GEAR FUNDAMENTALS

# Classification of Types of Gear Tooth Wear - Part II


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### Introduction

The first part of this article included abrasive wear with two bodies, streaks and scoring, polishing, and hot and cold scuffing. This part will deal with three-body wear, scratches or grooves, and interference wear. Normal, moderate, and excessive wear will be defined, and a descriptive chart will be presented.

### Wear With Three Bodies

This type of wear is characterized by the presence of a third body (in general abrasive) between the two surfaces in contact.

*Scratches, Grooves (Scratching).* This type of wear appears as isolated cavities and more or less deep streaks on the teeth flanks oriented in the direction of sliding motion. (See Fig. 1.) The intervals separating these scratches, their length, and their distribution on the teeth are very irregular. These scratches are generally caused by the introduction of foreign bodies of variable sizes in the gearing, particularly large dust particles, metallic particles, pieces of rust or calamine, molding sand, etc.

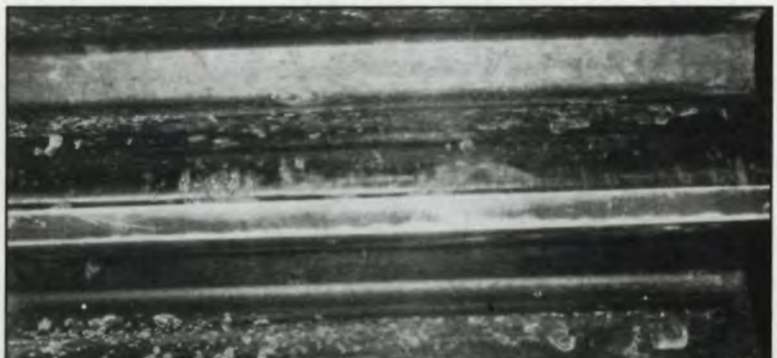

Fig. 1 - Scratches which can be seen on the uppermost part of the teeth profiles of a dryer wheel.

This type of wear can often be seen just after start-up, after the repair of an installation, or before the filter has had a chance to remove impurities from the lubricant.

Open gears lubricated with grease are, because of insufficient protection, very often susceptible to this type of deterioration. Scratches on the profiles are a sign of the presence of foreign bodies in the teeth. To avoid the development of abrasive wear, one should

- assure the structural integrity of the gear housing to prevent possible exterior pollution,
- check the state of the filters,
- filter the lubricant or change it,
- assure that no particles originating at the foundry may detach from the housing,
- lightly polish the scratched zones and assure that no hard particles are still embedded in the teeth surfaces.

This type of degradation, whose cause is to be looked for in the vicinity of the gear, is of little concern to the teeth if discovered in time, and if appropriate necessary measures are taken to stop its development.

We note a fundamental difference with the metal pull-off or adhesion phenomena, which are much more cause for concern, for they jeopardize the gearing conditions.

*Abrasive Wear.* This wear phenomon is caused by the presence of fine abrasive particles in the lubricant.

These particles may have come from the exterior environment of the gearing (dust, sand, miscellaneous impurities) and may have been introduced in the lubricant because of insufficient protection of the teeth. They may also have come from the inside of the gearbox (foundry sand particles, particles from metal burrs or pit holes, oil impurities).

The appearance of abrasive wear depends on the size and nature of the contaminating particles; for example, a fine abrasive dust will form a mixture with the lubricant, which will polish the teeth, giving them a dull, soft surface.

The presence of sand in the oil or grease (in the case of open gears) will generate a surface aspect rougher towards the tooth tip with a few scratches in the sliding direction and a polished zone below the pitch line.

On case-hardened gears, the presence of carbide near the surface may induce abrasive wear, especially if the load on the teeth is heavy, and if the sliding is high (as with hypoid gears).

When bigger particles are found in the lubricant, we may see the formation of a few scratches on the profiles (Cf. preceding paragraph.) They are generally present in the middle of the polished surfaces.

In the case of abrasive wear, the particles are constantly swept from the contact surfaces (in general by lubricant), and we never encounter local adhesions or micro-weldings.

Abrasive wear is thus totally different from scuffing phenomena because the scratches and the material removal seen are not the results of faulty lubrication or inadequate service conditions. The lubricant is often the vehicle which contains the abrasive particles and transports them throughout the system, causing pollution of the seals, bearings, bushings, the pumps, and all the meshings.

Abrasive wear is generally a phenomenon progressing very quickly and resulting in an increase of gear backlash in service, which may bring about modifications in dynamic behavior, and/or a distortion in the profile form which is the source of noises and vibrations.

If it is not detected, the erosion mechanism will continue and result in pointed teeth. It is not rare to discover worn teeth as shown in Fig. 2. Most of the time, when we attain a critical evolution as represented there, the tooth section has reduced greatly, and we often observe shearing effects in the zone BB.

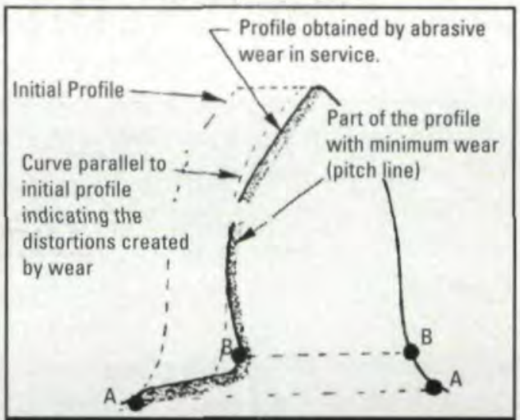

Fig. 2 - Abrasive wear mechanism.

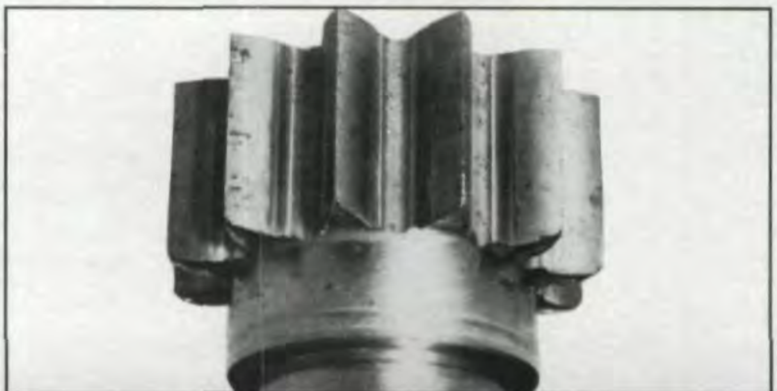
Fig. 3 - Abrasive wear of a pinion tooth. We can see on this figure the dull aspect of eroded flanks with the presence of a few scratches, the appearance of shouldering at the bottom of the active profile, and the tooth tips in knife-blade shape.

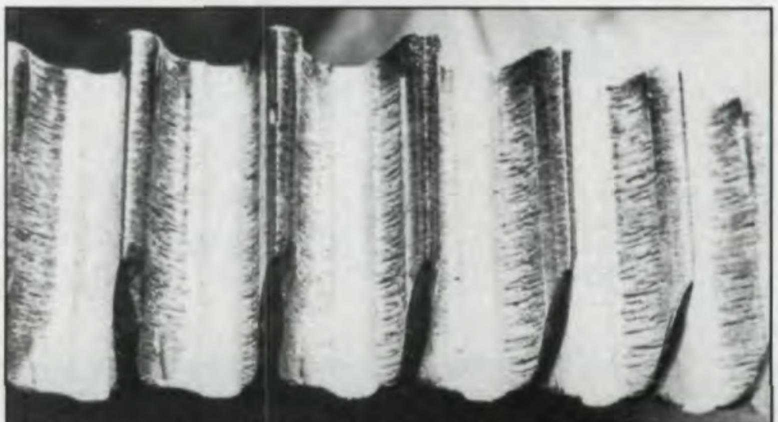
Fig. 4 - Abrasive wear with important loss of material.

In case-hardened gears, if the abrasive wear is intense, it will result in a rapid reduction of the thickness in the hardened surface on the teeth. This will bring about the formation of another type of deterioration (spalling), which will generally be fatal to the teeth, for the thickness of the hardened layer will no longer be sufficient to support the load to be transmitted. (See Figs. 3-4.) If the abrasive wear is detected in time, before its effect has caused a modification of the profiles and an increase of backlash incompatible

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with the gearing function, and if its causes are perfectly established so that efficient remedies can be undertaken, we will observe a durable stabilization of the state of the teeth.

**Interference Wear**

This type of wear occurs when contact between teeth happens in bad geometric conditions at the beginning or the end of meshing. This is the case mainly when the contact occurs outside of the action segment. The two profiles in contact are no longer tangent, and their faulty mating during this period of the meshing generates an overload or shock in the teeth zones concerned.

We observe during the beginning of meshing a concentration of the load on the low point of the driving element. At the end of the recession, we encounter the concentration of the load at the tip of the driving element profile.

This interface mechanism is illustrated on the sketch in Fig. 5. We have represented on each side of the segment of action *T1T2* two pairs of teeth meshing in interference position. In general, an interference wear appears at the low point of the profile in a narrow wear zone (sometimes with the presence of pitting or scratches), and at the tooth tip in the form of streaks prone to evolving into scratches and, in extreme cases, metal pull-off.

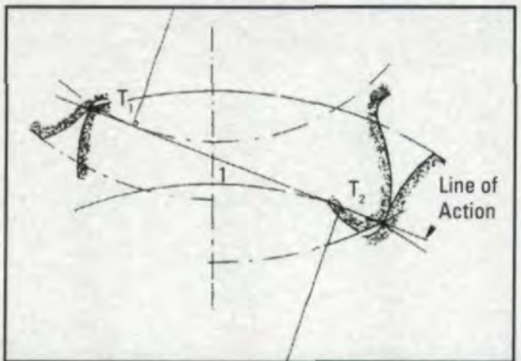


Fig. 5 - Line of action of a cylindrical gear.

Fig. 6 - Interference wear recorded on the base of a driven gear wheel profile.

In general, since we will detect shocks at extreme points of the meshing, this type of wear will result in an increase in gearing noise. In the case of through-hardened gears we observe a hollow in the lower parts of the profile, as well as a light flow on the high parts of the profile, which will result in the formation of a burr on the active ridge at the tooth tip. In general, interference wear is not dangerous, for as the gear wears off, we will observe a reduction of shocks and overloads at the extreme points of the meshing. The degradation which may be observed on the flanks will end up by running in and disappearing, and the noise level will reduce.

In general, interference wear is not influenced by the lubrication quality. We encounter this type of wear:

- When the design of the teeth was bad (primary interferences),
- When the teeth have undergone overloads which have brought about exaggerated deflections of the teeth in service,
- When the gear contains, in the critical zones of the profiles, excess material which results from cutting defects.
- When one or more teeth have been distorted, cracked, or broken in service. In this case, the meshing of the following tooth and perhaps a few other following teeth is no longer assured, and we observe shocks at the base of the profile which generally are extremely severe and can cause the formation of deep hollows. Fig. 6 gives an example of interference wear recorded on the flanks of a gear wheel.

**Normal Wear**

This is a slow, progressive wear which is not prejudicial to keeping the gear in service for the normal expected life.

In this class of wear we generally place common wear abrasion with two bodies in all its different possible manifestations. In the case of normal wear, we are not in the presence of damage, but of a normal appearance which shows proper operation of the teeth.

In general, this type of wear requires no special inspection or any systematic follow-up if we do not see any notable evolution after a certain time of gear operation. This type of wear appears very slowly in surface-hardened teeth. The same is true for lightly loaded gears.

For gears of moderate hardness, the wear will develop on each side of the pitch line where sliding is null by modifying the shape of the profile as indicated in Fig. 7. As long as the wear remains low, this type of profile form evolution of the teeth is beneficial at the meshing level, for it allows better absorption of the teeth impacts during their engagement.

We will thus often observe the disappearance in time of the streaks at the tooth tip or at the root of the teeth, which sometimes appear soon after first start-up of a gear (in the general case of gear teeth loaded at low speed or medium speed).

As wear progresses, the profile deviations will increase with such consequences as an increase of dynamic efforts during meshing, as revealed by the increase in noise and vibration levels or an increase in backlash.

We can fix a limit to normal wear by considering the following:

• The maximum value of backlash authorized in service by the designer of the gear. This tolerated value will be very much different whether the load direction changes or remains always applied to the same series of flanks during the rotation of one of the gear wheels.

• The vibration level or noise level, which should not surpass a certain preset value.

• The dynamic effects during meshing due to deviations of profile caused by wear. In fact, these deviations generate overloads on the teeth for which the gearing has not necessarily been sufficiently dimensioned when designed. They are generally difficult to estimate, but the appearance or the progression of pitting on the teeth can be a useable criterion to set the end of normal wear.

We will consider the criteria defined above each time that the mechanism in which the gear is placed transmits alternate effects or is subject to important torsional vibrations. They should also be considered in the case of gears used for driving alternative machines or machines of high inertia having long drive shafts or with low rigidity, or in the case of mechanisms with backlash compensation or gears used to carry out precise displacements.

To follow the evolution of backlash in service, we can periodically record the distance between the profiles, either with thickness gauges inserted between the teeth or by "rotating" the teeth and measuring with a comparator the relative movement of one element of the gear in relation to another near the pitch line.

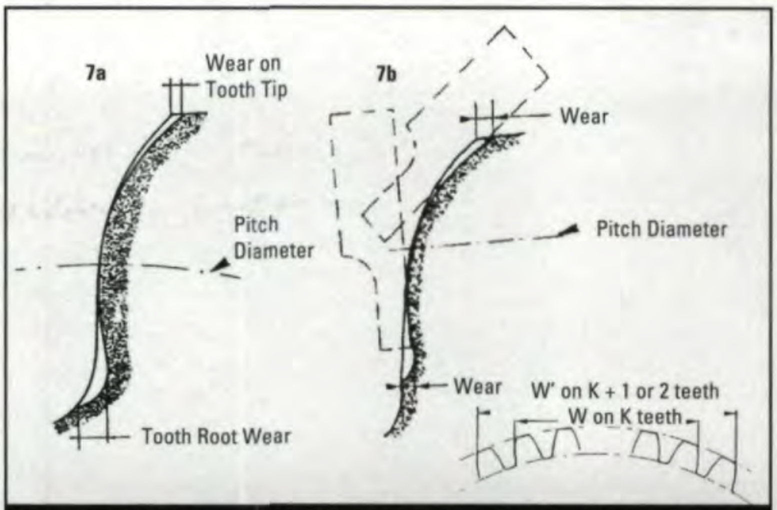


Fig. 7a - Distinctive aspect of distortion of gear teeth profiles under wear action. 7b - Principle of direct wear measurement.

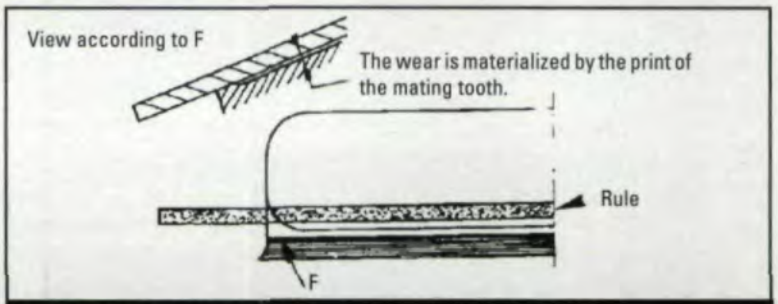


Fig. 8 - Measure of wear by comparison with initial profile.

We can also make a direct evaluation of wear on the teeth by using the following method:

• Check the value of *Wk* over *K* teeth, which gives the distance near the pitch line measured on the *K* teeth. At this point on the teeth, the wear is lowest. (Cf. Fig. 7b.)

• Check the value of the distance over the $K + n$ teeth ($n$ = 1 or 2) in such a manner as to tangent to profiles near the tip circle.

• Check the value of the distance over the $K - n$ ($n$ = 1 or 2) in such a manner as to tangent the profiles near the dedendum in the place where the teeth show the greatest wear (Cf. Fig. 8).

• Determine the wear value using the following formula:

wear on tooth addendum:

$$\frac{(W_K + n \cdot p_b - W_{K+n})}{2}$$

wear on tooth dedendum:

$$\frac{(W_K - n \cdot p_b - W_{K-n})}{2}$$

with $p_b$ = base pitch

The wear values obtained (reduced from tip relief if need be) will be used for maximum

Fig. 9 - Normal wear. Aspect of a large gear wheel flank lubricated with grease.

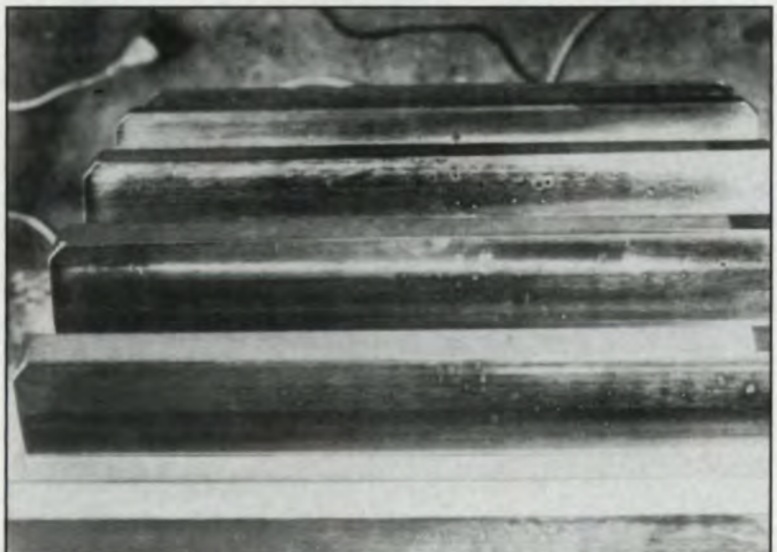

Fig. 10 - Normal wear. Normal aspect of gearing teeth flanks. We note a few traces of the passage of foreign particles between the teeth and some unimportant small pitting.

Fig. 11 - Moderate wear. We will note the trace of the operating pitch line on the teeth flanks and the presence of fine streaks indicating that the teeth operate near the limit rate of lubrication.

backlash calculation of the gear in operation. In certain cases, the wear on the flank dedendum may be obtained from the print left by the mating wheel by direct measurement with gauges (See Fig. 8). Generally we can classify as normal wear the following surface aspects:

• Streaks or scratches on the teeth surface, providing that they do not evolve while in service,

• Polishing, providing that its surface does not show localized traces of metal pull-off or scuffing,

• Abrasive wear, providing that its progression is slow or has become stabilized. This type of wear is often beneficial at the beginning of a gear life for it encourages the establishing of good contact surfaces.

• Interference wear when it is slightly marked on the teeth. In the case of through-hardened teeth, we can admit that normal wear is often accompanied by the formation of pitting in the heavy loaded zones of the gear. (See Figs. 9-10.)

### Moderate Wear

At this stage of wear development, the teeth appearance is such that we can easily notice that material removal has occurred during operation near the tip of the teeth and on tooth flank dedendum. In general the trace on the operating pitch line becomes apparent and appears as a continuous line of low thickness on the whole width of the teeth. On this line we do not notice any wear or material removal.

Moderate wear is characterized by loss of material along the profiles which is more rapid than that obtained in the case of normal wear. This wear appears most often when the gears operate near their limit rate of lubrication. Many gears, because of voluntary oil viscosity limits rendered mandatory by use conditions (cold starting without preheating, for example), operate under such conditions.

This type of wear appears almost systematically in the case of highly loaded gears made of through-hardened steel and running at low speed. In this case, we often see the appearance of pitting, which is more or less dense on the teeth profiles. (See Figs. 11-12.)

The presence of particles in the lubricant or the pollution of the lubrication device can also lead to the generation of this type of wear. The moderate wear seen on the teeth is not in most applications an abnormal phenomenon and may be considered non-destructive.

It can generally be tolerated, but can be reduced by increasing the oil film thickness, mainly by assuring a better cooling of the oil (reducing gearing operating temperature), or by increasing the oil viscosity. We can also possibly reduce the load on the teeth (for example by improving the dynamic conditions).

If the gearing is operating with lubrication by splashing, we will often obtain good results by installing an injection lubrication system with a filter to retain the metallic particles in suspension in the oil.

In the case of gear wheels lubricated with grease, we obtain a noticeable improvement by replacing this lubricant by oil whenever possible. This implies that the sealing conditions in relation to the environment, the conditions of exterior pollution by the oil, or the safety conditions (installation temperature) will allow such replacement.

A moderate wear can lead to an increasing the noise and vibrations of the gear which sometimes result in a reduction of anticipated gear life.

### Excessive and Destructive Wear

This type of wear is considered an anomaly which often leads to rejecting the gear or anticipating its replacement.

The result is an important change of teeth shape and in most cases in a great reduction of their thickness. This deterioration of teeth can result from separate or joint action of one or more wear phenomena described in the preceding paragraphs. We can, for example, find teeth whose general appearance is comparable to that of moderate wear, but the volume of material removal is very large. We note the appearance of a step near the tooth root, the very low residual tooth thickness, and the destruction of the overall shape of the profile. This type of deterioration is generally generated by abrasive wear, which can in certain cases, when the residual thickness of the teeth becomes weak, end up in the total breakage of whole teeth by shearing.

We can also find destructive wear which is the result of adhesive wear and is due to direct contact between teeth flanks because the load transmitted was too large for the lubricant used. It is often the case for highly loaded gearing running slowly, where we observe the development of cold scuffing or of deep scratches.

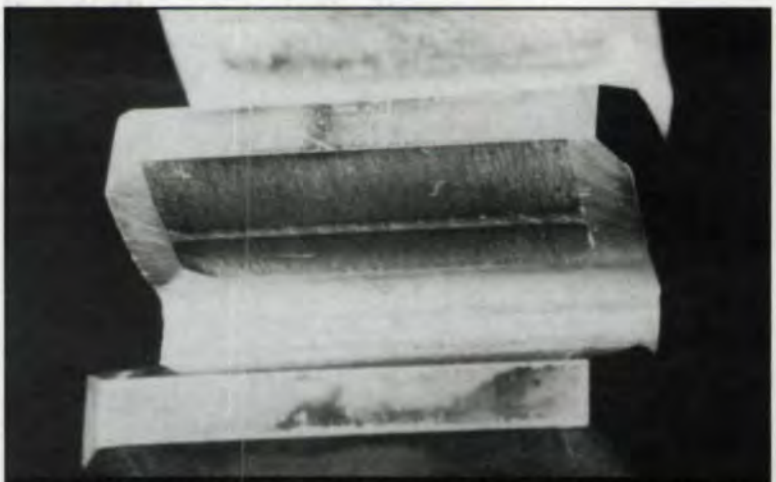

Fig. 12 - Moderate wear. This moderate wear has been caused by hot scuffing, which was stopped in time. We clearly note the traces of material pull-off near the tooth tip and root. The operating pitch surface is not altered.

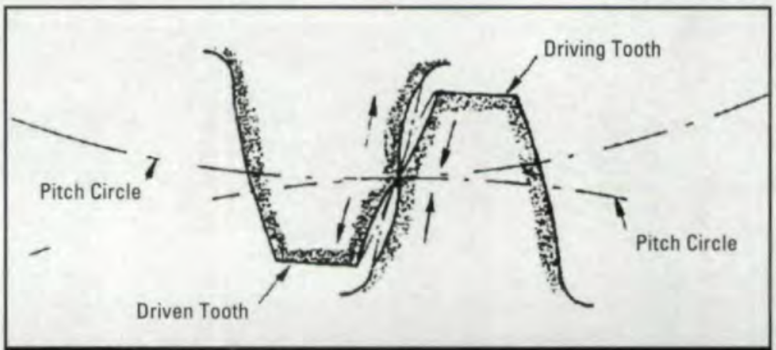


Fig. 13- Mechanism of destructive wear.

Fig. 14 - Excessive wear of a spiral pinion. We note the presence of steps in the profile root and pointed tooth tips. This pinion is near the end of its life.

The sketch in Fig. 13 shows how the destruction occurs on teeth profiles.

In the case of through-hardened gearing, undetected hot scuffing can most of the time result in destructive wear which will take the gear out of service.

Destructive wear can also be caused by the development of severe pitting, which most of the time is localized below the pitch line, and which is caused by multiplying the falling in of the teeth surface in the region affected, thus destroying the general profile shape. (See Figs. 14-16.)

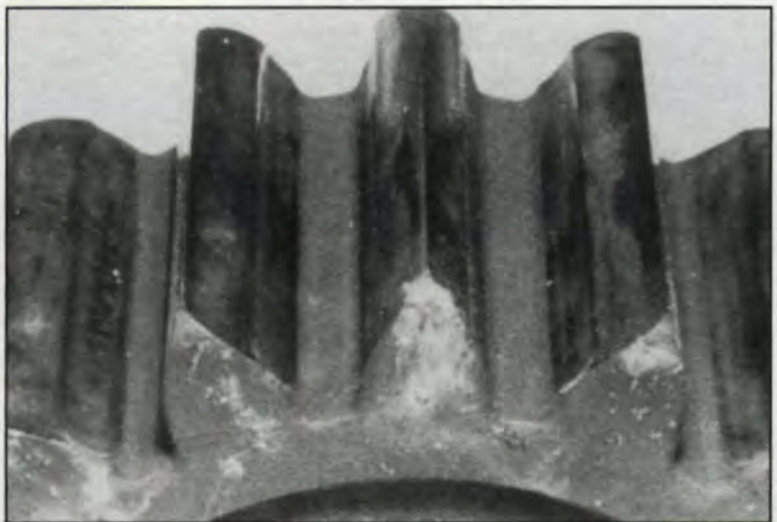

**Fig. 15 - Excessive wear of a pinion. We note the presence of pointed teeth and important distortion of the profile in the dedendum.**

**Fig. 16 - Excessive wear of a pinion. This wear, which has been caused by extended scuffing, has brought about a spectacular reduction of tooth thickness in the meshing zones. We note the presence of deep grooves in the direction of slippage motion, the presence of a line at the pitch diameter, and the presence of pointed teeth. This pinion is out of service.**

**Table I**

| | Abrasive wear with 2 bodies | | Adhesive wear | | | | Wear with 3 bodies | | |
|---|---|---|---|---|---|---|---|---|---|
| | Wear with 2 bodies | Scoring Streaks | Polising | Adhesions or metal pull-off | Hot scuffing | Cold scuffing | Scratches Grooves | Abrasive wear | Interface wear |
| Normal wear with slow progression | ⊗ | ⊗ | ⊗ | | | | | ⊗ | ⊗ |
| Moderate wear can be tolerated Progression to be surveyed | | ⊗ | | ⊗ | | | ⊗ | ⊗ | ⊗ |
| Excessive wear can be considered as gear limit use. | | ⊗ | | | ⊗ | ⊗ | ⊗ | ⊗ | |
| | | | | | Breakage | | | | |

Before trying to find a remedy for excessive wear to save the gear, the underlying cause (or causes) must be determined.

• In the case where the lubricant is responsible, its performance must be increased (viscosity choice), or the load to be transmitted must be reduced. If the profiles are deeply distorted, this remedy will be efficient only if a run-in or a re-machining of the teeth is performed to re-establish a good conformity of the contact surfaces (in the case of through-hardened gears).

• In the case of excessive wear caused by abrasion, an improvement of the housing sealant or lubricant filtration will quite often solve the problem. However, we must be certain that the excessive wear demonstrated by increase of backlash between the teeth is compatible with the full safety operation of the driven element. When there is a doubt, a gear replacement must be performed.

• When we see excessive wear caused by the multiplying of pitting on the teeth and often accompanied by an increase of noise and gear vibration, (in the case of through-hardened teeth) we can proceed to a re-machining of the teeth or a grinding of upper parts of flanks which are too thick, to try to re-establish a good conformity of the geometry of the teeth in contact. We can also increase the lubricant viscosity, which would effect a reduction in pitting development.

If despite this treatment, such wear continues to develop, it means that the load transmitted is excessive for the material performance and the causes have to be looked for in the unforeseen overloads which happen in service, or in the insufficient hardness of the teeth flanks (in the case of through-hardened teeth). The entire design of the gear has to be re-examined.

## Conclusion

To complete this article, we propose a classification of wear phenomena which has been established as follows: We have recorded in a double chart different wear forms on one side, and on the other side, different characteristic wear levels. (See Table I.)We have placed with references and arrows arranged in chart boxes each type of wear at its initial development stage (which we can usually ascertain), and possible evolution which we may ascertain for each phenomenon previously described. ■

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