[Proceeding] Fretting damage parameters in splined couplings

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V. Cuffaro, F. Curà, A. Mura
Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Torino (Italy)
vincenzo.cuffaro@polito.it, francesca.cura@polito.it, Andrea.mura@polito.it

ABSTRACT. This work focuses on the analysis of the debris found in the lubrication oil produced by the wear abrasion during wear tests conducted on crowned splined couplings. During each test the presence and the dimensions of the debris in the oil have been monitored. Tests have been performed by means of a dedicated splined couplings test rig and they have been performed by imposing an angular misalignment on the axes of the components.
Results shows that when these components work in misaligned conditions, the relative motion between engaging teeth brings to the rise of a wear phenomenon called fretting wear.

SOMMARIO. Questo lavoro riguarda lo studio delle particelle metalliche presenti nell'olio lubrificante, prodotte durante prove di usura di accoppiamenti scanalati bombati. Per ogni test sono state monitorate la presenza e le dimensioni delle particelle nell'olio. Le prove sono state svolte grazie all'ausilio di un apposito banco prova per accoppiamenti scanalati e sono state eseguite imponendo un appropriato disallineamento tra l'asse dell'albero e quello del mozzo dell'accoppiamento scanalato in prova.
I risultati mostrano che quando questi componenti lavorano in condizioni disallineate, il movimento relativo dei denti a contatto fa nascere un fenomeno di usura superficiale denominato fretting wear.

KEYWORDS. Spline coupling; Wear; Oil debris; Fretting.

INTRODUCTION

In the design phase, above all in the aeronautical environment, special emphasis may be given to the dimensioning and verification of all structural elements used for the power transmission.
Due to the field of applications, these components must have high safety characteristics.
To allow the production of more light and efficient structural elements, the design phase has to become more accurate from both choosing of material and dimensioning point of view.
Among these components, splined couplings are often used because they are the most efficient torsional connections and because they are removable and therefore easy to replace in case of failure.
In addition to this, these components allow small axial movements and a misalignment degree between axes of the shaft and of the hub.
The latter characteristic, however, is a major cause of these components failure because it produces a wear phenomenon between the surfaces of the teeth in contact, called fretting.
The fretting phenomenon occurs when two bodies come into contact and oscillate the one above the other with an amplitude range typically between 5 and 100 microns.

The resulting damage may be either fatigue (fretting fatigue) or wear (fretting wear) and it depends on the value of the force that holds down the two bodies in contact and the amplitude of the relative displacement [1].
When the sliding between two elements has a small amplitude, the first case is present, while when the sliding is greater wear phenomenon will be predominant.
From the design point of view, it is difficult to take into account the fretting, especially when complicated geometries such as splined couplings are considered.
To analyze its evolution, it is necessary to use complicated FEM models quite expensive from both computational and time point of view [2].
For this reason, in recent decades, a great interest has been risen by the companies that work in the aerospace industry for the study of this phenomenon (which leads to a premature replacement of components) and particularly an analytical methodology that is able to predict the occurrence of fretting, as a function of the operating conditions to which the component will be subjected, is trying to be accomplished.
Several studies [3-9] pointed out that the phenomenon of fretting is affected by many factors; the most important are: presence or absence of lubrication, load distribution (contact pressure) [10] and relative sliding between the teeth (realized by the entity of misalignment between axes of the shaft and of the hub).
In this work it has been tried to understand how the misalignment, and then the relative movement of the surfaces in contact, may influence the phenomenon of wear and/or fretting fatigue; for this reason, a splined couplings test bench has been designed and built [11], whose peculiarity is to be able to accurately reproduce the real working conditions into an aeronautics transmission of these components.
During a wear test it is possible to vary some parameters as: torque, rotation speed, degree of misalignment, number of cycles and presence or absence of lubrication. It may also be monitored some indexes as temperature, deformation of the spline coupling and both quantity and size of the debris particles present in the lubricant.
The survey methods adopted for monitoring the damage caused by fretting phenomena may be divided into two main family; the first family can be defined as global methods: the Ruiz parameter, the study of the dynamic response, the backslash between the teeth and the presence of debris into the oil can be considered into this group; the second family is defined as punctual methods and as an example the study of the roughness parameters [12] trend of the tooth surface can be considered into this group.
In particular, this work focuses on the analysis of the debris present in the lubrication oil produced by the wear abrasion. During each test the presence and the dimensions of the debris in the oil have been monitored.
As a matter of fact, due to the wear phenomenon, a part of the surface coating of the spline coupling teeth has been wear out; this phenomenon causes the presence of micro-particles of metal inside the lubrication oil.
In order to monitor these particles a special instrument called ICM (In-line Contamination Monitor) of the MP-filters has been installed; thanks to this it is possible to determine the number and the size (from 4 at 25 microns) of the debris particles present into the oil
The debris monitoring is very important, not only to quantify the removed material, but also to understand how the damage is evolving and in particular which kind of fretting is going on (fretting wear or fretting fatigue) and to verify if the prediction of the wear damage that may be done by means of fretting maps is consistent and reliable [1].

EXPERIMENTAL SETUP

Wear tests have been performed by means of a dedicated test bench for splined couplings [11].
The test bench has a mechanical power recirculation scheme, since the external power to be applied offsets only the power dissipated in friction and allow to apply a specific angular misalignment between spline coupling in order to reproduce the real operating conditions of the component.
It is possible to simulate the misalignment that may occur in the real case, the test bench allowing a maximum inclination of 10' obtained by progressive increments of 0.5'.
During the tests it is possible to monitor a lot of experimental data (debris present in the oil, temperature and strain of the specimen, speed rotation, torque, etc..), in particular the debris monitoring has been done by means of the inline contamination monitor (ICM) that measures and quantifies the numbers of solid contaminants in hydraulic, lubrication and transmission applications [13]. The instrument uses a light extinction principle whereby a specially collimated precision LED light source shines through the fluid and lands on a photodiode. When a particle passes through the beam it reduces the amount of light received by the diode, and from this change in condition, the size of the particle can be deduced.

Figure 1: Inline contamination monitor connected to the lubrication system of the splined couplings test rig.

The ICM is designed to be an accurate instrument for permanently installed applications utilizing mineral oil as the operating fluid. The unit can operate using any of the international standard formats ISO 4406:1999, NAS 1638, AS 4059E and ISO 11218 [12].
A forced lubrication system is present and reproduces the operating lubrication conditions of splined couplings. It is provided a heating system for the oil so that it can lead to a maximum temperature of 60 ° C.
Splined couplings specimens are steel made (42CrMo4) nitrogen-hardened; they have crowned tooth profile and the main characteristics are: 26 teeth, 1.27 mm modulus, 30° pressure angle, 200 mm crowing radius and 12 mm face width.

RESULTS AND DISCUSSION

In this work three wear tests are presented; these tests have been carried out specifically to understand how the misalignment affects the phenomenon of fretting wear.
All the tests have been done with the same torque value, the same rotation speed and, since they were wear tests, also the same temporal duration.
The differences between the tests have been focused on the variation of the misalignment angle between shaft and hub axes of the spline coupling; in particular, the test MB1 has been done aligned, the test MB2 has been done with 5 ' of misalignment and finally the test MB3 has been done with 10'. Tab. 1 resumes the tests parameters.

Test	Torque [Nm]	Speed [rpm]	Misalign. [‘]	Lubr.	N° of cycles
MB1	700	1500	0	Yes	10M
MB2	700	1500	5	Yes	10M
MB3	700	1500	10	Yes	10M

Table 1: Tests parameters.

Fig. 1, 2 and 3 show teeth after wear test of respectively specimen MB1, specimen MB2 and specimen MB3
It is possible to point out that after test MB1 (performed without misalignment) the teeth surface doesn’t show any evident trace of wear damage. Considering tests MB2 and MB3 it is possible to observe that the wear damage appear on teeth surface and the damage in test MB3 is bigger than in test MB2, that is reasonable because test MB3 has been performed with higher misalignment angle (10’) respect to test MB2 (5’).
Fig. 4-9 show the trend of the number of the debris particles during a wear test; in abscissa is reported the duration of a test dimensionless and in ordinate is shown the number of particles detected by the oil debris system.
In Fig. 4 is shown the trend of the particles number with a dimension of 4 μm referred to tests MB1, MB2 and MB3. As it can be seen the number of the particles for the first test (in this test the axes of the hub and the shaft were lined) is low and it stays more or less the same throughout the test; on the other hand during the tests MB2 and MB3 the number of the particles presents an increasing trend and in particular the value of debris for the last test is the highest.

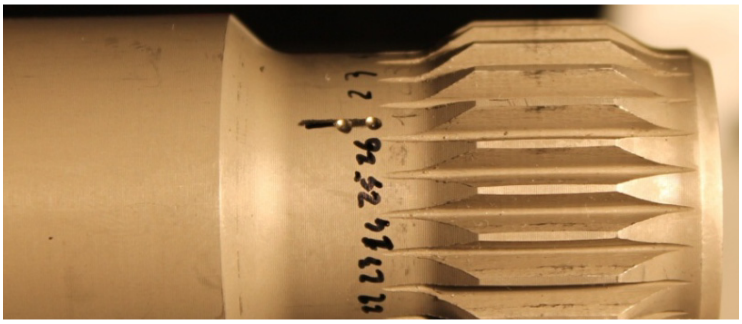

Figure 1: Specimen MB1 after test.

Figure 2: Specimen MB2 after test.

Figure 3: Specimen MB3 after test.

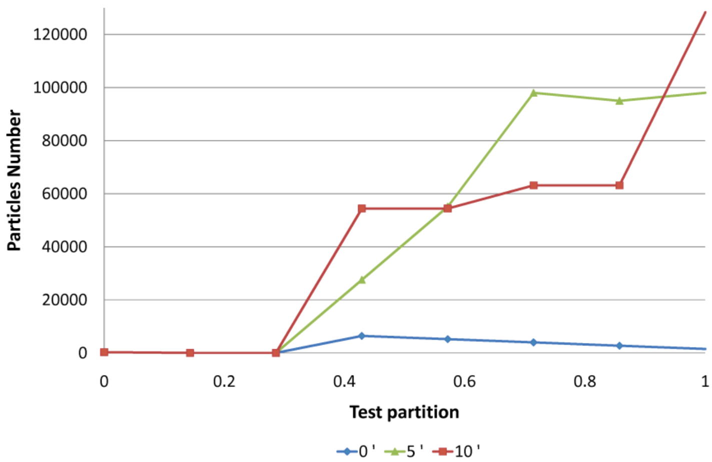

Figure 4: Trend of 4μm particles during the test.

In Fig. 5 is shown the trend of the particles with a dimension of 6 μm; as it can be observed, the trend is similar to that of Fig. 4, the only difference, compared to the previous ones, is the number of the particles; in fact it is less for all tests.

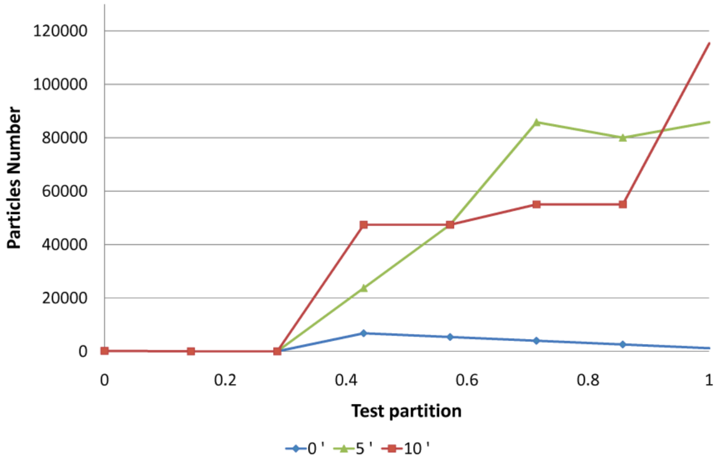

Figure 5: Trend of 6μm particles during the test.

Observing Fig. 6-8 it is possible to note that the trends of the particles during the test are very similar, the only difference, like previously described, is the number of the debris particles that, in reference to the increase of the size, decreases.

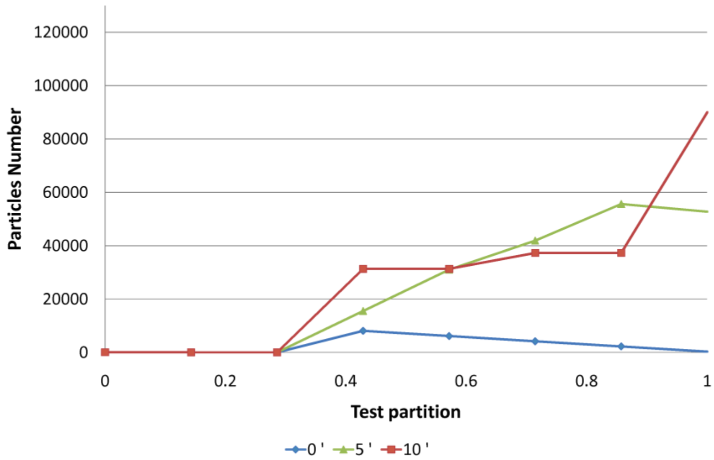

Figure 6: Trend of 14μm particles during the test.

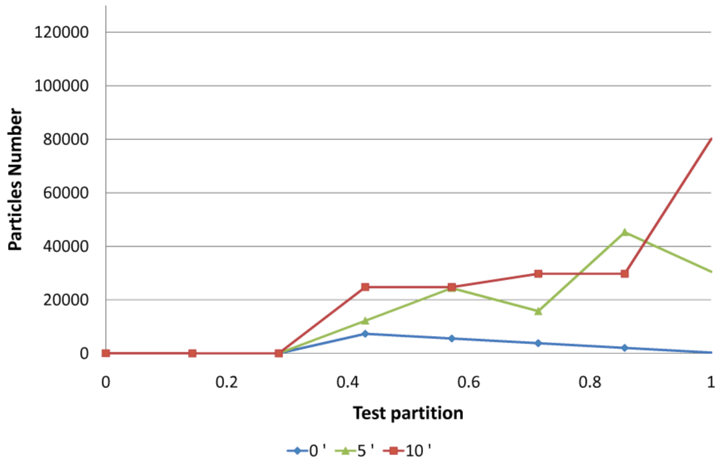

Figure 7: Trend of 21μm particles during the test.

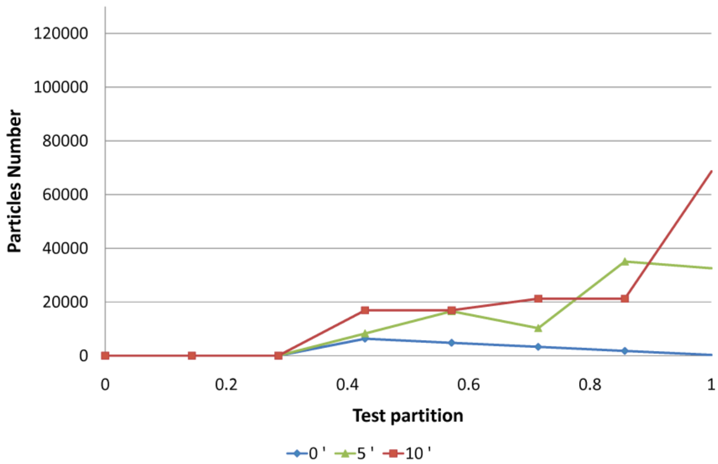

Figure 8: Trend of 25μm particles during the test.

In Fig. 9 is represented a graph where in abscissa is reported the dimension of the particles for the three tests and in ordinate is reported the maximum number of the particles detected by the oil debris system during a whole test.
As it can be noted, the number of particles for all tests decreases respect to the increase of the size of these.
The maximum number of the particles has been obtained for the test MB3 where it has been performed with higher misalignment angle (10'), and the lowest number of debris has been achieved for the MB1 test that has been performed without misalignment.

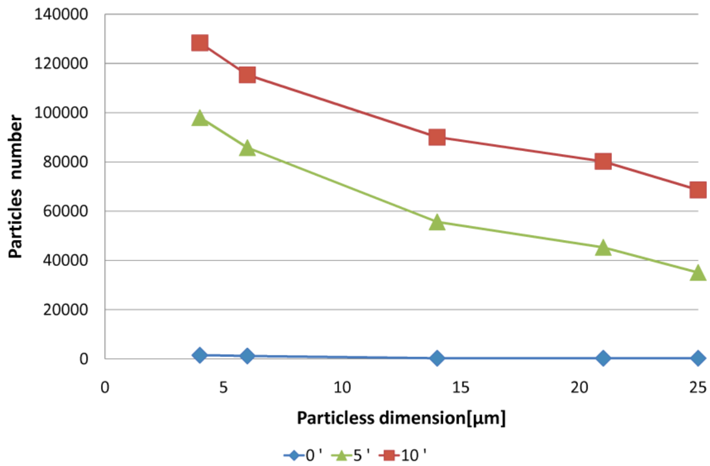

Figure 8: Trend particles number during the test.

Conclusions

This paper deals with the analysis of debris produced during wear tests of splined couplings. In particular the tests have been performed by imposing an angular misalignment on the components and the effect of this parameter on debris production has been investigated. Tests have been performed by means of a dedicated splined couplings test rig. Results shows that when these components work in misaligned conditions, the relative motion between engaging teeth brings to the rise of a wear phenomenon as fretting wear. The wear damage produce particles that remain in the lubrication oil. Thanks to an inline contamination monitor, the debris present into the lubrication oil have been monitored, showing that by increasing the angular misalignment, the number of particles of different dimension increase.

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