and hub and applied torque.

Nine roughness parameters have considered: the roughness profiles have been measured on the teeth surface before and after each test by means of a profilometer. The corresponding signals have been processed and the related roughness parameters calculated.

For the evaluation of the wear damage only four most representative roughness parameter (between the nine measured parameter) have been selected: R_a, R_{tm}, R_{sk}, P_c.

From the analysis of the obtained results, in terms of roughness parameters variations, it may be observed that this experimental procedure is able to characterize, from a quantitative point of view, the fretting damage in real components.

The variation of all roughness parameters well describes the different wear regimes due to both angular misalignment entity and applied torque level, still pointing out both abrasive and adhesive phenomena.

Finally, it may be concluded that the evaluation of the surface topography by using the roughness parameters well describes how it may change after a wear test; in particular, the percentage difference of the subtended polar graph area better empathizes the profile variation, providing an original representation of the damage entity.

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