

# Scuffing & micropitting: Special considerations of gear tooth surface distress

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## Scuffing


Another design consideration in addition to bending and pitting with high capacity high-speed gears is a surface distress phenomenon referred to as scuffing. When gears are subject to highly loaded conditions with high sliding velocities the lubricant film may not adequately separate the surfaces. This results in localized damage of the tooth surface referred to as scuffing. As the gear teeth engage and disengage, a welding and tearing of the tooth surface from one tooth flank to another occurs. It appears as a dull matte finish at the extreme end regions of the contact path or near the points of a single pair of teeth in contact resulting in adhesive wear.

API 613 5<sup>th</sup> edition has referenced paragraph 2.2.6 entitled "Scuffing". This mandates scuffing as a design factor for API gear rating.

Scuffing is not a fatigue phenomenon and may occur instantly, many times during early stages of operation. This is because the threshold for scuffing resistance may not have been achieved inherently in the geometry of the gasket design or the lubricant selected was not in accordance with the original lubricant intended for the application or perhaps the surface roughness of the gasket was excessive. Two important aspects to reducing risk are assuring uniform load distribution along the tooth flanks and proper selection of the lubricant. Proper & careful adjustment to any one or a combination of these criteria can reduce scuffing risk.

A tempting solution to reduce the sliding velocities in the mesh is to reduce the pitch line and sliding velocities by reducing the gear center distance and make up the rating by increasing face width. However, except for special cases, in spite of modified leads, L/D's greater than those recommended by API 613-5 is not good design practice. Long face widths increase toothing distortion with increased thermal losses due to oil quenching as it is pumped across the face width in the gear mesh. Mechanical deformation requires a deeper correction to the lead as well. Therefore the lead modification becomes more sensitive to good control of even load distribution over the entire face width.

The criteria with which to determine how much sliding velocity is allowed is directly related to the local temperature occurring in the contact area of the gear teeth. This temperature is known as the flash temperature and can be calculated for any local point on the involute along the path of contact. The maximum flash temperature calculated becomes a criterion by which a gearset is rated for its maximum power transmission capability. Therefore, a permissible flash temperature is an additional criterion for determining the power rating of a particular gearset. In API this additional criterion is treated with equal importance as the contact power and the bending strength power ratings.

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Analysis of scuffing is difficult. There are few methods available. And industry does not have a single-minded perspective as to its analysis but acknowledges its existence. Experience is a key consideration in high capacity gears. Suppliers should demonstrate a selected method of analysis. AGMA 925-A03 discusses the problem in detail. ANSI/AGMA 6011-I03 Annex B has also proposed a verification check for scuffing risk. It is simple to apply. It is not a design solution, rather a design check against a go-no go criteria.

### Scuffing Damage, Selection of a Proper Lubricant

API-613 has always considered pitting and bending as the fundamental basis for rating a gearset rotor. The 5th edition has now incorporated scuffing as a rating consideration as well.

The risk of scuffing damage is dependent on sliding velocity of the mesh, tooth surface roughness (finish), lubricant employed and appropriate load distribution of the contact area due to improper or lack of tooth modification. Proper and careful adjustment to any or all of these factors can avoid scuffing.

As an adhesive wear phenomenon, scuffing occurs when the lubricant film does not adequately separate the gear teeth surfaces. This is most likely to manifest itself in high speed case hardened gears subject to high loads and high sliding velocities. Localized damage to the teeth will result in a dull matte or rough finish most often at the extreme ends of the contact regime.

A major variable that can be considered after manufacturing is the gear lubricant. In most turbogear applications light turbine oil such as ISO VG32 is commonly employed. This lubricant has lighter viscosity when compared to higher viscosity oils. Generally, higher viscosity oils have a better resistance to scuffing. However natural higher quality in the lubricant can achieve improved resistance to scuffing within the same viscosity range.

A standard test known as an FZG test rates different lubricants for resistance to scuffing. A higher passed load stage assigned to a lubricant means better resistance to scuffing. Lubricants are rated accordingly identified by either the highest load stage passed or the first load stage failed.

Data for light turbine oil comparisons:

Lubricant Manufacturer	Lubricant Name	FZG Pass	FZG Fail
Exxon	Terrestic 32	6	7
	Terrestic 46	6	7
Mobil	DTE light (32)	7	8
	DTE medium (46)	8	9
Texaco	Regal A R&O (32)	5	6
	Regal B R&O (46)	6	7
Total Fina Elf	Presilia 32	8	9



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There is a big spread in scuffing risk depending on lubricant employed. Each stage translates to approximately 6-7 % improvement in risk against scuffing; likewise each step or increase in viscosity has about the same effect. So if for example you employ Mobil DTE medium there is a significant gain against scuffing risk.

Scuffing risk calculations for the applied gearset can be checked with a number of either published methods or company own developed empirical methods. A reliable method referred to by both AGMA and API is found in annex B of ANSI/AGMA 6011-I03.

The scuffing risk calculation in Annex B of AGMA 6011-I03 is based on MAAG criteria. While the application is correct for FZG pass load stage 5 it assumes 49 deg C inlet oil max 60 deg C.

API 613 5<sup>th</sup> clearly states oil inlet temperatures in excess of 49 deg C requires special consideration for the gear unit.

There are several analytical methods of evaluating scuffing risk however the threshold for determination of when a gearset will scuff is largely empirical. When MAAG conducts its performance testing of a gear unit the gear teeth are always examined for tooth contact patterns as well as any signs of tooth distress such as scuffing. If a gearset is at risk for scuffing it should be evident at the very early stages of operation. The highest risk of scuffing is with lighter viscosity lubricants where the potential for the oil film thickness to breakdown is the greatest. The use of ISO VG 32 as a testing lubricant provides the lowest threshold for scuffing to the gearset. Higher viscosity oils can only increase the gearset's resistance to scuffing. The use of VG 32 lubricant during testing is the most conservative approach to verify scuffing risk.

## Micropitting


The presentation by Dr. Andy Olver, Imperial College, London is summarized below;

Early stages of micropitting to sub-surface fatigue of the tooth flank material are due to surface roughness. Asperities in the tooth flank surface create stress risers which are spread out over the tooth dynamically during the mesh cycle. This causes a sub-surface fatigue of material which results in the separation of small elements of the gear tooth from the flank surface.

Unlike macropitting, micropitting occurs away from the pitch line on the gear teeth addendum and dedendum. Most often the highest susceptibility to micropitting is the driving dedendum and the driven addendum. It is observed the failure takes place about 20 um below the surface element.

Different surface finishes may produce, more or less, stress produced risers. Improved surface finish will reduce the chance for micropitting significantly. While EP oils will improve resistance to scuffing, the EP additives react with the tooth surface, reducing the fatigue life of the gear teeth surfaces and therefore are not a good alternative.

Micropitting in itself is not problematic but may eventually lead to macropitting if the condition does not reverse itself. But it is a failure due to surface roughness not to Hertzian stress. Surface roughness produces higher stresses below the surface resulting in micropitting. Non metallic inclusions in the path of the micropitting can lead to a crack generated by the very local stress riser.

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## Technical Document


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This subject matter is not conclusive; hence the desire to proceed with the FZG gear type tests planned by the AGMA Helical Gear Rating Committee is important. There are certainly open questions demanding answers, in particular the question of long term micropitting.

Examination of the tested gear elements at Lubrizol support what Dr. Olver has reported. There are two distinct types of micropitting patterns observed on the test gears however. One pattern has a sort of "glitter" to it whereas the other is dull and gray.

The subject of Tribology is an important aspect to the resistance of gears to micropitting. Of particular interest is an AGMA FTM paper entitled, "Basic Studies on Fatigue Strength of Case Hardened Gear Steel-Effects of Shot Peening and or Barreling Processes". This so called "barreling process" is interesting in the fact it does not harm the tooth form. Investigating this method further, there is a company in the U.K. that has a similar process. They refer to it as the "CASE" finishing method: "Chemically Assisted Surface Enhancement".

There is no question the grinding finish affects the tooth resistance to micropitting. And, the slide-roll ratio affects not only micropitting but under high loads can cause scuffing.

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