Special Lubricants

RAW MATERIALS PROCESS INDUSTRIES



LUBRILOG

LUBRICATION ENGINEERING

Open Gear Drives Lubrication

The Future Right Now

In den Gebieten, mit denen wir es zu tun haben, gibt es Erkenntnis nur blitzhaft.
Der Text ist der langnachrollende Donner.
Walter Benjamin,
Das Passagen-Werk, N.I.I

In the fields we are dealing with, knowledge appears in a flash.
Text is only the belated rumble of thunder.
Dans les domaines auxquels nous avons affaire, la connaissance ne se présente qu'en éclair. Le texte est le roulement bien tardif du tonnerre.

I am always ready to learn although I do not always like being taught.
Winston Churchill

Je suis toujours prêt à apprendre, bien que je n'aime pas toujours qu'on me donne des leçons.

Design:

LUBRICATION ENGINEERING
Z.I. des Chasses, 18, Rue Nicolas Appert, B.P. 60261
26106 Romans sur Isère cedex, France
Tél. : + 33 475 452 600 - Fax : + 33 475 451 865
E-mail : contact@lubrilog.fr

Issued: April 2011.

Engineering design: Jean-Philippe MERLO
Technical supervision: Claude GIRAUD, Technical Manager

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1 - Rotary drum open gear drives

LUBRILOG is dedicated to resolve lubrication problems that may occur as a result of the treatment of Raw materials such as mining, cement, fertilizer, thermal power plant (coal fired), steel, aluminum, chemical, paper, environment industries, etc... These industries inevitably involve the use of heavy powered rotary drums in which a defect in the drive system can bring the entire operation unit to a complete halt for several weeks (kilns, dryers, coolers, rod mills, ball mills, S.A.G. mills, autogenous mills, etc.).

In view of the strategic advantage of good quality open gear drives as well as all periphery equipment associated with rotary drums, **LUBRILOG** offers for this type of machinery, concrete and affordable lubrication solutions designed to minimize no only risks of major failures but also its maintenance costs.



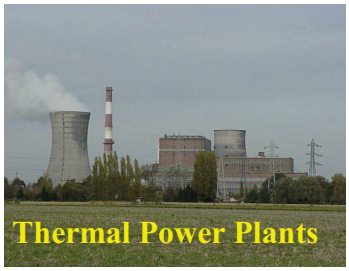


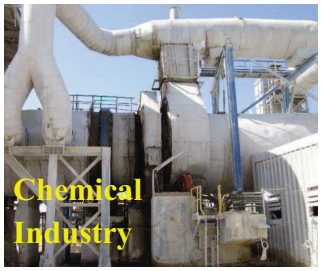






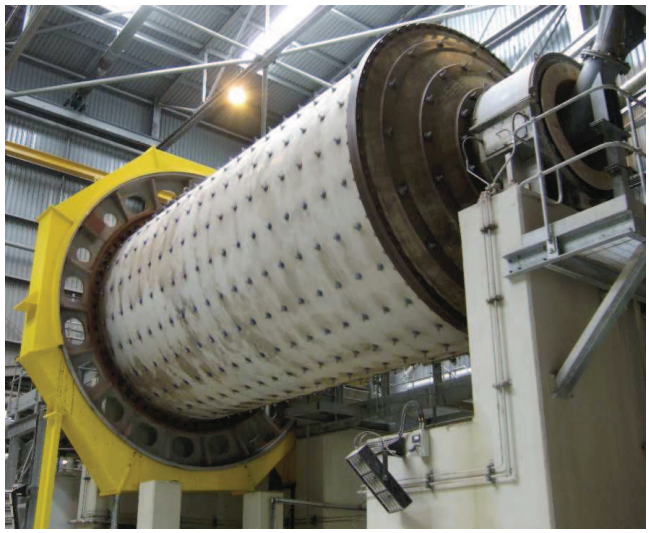






Today, most rotary drum drives are operated by lateral open gear drives.
Open gear drives are « open » type drives made of a wide diameter girth gear and one or two drive pinions.





In harsh environments, lubrication is essential to the performance and longevity of the gear set.

This lubrication must take into account different parameters, which are specific to large rotary drum open gear drives:

- Machinery and gear set type and design

- Environment

- Operational conditions related to the material's specific process

Based on these main parameters, **LUBRILOG** is able to suggest the most appropriate lubricant and application method for the specific situation.

LUBRILOG offers the most complete range of lubricants and lubrication methods designed to improve all operational phases of large open gear sets.



2 - Open gear: rotary drum drives

The teeth of large lateral open gear drives are involute to a circle profile, of parallel axis, spur, helical or, less frequently nowadays, double helical.

Gear set design must comply with very strict service conditions, such as:

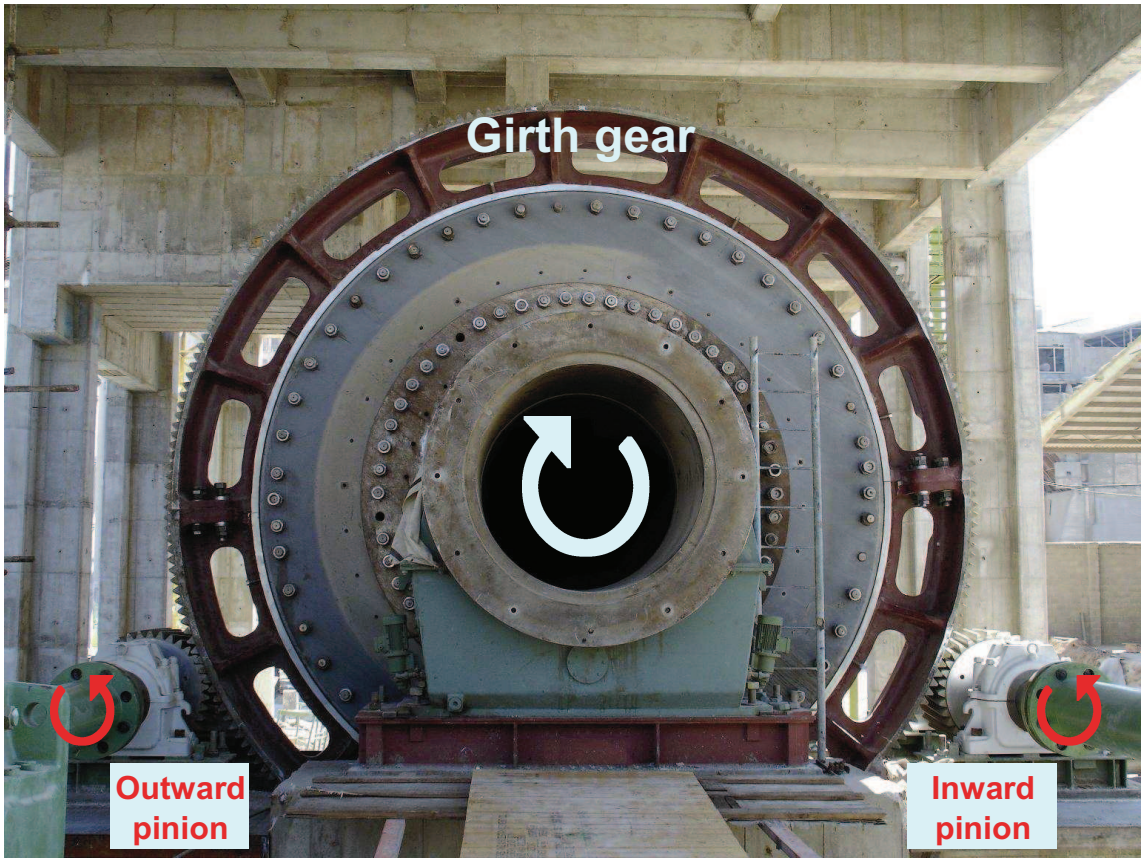
- Girth gear rotational speed (1 to 5 RPM kilns and 15 to 20 RPM mills)

- Large center distance

- Large diameter difference between girth gear and pinions

- Very heavy drive load (sometimes > 7500 kW)

Such service conditions require large diameter (> 3000 mm), large module (often m > 20), and large width (sometimes b > 1000 mm) gear sets with teeth addendum modifications, gear ratios (i) often between 6 and 15 and an average production quality of 8 to 10 for mills or kilns (ISO standard 1328: Cylindrical gear pairs, ISO precision system).



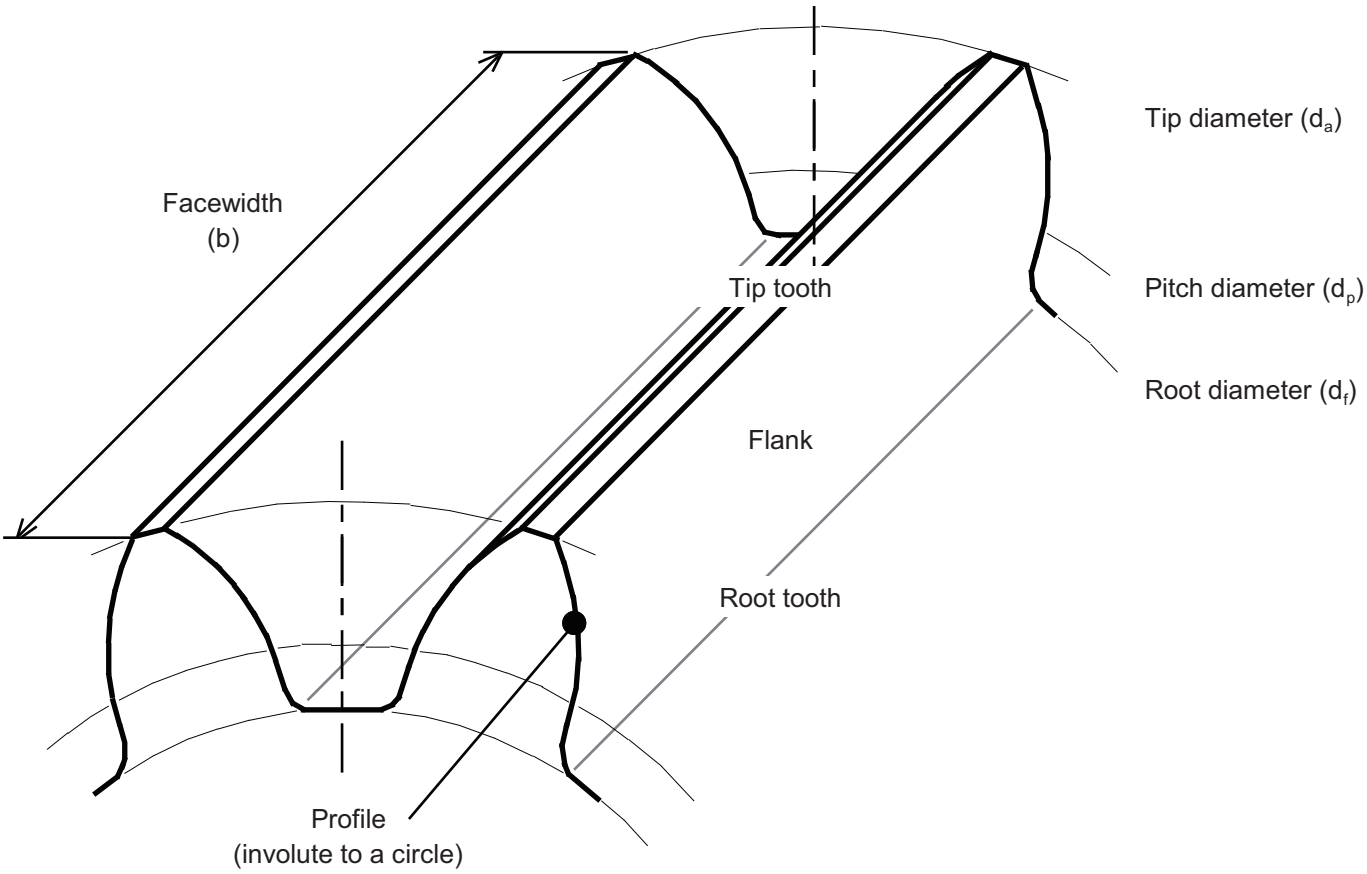
Erection of a ball mill (double drive, cement mill)

Position of pinions and girth gear on a ball mill

3 - Gear: geometrical designation reminders

The following diagram is a reminder of the main designations of geometrical elements in an external spur tooth.
The terminology in the following two pages is used in our preventive maintenance technical expert reports.
For additional information, please refer to our document « Teeth damages in large open gear drives ».

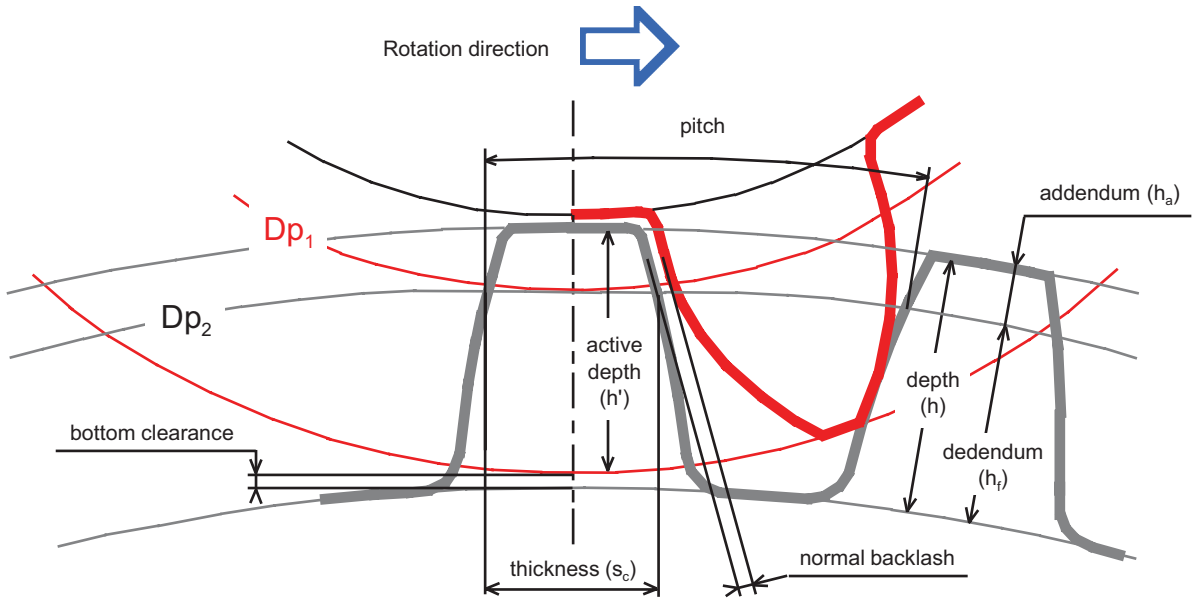
3. A - General aspect of a tooth



The flank in contact when the gear is operating is called the « working flank » and the other, the « non-working flank » or « back flank ».
The numbers 1 and 2 indicate the pinion and girth gear respectively for instance, b_1 is the facewidth of the pinion tooth.



3. B - Tooth terminology (diagram of a tooth with addendum modification or correction(*))



Dp_1 : pinion working pitch diameter (driving)
Dp_2 : girth gear working pitch diameter (driven)
p : pitch (length of the pitch circle's arc comprised between two consecutive homologous profiles)
m : module (quotient of pitch indicated in millimeters by the number π, or the pitch diameter by the number of teeth)
z_1 : number of teeth on pinion
z_2 : number of teeth on girth gear
α : pressure angle (acute angle between the line of action and the pitch circle tangent)
β : helix angle (helical teeth: acute angle between the helix and the pitch cylinder generators)

(*) : The addendum modification coefficient (addendum modification) is the shift of profile brought back to the unit module of the counterpart rack; its symbol is x (x_1 for the pinion, x_2 for the girth gear).



3. C - Large open gear drives teeth quality surface

For production and cost reasons, large open gear teeth are usually manufactured with the following quality:

- Girth gears : tooth quality of 8 to 10 and
- Pinions : tooth quality of 6 to 9

(ISO standards 1328 and 10064 - part 4, NF E 23-038).

The surface roughness and waviness must be improved (quickly and in a controlled manner) in order to guarantee the formation of an efficient lubricant film (see the chapter titled « Elastohydrodynamic lubrication »).

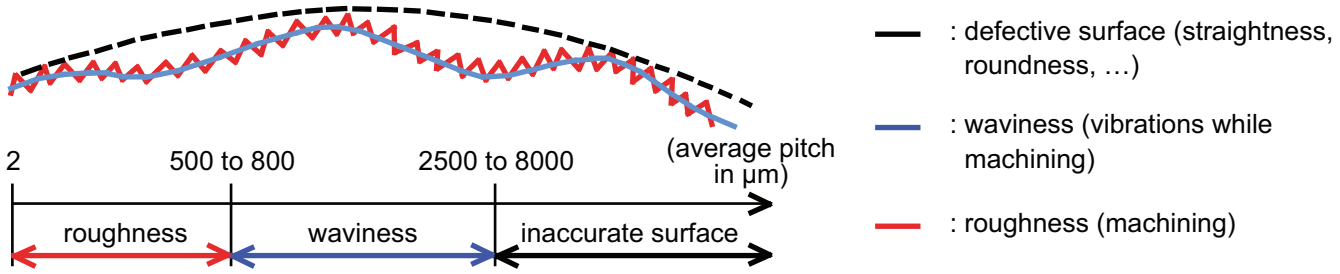
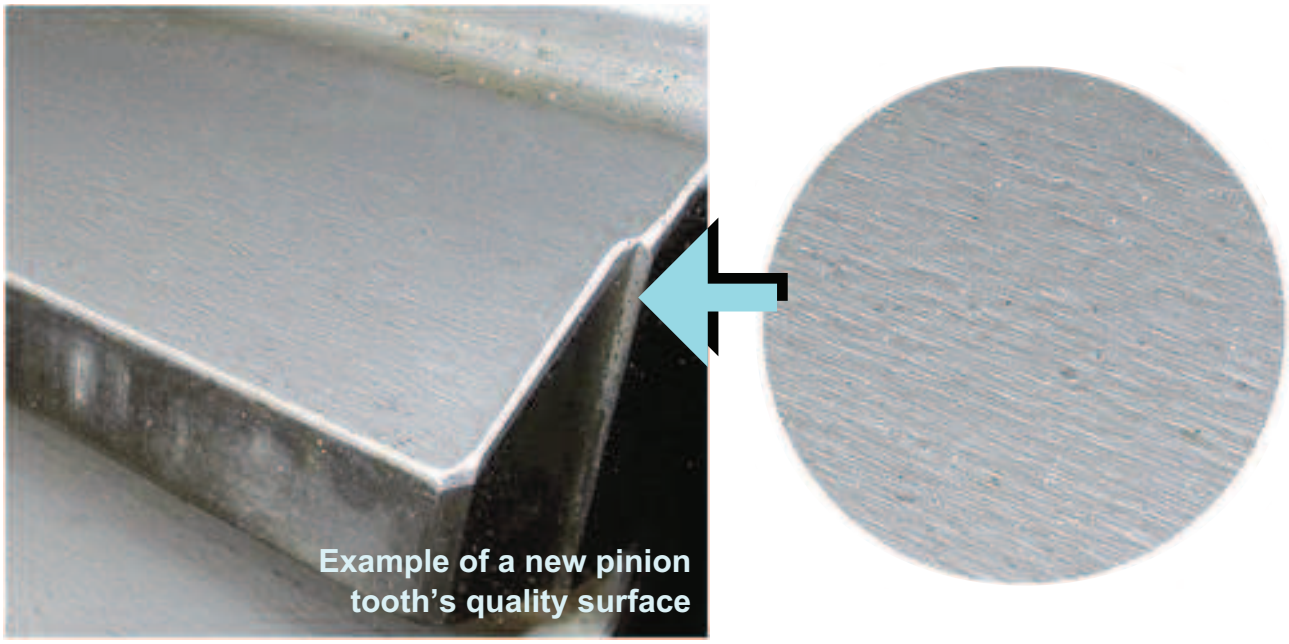
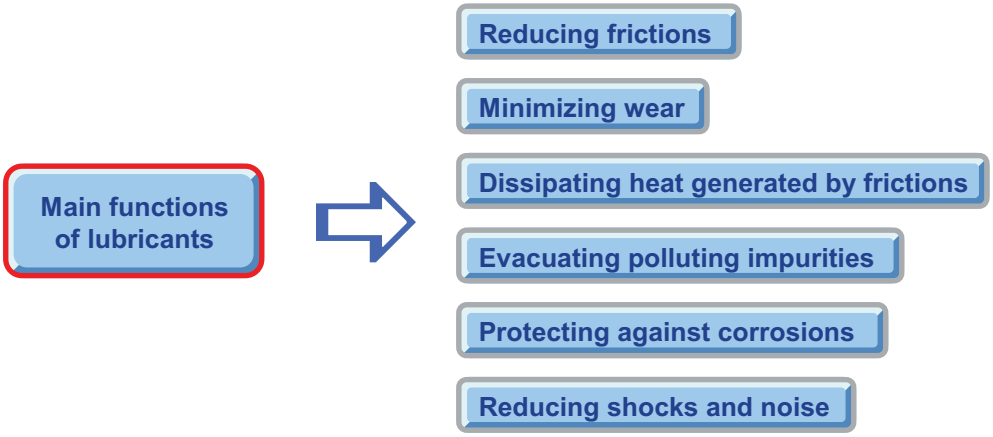


Illustration of a surface: combination of defective surface, waviness and roughness



4 - Lubrication: tribology reminders

For an efficient operation, a gear set requires appropriate lubrication like insertion of a liquid, pasty or solid lubricant at the point of contact of two surfaces.



The purpose of these functions is to increase the longevity and reliability of large rotary drum gear drives.

LUBRILOG lubricants are designed to respond to different criteria induced by necessary functions in order to guarantee optimal lubrication particularly the nature and viscosity of base oils and additives and the quality of grease thickeners.

4. A - Lubrication regimes

The contact between a gear set's active flanks is called « hertzien ». The theoretical contact area is limited to one generator.
When the gear set is in motion, different lubrication regimes come into play.
The operational lubrication's performance can be monitored by calculating the surface roughness factor λ, which corresponds to the relationship between the lubricant film's thickness and the combined roughness of the surfaces in contact.

Boundary (or unctuous) lubrication:

In this situation, surface interactions are very significant. There are many cases of metal-to-metal contact and surfaces are only separated by a film formed by the chemical reaction of additives contained in lubricants. These chemical reactions may punctually protect surfaces, however, in case of an open gear drive these surfaces must be separated rapidly.
When starting up the gear set, this boundary lubrication situation is inevitable (the surfaces must be protected by a « priming » lubricant) but can be very dangerous when the gear set is operating.

Mixed lubrication:

Transitional area: state of intermediary lubrication between boundary lubrication and elastohydrodynamic lubrication.

When starting up the gear set, surfaces progressively separate as speed increases and the lubricant film forms (the running-in phase must imperatively be controlled by using the appropriate lubricant; see chapter titled « Open gear drive running-in procedure »).
Interactions between the roughness and waviness of the two surfaces in contact decrease and the elastohydrodynamic regimes set into place.
Operation of the gear set becomes acceptable, although the surfaces are still fairly solicited (with localized overloads).
This lubrication regime may continue in the frequent case of mediocre pinion positioning in relation to the girth gear such as the faulty alignment or inappropriate backlash.
In this type of situation, lubrication must be closely monitored, and mechanical parameters must be adjusted rapidly.

Elastohydrodynamic lubrication (EHD):

In this operational phase, the lubricant totally separates the surfaces.
The EHD regime combines a hydrodynamic regime with an elastic distortion of the surfaces. Unlike the hydrodynamic regimes found in normal bearing operations the applied loads weigh up to several GPa and the formed film is thinner.

The ultimate lubrication goal is to minimize energy loss by guaranteeing efficient surface separation.

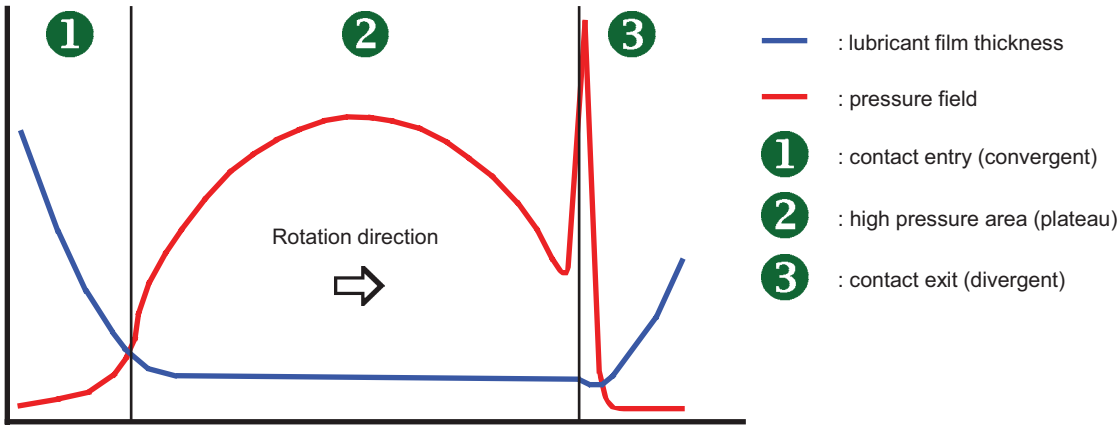


Illustration of EHD contact with surface distortion in the contact area.

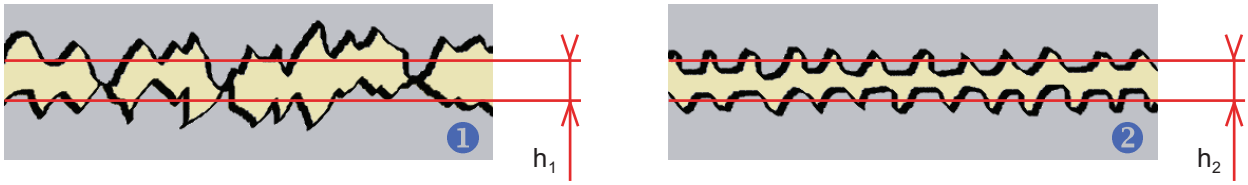
With elastohydrodynamic lubrication, it is possible to calculate the lubricant film's thickness between the teeth.

Thickness calculation methods are not presented in this document; however, one of the elements of this calculation is described, namely the determination of the roughness **factor λ** (see AGMA 2101 standard) in order to demonstrate the crucial advantage of completing a surface lapping phase when running-in the open gear.

The roughness factor **λ** is determined by:

$$\lambda = \frac{h}{\sqrt{Ra_1^2 + Ra_2^2}}$$

with : λ = surface roughness factor
h = average thickness of the lubricant film (in µm)
Ra_1 and Ra_2 = average arithmetic gap between the profiles in contact (in µm)



In both diagrams above, h_1 and h_2 have the same value; however, the situation in figure 1 to left is much less favorable than the situation in figure 2 to right.
For this reason, the roughness factor has been introduced and proves its importance in the calculation of the lubricant film's thickness.

The roughness factor values **λ** allow the definition of a deterioration probability according to the tangential velocity of the surfaces.

It is generally accepted that:

λ ≥ 2	:	The risk of deterioration decreases (EHD lubrication)
0.7 < λ < 2	:	Mixed lubrication but boundary lubrication may occur with a risk of scuffing (depending on operational and lubrication conditions)
λ ≤ 0.7	:	**Boundary lubrication. When the gear set is in service, the risk of quick deterioration of the contact surfaces is permanent**

Even though calculating the lubricant film's thickness between two teeth is complex (as it depends on the three following concepts: hydrodynamics of viscous fluids in thin films, lubricant behavior under high pressure, and contact surface distortion), the **DOWSON** formula produces an acceptable value.
With a chosen **λ** value and the knowledge of the teeth surface condition, the thickness of the film h can be defined.

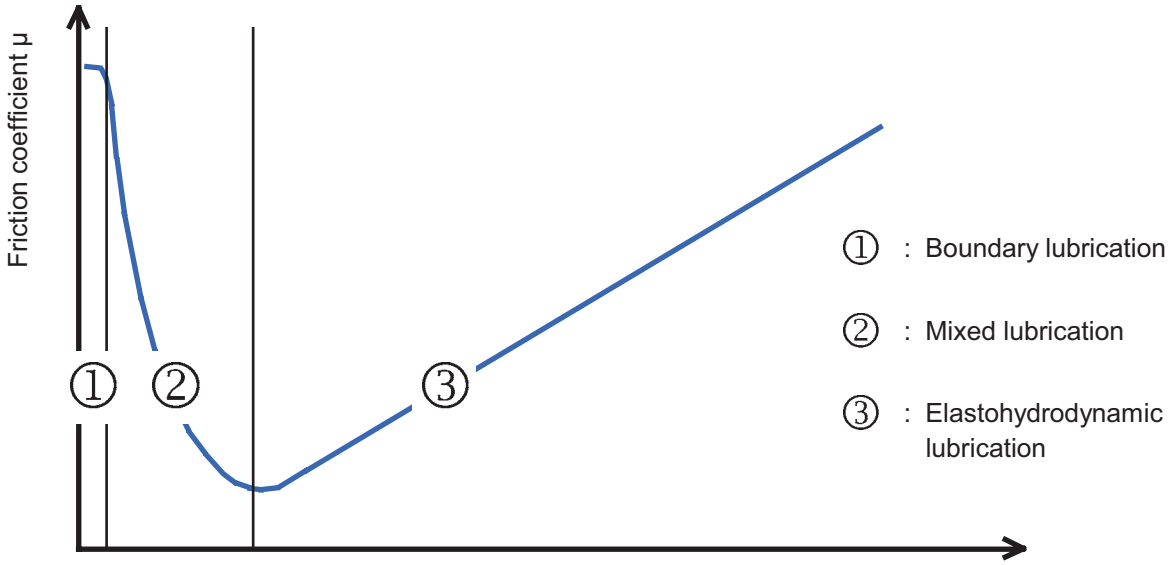
$$h_{mini} = 0.035\,(\eta_0 + U + \rho_r)^{0.05}$$

with : h_{mini} = minimum thickness (in µm)
η_0 = absolute viscosity in poise
U = average rolling speed (in $cm.s^{-1}$)
ρ_r = relative radius with the point of contact such that:

$$\frac{1}{\rho_r} = \frac{1}{\rho_1} + \frac{1}{\rho_2}$$

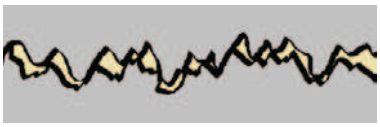
Diagram of the different lubrication regimes:

The curve below shows the friction coefficient variation according to speed (with a high viscosity lubricant). The curve resembles a STRIBECK curve (even though there is no surface contact). The contact between the surfaces in the three different areas is illustrated beneath the curve.



Friction coefficient variation with speed
(high viscosity situation)

Area ①



Boundary lubrication (or in some cases, extreme pressure):
High-risk situation for the gear set.

Area ②



Mixed lubrication:
The EHD in-service lubrication regime has not yet been reached.
Intermediary situation with risks of deterioration.

Area ③



Elastohydrodynamic lubrication (EHD):
High quality lubrication.

4. B - Conclusions on the formation of lubricant films

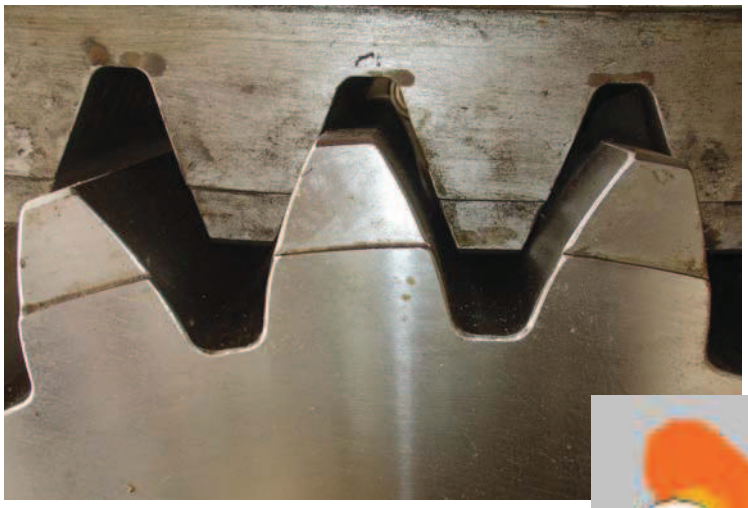
The formation of a lubricant film between an open gear drive's mating profile teeth is a complex phenomenon.

Many factors come into play in this formation and some evolve in the course of the gear set's operation, including:

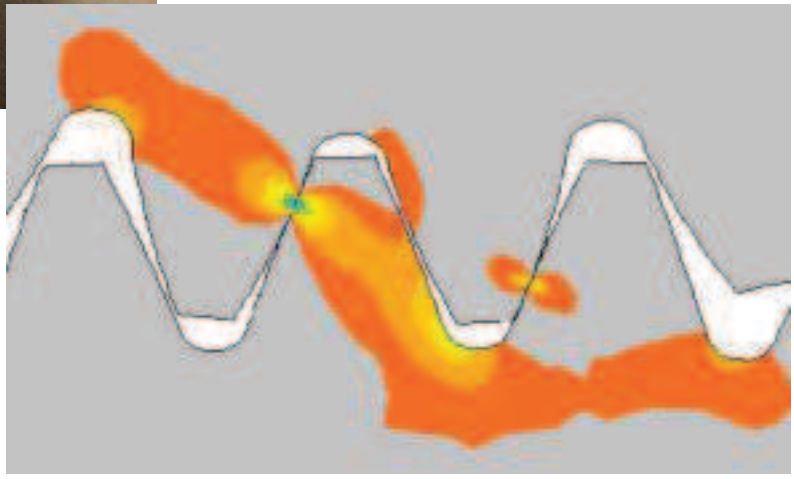
- Gear set geometry (including the radius)
- Gear set materials
- Working flanks' quality surfaces
- Applied load on the teeth
- Gear set kinematics (including rolling and sliding speeds)
- Gear set erection and installation (particularly clearance and alignment)
- Running-in lubrication procedure and the applied lubricants
- Operational lubricant used (grease, oil, viscosity, piezoviscosity, temperatures, application method)

It is generally admitted that the lubricant film will be thicker if:

- The radius is large
- The applied loads are light
- The rolling speeds are high (more appropriate lubricant amounts in the contact area)
- The lubricant viscosity is high
- The temperatures are low
- The surface quality is good



Example of load distribution during meshing



7. E - LUBRILOG services: in-service cleaning, LUBRICLEAN EP

Large open gear drives operate in difficult environments and are subject to pollution by abrasive dusts such as clinker, coal, sand, abrasives, metallic powders, etc...

For this reason, traditional operations designed to limit the effects of pollution must be strictly implemented, these include:

- Installation of housing protections around the open gears and control of the sealing
- Lubricant replacement and analysis (splash or circulation lubrication)
- Filter maintenance and cleaning (circulation lubrication)
- No lubricant contamination at installation
- Inspection of the condition and lubrication of the working flanks

However, these are not always sufficient in case of serious abrasive pollution.

LUBRILOG technical department have therefore developed a specific « green » solvent, the **LUBRICLEAN EP**, designed to scour and clean very dirty open gear drives while in-service, even under heavy loads.









The lubricant and its application system must be protected.

Cleaning operations must be executed by plant technicians or by specialized companies. A **LUBRILOG** technician may be available to perform primary cleaning and demonstrate the in-service cleaning method's efficiency.
He can also train plant technicians for this operation.

7. E - 1 - LUBRILOG services: in-service cleaning objectives

The two major situations in which in-service cleaning with **LUBRICLEAN EP** is recommended are:

- **Preparation of an action on the gear set to clean the old lubricant**
- **Acting, preventively or not, on the abrasive wear caused by polluting material**

Preparation of an intervention:

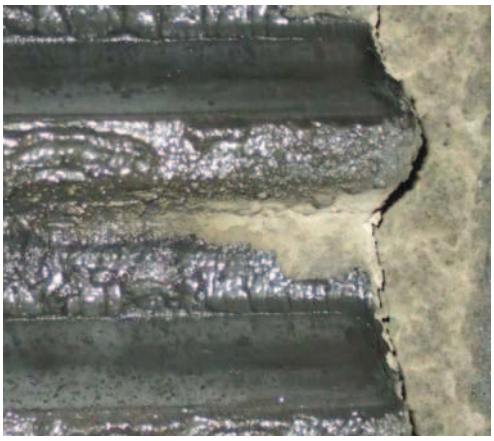
Prior to any intervention on an open gear drive, whether for gear set inspections or for any other mechanical operation (alignment, repair, reverse, replacement), **LUBRICLEAN EP** can be used to prepare it. This cleaning agent provides a quick and affordable cleaning solution for the lubricant present on the teeth and inside the housing.

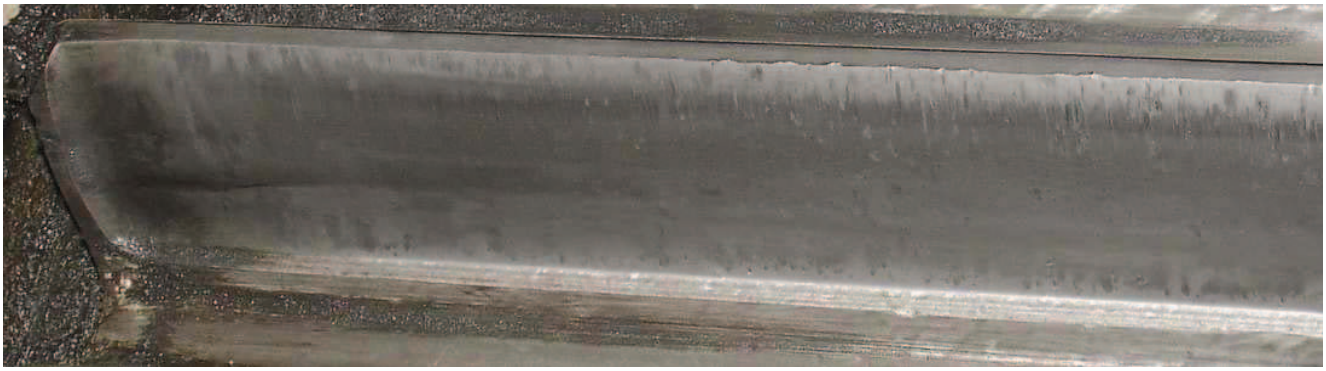
Protection against abrasive wear:

« Abrasive wear » (ISO standard 10825) can cause serious deterioration to fast gear set working flanks.
The damages caused by this type of wear are not hazardous if stopped promptly.

For this reason, it is crucial to protect the working flanks and, in the most severe cases, preventive cleaning with **LUBRICLEAN EP** can provide this protection at an affordable cost a common situation in the mining industry.







Examples of teeth needing to be cleaned (images above) and of the effects of abrasion on working flanks (lower image).

7. E - 2 - LUBRILOG services: in-service cleaning advantages

The main advantages of in-service cleaning for large open gear drives are:

- **Effective cleaning and associated lubrication (in-service operation)**
- **Reduced production interruptions**
- **Simple, secure and quick setup (1 hour cleaning operation)**
- **Non-toxic for the environment and the operators (« green » solvent)**

These aspects make **LUBRICLEAN EP** an affordable and efficient cleaning method.

7. E - 3 - LUBRILOG services: in-service cleaning methodology

In-service cleaning can be performed on any type of lubrication system permanent or intermittent lubrication. We will describe the cleaning method applied on a spray lubrication gear set. **LUBRILOG** will provide its clients with the appropriate procedure for the methods to use on splash and circulation lubrication gear drives.

Gear drives that are spray-lubricated with grease are most subject to abrasive wear pollution, called « wear with three bodies ». The low circulation of lubricant on the active flanks allows abrasive particles to agglomerate with the lubricant at the bottom of the teeth and to frequently pollute the working flanks.

Cleaning preparation:

- **Installation of a recuperation tank for the used solvent under the housing**
- **Preparation of the high-pressure pump and prior operating tests**
- **Installation of the LUBRICLEAN EP drums**

Note:
The processed load, in the case of a mill, will be reduced for the duration of the cleaning intervention.

The cleaning operation will be completed through the inspection door of the inward pinion (IN pinion) for double drive gear sets and through the inspection door of the outward pinion (OUT pinion) for single drive gear sets.



Example of a used solvent evacuation tank.



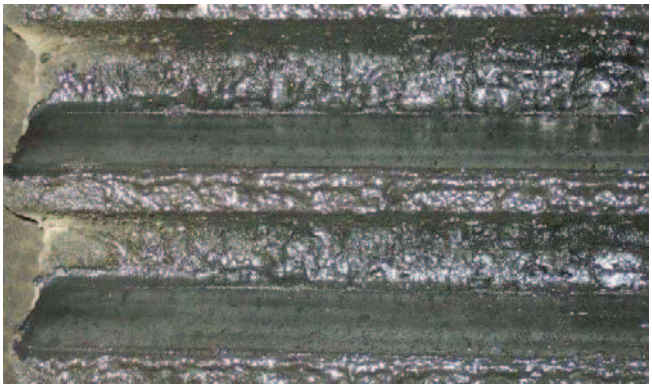
Spray lubrication: steps of in-service cleaning:

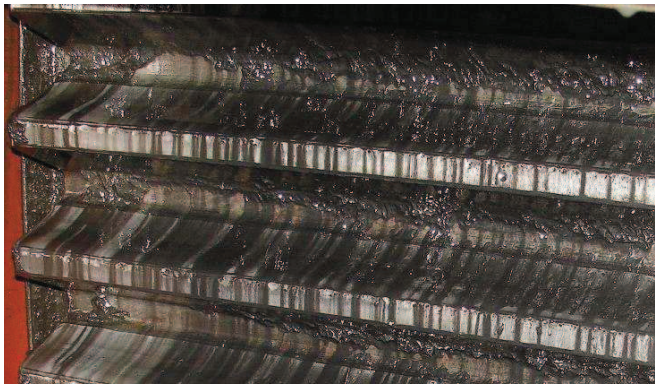
- **Open the inspection door**
- **Stop the lubrication system**
- **Spray LUBRICLEAN EP for 10 minutes at low pressure (15 to 20 bars or 220 to 290 psi)**
- **Stop spraying LUBRICLEAN EP for 10 minutes to let it soak in**
- **Spray LUBRICLEAN EP again at high pressure (150 bars or 2176 psi, at 16 liters per minute)**

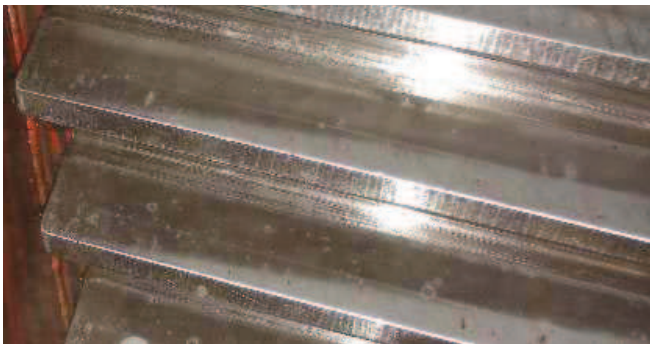
A very short interruption is necessary to verify the cleanliness. Depending on the level of cleanliness observed and the operational lubricant to be cleaned, slow finishing with an auxiliary drive may be useful to clean the bottom of the teeth (slow cleaning for about 5 minutes).

The cleaning operation will last about an hour. The teeth will then be covered with an extreme pressure protection film.

Warning:
Before restarting the gear drive, it is necessary to complete the lubrication of the teeth with the priming grease **GRAFOLOG H 1** or with the operational lubricant. The gear drive will be sprayed continuously for at least 4 hours.









Different phases of a mill's open gear drive in-service cleaning.

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The rest is silence.
W. Shakespeare,
Hamlet, Act 5, Scene 2.

LUBRILOG

LUBRICATION ENGINEERING

Z.I. des Chasses, 18, Rue Nicolas Appert, B.P. 60261
26106 Romans sur Isère cedex, France
Tél. : + 33 475 452 600 - Fax : + 33 475 451 865
E-mail : contact@lubrilog.fr

www.lubrilog.com

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