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Gear Degradation Under Pollution Effect

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Abstract: In this study we are interested in gear degradation under solid pollution effect. With this intention, An experiment which simulates operation of gears loaded in polluted media was carried out. The study tries to answer questions in relationship with the presence effect of solid particles in lubricants on surfaces contact. We show that the use of a lubricant polluted by very fine sand particles, leads to notable wear at first operations cycles. The pollutant presence in the first hand, increases friction, therefore rises the temperature and on the other hand, leads to a bad quality of surfaces.

Key words: Solid pollution, degradation, wear, bad surfaces quality

INTRODUCTION

Today it is well known that the presence of solid particles in lubricant is inevitable. Lubricants used are already polluted even in new state they are more at time of maintenance and assembly operations. These undesirable particles can damage surfaces and lead to fatigue and wear of machine elements. In mediums polluted like the Sahara, quarriess or mines, sand concentration in air is very high (15 to 35 mg m^{-3}) and it is 10 to 100 times higher in the presence of the winds. The dust particles carried by winds have various sizes going from smallest than the micron to a few millimetres. In addition, filters which play a key-role for mechanisms protection are used to clean lubricants, but filtration does not eliminate the problem completely because very small particles manage to pass through the filter meshes and when their size is higher than oil film thickness, they disrturb the separation, dent and causes surfaces wear. Solid pollution of lubrication is thus very important in particular for Life Cycle evaluation (LCA) (Taylor *et al*., 2004).

In these last years, several studies were undertaken on solid pollution of lubrication.The majority of authors used a ball-plane test rig where the ball is animated by rotational movement on a glass disc. Wedeven and Cusano (1979, 1982) Kaneta *et al*. (1992, 1997) Kaneta and Nishikawa (1994) have used this device in their studies. They dent ball surface and they followed dent evolution in the contact and its effect on the oil film thickness. Coulon *et al*. (2004) showed that the presence of sliding leads to a significant modification of oil film thickness around and to the level of dent. This modification increase stresses and consequently leads to a significant risk of fatigue. Wan and Spikes (1988) in their study which consists to follow the particles behavior in the contact used a device equipped by a high speed camera. They described the behavior of a whole range of various particles in EHL contact. (Dwyer-Joyce *et al*., 1990) undertook a study by using various particles. It thus established a classification of particles (ductile, brittle and ceramics-hard) according to their behavior in the contact. This study based mainly on impact of ceramics-hard particles is compared with ductile particles in term of damage which they produce. Cann *et al*. (1996) by an optical interferometer technique observed the entry and deformation of particles in the contact. Ville and Nelias (1999) also undertook an experimental study, which shows the presence and deformation effect of spherical ductile metal particles in EHL contact. Many authors calculated pressure field with presence of one dent (Ai and Lee, 1996; Gupta *et al*., 1995). They showed that dent increases stresses in solid bodies. Recently, Kang *et al.* (2000) developed a model which takes account solid particles effect on pressure field and oil film thickness in EHL contact. This model was obtained by introducing the geometry of one ellipsoidal shape particle in Reynolds equation. Dwyer Joyce (2004) gave an overall picture on significant variations of wear debris life cycle in EHL contact. De Pellegrin and Stachowiak (2005) for their part, simulated real three-dimensional abrasive particles produced while cutting a body by a random plane of orientation and a random penetration depth.

Other studies were undertaken on the oils employed in aeronautical applications (Nelias, 1989) they show that

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there are several types of particles. similarly (Akl, 1983; Akl *et al*., 1987) while basing on oils analysis used during tests on a roller machine simulating a lubricated hertzian contact carried out a classification of particles. They thus classified particles in four classes corresponding to break-in periods, normal operation, transition and fracture of mechanism.

Finally wear can occur by two mechanisms (Cornet and Deville, 1998). Firstly particles can remain stuck (or encrusted) in the most tender surface and damage hardest. This one is known like two-body wear. Particle can also roll through the contact causing dents on the two surfaces; it is three bodies abrasive wear. Particles can be foreign or from degradation of same surfaces.

For our part, we are interested to the effect of solid pollution of lubrication on gear wear (thickness loss) and its distribution on tooth profile according to cycles number for pinion and wheel. We also interest to the temperature evolution at tooth base and surfaces roughness for an operation in such polluted media.

EXPERIMENTAL PROCEDURE

In order to study degradation of machine elements under accentuated effect of dusty environment, an experiment which simulates mechanism operation in a sandy or dusty medium (quarries or mines for example) was carried out. We observe during tests, the effect of polluted lubricant on gear surfaces.

Experimental device: Tests were carried out on an experimental device where a pinion and wheel are placed in contact. The pinion is actuated at a constant speed and wheel is loaded by friction torque ensured by dynamometric tightening. Lubrication is ensured by supply of polluted oil in the contact (Fig. 1).

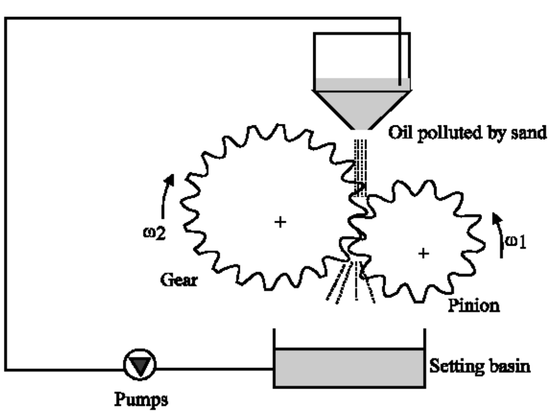

Fig. 1: Test rig of gear

Toothed wheels: Toothed wheels of gears are connected according to AFNOR NFA 35-552-553 standards with sub-category XC48. We considered only one type of material. Table 1 and 2 show principal mechanical and chemical characteristics of toothed wheels. Rotational speeds of wheels are constant during all test.

Mechanical and functional parameters of contact are represented in Table 3 (Flamand, 1993). It gives values of these parameters at remarkable points of engaging according to the line of action (Fig. 2).

Lubricant: The used lubricant is ISO VG 220 oil. It has a dynamic viscosity $\mu_{\_0}$ = 0.033 Pas at T0 = 40°C and a piezo-viscosity coefficient $\alpha_{\_p\text{-}v}$ = 18.2 10^{-9} Pa^{-1}. It represents transmission oil and used for gears greasing and reducers loaded under casings by splashing and circulation.

Table 1: Mechanical and geometrical gear properties

Characteristics	Pinion	Wheel
Number of teeth (z)	32	55
Transmission ratio	1.71	875
Deport angle (x)	0.00	0.00
Pressure angle (α)	20°	20°
Height (mm)	5.40	5.40
Modulus (mm)	2.40	2.40
Face width (mm)	17.50	17.50
Pitch diameter (mm)	76.84	135.10
Diameter of base (mm)	72.20	126.95
Diameter of tip (mm)	81.64	140
Materials	XC48	XC48
Hardness (HRB)	86.00	86.00
R_{eq} (N mm^{-2})	540	540

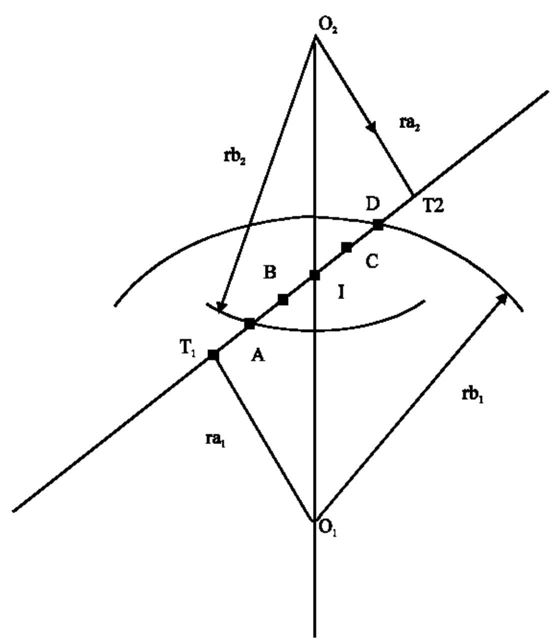

Fig. 2: Remarkable points of engaging

Table 2: Chemical gear properties

Methods and tests standards	Analysis by x-rays fluorescence Carbon and sulphur by infra-red absorption spectrometry									
Components	C	Mo	Cu	Ni	Mn	Cr	P	Si	V	S
Mass (%)	0.520	0.007	0.082	0.056	0.625	<0.05	0.009	0.454	<0.01	0.0345

Table 3: Mechanical state and contact operation parameters

Mechanical state					Contact operation		
Points	R_x (mm)	$\|u_1+u_2\|$ (m s^{-1})	$\|u_1-u_2\|$ (m s^{-1})	W(N)	h_m (µm)	P_0 (Mpa)	$\|u_1+u_2\|$
A	5.788	0.504	0.202	132.5	0.095	219.15	0.40
B	8.138	0.549	0.033	265	0.107	261.38	0.06
I	8.376	0.556	0.006	265	0.109	257.64	0.01
C	8.661	0.566	0.032	265	0.112	253.36	0.056
D	9.103	0.610	0.202	132.5	0.132	174.75	0.33

The pollutant: The used pollutant is a sand filtered to 40 µm which simulates pollutant resulting from external media. It is primarily composed of Silicon Oxide (SiO2) known for its brittleness and its raised hardness, about 1.079 to 1.117 GPa. The preparation of polluted solution is obtained by mixture of 2 liters oil with 10 g of sand.

Experimental measurements: The wear is evaluated by thickness loss measurement. Measurements were taken in three different places, at the level of tooth base, its tip and its pitch diameter. Measurements were reproduced on three teeth forming 120 angle degrees between them as well on pinion as on wheel. The average value was considered. The temperature is evaluated on tooth base. An infrared thermocouple was used where measurements were raised for an operation with a polluted oil and whitout pollutant presence. Finally roughness is evaluated before and after operation.

RESULTS AND DISCUSSION

The sand being composed primarily of quartz (SiO2) is brittle and has a very high hardness. They roll or slip into the contact leading to wear and leaving micro-stripes or micro-furrows on surfaces. They wear by abrasion, surfaces which present a high rate of sliding and by fatigue, surfaces near pitch diameter. In this last zone, the sand particles roll and leave furrows or dents on surfaces. Figure 3 and 4 shows that the presence of sand particles in lubricant causes notable thickness losses at the first operations cycles. Wear is very significant on the level of tooth base and little less on the level of tip. That is explained by association of indentation and sliding which is at its maximum in tooth base and on the other hand, by the rigidity of deflection which is larger in base. On the level of pitch zone, wear degree is relatively less compared with base or tip of tooth. In this last zone, sliding is near-total absence. This type of wear is with indentation, adhesion and micro-fatigue.

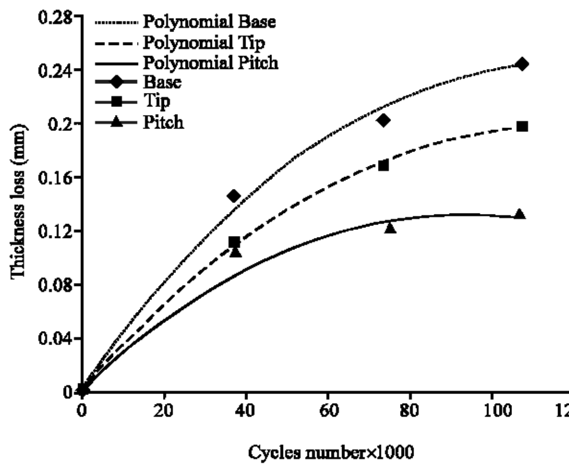

Fig. 3: Thickness loss on pinion (mm)

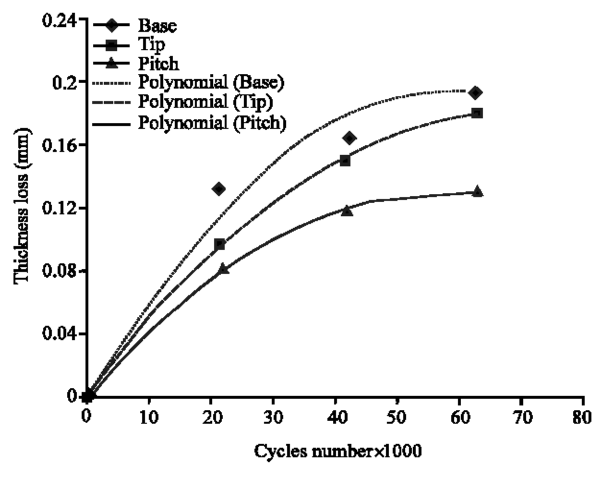

Fig. 4: Thickness loss on wheel (mm)

Results obtained for pinion and wheel (Fig. 5) show that thickness loss undergone by pinion is more significant than that undergone by wheel for a number of cycles obviously higher.

The mechanical energy lost by friction, transformed into heat, is generally irrecuperable and sometimes very difficult to evacuate. The thermal aspects of friction can have unexpected consequences. Indeed we note according to the obtained results (Fig. 6) that the temperature increases during first operations cycles, then stabilizes itself. This heating comes from elastic and plastic deformation, repeating itself at high speed accompanied by sliding and friction stresses. This increase is caused by pollutant presence. This is confirmed by the represented results (Fig. 7) where the roughness increases. Indeed, the latter has more doubled as well for pinion as for wheel with presence of brittle particles lower than 40 μm.

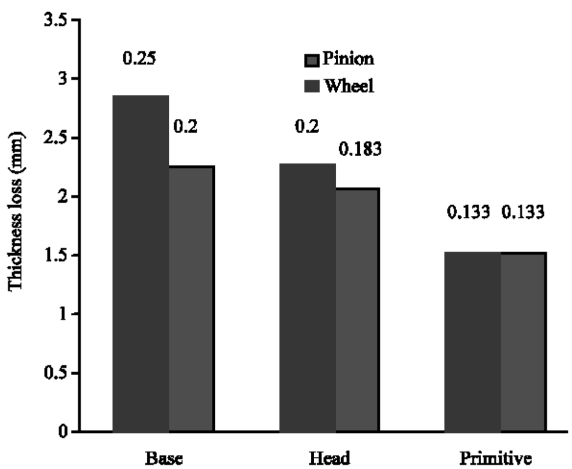

Fig. 5: Thickness loss confrontation at various places

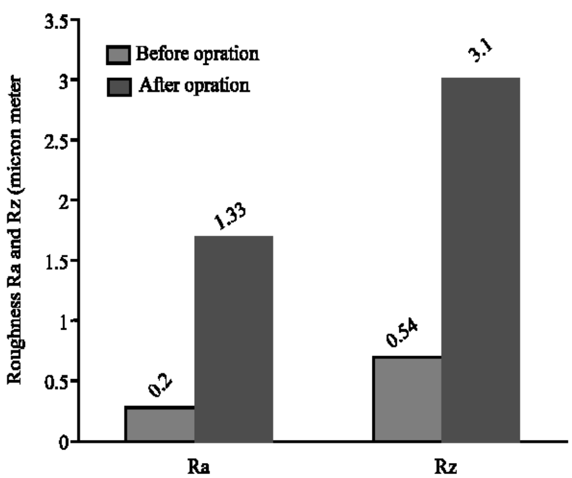

Fig. 6: Temperature evolution (°C)

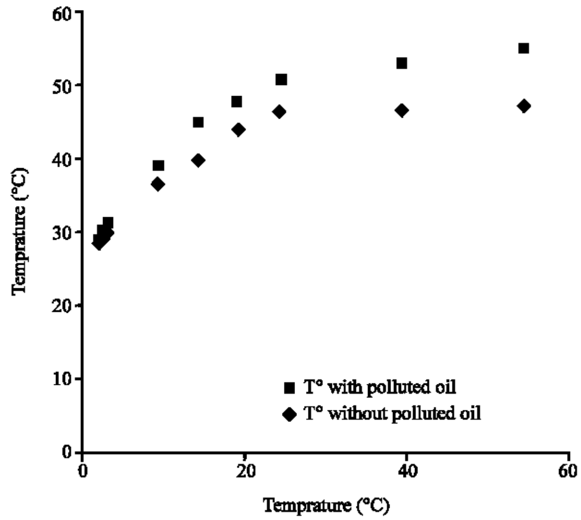

Fig. 7: Roughness before and after Operation (μm)

CONCLUSION

The aim of this research in the first hand, well understand solid pollution effects on surfaces contact and on the other hand, to apprehend surfaces wear related to this type of problem. With this intention, a device which simulates real operation conditions of gear was built. The solid pollution of lubricant is controlled in rate and size.

The principal conclusions which one can draw from this study are:

- The presence of sand particles in lubricant causes notable thickness losses at the first operations cycles.
- These particles accelerate and increase abrasive wear in zones with a high sliding.
- The highest wear is at tooth base because; on this level we find the greatest sliding and great deflection rigidity in comparison with tooth tip.
- On the level of pitch zone, wear is not higher because, on this level sliding is very less. Particles roll and dent surfaces. They thus create a geometrical defect which becomes a specific site of fatigue.
- The presence of abrasive particles in lubricant increased also temperature.
- These abrasive particles increase roughness. The latter has clearly increased in the presence of sand particles.

Therefore, in the first hand inevitable presence of solid particles in lubricant has a double effect, it increases tooth profiles wear in zones with a high sliding and lead to fatigue by indentation near the pitch diameter. On the other hand, it increases temperature at tooth base and consequently leads to a bad quality of surfaces.

Nomenclature

Symbol	Units	Définition
h_m	µm	oil film thickness.
HRB	……………..	Brinell hardness.
L	m	Face width gear.
P_0	Mpa	Maximal hertzian pressure.
R_{eq}	N/mm^2	Equivalent resistance.
R_x	mm.	Radius of relative curvature: $R_x = \left(\frac{1}{R_{x1}} + \frac{1}{R_{X2}}\right)^{-1}$
T_0	°C	Temperature of reference.
W	N	Load normal (along line of action).
x	…………….	Deport angle..
Z	………………	Number of teeth.
$\|u_1+u_2\|$	m s^{-1}	Driving velocity.
$\|u_1-u_2\|$	m s^{-1}	Relative sliding.
$\|u_1+u_2\|$	%	Specific sliding.
α	(°)	Pressure angle.
α_{p-v}	Pas^{-1}	Piezo-viscosity coefficient.
μ_0	Pa. s	Dynamic viscosity at reference conditions (T_0, P_0).

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