RAW MATERIALS PROCESS INDUSTRIES

LARGE OPEN GEAR DRIVES

LUBRICATION

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LUBRICATION ENGINEERING

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/01

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.


Cement Industry


Paper Industry


Fertilizer Industry


Environment Industry

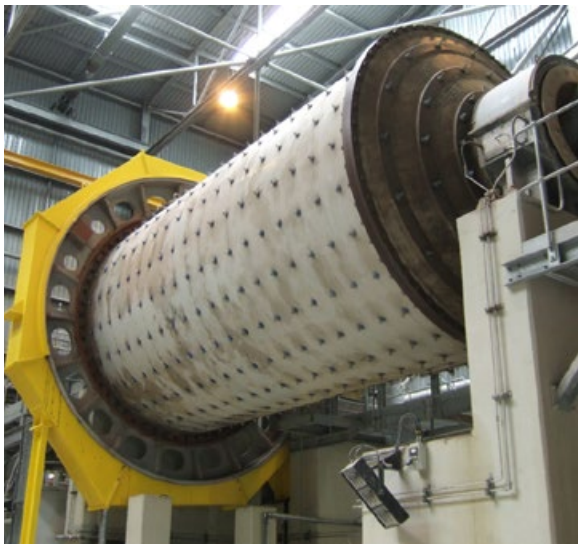

Mining Industry


Lime Manufacturing


Thermal Power Plants


Chemical Industry

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.

/02
OPEN GEAR: ROTARY DRUM DRIVES

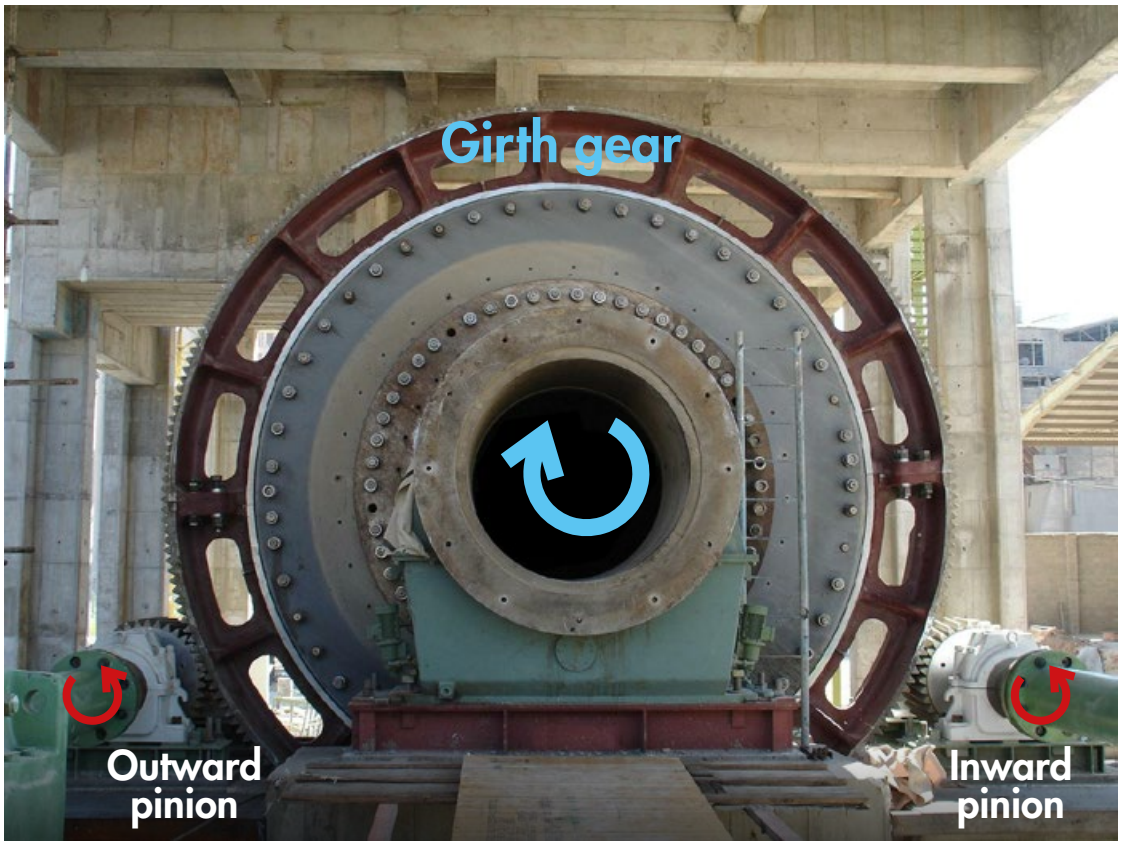
The teeth of large lateral open gear drives are involute to a circle profile, of parallel axis, spur, helical or, less frequently nowadays, double helical or herringbone.

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)



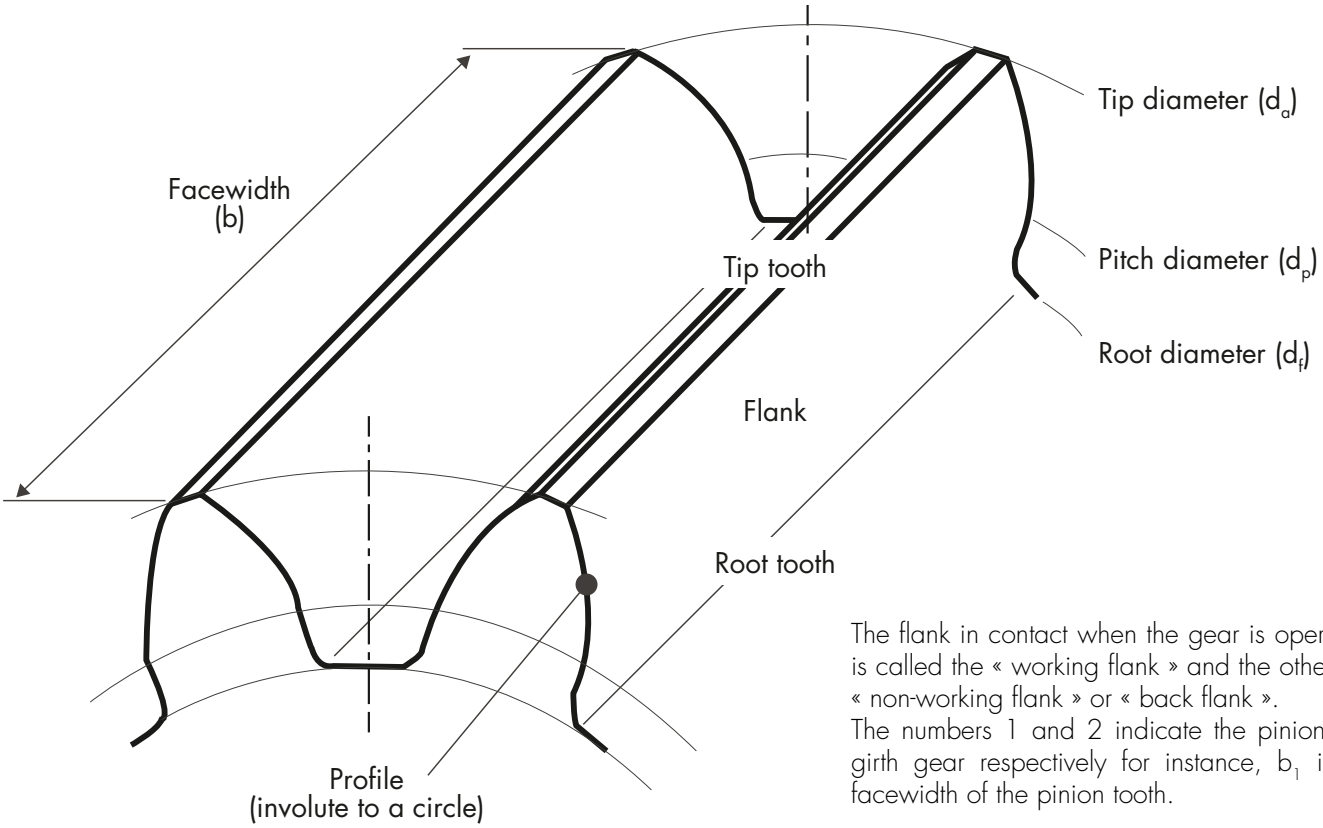
Position of pinions and girth gear on a ball mill

/03

GEAR: GEOMETRICAL DESIGNATION REMINDERS

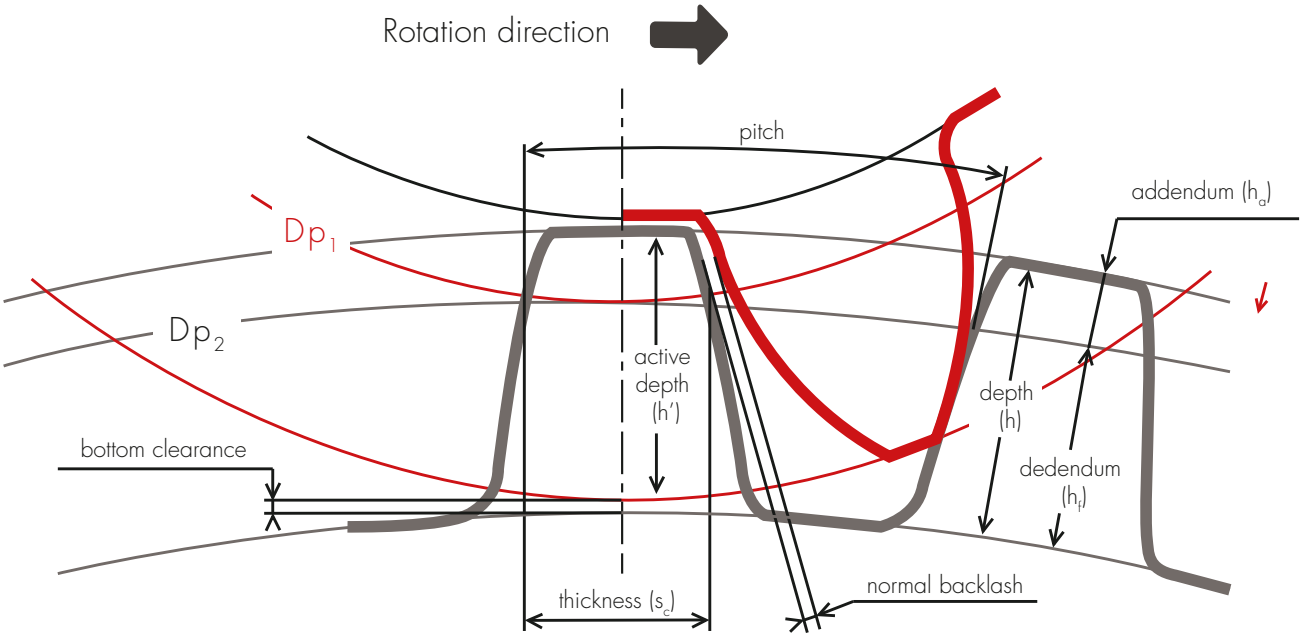
The following diagram is a reminder of the main designations of geometrical elements in an external spur tooth. The terminology in the following two pages is used in our preventive maintenance technical expert reports. For additional information, please refer to our document « Teeth damages in large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

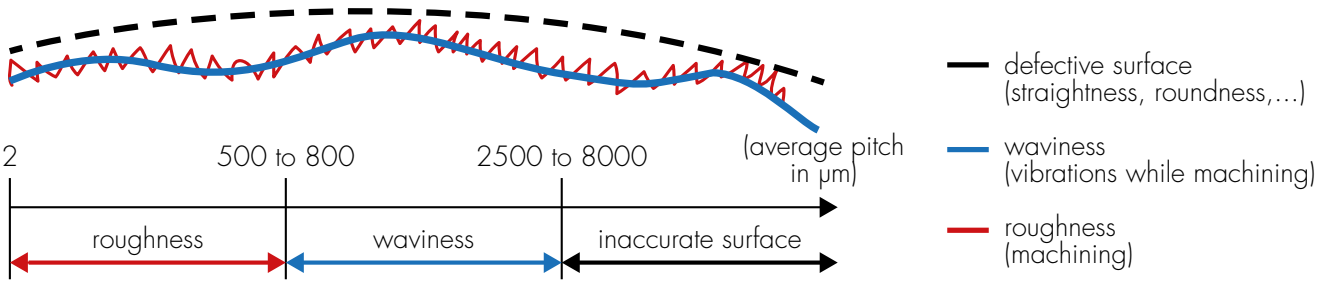
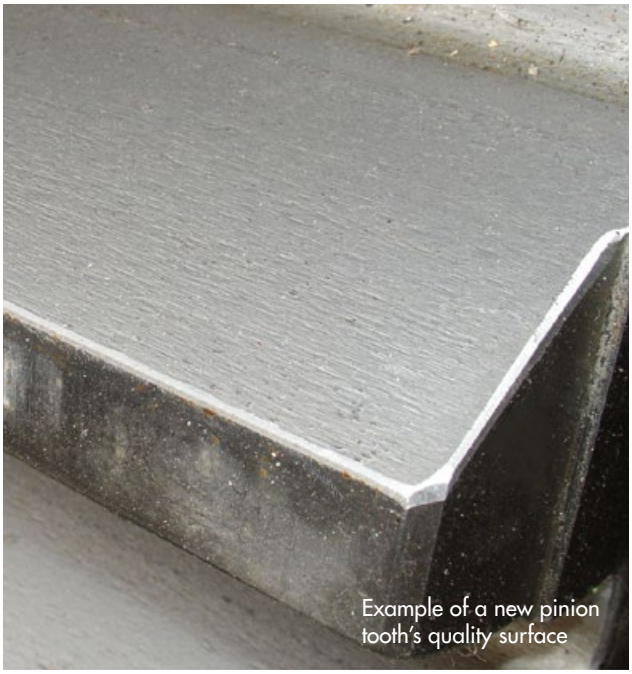
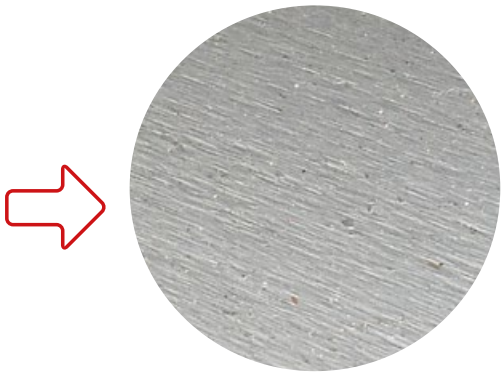


Illustration of a surface: combination of defective surface, waviness and roughness



Example of a new pinion tooth's quality surface



/04 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.

Main functions of lubricants →

- Reducing frictions
- Minimizing wear
- Dissipating heat generated by frictions
- Evacuating polluting impurities
- Protecting against corrosions
- Reducing shocks and noise

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.

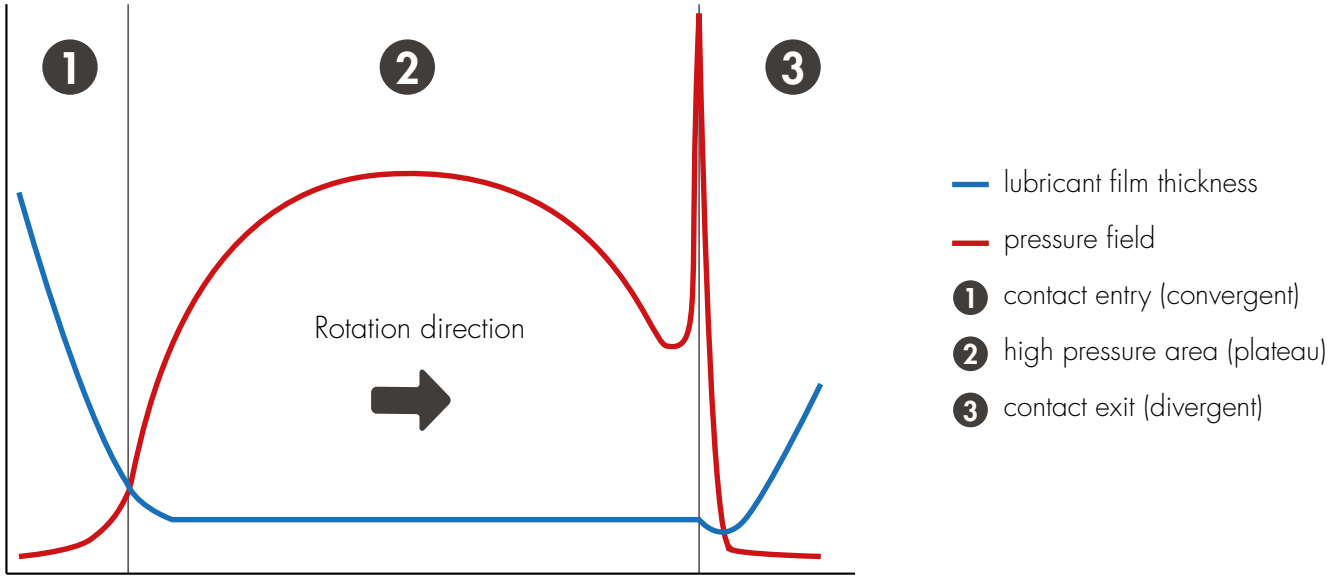


Illustration of EHD contact with surface distortion in the contact area.

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.

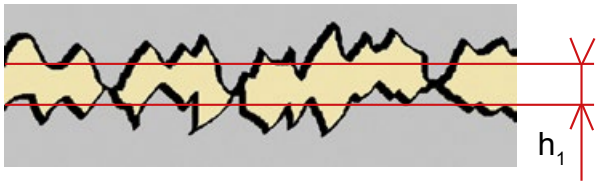
The roughness factor λ is determined by:

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

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)

1



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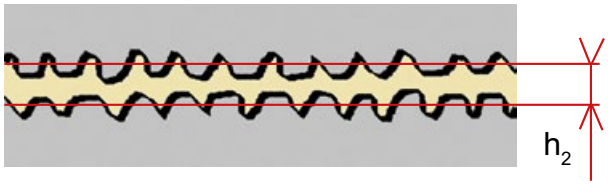


In both diagrams above, h_1 and h_2 have the same value; however, the situation in figure 1 to left is much less favorable than the situation in figure 2 to right. For this reason, the roughness factor has been introduced and proves its importance in the calculation of the lubricant film's thickness.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

$\lambda \geq 2$	:	The risk of deterioration decreases (EHD lubrication)
$0.7 < \lambda < 2$	:	Mixed lubrication but boundary lubrication may occur with a risk of scuffing (depending on operational and lubrication conditions)
$\lambda \leq 0.7$	:	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.

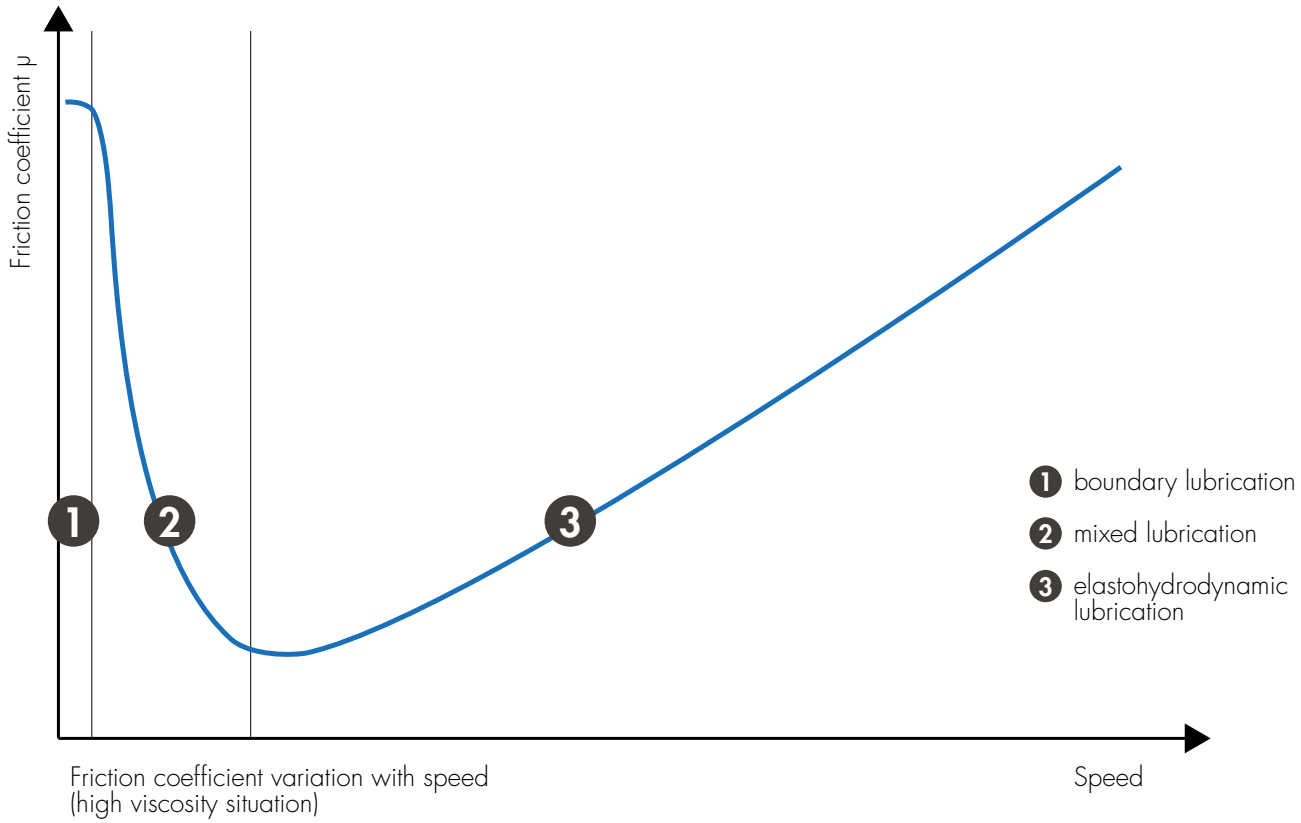
$$h_{mini} = 0.035\,(\eta_0 + U + \rho_r)^{0.05}$$

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

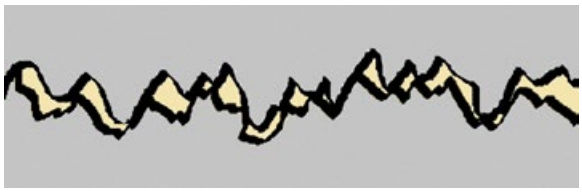
Diagram of the different lubrication regimes:

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.



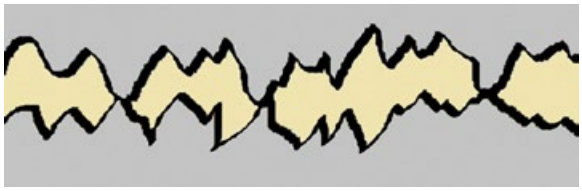
Friction coefficient variation with speed (high viscosity situation)

Area 1



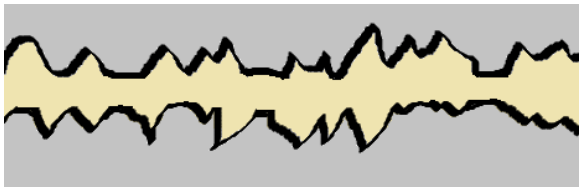
Boundary lubrication (or in some cases, extreme pressure):
High-risk situation for the gear set.

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. A - 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.

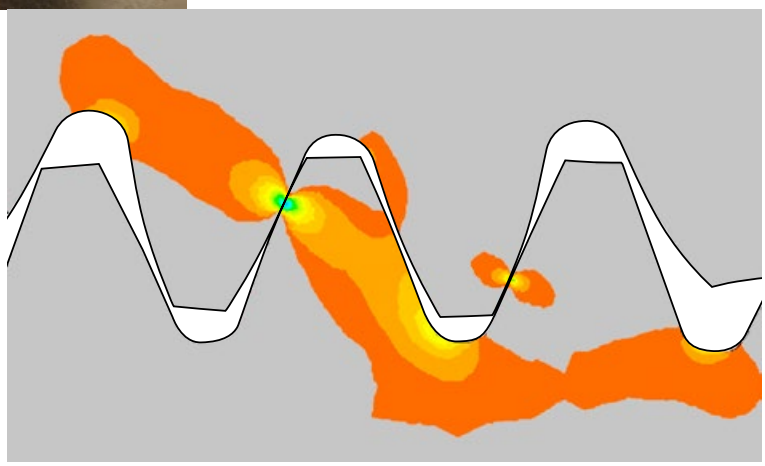
Many factors come into play in this formation and some evolve in the course of the gear set's operation, including:

- 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



/05
TYPOLOGY OF LUBRICATION METHODS

Understanding the installation and operational conditions of large rotary drum open gear drives is the only way to offer our clients perfect adequacy between lubricants and application methods.

Driving the appropriate lubricant onto active surfaces and guaranteeing the formation of an efficient protective lubricant film is our ultimate objective.

LUBRILOG's expert knowledge makes this technical objective possible with very affordable means.

Our knowledge of the different types of machinery and their associated open gear drives allows us to define the appropriate lubricants and application methods at the development stage.

Today, the four most common lubrication methods are:

- Splash lubrication
- Circulation lubrication
- Automatic spray lubrication
- Manual lubrication

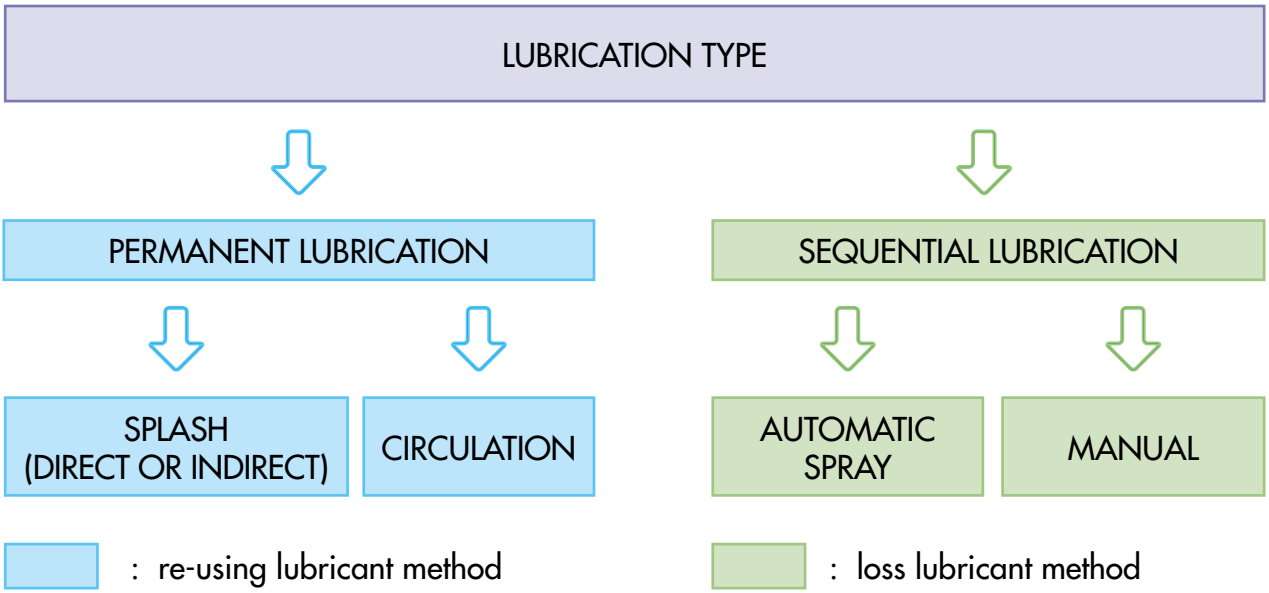
These four methods are further categorized into two types of lubrication:

- Permanent lubrication (or continuous)
  and
- Sequential lubrication (or intermittent)

The diagram on the following page describes the typology of the most common industrial lubrication types for large open gear drives.

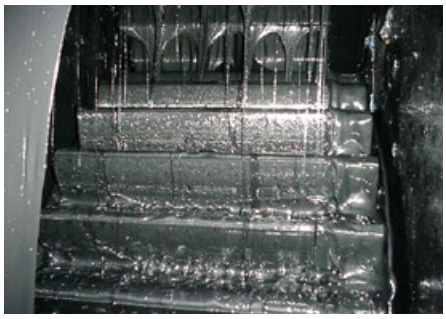
3. A - Typology of lubrication types

The following diagram illustrates the most common current industrial lubrication methods for large open gear sets.



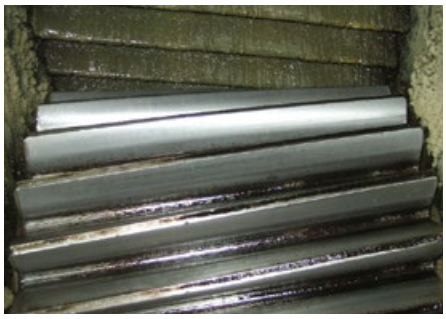
Mineral or synthetic, oils or fluid greases, extreme pressure (EP) components, high viscosities, with or without solid lubricant, biodegradable or not (total absence of bitumen)

Mineral or synthetic, oils or greases, adhesive, high viscosities, EP components, with or without solid lubricant, biodegradable or not (total absence of bitumen)

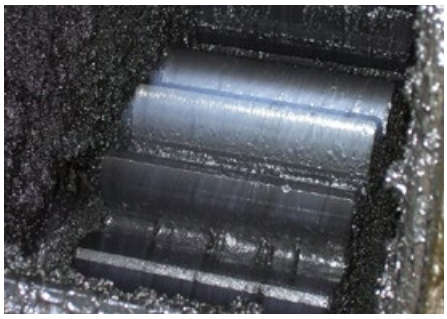


Splash lubrication

Circulation lubrication



Spray lubrication



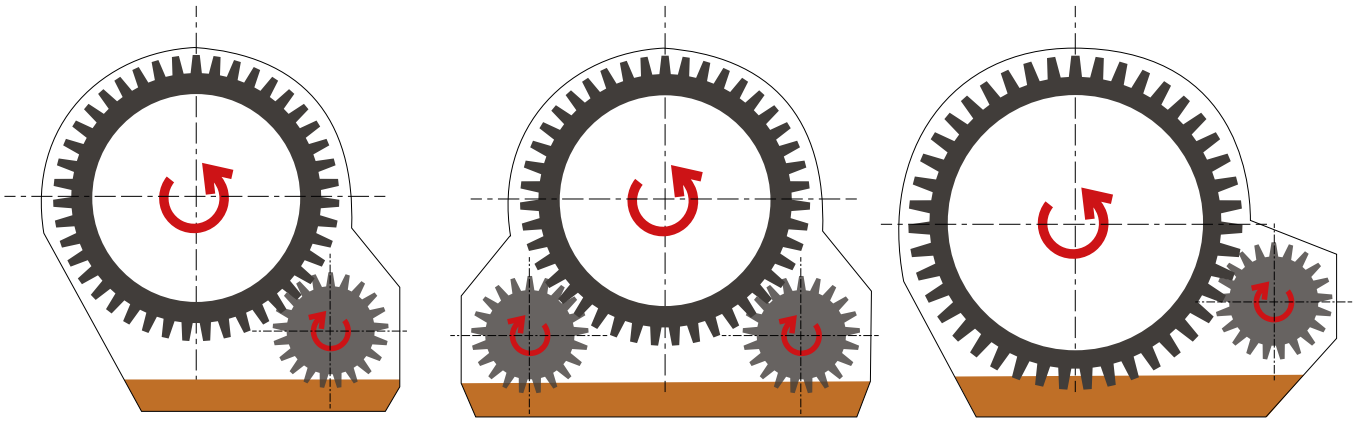
Manual lubrication

5. B - Permanent lubrication: re-using the lubricant

The objective of permanent lubrication is to guarantee continuous lubrication on the gear set's working flanks' contact points (contact generator).
The quality of the lubricant applied to the working flanks may vary according to the lubrication method, but it must remain sufficient to guarantee efficient lubrication.

5. B - 1 - Splash lubrication

If properly done, the direct splash lubrication of teeth is the most reliable and affordable lubrication method. This method consists of permanently dipping the teeth (girth gear or pinions) in a lubricant bath located at the bottom of the gear set's protective housing.



Splashing of the pinion | Splashing of the pinions | Splashing of the girth gear

This lubrication method allows the use of very high viscosity lubricants such as oil or grease (no external mechanism is needed to drive the lubricant onto the working flanks.)

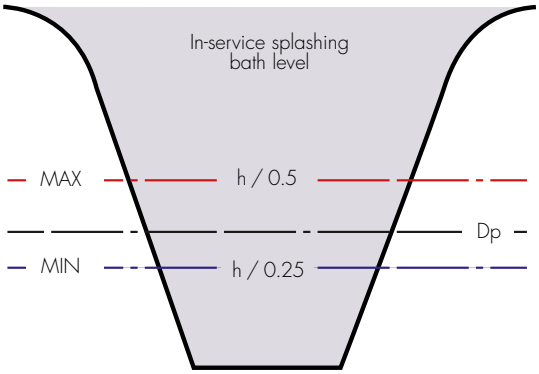
In correct conditions, the quantity of lubricant caught by the girth gear can vary between 30 and 180 l/mn depending on the size (estimate for girth gears with diameters 4000 to 8000 mm).
In this case, normal sealing is sufficient, even for operational temperatures 40 to 60°C (104 to 140°F), as long as the appropriate lubricants are used (that is, high viscosity index lubricants, which are less affected by variations in temperatures).

The splashing bath level in the housing must be monitored regularly and must take into consideration:

- The quantity of lubricant present on the working flanks (different quantity when out-of-service and when in-service)
- The bath temperature (different between day and night, out-of-service and in-service, summer and winter)
- The bath surface area (a large area is less affected by lubricant volume variations)
- The lubricant's ability to resist « thickening » during operations (risk of channeling) with very small losses through evaporation

The in-service bath level to be maintained must be, at the most, about half of the teeth height (depending on the viscosity and/or consistency of the lubricant used and the machinery).

Example of splash lubrication on kiln pinion with **GRAFOLOG M FLUID** grease



The use of a weak consistency but high base oil viscosity grease reduces the risk of lubricant leaks.

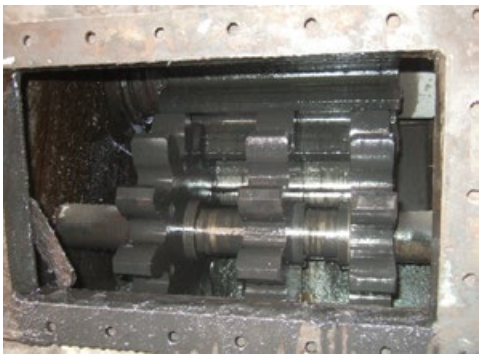
The lubricant quality must be monitored to prevent pollution and avoid the deterioration of the open gear drive's working flanks, mainly because of abrasion.

We recommend draining the lubricant frequently. This can be done by cleaning the housing annually, depending on the processed products and the machinery environment. The housing must be specifically designed for these operations.

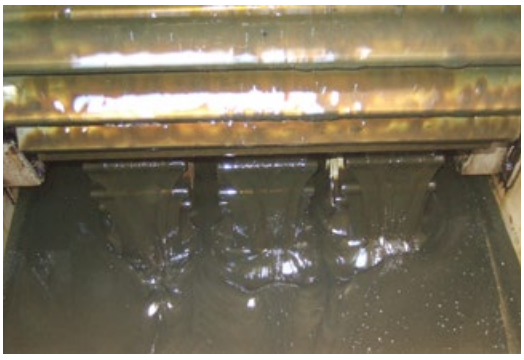
Warning: A specific splash lubricant is designed for this application. Except for extreme situations, we do not recommend mixing two lubricants (often grease and oil). This can weaken the priming lubricant's characteristics. In this case, we suggest using a lubricant designed for splash lubrication, this information for which can be found by contacting our Technical Department.

5. B - 2 - Splash lubrication: using an intermediary paddle wheel

In this particular case of splash lubrication, the gear's teeth are not in direct contact with the lubricant bath. An idling pinion called « paddle wheel », in contact with the bath and lead by the drive pinion, transfers the lubricant onto the working flanks.
With this method, smaller amounts of lubricant may be used than with the classic splash lubrication method with fewer housing leaks and is usually only used for slow rotating drums mainly cement rotary kilns.



Example of lubrication with different types of intermediary «paddle wheels»



5. B - 3 - Splash lubrication: equipment inspection

To guarantee the best and most secure lubrication conditions, the gear's splashing system must be monitored regularly throughout the year.

We recommend setting up and implementing action procedures and recording and archiving all information gathered during inspections.

SPLASH LUBRICATION:
Following is a list of the main inspection and maintenance operations required:

1. Inspect the quality of the working flanks lubrication. Working flanks must be heavily covered with lubricant (less so in case there is an intermediary paddle wheel).
   Immediately correct an insufficient lubrication.
2. Inspect alarms and defect indicators (bath temperature and lubricant level).
3. Regularly check the splash lubricant quantity. When filling, it is important to avoid polluting the lubricant.
4. Inspect the gear housing seals. In case of significant wear or important leaks, seals must be replaced (check clearance, which may be too small after tightening).
5. Drain the lubricant frequently, with a complete cleaning of the housing (depending on operational conditions, but approximately every 8000 hours; the lubricant can be analyzed to reveal its pollution level and the aging of its components).
6. Inspect the area around the installation for cleanliness. All leaks must be reported to the authorized maintenance service.
7. When using an intermediary paddle wheel, inspect its rotation and ability to maintain the good transfer of lubricant onto the working flanks.

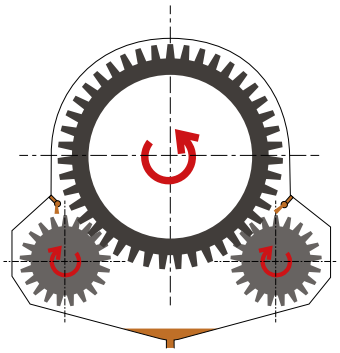
5. B - 4 - Splash lubrication: list of LUBRILOG operational lubricants

Direct or indirect splash lubrication onto the gear's teeth (bath or immersion), through the action of a transfer pinion, is the most appropriate use for lubricants listed in the table below.

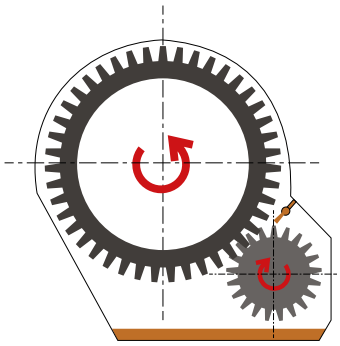
LUBRILOG SPLASH LUBRICANTS				CHARACTERISTICS		
name	graphite or MoS_2 ●	non graphite ○	structure	40°C viscosity (mm^2/s) / Consistency	welding (daN)	color
GRAFOLOG M FLUID	●		grease	3,000 / 000	> 800	black
GRAFOLOG MT FLUID	●		grease	7,500 / 000	> 800	black
LUBRILOG L CC 3200 M	●		oil	3,040	> 400	black
GEAR FLUID 180		○	oil	4,600	≥ 980	brown
GEAR FLUID 300		○	oil	9,000	≥ 980	brown
GEAR FLUID 550		○	oil	17,000	> 980	brown
GEAR FLUID 1000		○	oil	25,000	> 980	brown

5. B - 5 - Circulation lubrication

Circulation lubrication consists of consistently pouring lubricant onto the gear's working flanks, using the lubricant collected at the bottom of the housing after it has been settled, pumped and filtered.
This application is executed by manifold.
The main difference between this lubrication and splash lubrication is the filtration process prior to application, which cleans the lubricant of most polluting particles contained in it.
As with splash lubrication, the housing seals must be in good condition in order to avoid lubricant leaks and contamination by polluting particles.



Double pinion circulation lubrication



Single pinion circulation lubrication

The plant's environmental conditions may require that the lubricant be heated.

The most efficient pumps, installed on the circulation system, may allow the use of oils or fluid greases with an output capacity of 5 to 50 liters/minute. The position of the ramps must allow lubrication the working flanks of pinions.

As with splash lubrication, **this permanent lubrication method is extremely efficient as long as the housing is well sealed, the circulation system is in good condition, and the appropriate lubricant is used.**

For the circulation system, **LUBRILOG** recommends using its **COMPACT CX** system, specifically designed to provide optimal circulation lubrication.

5. B - 6 - Circulation lubrication: list of LUBRILOG operational lubricants

The design of the gear's protective housing, the sealing and the pump system's performance will dictate the choice of lubricants among those mentioned below:

LUBRILOG CIRCULATION LUBRICANTS				CHARACTERISTICS		
name	graphite or MoS_2 ●	non graphite ○	structure	40°C viscosity (mm^2/s) / Consistency	welding (daN)	color
LUBRILOG L CC 1200 M	●		oil	1,200	> 400	black
LUBRILOG L CC 1500 M	●		oil	1,500	> 400	black
LUBRILOG L CC 2200 M	●		oil	2,200	> 400	black
LUBRILOG L CC 3200 M	●		oil	3,040	> 400	black
GEAR FLUID 180		○	oil	4,600	≥ 980	brown
GEAR FLUID 300		○	oil	9,000	≥ 980	brown
GEAR FLUID 550		○	oil	17,000	> 980	brown
GRAFOLOG M FLUID	●		grease	3,000 / 000	> 800	black
GRAFOLOG MT FLUID	●		grease	7,500 / 000	> 800	black

Example of a double drive mill outward pinion lubrication with GRAFOLOG M FLUID graphite grease

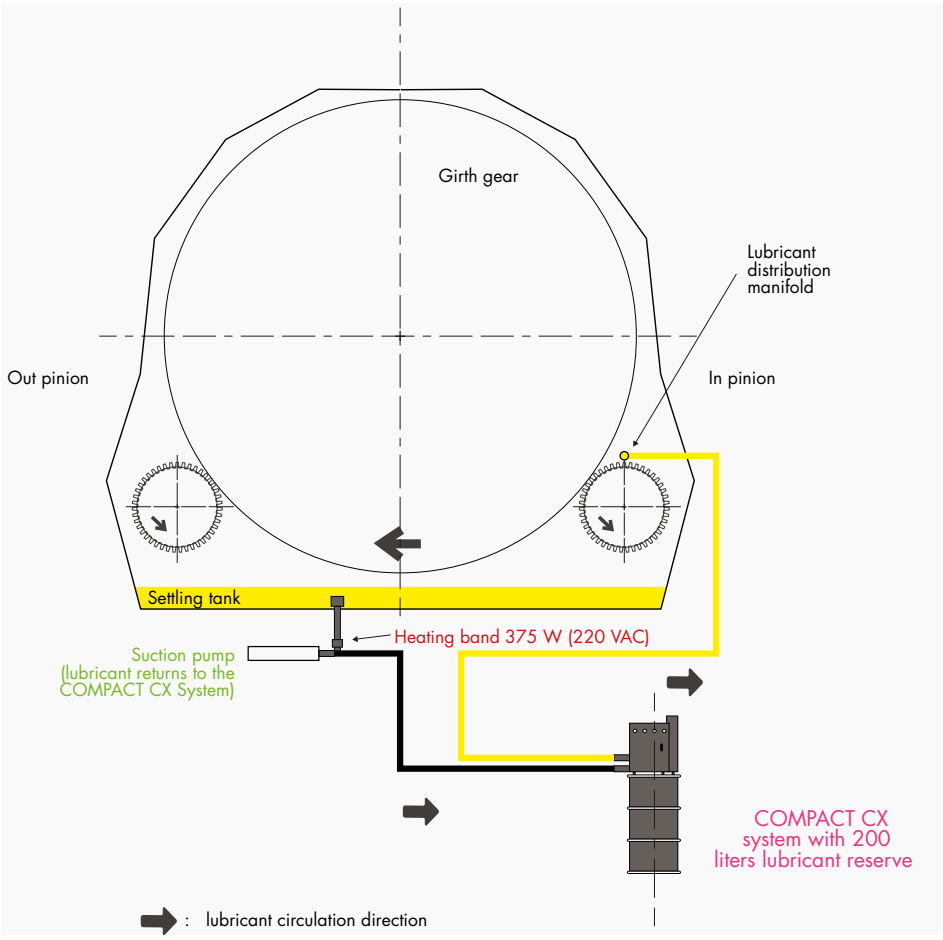
Warning:
For viscosities exceeding 1500 mm²/s, the circulation system must imperatively be tested (particularly in cold temperatures and in the running-in phase).

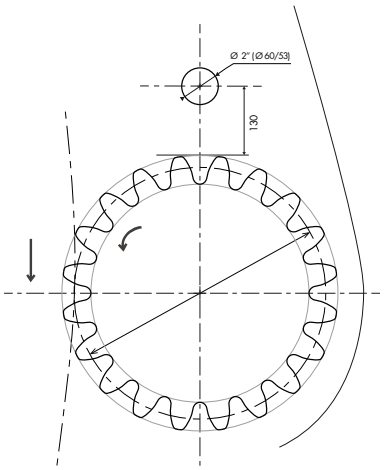
Replacing the operational lubricant:
Although we recommend draining the lubricant annually (about every 8000 hours), the specific operational conditions of the machinery must be primarily taken into account for this operation.

5. B - 7 - Circulation lubrication: LUBRILOG COMPACT CX system

With the secure **COMPACT CX** lubrication system, **LUBRILOG** offers a simple, reliable and secure installation with alarms controlling the flow and pressure, allowing for the use of fluid greases with high base oil viscosity and very viscous oils (up to 17,000 mm²/s).

For any additional information, we recommend reading our specific « **COMPACT CX** » documentation.





COMPACT CX: lubricant circulation diagram (example on an inward pinion)

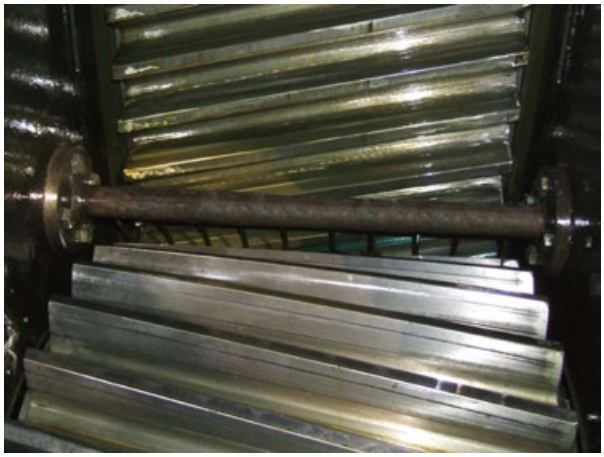
5. B - 8 - Circulation lubrication: equipment inspection

To guarantee optimal and secure lubrication conditions, the gear's circulation equipment must be inspected regularly throughout the year.

We recommend setting up action procedures to be implemented and recording and archiving all information gathered during inspections.

CIRCULATION LUBRICATION:
Following is a list of the main inspection and maintenance operations required:

1. Inspect the lubrication quality of the working flanks. The circulation manifold's drillings must all be operational (open).
   Immediately clean the manifolds in case of partial sprinkling.
2. Check alarms and defect indicators.
3. Regularly check and clean lubricant filters.
4. Regularly check the circulation lubricant quantity. When filling, pollution of the lubricant must be avoided.
5. Inspect the pumps and make sure they are running properly according to the descriptions above.
6. Inspect the gear housing seals. In case of significant wear or important leaks, seals must be replaced (check clearance, which may be too small after tightening).
7. Drain the lubricant frequently, with a complete cleaning of the housing this depends on operational conditions, estimated at approximately every 8000 hours; the lubricant can be analyzed to reveal its pollution level and the aging of its components.
8. Inspect the area around the installation for cleanliness. All leaks must be reported to the authorized maintenance service.



5. C - Sequential (or intermittent) lubrication: loss lubricant

The objective of **sequential lubrication** also called intermittent lubrication is to guarantee discontinuous application of lubricant on the gear's working flanks' point of contact like contact generator.

The application of lubricant is discontinuous and alternates in **two periods**:
a non-lubrication period and a lubricant application period.

The cycle must be repeated regularly.

This type of lubrication is called **« loss lubricant »**: unlike in continuous lubrication the lubricant applied is always new.

For this reason, when choosing this type of lubrication, it is very important to analyze the cost/performance ratio of the acquisition, installation, maintenance, lubricant and environmental costs and lubrication performance.

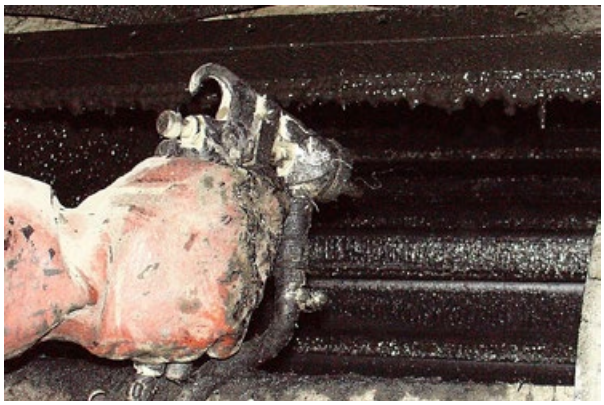
The two main sequential lubrication methods are:

- **Manual lubrication** (completely manual or with a spray gun) and

- **Automatic lubrication**

Our **Technical Services** are available to help you define the most appropriate solution for your situation: adequacy between « gear to lubricate, application method and choice of appropriate lubricant ».

Automatic spray lubrication



Manual spray lubrication

5. C - 1 - Automatic spray lubrication

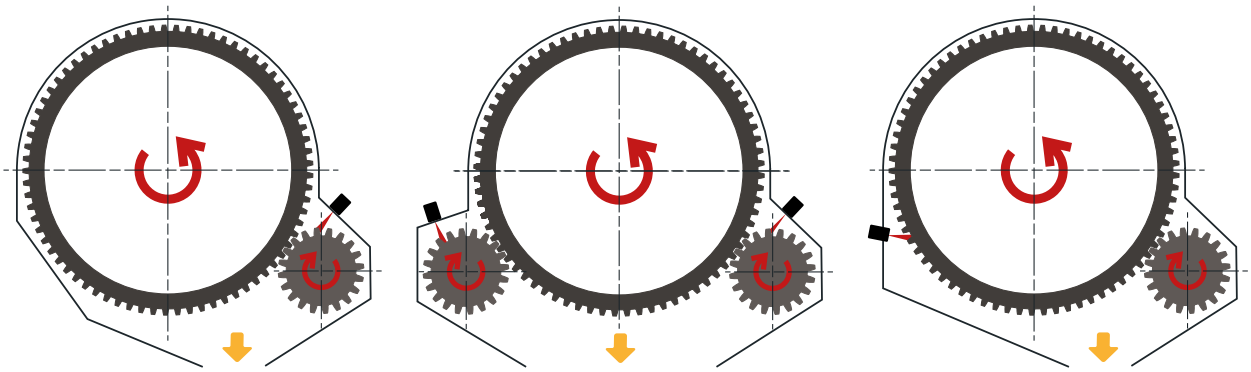
The sequential lubrication method most commonly used in industry is the automatic **spray lubrication**. This method consists of spraying the lubricant with compressed air onto the pinion(s) or the girth gear's working flanks with automatic systems equipped with alarms on their strategic components.

This method is recommended for gear sets of all dimensions when the housing's sealing is mediocre, the housing is not designed for continuous lubrication, or the lubricant function called « dissipation of the heat created by frictions » is not mandatory.

The lubrication is not continuous but periodical, with cycles composed of active spraying periods and pause periods. These cycles are repeated regularly according to the open gear's lubrication needs.

The spray system must imperatively be defined according to the machinery's operational requirements and thus according to its associated open gear drive.

As different lubricants will be applied on the gear set throughout its operation (running-in, operational, cleaning and repair lubricants), the automatic spray lubrication installation must imperatively tolerate the use of these different lubricants.



Spraying to pinion | Spraying to pinions | Spraying to girth gear

Although several existing automatic spray lubrication systems can guarantee efficient lubrication, the following parameters must be considered at the initial design phase of the installation:

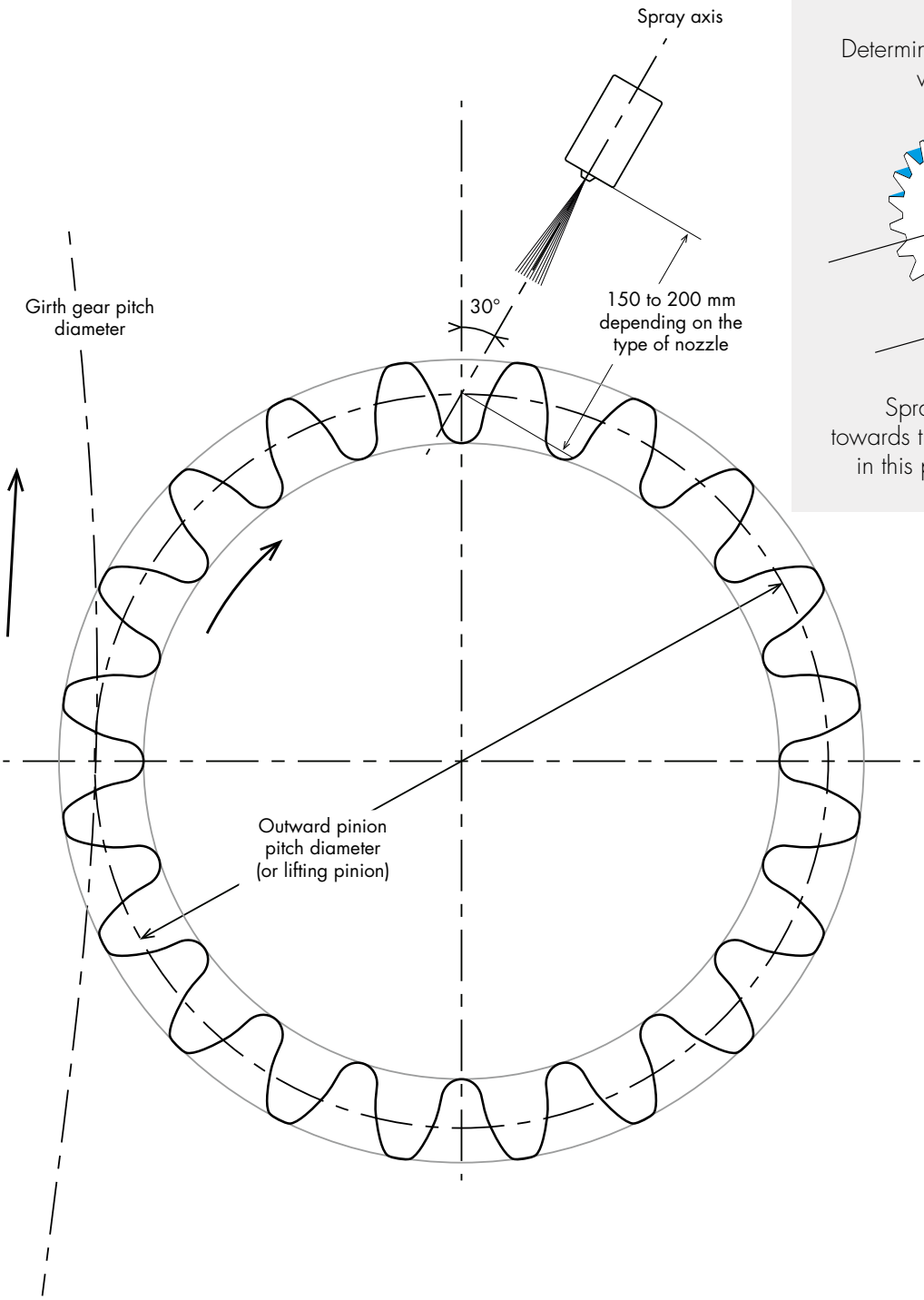
- Number of spray nozzles
- Spray nozzle positioning
- Spray cycle, with lubricant quantities to be applied (in the initial running-in phase and while in-service)
- Spray lubricant characteristics (grease, oil, consistency, base oils viscosity, with or whitout solid lubricant, percentage, etc.)
- Monitoring and maintenance possibilities
- Necessary alarms and security systems
- Choice of the PLC functions and alarm mechanisms, connection with existing installations

5. C - 2 - Automatic spray lubrication: spray nozzle positioning

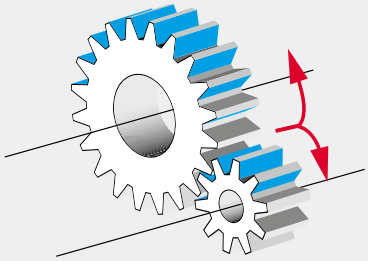
The spray jets must be directed towards the pinion or girth gear's working flanks. The following diagram describes the appropriate jet positioning. **Both axes: «spray axis» and «pitch radius» must make a 30° angle at the intersection point on the pitch diameter.**

The distance between spray nozzles and working flanks is defined by the type of nozzles installed (between 150 and 200 mm).

Notes: Spray lubrication can be applied on the girth gear, but the spray duration must be superior or equal to one full rotation of the girth gear. Ideally, the nozzles should spray downwards in order to avoid being polluted by an accumulation of lubricant, dust or foreign particles.



Determination of the gear set's working flanks:

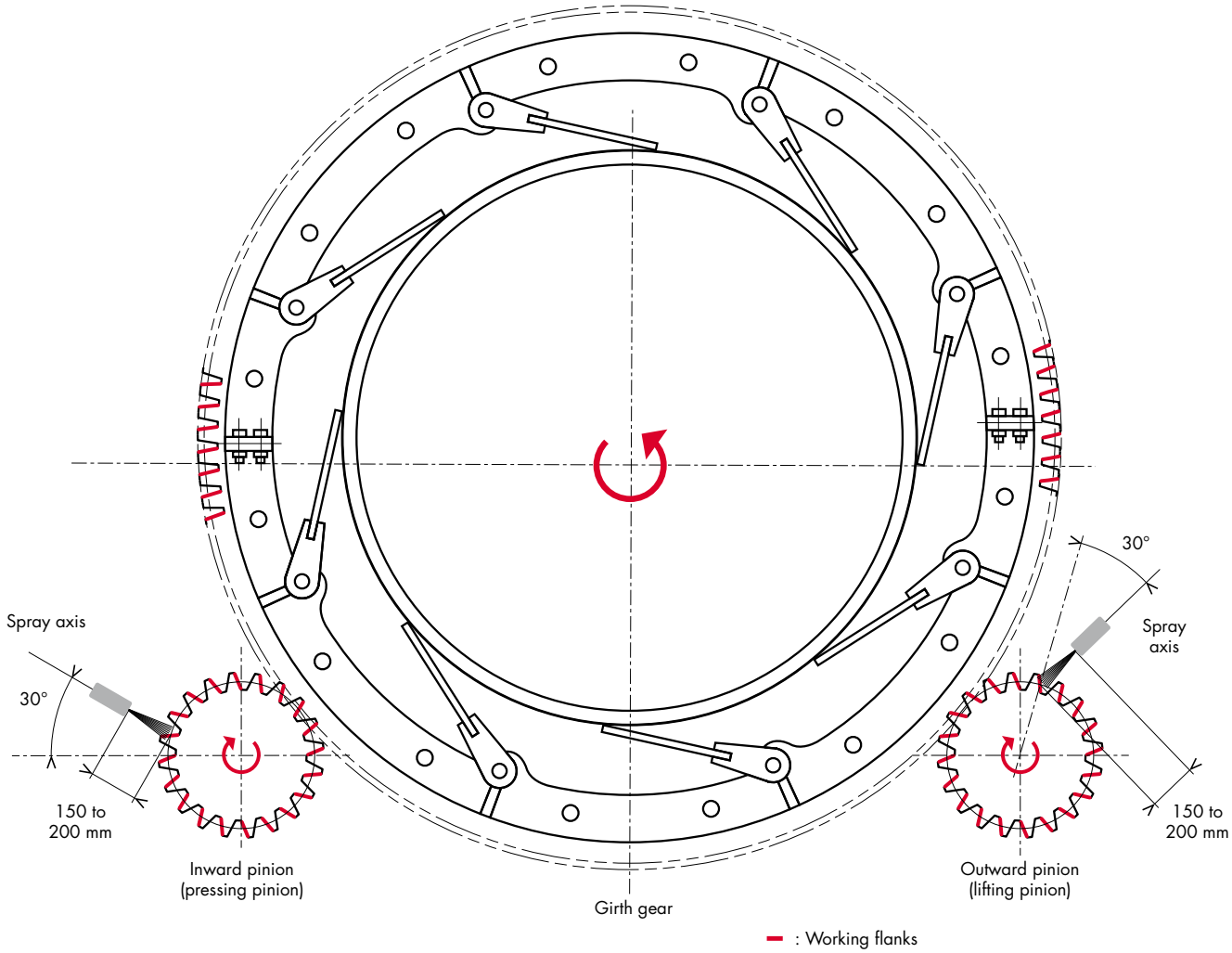


Spray jets direction = towards the working flanks (blue in this positioning example)

Warning: It is crucial that the spray jets be correctly **directed towards the working flanks.** Errors in orientation are frequent in the case of double pinion drives or when the spray lubrication is directed towards the girth gear's working flanks.

Diagram of a double drive situation:

Below is an example of the spray nozzle positioning on both pinions



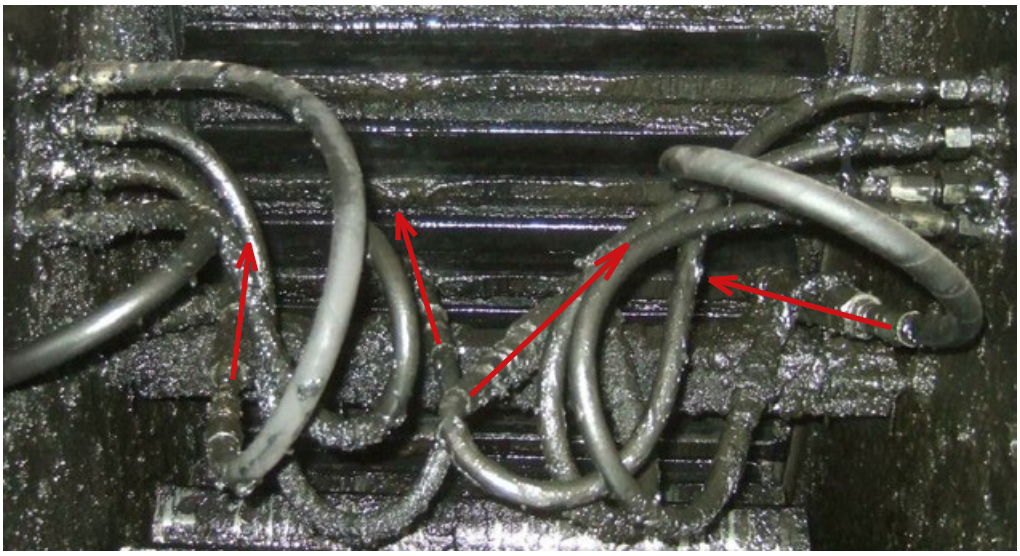
Nozzles correctly directed towards the inward pinion's active flanks

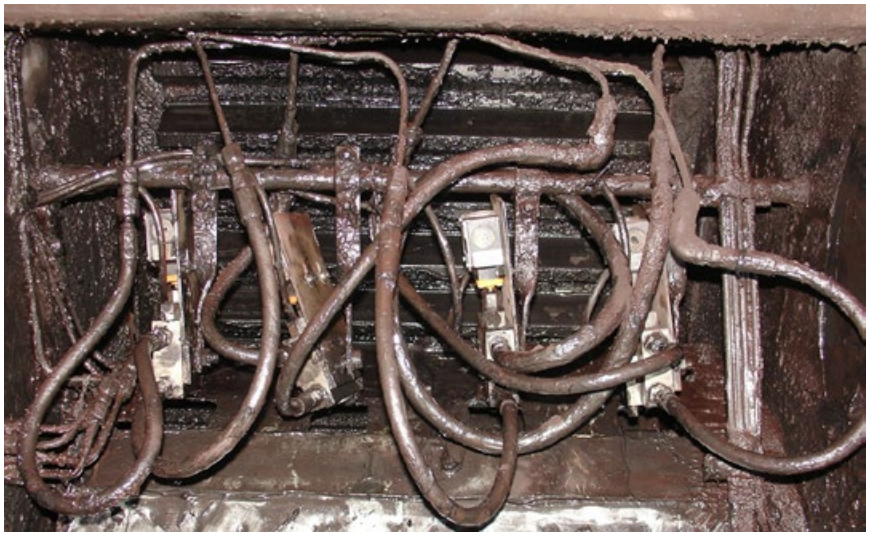
The nozzles must be positioned in such a way that the lubricant sprays both pinions' working flanks. When setting up spray nozzles on the pinions, you must determine which flanks are the working flanks and position both spray panels according to the diagram on page 23. The nozzles' spray axes must be at a 30° angle with the pitch radius, and directed towards the working flanks.

The distance between spray nozzles and working flanks is defined by the type of nozzles installed (between 150 and 200 mm).

5. C - 3 - Automatic spray lubrication: examples of poorly positioned nozzles

The following example illustrates an abnormal positioning of the spray nozzles with a very high risk of parts of the working flanks not being covered with lubricant.





The example on the left illustrates:

1°) Random nozzle positioning
2°) The impossibility to control the correct operation of the nozzles
3°) An extremely obstructed access to the nozzles making maintenance operations very difficult

Note: for helical teeth, the spray rack does not have to be positioned relatively to the helix angle ß of the teeth! In rotation, all working flanks are lubricated.

5. C - 4 - Automatic spray lubrication: equipment inspection

As with circulation lubrication, in order to guarantee optimal and secure lubrication conditions, the spraying equipment must be inspected regularly throughout the year.
We recommend setting up action procedures to be implemented and recording and archiving all information gathered during inspections.

AUTOMATIC SPRAY LUBRICATION:
Following is a list of the main inspection and maintenance operations required:

1. Inspect the lubrication quality of the working flanks, both visually and by recording spray patterns (full covering of the working flanks).
   Immediately correct defects observed in abnormal spray patterns.
2. Check the duration of the lubrication cycles and adjust if necessary: pause periods and spray periods, distributor cycle.
3. Check the lubricant quantity sprayed in each lubrication cycle by weighing the spray patterns.
4. Regularly check the tanks' lubricant level. When filling or changing the drums, pollution of the lubricant must be avoided.
5. Check alarms and defect indicators.
6. Check the compressed air's pressure according to manufacturer recommendations. Generally, the pressure must reach at least 4 bars. Check the associated compressor.
7. Regularly check and clean the lubricant and compressed air filters.
8. Regularly inspect and clean the spray nozzles as well as their access inside the housing. We recommend cleaning the spray and distributor nozzles completely at least once a year.
9. Check the pumps operation.
10. Regularly clean the lubricant gathered inside the housing and inside the dedicated vat underneath the housing. The open gear must and under no circumstances touch the used lubricant which can cause the risk of pollution.
11. Inspect the area around the installation for cleanliness. All leaks must be reported to the authorized maintenance service.

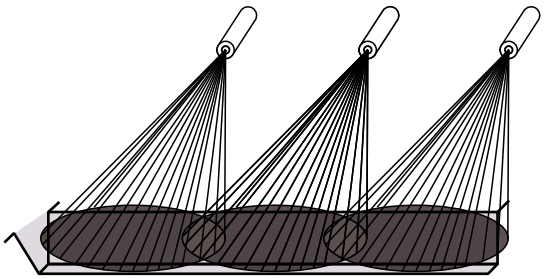
5. C - 5 - Automatic spray lubrication: spray patterns inspection

It is mandatory to continuously monitor the operation of the various elements of the spray system and to control the actual result of the total surface of sprayed working flanks.

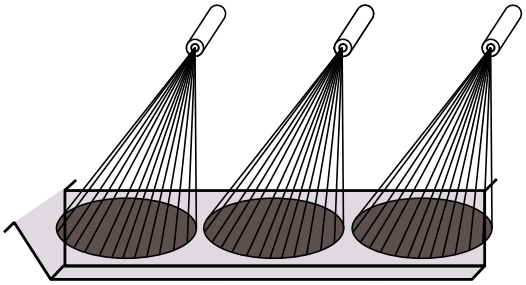
The spray nozzle jets must imperatively overlap to cover the entire operational area (see diagrams below). If possible, the medium (paper, corrugated or metal plate) on which control is performed can be used to control the amount of lubricant applied (weighed before and after spraying lubricant).

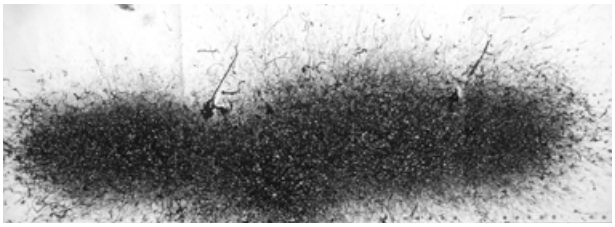
Despite of the efficiency of new automatic nozzle control system the « spray pattern » must be regularly inspected by the maintenance service in charge of the open gear drive's preventive maintenance.

Correct spray pattern
=
The teeth's working flanks are well covered

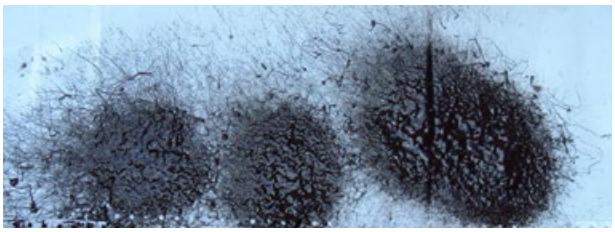


Insufficient spray pattern
=
The working flanks are not completely covered





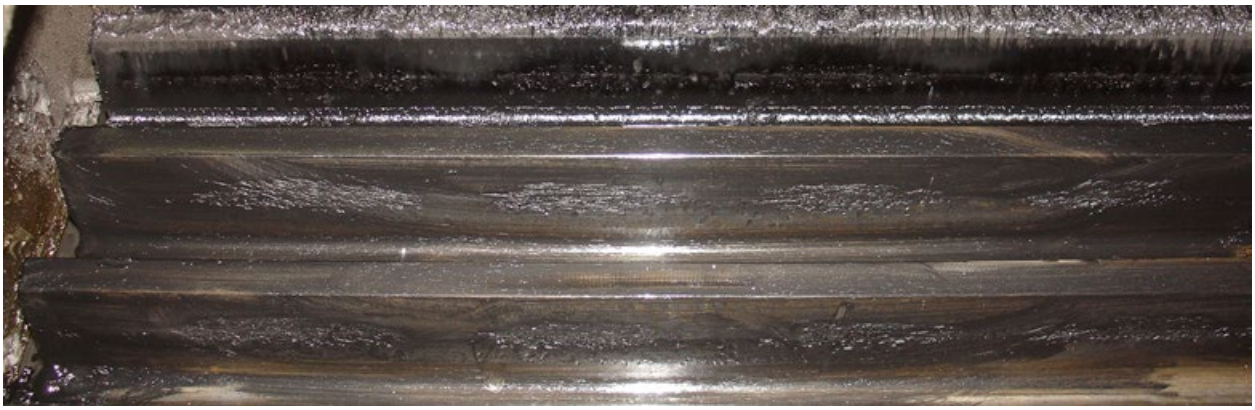
Correct spray pattern



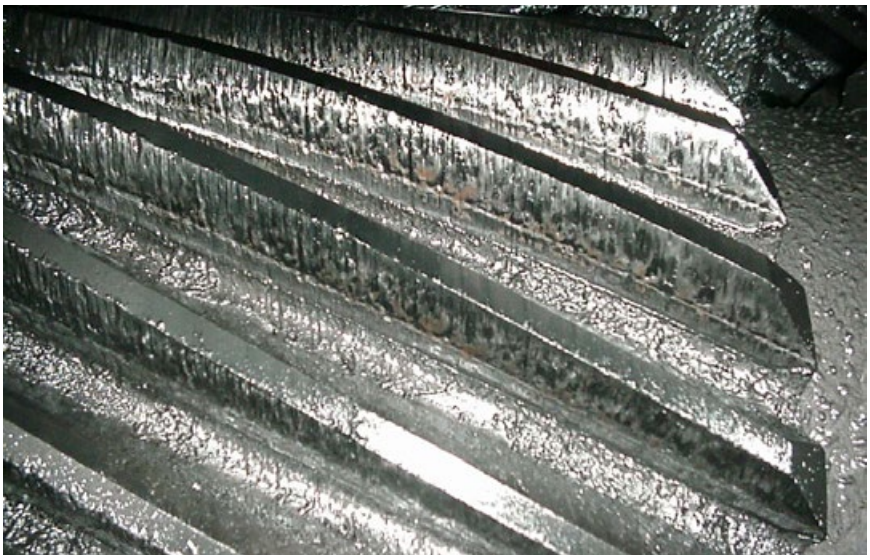
Unsatisfactory spray pattern

5. C - 6 - Automatic spray lubrication: lubrication damages

The types of damages observed on open gear drives' working flanks are described in our document « Most common teeth damages in large open gear drive ». However, we wish to describe two common damages encountered with incorrect spray lubrication:



Defective spray lubrication system (a mill girth gear's working flanks).
The scuffed areas indicate areas not covered with the lubricant.



Insufficient lubrication (insufficient lubricant quantity on a mill pinions' working flanks).
The recommended quantities have not been applied.

5. C - 7 - Automatic spray lubrication: operational lubricant quantities

Based on its knowledge of lubricants, its understanding of rotary drums' open gear drive operations and its experience, **LUBRILOG** has defined the following calculation method to determine the quantity of lubricant to be applied on open gear teeth.

Nonetheless, in case of extreme teeth types (large or small modules, very high temperatures, deteriorated teeth), we encourage our customers to contact our Technical Services, who will collaboratively define the most appropriate solutions.

The determination of the operational lubricant quantity is completed in three steps, which include the main criteria required for appropriate gear set operation.

1°) Dimensional factor defined by the teeth's facewidth and applied load:

Table 1:
This table takes into consideration the machinery's power capacity, kiln single drive (only one drive pinion), ball mill single drive and double drive (two drive pinions) as well as the teeth's facewidth which is a parameter defined by the gear set manufacturer and is easy to insert into a formula (the other dimensional parameters are associated with the power of the machine).

2°) Temperature factor:

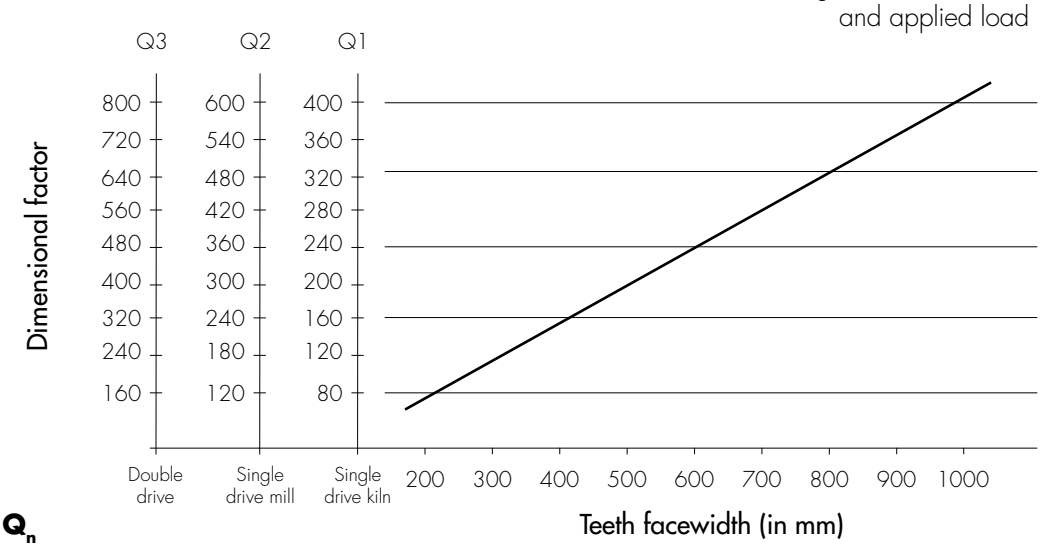
Table 2:
This table takes into consideration an important factor: temperature. Indeed, temperature can significantly affect a lubricant's behavior (particularly viscosity), and the quantity of applied lubricant must increase as temperature rises. To choose an appropriate lubricant, it is very important to know the gear's working flanks' operational temperature (on a cement kiln, for example, temperatures can exceed 70°C (158 °F) and in this case, the thickness of the lubricant film can be reduced dangerously in case of under-lubrication).

3°) Surface contact factor:

Table 3:
This table takes into consideration teeth condition and the quality of the surface contact between teeth. Although the condition of the contact is not always easy to determine, in the case of mediocre contact and deteriorated teeth, the quantity of lubricant distributed must be increased.

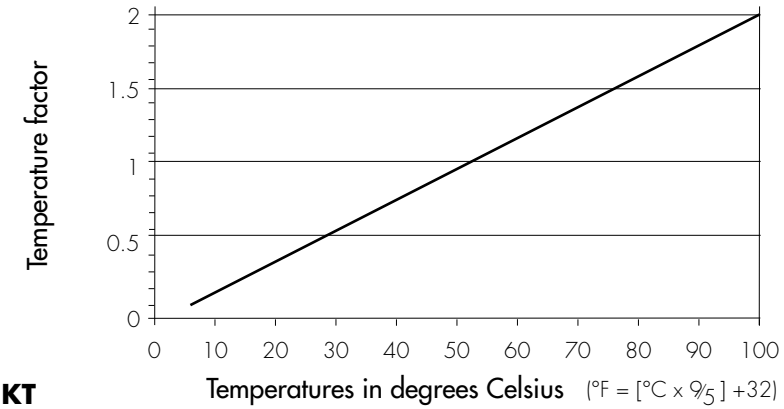
The following tables can help you determine the theoretical lubricant quantities to be applied when spraying GRAFOLOG graphite operational greases.

Table 1: Dimensional factor according to teeth facewidth and applied load



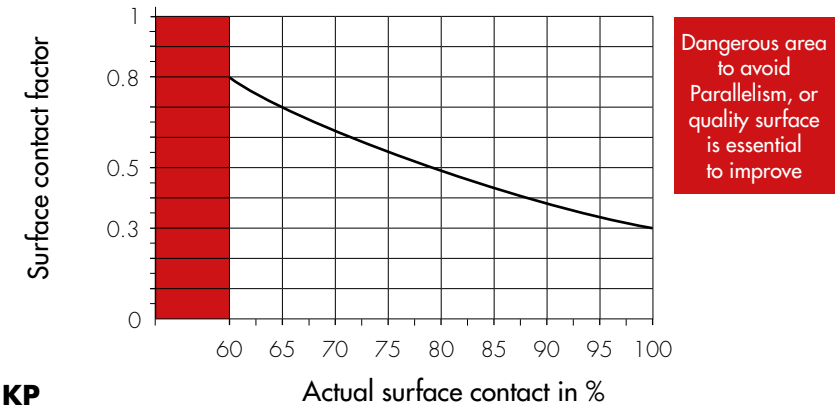
Q_n

Table 2: Determining the K T temperature factor



KT

Table 3: Determining the K P surface contact factor



KP

Calculating lubricant quantity **D** to apply (in cm^3 / hour):

D = Qn x KT x KP

(with n = 1, 2 or 3)

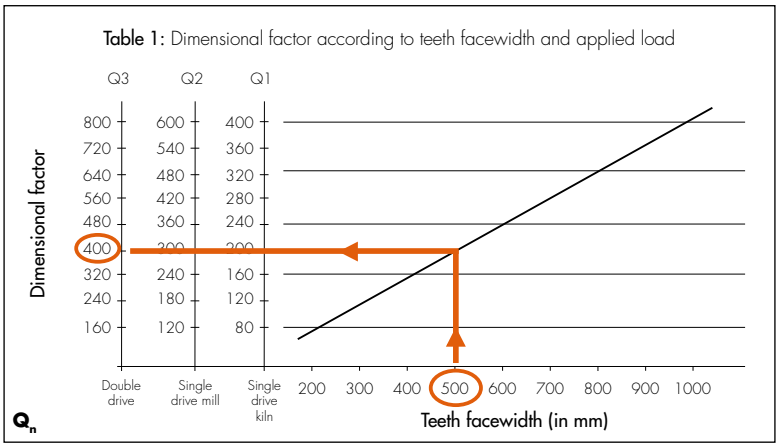
Consider the result with a tolerance of ± 5%

For very high viscosity lubricants such as our **GEAR FLUID 550** oil, the result must be multiplied by the factor 0.60

The following example provides a calculation method guideline:

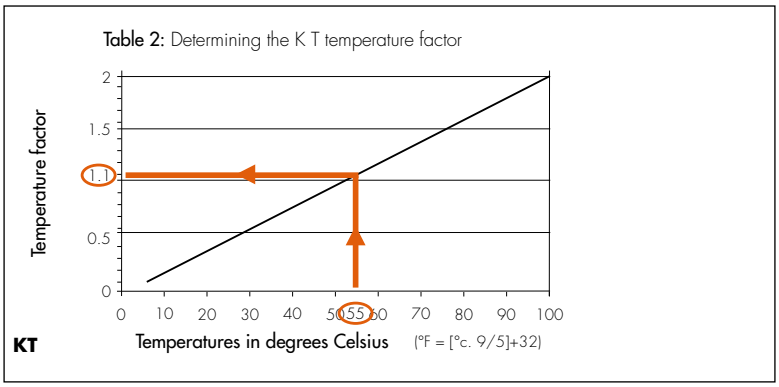
Calculating the grease quantity to spray on a ball mill's open gear drive.

Hypotheses:
Double drives (two pinions)
Working flanks facewidth, b = 500 mm
Operational temperature, Θ = 55°C (131°F.)
Teeth working flanks are in good condition but old, surface contact estimated at 85 %



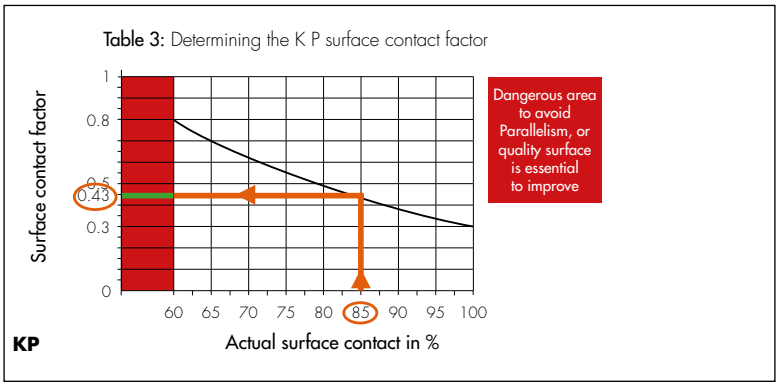
Step 1:
Data:
Teeth facewidth: 500 mm,
Double drive: Q3.

Dimensional factor to be applied:
400



Step 2:
Data:
Temperature of the working flanks to lubricate:
55°C (131 °F.).

Temperature factor to be applied:
1.10



Step 3:
Data:
Surface contact: 85%.

Surface contact to be applied:
0.43

Total quantity D of lubricant to be applied: $D = Q_n \times KT \times KP$

D = 400 x 1.1 x 0.43 = **189.2 cm³ / in-service hour** and with a lubricant of a density = 0.9
D = **170 g / in-service hour (± 5%)**

5. C - 8 - Automatic spray lubrication: lubrication cycles

According to sequential or intermittent lubrication principles, the addition of lubricant onto surfaces to be lubricated is discontinuous.

Two periods alternate: a lubricant spraying period and a non-spraying period.

The combination of both periods must allow the formation of an efficient lubricating film on the gear set's working flanks.
Once the quantity of lubricant to be applied per service-hour has been determined by calculating, using the method above, it is important to determine pause and spray period duration. The basic principle for a good lubrication system is to distribute this calculated quantity as evenly as possible, by applying small quantities as frequently as possible. Indeed, as soon as the spray period is finished, the lubricant film's thickness will decrease at a speed that depends on the lubricant used and the gear drive being lubricated.
The selected spray system must allow the distribution of small quantities of lubricant (to be defined beforehand by the system manufacturer).

We recommend the following settings to our customers:

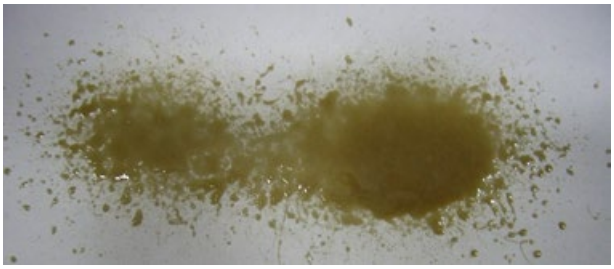
Pause period: under 5 minutes.

Spray period: over 10 seconds.

For fast rotary drums (> 10 rotations / minute, such as mills), we recommend these settings, and for slow rotary drums (kilns, dryers, coolers), the duration of the pause can be increased to 10 minutes. In this case, we recommend contacting our Technical Services.

With some lubrication systems, the exceedingly short spray duration does not allow the lubricant to be sprayed. The spray duration to be taken into account is the actual duration the lubricant is being sprayed during this process one must particularly pay attention to the opening of the compressed air solenoid valves. The quantity of sprayed lubricant must be verified frequently.

Cycle durations are also determined by the type of lubricant used, as viscosity may vary between 460 mm^2/s to 17000 mm^2/s and more, in the form of oil or grease.



Laboratory spray experiment:
GEAR FLUID 550 D,
4 bars (58 PSI), 1cm^3/mn, + 5°C. (41°F.)

5. C - 9 - Automatic spray lubrication: list of LUBRILOG operational lubricants

The following table shows the different greases and oils designed for spray lubrication (lubricant projection onto the gear set's working flanks). **LUBRILOG** has compiled specific recommendations when defining the best lubrication parameters such as the type of lubricant, the quantity to apply, lubrication cycles and the inspections to be completed for optimal preventive maintenance.

LUBRILOG SPRAY LUBRICANTS				CHARACTERISTICS		
name	graphite or MoS_2 ●	non graphite ○	structure	40°C viscosity (mm^2/s) / Consistency	welding (daN)	color
GRAFOLOG H 0	●		grease	500 / 0	> 620	black
GRAFOLOG H 0 +	●		grease	1,100 / 0	> 700	black
GRAFOLOG H 1500	●		grease	1,500 / 0	> 700	black
GRAFOLOG H 3000	●		grease	3,200 / 0	> 700	black
INVERTA RUN PLUS		○	grease	1,000 / 0 - 1	> 700	brown
INVERTA RUN HT		○	grease	460 / 00* 12,500 / 0**	> 800	beige
GEAR FLUID 180		○	oil	4,600	≥ 980	brown
GEAR FLUID 550 D		○	oil	1,000* 17,000**	> 980	brown
GEAR FLUID 1000 D		○	oil	1,600* 25,000**	> 980	brown

*: before solvent evaporation
**: after solvent evaporation

Warning:
It is important to ensure that the spray system has been designed for the selected lubricant particularly in cold temperatures and during the running-in phase and that the PLC can sustain the calculated lubrication cycle.

Preventive maintenance:
In addition to regular inspection we recommend thoroughly cleaning the spray system each year.

5. C - 10 - Manual sequential lubrication

Manual lubrication may be considered for medium size open gear drives and/or drives that are not highly solicited and thus necessitate smaller amounts of lubricant, or for machines that do not operate continuously.

Two processes are often used:

- **Fully manual lubrication** (not recommended) and
- **Lubrication using a manual pneumatic spray gun**

In both cases, it is imperative to use of a specific, very viscous and adherent open gear set lubricant, and to apply lubrication cycles (lubricant application regularity).

We do not recommend fully manual lubrication, which is often executed between shifts by under-trained employees. The proximity with the gear set and the extended periods of time between lubricant applications are a high level of risk for the operators and the gear sets.
This particular lubrication method must be monitored closely and often causes abnormal wear damages, sometimes as serious as teeth scuffing when the rupture of the lubricating film is sudden applying lubricant directly onto an outward pinion's working flanks is particularly difficult.

Lubrication with a manual pneumatic spray gun should be considered for its simplicity of use and the safety it provides. The spray gun guarantees the formation of a perfect lubricant cover on the working flanks, but the duration of the pause between each application must be strictly defined and observed to avoid under-covering working flanks with lubricant.

We recommend contacting **LUBRILOG**'s **Technical Services** for information regarding lubricants to select for manual gear-drive lubrication in in-service and running-in phases (in the running-in phase, fast lapping is recommended).

Gravity manual lubrication on the outward pinion
= High-risk method

Manual spray lubrication equipment

/06
OPEN GEAR DRIVE RUNNING-IN

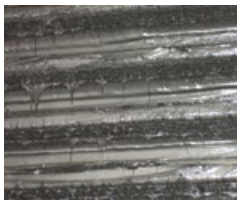
Based on experience, **LUBRILOG** has developed an initial running-in process for large open gear drives, providing maximum security and increased longevity and integrating the most recent tribological results (new or repaired gear drive).

After setting up and installing the gear drive (girth gear and pinions), **LUBRILOG** recommends observing both phases described below, namely priming and running-in, by using specific lubricants designed for those functions.

Depending on the lubricant application method (splash, circulation or spray lubrication), **LUBRILOG** offers different lubricants specifically designed for this running-in phase.

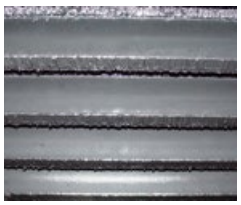
Warning: in the absence of specific explanation, the term « running-in » must be understood as the initial start-up of a new or repaired open gear drive.

Running-in phase 1: preparing surfaces

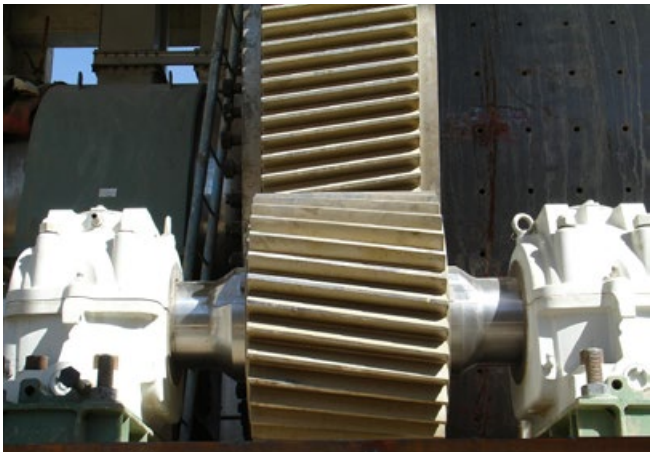


Priming = GRAFOLOG H 1

Running-in phase 2: improving surfaces quality



Open gear drive running-in
(lubricant type depending on lubrication method)



Erection of an open gear drive

6. A - Running-in phase 1: Initial lubrication (priming)

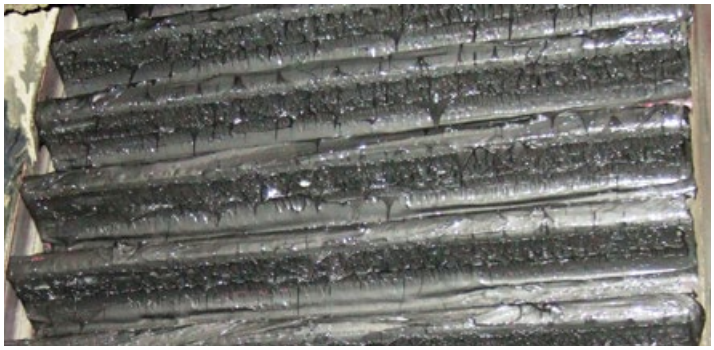
Priming (or initial coating) is the gear drive's first lubrication process.
A specific and very adherent graphite lubricant is manually applied in thick layers on the working flanks (about 2 mm, brush application, with no inclusion of air, onto previously cleaned surfaces) as soon as the mechanical settings are in place. All other teeth surfaces must also be covered, but in fewer quantities.

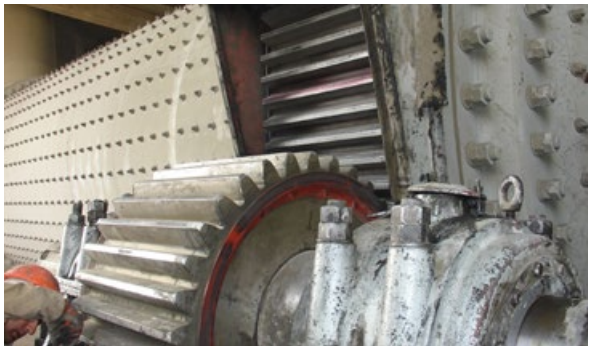
The main functions of this priming phase are to:

- Avoid corrosion
- Guarantee the perfect protection of the teeth from the first contacts by creating an efficient lubricant film, regardless of the initial surface quality and mediocre contact quality, when lubrication is in a boundary regime
- Evaluate the actual surface contact dynamics in order to adjust the mechanical settings if necessary

The lubricant is only applied manually, before the running-in phase (in the case of a rod, ball or SAG mill) and preferably before installing the housing for correct implementation.

LUBRILOG PRIMING LUBRICANTS				CHARACTERISTICS		
name	graphite or MoS_2 ●	non graphite ○	structure	40°C viscosity (mm^2/s) / Consistency	welding (daN)	color
GRAFOLOG H 1	●		grease	1,000 / 1	> 500	black
GEAR FLUID P		○	oil	25,000	> 800	brown





6. A - 1 - Priming lubrication: quantity to apply

Our Technical Services are available to help you determine the amount of priming lubricant to apply. The elements required in order to calculate this amount are:

- Girth gear pitch diameter (Dp) and
- Girth gear working flanks facewidth (b)

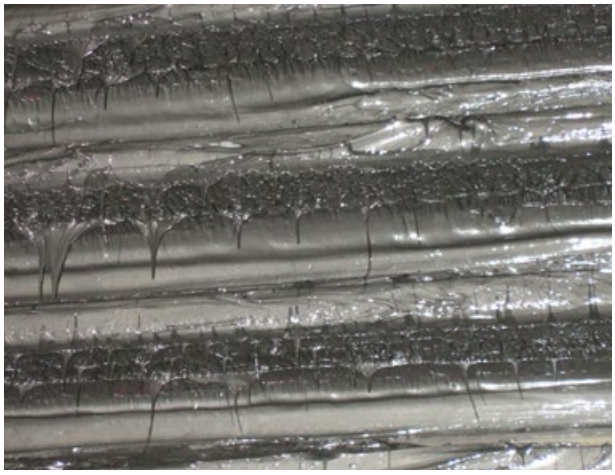
Nevertheless, the following formula can be used to determine the quantity to apply:

Quantity = 6 x b x Dp

(with the quantity in kg, b and Dp in meters)

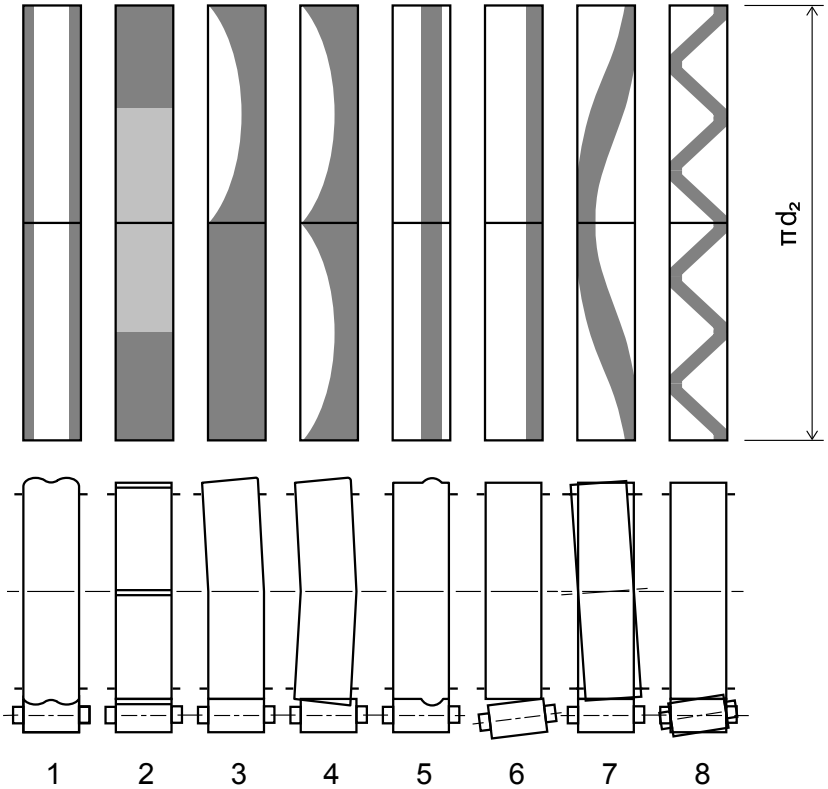
For example, for a girth gear with a pitch diameter of 5500 mm and a working flank width of 500 mm, the required quantity of priming lubricant will be 16.5 kg and the quantity to order is 17.5 kg.

The GRAFOLOG H 1 and GEAR FLUID P lubricants are available in 50 kg drums, 12.5 or 5 kg pails.



6. A - 2 - Priming lubrication: visualizing the contact between working flanks

In addition to its primary tribological function, the priming lubricant also serves to precisely visualize the dynamic surface contact areas between pinions and girth gear (only with GRAFOLOG H 1).
The presence of a solid, black tint lubricant is important as it helps evaluate contact intensity and positioning between the active flanks.
The load must be distributed across the widest surface possible on the working flanks.
The contact can then be improved as early as in the running-in phase, before damage due to excessive constraint concentration may occur.
The following diagrams illustrate a few surface contact examples.
In all cases, **LUBRILOG** recommends contacting the manufacturer or mechanic responsible for gear implementation and following his/her instructions.



Open gear drive ready for start-up

1: Excessive housing seals temperature: **check the lubrication, the position and the clamping of seals**

2: Girth gear misalignment about half of the circumference
Irregular contact on the girth gear perimeter: **adjust the girth gear position**

3: Half-girth gear positioning defect: **correct the girth gear installation (assembly)**

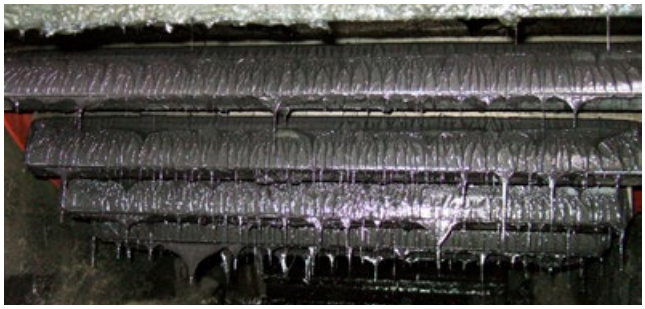
4: Positioning defect of both half-girth gears: **correct the girth gear installation**

5: Heavy contact area: manufacturing or thermal concentration defect (relief)

6: Poor alignment quality: load concentration on one side of the teeth: **adjust the alignment of the pinion(s)**

7: Girth gear movement: **correct the girth gear installation**

8: Pinion movement: **correct the pinion bearings installation**



Priming lubrication

6. B - Running-in phase 2: Improving surface geometric condition

The priming phase is very important and decisive for gear set longevity (see chapter on lubricant film formation) as it improves the geometric condition of the surfaces in motion, mainly by adjusting surface compliance and roughness. Indeed, damages may appear very quickly after initial start-up. Even with optimal mechanical settings, surface quality is not perfect and initial surface contact can be as low as 50 to 60% due to manufacturing or geometrical imperfections.

To improve lubricant film formation and, in particular, to comply with the mechanical constraints for which the gear drive has been designed, it is crucial to use running-in lubricant (controlled slow lapping with no abrasive particles) to improve working flank (or active flank) surface quality by distributing the transmission and effective load over the defined surface.

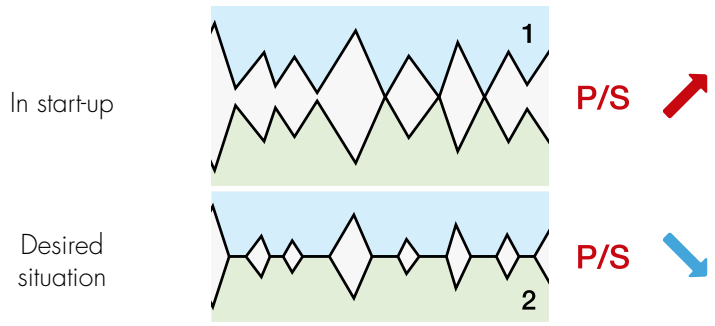
This running-in procedure will vary according to the machinery being pulled (cement mills or coal power station mills, kilns, etc.). For example, for a cement ball mill, the load should be increased progressively (load stages to be determined by the manufacturer).

Two main surface wear processes take place in the lapping phase:

- Shearing-pulling with creation of particles (coming from the surfaces) and

- Wear-consumption-smoothing by chemical action of the lubricant

The first process is very random as it is often completed with operational lubricant, not designed for the type of control required in this particle elimination phase and, in 90 % of the cases especially on heavily solicited teeth, causes early signs of later damage which eventually causes micro-cracks and initial pitting.



In the n°2 position, strength are spread over a larger surface
=
less concentration of strength and temperature, the initial training of damages is very limited

with P: pressure and S: surface

LUBRILOG recommends the second process, with the use, in the crucial running-in phase, of a chemically active (extreme pressure and anti-wear additives) running-in lubricant (or slow lapping lubricant), designed for the machinery's existing lubrication method.

The table below shows the various **LUBRILOG** lubricants offered for the various lubrication methods:

LUBRILOG RUNNING-IN LUBRICANTS					CHARACTERISTICS		
application method	name	graphite or MoS_2 ●	non graphite ○	structure	40°C viscosity (mm^2/s) / Consistency	welding (daN)	color
SPRAY	GRAFOLOG H 00 R	●		grease	320 / 00	> 800	black
SPLASH	GRAFOLOG R FLUID	●		grease	2,000 / 000	> 800	black
CIRCULATION	LUBRILOG LCC 680R		○	oil	680	> 750	brown
FOR THREE METHODS	GEAR FLUID R		○	oil	680	> 800	brown

6. B - 1 - Running-in lubrication: quantity to apply per automatic spray

In total absence of abrasive components, our chemically active running-in lubricants (action in the surface contact areas) may be used with existing lubrication systems with no risk of deterioration.

Running-in lubricant quantities are higher than in-service quantities with sequential lubrication. In this critical phase, surfaces imperatively require a higher dose of less thick lubricant necessity to obtain a controllable contact between the surfaces.

Quantities to be applied are listed in the following table. However, under all circumstances the recommendations of the machinery manufacturers (OEM) and process experts must be observed in priority.

TYPE OF OPEN GEAR DRIVE		GRAFOLOG H 00 R or GEAR FLUID R QUANTITY TO APPLY (in grams . mm . service hour)
Q1 -	Single drive (one pinion) for kiln, dryers, cooler	0.50
Q2 -	Single drive (one pinion) for mill	0.70
$Q3_{1.}$	Double drive (two pinions) for kiln	0.80
$Q3_{2.}$	Double drive (two pinions) for mill	1

The indicated quantity of our GRAFOLOG H 00 R running-in grease or our GEAR FLUID R running-in oil for spray lubrication, also called slow-lapping grease, is expressed in grams per working flank millimeter (facewidth) and per service hour.
For double drives (two pinions), the quantity of calculated lubricant is global and must be spread evenly between both pinions.

For example, for a single drive (one pinion) ball mill girth gear, with working flanks 500 mm facewidth, the quantity to be applied is:

500 mm x 0.70 = **350 grams per service hour** (8.4 kg per 24 hours of service).

The application rate (pause and spray durations) for the release of these 350 grams per hour is generally identical to operational lubrication rates. In other words, the lubricant must be distributed in the best way possible given the capacity of the spray system, with pauses, for a mill, inferior or equal to 5 minutes. The spraying duration should not be inferior to 15 seconds.

Basic lubrication principle: apply the defined quantity of lubricant evenly, so as to maintain appropriate thickness of lubricant film on the surface.

For additional information, please contact our Technical Services.

Running-in with **GRAFOLOG H 00 R**

6. B - 2 - Running-in lubrication: industrial open gear running-in methods

LUBRILOG develops and manufactures two types of running-in lubricants.
The first type of lubricant is a progressive running-in lubricant called « slow » and the second is an accelerated running-in lubricant called « fast ».
Both methods are identical in their objectives but very different in their application.

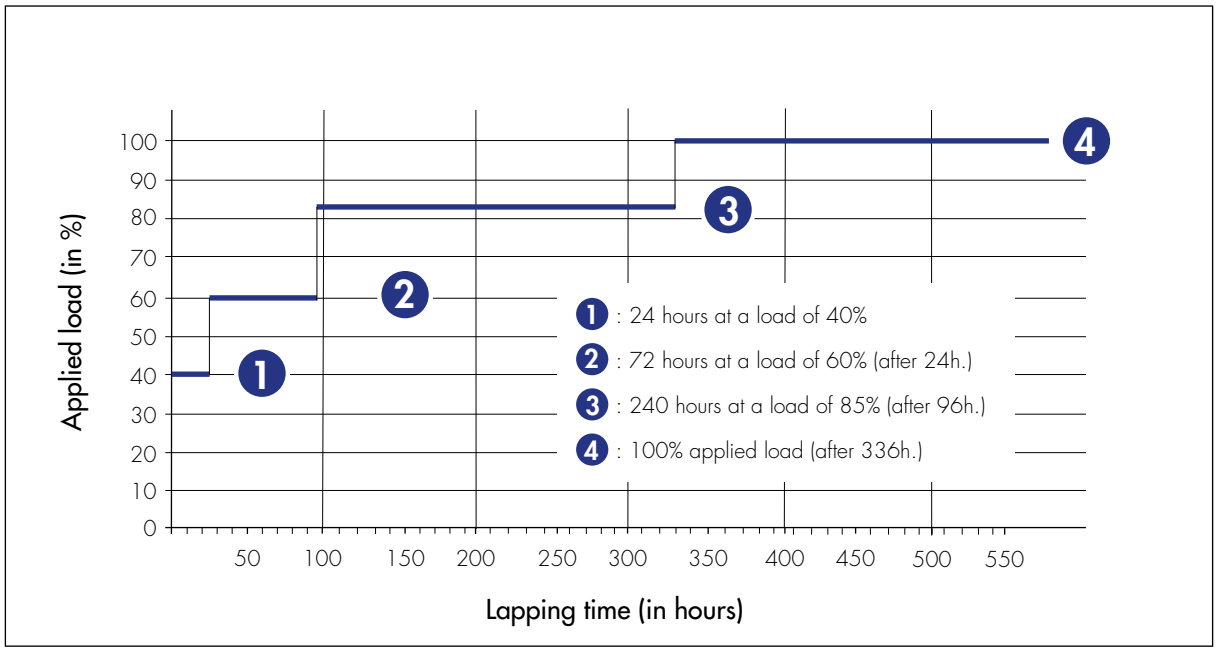
6. B - 2 - 1- Running-in lubrication: progressive running-in (or slow lapping)

The progressive running-in method guarantees the most secure starting up combination for an open gear drive: surface enhancement action for more evenly distributed applied loads, with progressively increasing transmitted load.

Nonetheless, certain machinery or manufacturing processes require that the open gear drive be started up in full load (see chapter B – 2 – 2).

Ideal contact cannot be reached in the initial start up and a progressive increase of the load is recommended in order to avoid initial damages on the working flanks.
For ball mills, the progressive increase of the milling balls load allows for this progression.

The following curve is an example of a milling balls load increase for a mill; however, in all cases, the manufacturer's recommendations must be complied in priority.



Example of the milling balls load increase in the running-in phase of a ball mill

Lapping finishes when the load is complete and surface contact between teeth is over 80%. The switch to operational lubricant is determined by the machinery manufacturer expert instructions. **LUBRILOG** experts are available for advice (progressive switch between the running-in phase and the operational phase).
The running-in phase is critical for open gear drive longevity, and frequent inspections are mandatory in the first 24 operating hours.
After that, and until the end of the lapping phase, daily supervision must be implemented.

The main inspections to be completed are:

- Control of the surface contact and its distribution
- Control of the lubrication system operation
- Control of the pinion bearings vibrating level

Note: The same controls are to be implemented with the use of fast lapping lubricant.

Example of cement rotary kiln open gear: start-up with no technical assistance.

In the previous example, the new open gear drive's running-in phase was not monitored. Pinion positioning had not been correctly adjusted and the load was not distributed evenly. Damages appeared in the most solicited area shown are in the figure on the left, on the other hand, the figure on the right shows the still visible manufacturing marks which indicates the extreme reduced surface contact.

6. B - 2 - 2 - Running-in lubrication: accelerated running-in (or fast lapping)

Using this second open gear drive running-in method, it is possible to obtain, in the end, the same result as with the previous method.

The accelerated running-in, or fast lapping process, is to be used when high quality surface contact is obtained in a short amount of time. This situation occurs when the rotary drum operate in full load from start up (example of kilns, of coal power station mills).

A **LUBRILOG** technical expert sprays a specific GRAFOLOG RPR lubricant, also used in repair situations, on the pinion's working flanks with an autonomous spray gun. These lubricant components are extremely active and the lubricant must never be applied through operational lubrication systems (complete cleaning is mandatory before implementing splash and circulation lubrication methods. We recommend continuously spraying slow lapping lubricant to clean working flanks).

Before lubricant is applied by an expert technician trained for this operation, manufacturer authorization is required in order to set up a fast running-in operation in compliance with the warranties associated with new installation.

At the end of the fast lapping phase, determined by the **LUBRILOG** expert, a slow lapping lubricant is applied for a short period of time prior to applying operational lubricant.

Warning:
Regardless of the quality of current materials and the quality of the installation, **LUBRILOG** always recommends performing a running-in phase with our specifically designed new gear drive running-in lubricants.

Initial surface quality

GRAFOLOG RPR application

Resulting quality surface

6. B - 2 - 3 - Running-in lubrication: necessary inspections

Both open gear drive running-in methods (progressive and accelerated) require the same inspection controls to monitor the gear set operation (correct load transmission) and the machinery on which it is installed.

The main inspections to be completed are:

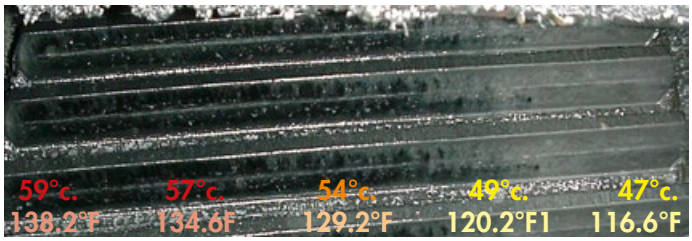
- Control of the surface contact and its distribution
- Control of the lubrication system operation
- Control of the pinion bearings vibrating level

Control of the surface contact and its distribution:

The control of the surface contact and its distribution is executed dynamically, most often through the inspection door of the pinion(s).
This operation, completed with the inspection door open, can only be done with plant authorization and by an expert technician trained for this operation due to the high level of risk associated with operating machinery, this may not be executed by one person alone.
The load concentration on working flanks generates a temperature rise. Highly loaded areas are therefore easily controlled with a contact-free infrared thermometer.
The gathered data and the difference between extreme temperatures can help illustrate surface contact distribution.
A 5°C temperature gap shows a poor contact distribution (41°F).

However, this figure is to be considered relatively depending on the facewidth of the teeth.

The pinion's geometrical positioning in relation to the girth gear must also be monitored dynamically with a stroboscope and the combination of both control measures provides accurate understanding of the surface contact and its distribution. In the case of a mill, temperature outside the shell and room temperature must also be measured.



Example of unbalanced surface contact:
The stroboscopic view illustrates surface contact on a cement mill girth gear working flanks. The heaviest loads correspond to the highest temperatures and contact must be readjusted quickly to avoid damages in these areas.

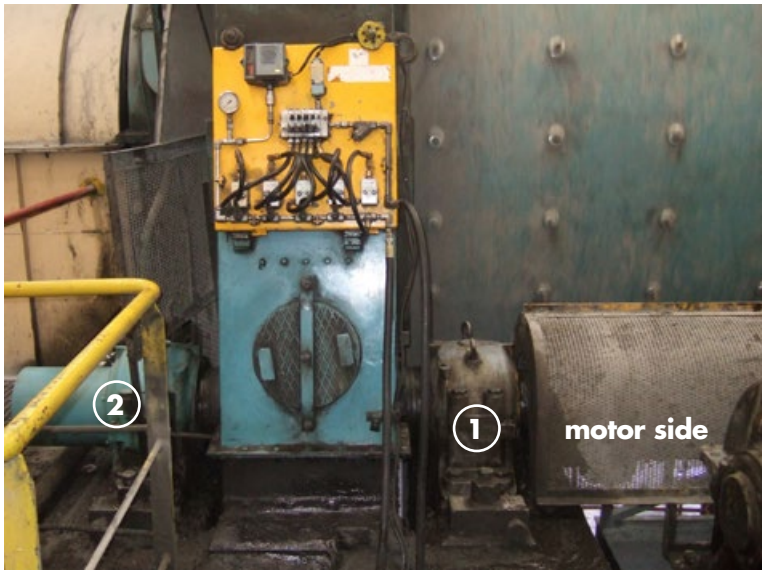
Inspecting lubrication system operation:

In the running-in phase, the lubrication system operation must imperatively be controlled. The controls mentioned in the chapter titled « Automatic spray lubrication » must be executed before and during the running-in phase.
The temperature control on working flanks and load distribution demonstrate the lubrication quality. If temperatures are balanced on the entire facewidth of the working flanks, but are too high in absolute value, lubrication must urgently be controlled to avoid the risk of scuffing due to insufficient application of lubricant.

Spray pattern of good quality with running-in grease. The working flanks are completely covered and the quantity is adequate (control of quantity by weight).

Control of the pinion bearing vibrating level:

As part of later damage prevention, it is necessary to control the pinion bearings vibrating level. **LUBRILOG** experts measure these vibrations on each pinion's three axes and two bearings (the bearing on the motor side and the bearing on the side opposite to the motor, called « free »; see picture below). **LUBRILOG** measures vibrations in speed (mm/s) in order to evaluate the global transmission condition in relation to the other measures and controls gathered.
As for temperatures, the recorded vibrating level is included in our inspection reports.



In our inspection reports, the two pinion bearings are differentiated based on their position.
Figure 1 shows the « **motor side bearing** » and figure 2 shows the « **free side bearing** » (as it is on the end of the shaft).

It is also important to note the relative position of the open gear drive with the rotary drum body (to evaluate load position).

The values that should not be exceeded on the three axes are 7 mm/s, depending on situations. These values should be measured throughout the entire running-in phase.
These measures are also gathered as preventive maintenance data in our normal inspection visits to our customers throughout the year (see chapter titled « **LUBRILOG** Services »).

Information: The pinion bearing vibrating level will not be controlled on kilns or other slow speed machinery. The transmission operation has no significant incidence on the vibrating level.

Warning:
In case of abnormal conditions, an intervention request is immediately sent to avoid initial damages.

Completing both running-in phases: surface preparation and surface enhancement, as well as executing controls, provide the best results by guaranteeing optimal gear set longevity to our customers' strategic machinery.

/07

LUBRILOG EXPERT REPORTS AND TECHNICAL SERVICES

As a special lubricant designer and manufacturer since 1987, **LUBRILOG** has combined its activity devoted to lubricants with expert gear set mechanical, theoretical and practical knowledge and is committed to provide its customers with services designed to increase large open gear drive longevity, in collaboration with rotary drum and gear set manufacturers.

Lubricants are crucial for the good operation of gear sets and can only be recommended by professionals. Because of their purpose, lubricants are used daily and only lubrication experts are entitled and capable of executing continuous supervision of large open gear drives with our clients' « plant » experts.

LUBRILOG has a trained team of technicians available for efficient and timely services on all continents to assist with large open gear drive maintenance or repair operations.

Global expert reports describing the situation allow our experts to provide optimal advice to our customers.

A complete range of services:

Preventive maintenance and expert reports

Repair lapping

Teeth grinding

In-service cleaning

Training

7. A - LUBRILOG services: preventive maintenance and expert reports

All our customers are facing challenging production conditions. Production methods are usually continuous and are applied at the limit of equipment capacities. For this reason, we offer our customers an open gear drive preventive maintenance free service (in-service and on-stop controls with extensive follow-up report). We also offer gear set expert reports, lubrication training courses or teeth defect repair interventions for all companies. In this case, our services are charged.

The regular check-ups we perform for our customers are the same as those made at start of open gear drives (see chapter 6 – B – 2 – 3):

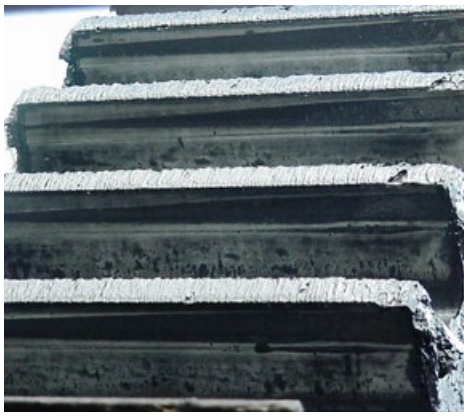
- Control of the surface contact and its distribution
- Control of the lubrication system operation
- Control of the pinion bearings vibrating level

These dynamically executed controls are combined, if production allows it, with on-stop working flank controls. In fact, some controls, such as working flank inspections, can only be executed on-stop. Applying implemented procedures helps raise the awareness of the plant's lubrication experts regarding crucial elements to monitor between out visits.

7. A - 1 - LUBRILOG services: in-service inspections

Controls executed during service are identical to those described in chapter 6 – B – 2 – 3.
Photos are systematically taken and are included in our expert reports.

Measure of working flank temperatures and stroboscopic analysis = surface contact and load distribution view (view of working flanks when using lubricant without solid lubricant)



Measure of the pinion bearings vibrating level = assessment of the meshing quality and kinematic linkage

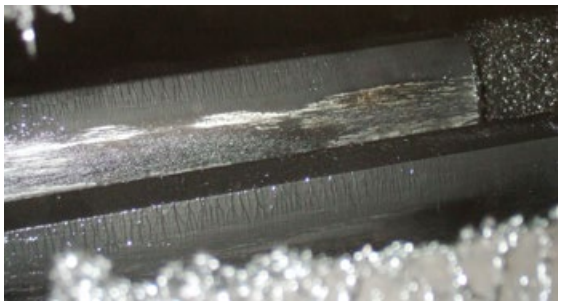


Image (example of highly reduced contact)

Lubrication control (grease spraying example)

Images above represent controls executed dynamically.

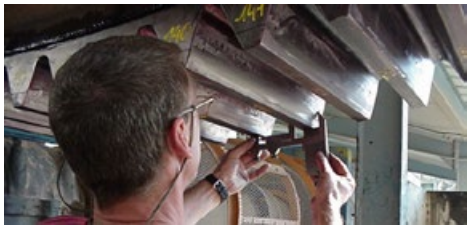
7. A - 2 - LUBRILOG services: on-stop inspections

Static controls allow for perfect inspection of the working flanks and their change. These controls serve to monitor surface contact quality as well as potential damages and their origin in order to recommend the best actions to our customers and keep the machinery in optimal operational condition.

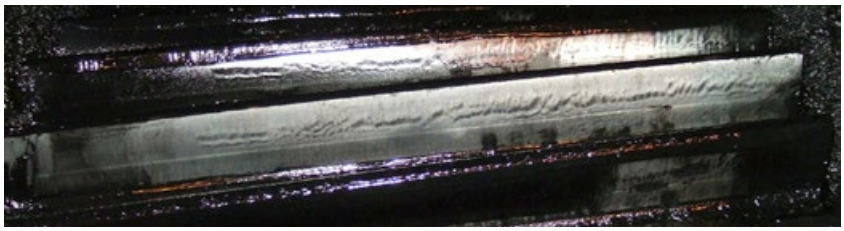
Once the machinery has been securely stopped, working flanks (pinions and girth gear) are cleaned and the inspection is executed by one of our experts. In order to complete this process controls have to be performed on several points of the pinion and girth gear circumference.
The main controls are used to measure profiles and working flanks condition.

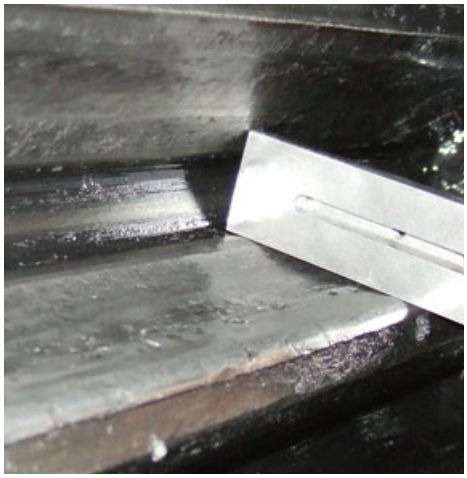
The images below illustrate our on-stop controls. Manufacturers and customers may request specific controls. In that case, we recommend contacting our Technical Services responsible for on-site interventions.

On-stop controls have to be combined with in-service controls in order to obtain a global representation of open gear drive condition.
With current production needs and machinery operations, on-stop controls must be planned ahead and we ask our customers to inform us in advance.



Teeth inspection after cleaning = view and measure of working flanks condition (normal and abnormal wear, surface damages).





7. A - 3 - LUBRILOG services: expert report documentation

Controls and measurements are recorded in a written report, along with photographs underlining important elements, which we send to our customers' Technical and Buying Services.

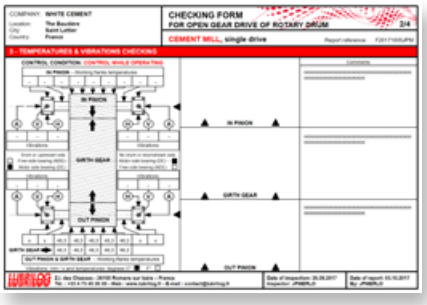
The documentation provided is generally comprised of three elements:
- An **expert report** with our recommendations and conclusions
- A **checking form** indicating the measures and data gathered on the site
- **Additional photographs** underlining important elements in our report

Recommendation: For questions regarding the condition of teeth working flanks, we ask our customers to send us an email describing the specific situation along with photographs (we recommend that the photographs be taken of the damage as well as the entire facewidth of the working flanks in order to know the global situation of the working flanks).

Our Technical Services will then be able to respond promptly.

Example of the elements contained in our technical reports

Specifications



Checking form

Conclusions & Advices

Additional photographs with notes

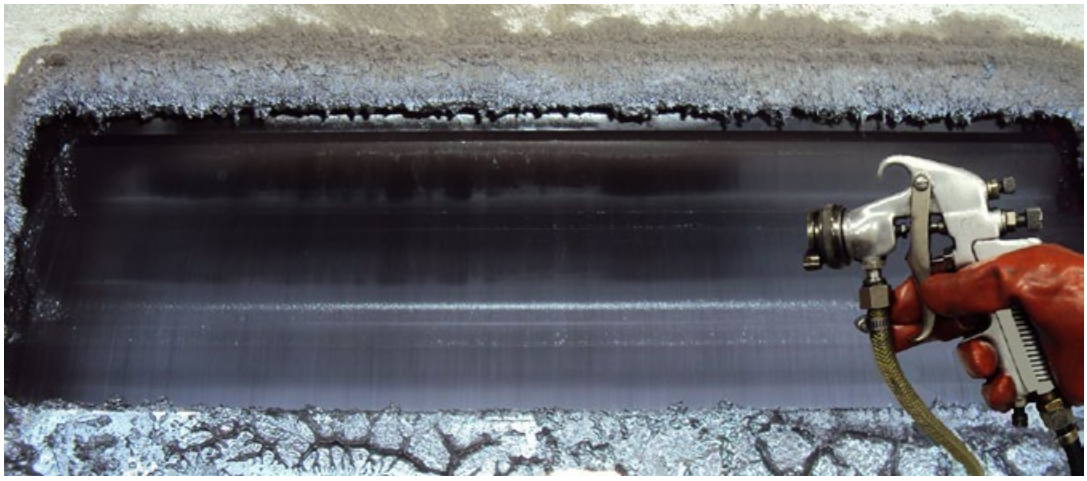
These documents allow maintenance engineers to control the change of large open gear drives.
Our control measures are intended to:
- Check the open gear drive operational conditions
- Check lubrication quality

7. B - LUBRILOG services: repair lapping

Based on their experience with lubricants and gear set operations, **LUBRILOG** experts have developed a quick, on-site repair method using specific lubricants, which combines lubrication and addition of active abrasive components.
This method can often replace or simplify the manual traditional grinding method which is also executed on-site to repair damages and obtain perfect contact between open gear set working flanks.

As with any durable repair operation, it is mandatory to determine the origin of the damages and to correct it. Failure to do so will result in the damages reappearing in a short time.

For optimal efficiency, this repair operation must be completed in normal machinery service conditions (for an adequate lapping between main surface contact areas), which guarantees conservation of the installation production capacities.



7. B - 1 - LUBRILOG services: repair lapping objectives

The objective of the accelerated lapping operation is to repair damages and obtain sufficient and durable surface contact for load transmission between gear set working flanks.

The most common situations are as follows:

- Gear drive start up in full load (previously mentioned in chapter B-2-2)
- Insufficient action of running-in lubricant (for example, when associating a girth gear with worn working flanks with a new pinion, although this situation is clearly not recommended)
- Damages repair (see list of most common damages below)
- Quick close-up after a purely mechanical repair operation (manual grinding or machining)

7. B - 2 - LUBRILOG services: repair lapping repairable damages

The fast lapping operation is highly efficient as it uses the very principles of involute to a circle profile operations.
The phenomenon is similar to that which causes profile wear, with the difference that effects are controlled.
Between two involutes to a circle, the relative sliding is null at the pitch point and increases progressively as it moves away from that point.

[For information purposes, at any contact point, the relative sliding speed of an exterior gear is:

$$Vg = 9554^{-1} (n_1 + n_2) T$$

with Vg in m/s
n_1 and n_2, pinion and girth gear angular velocity in RPM and
T distance between the contact point and the pitch point I in mm

The specific sliding ratio between sliding and rolling is to be taken into account for surface wear, and therefore for the repair lapping effects, which increases as it approaches the tooth root, even for teeth with addendum modification].

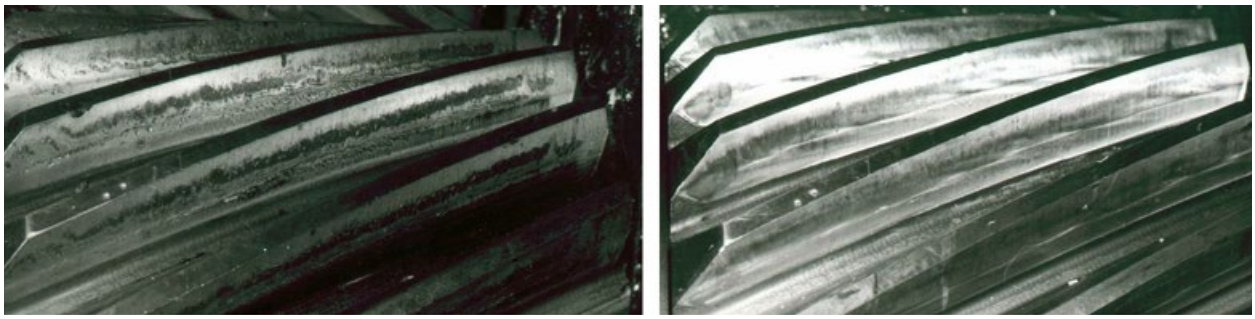
Sliding between surfaces explains why the fast lapping method becomes more efficient as it moves away from the pitch diameter, and shows damages that are very easily repaired.
Because the sliding speed's dependent of speed, fast lapping operations are much quicker on a mill (fast rotary drum) than on a kiln or dryer (slower rotary drum). The quantity of necessary lubricant is also higher on slow rotary drum than on fast rotary drum.

Note:
Areas close to the pitch line, and the pitch line itself, are also subject to the repair lapping lubricant's effect. The effect is less significant, but does exist through the action of large open gear drives for instance, in the case of girth gear deformation and movement as well as vibrations. The loads are also heavier in those areas.

The most commonly repairable damages are:

- Scuffing, even significant
- Initial pitting and spalling and/or stopping progress (advantage of spreading load over a larger surface)
- Surface contact imbalance (only after open gear drive position geometrical adjustment)
- Profile pairing

Important:
The very principle of fast lapping repair methods does not allow to modify surfaces that are not in contact during the meshing. For that reason, in certain situations (deformation of the pitch diameter, burr, step, etc.), a preparatory operation may be necessary. Our experts will include this preparatory work in the final repair offer.



Active flanks pinion, before and after fast lapping repair operation

7. B - 3 - LUBRILOG services: repair lapping methodology

The technical fast lapping operation is only completed by **LUBRILOG** technicians, with manufacturer and customers authorizations.

The necessary repair steps are as follows:

- Inspection of the situation
- Expert report of the damages and their origin
- Repair offer to our customer

Once the repair operation has been approved, the **LUBRILOG** technician will apply the repair lubricant directly on working flanks with an autonomous manual spray system through the inspection door. Depending on the situation, a running-in lubricant (slow lapping) may be applied during the repair lapping.
The procedure selected by **LUBRILOG** will be applied by taking into account our customers's constraints.

Warning:

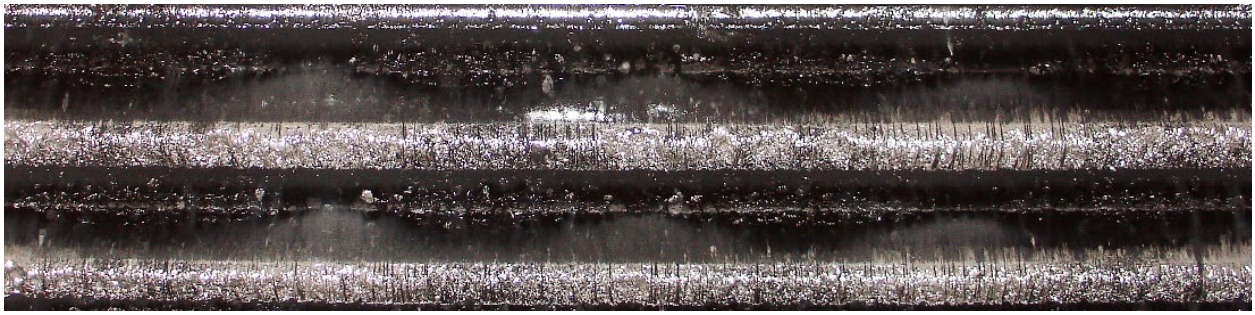
Repair lubricants may never be applied using operational lubrication systems. Their effectiveness is such that systems could be damaged by their active components.
The procedure that **LUBRILOG** offers its customers, includes operations that need to be performed after repair lapping in order to securely re-start the existing lubrication systems.

7. B - 4 - LUBRILOG services: repair lapping examples

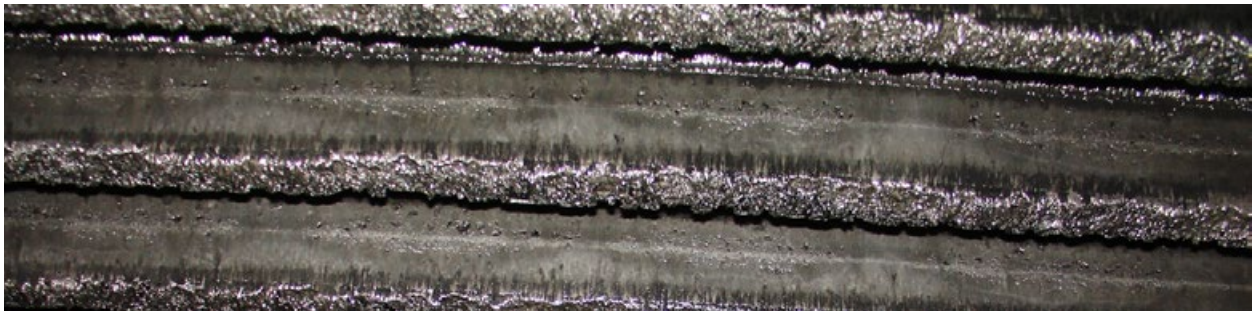
The following photographs show two examples of repair lapping operations.
The first example was completed after a spraying defect on a cement mill.
The second example occurred on a mill for which the pinion was replaced with no repair intervention on the girth gear.
We absolutely do not recommend replacing the pinion without repair intervention of the girth gear.
This solution, the quickest and most affordable short term, makes it impossible to retrieve acceptable meshing conditions by combining new surfaces with deteriorated surfaces.

The new pinion working flanks deteriorate quickly when exposed to high vibrating levels. It is necessary to repair the girth gear working flanks (if wear is not too important) and to install a harder pinion than the original pinion and to complete the repair lapping operation during running-in phase.

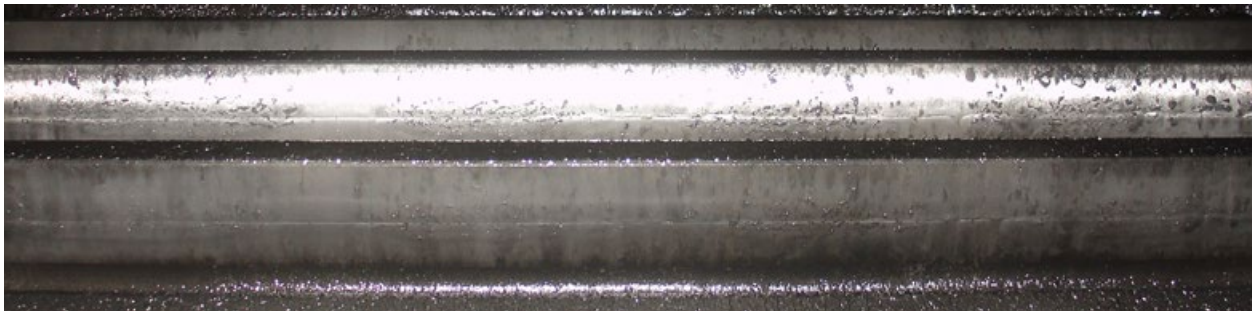
Example 1: Spraying defect on a cement mill (single drive):



Before repair lapping (image of the girth gear taken in-service):
the dark areas show deterioration caused by load concentration.



After repair lapping (image of the girth gear taken in-service; 4-hour intervention):
The severe pitting-spalling is still present but the working flanks after lapping show a better load distribution. The vibrating level is acceptable, the operational mill and production can restart immediately.
The working flanks, after intervention, are in perfect operational condition (image below).

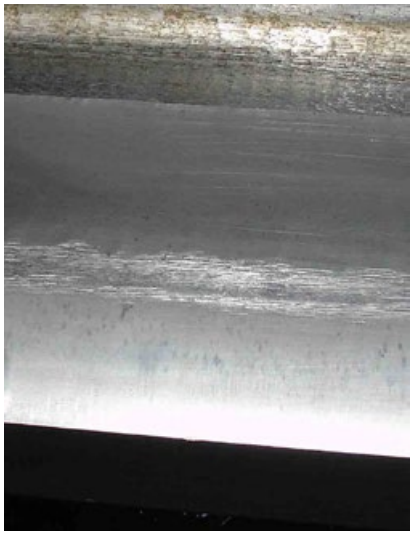


Graphite lubricants allow for good visualization of the more heavily loaded areas while the machine is in-service (with photographs or stroboscope). These areas are the hottest due to the concentration of applied loads.
Clear lubricants, with or without solid lubricants, do not allow this visualization, on the other hand the working flanks condition is more visible.

Example 2: High vibrating levels on a single drive cement mill open gear:

After replacement of the pinion, high vibrations which are dangerous for the entire kinetic linkage were recorded (as a result there was an increase of 15 mm/s, depending on the pinion bearings' horizontal axis).
No intervention had taken place on the girth gear's working flanks prior to the pinion replacement, although they were significantly worn.
A fast lapping operation, designed to pair the working flanks, was suggested and approved.

Step 1



Step 2

Step 3

Step 1:
Due to wear of the girth gear working flanks, surface contact with the pinion was only present at the tooth root and tip. The profile center area still showed traces of machining.
The goal was to quickly increase the contact area in order to reduce vibrations and avoid local damages.

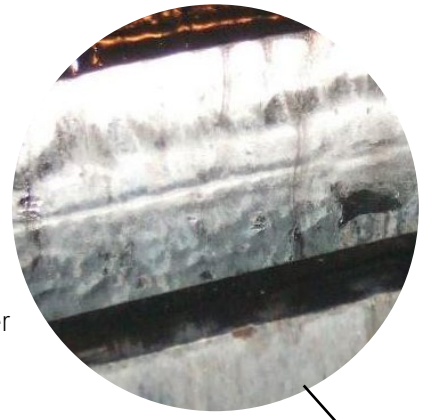
Step 2:
After 4 hours of fast lapping, surface contact was almost reestablished on the entire profile.

Step 3:
After 6 hours of fast lapping, surface contact seemed sufficient to stop the operation. Following the accelerated lapping phase, running-in or slow lapping grease was continuously applied for 12 hours through the open gear lubrication system.
Vibrations were all under 4 mm/s.
The operation only caused a very slight tooth-root step and no tooth-tip burr.

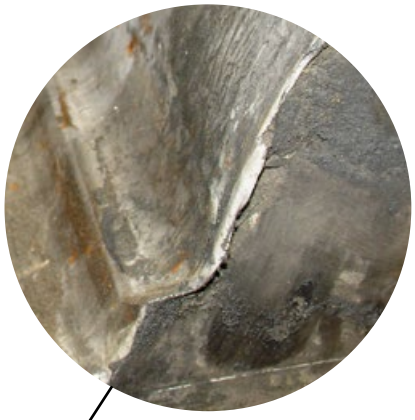
Any mechanic will recognize the advantages of this large gear set repair method, which associates efficiency with a low consumption of the teeth's thickness. This method is irreplaceable for gear set teeth pairing, which is impossible to perform in static form.

7. B - 5 - LUBRILOG services: repair lapping non-reparable damages

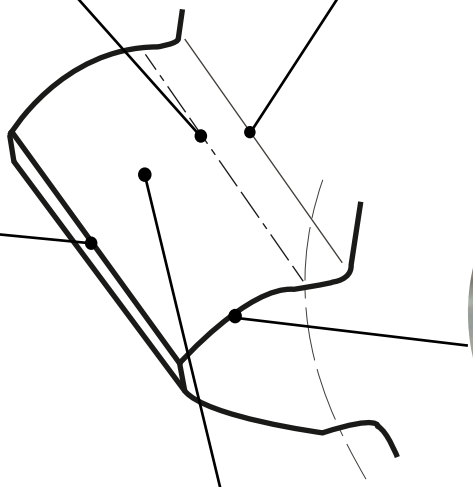
The following damages are the main damages that cannot be repaired through repair lapping. For repair lapping, it is necessary to combine contact and sliding between the working flanks.
Mechanical preparation must be done beforehand (grinding, machining, etc.).

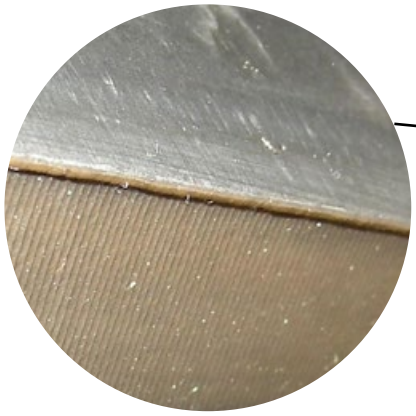


Pitch diameter deformation

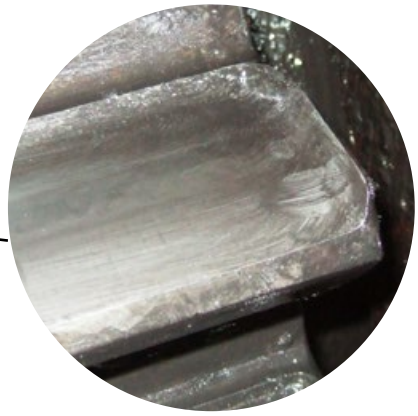


Step at tooth-root

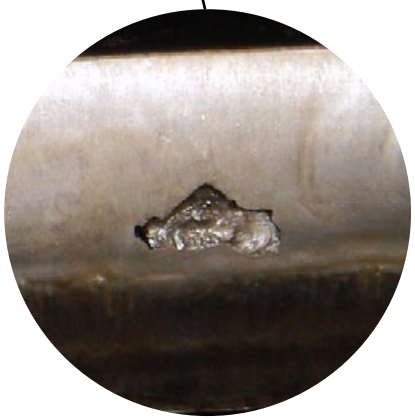




Burr at tooth-tip



Burr or no-contact area on tooth ends



Deep spalling

To obtain high quality repair lapping one of the two involutes to a circle must be correct.

Obviously, damages due to poor gear set design cannot be repaired.

7. C - LUBRILOG services: teeth grinding

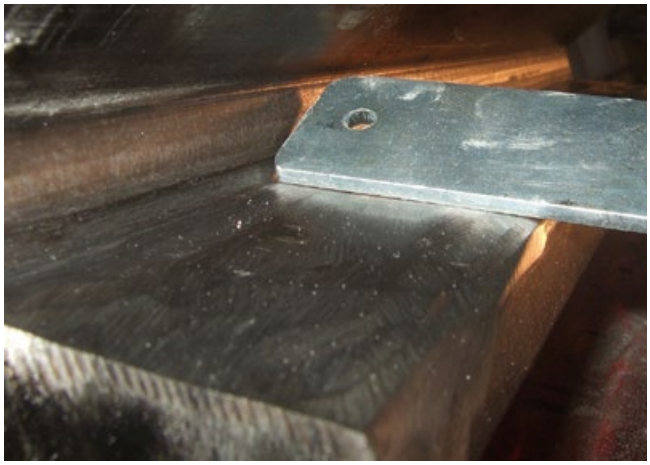
Among the repair solutions suggested to our customers, we offer on-site teeth grinding by our technicians, which is designed to complement repair lapping operations. Although gear sets are defined through calculations and manufactured on machine tools, on-site grinding can be performed with great results in increasing longevity. As with fast lapping operations, the origin of the damages must imperatively be identified and corrected if abnormal.

Warning: Although this technique shows great results, **LUBRILOG** cannot guarantee the same results as those obtained with gear-cutting machines. If this were the case, no gear set manufacturer would justify the investment represented by those machine tools.
The geometrical quality of a manual grinding operation decreases as the facewidth of the tooth increases.

7. C - 1 - LUBRILOG services: teeth grinding objectives

The objective of the grinding operation is to repair damages and obtain sufficient surface contact, durable or not, depending on the severity and nature of the damages, for the transmission of the load between the gear set working flanks.

We call the reparation cases « non-durable » which involve the temporary reparation of serious damages prior to a gear set reverse or replacement. This temporary repair maintains the machinery in operation until one of these interventions can take place.



A ball mill gear set damaged the shape of the teeth. A grinding operation made it possible to reshape the tooth and reduce the vibrating level.

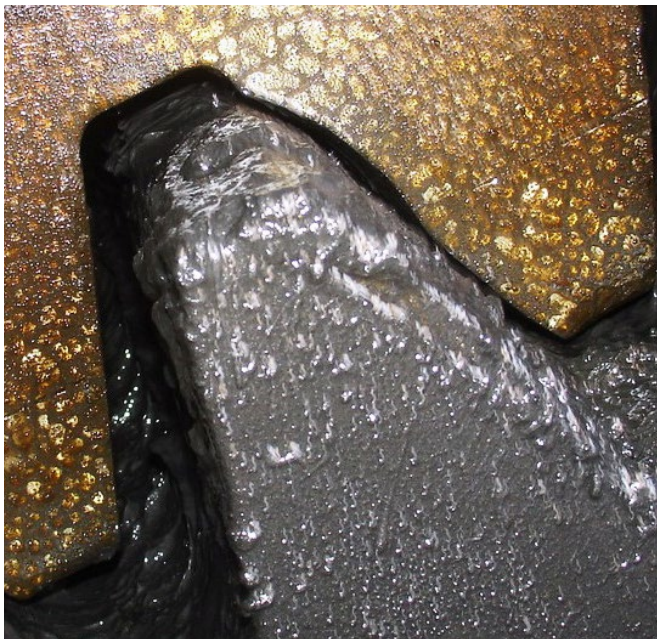
After grinding, including fast lapping surface finishing (fast lapping operation not yet achieved on this picture), surface contact with the new pinion, made slightly harder, will create an acceptable quality surface and good surface contact.

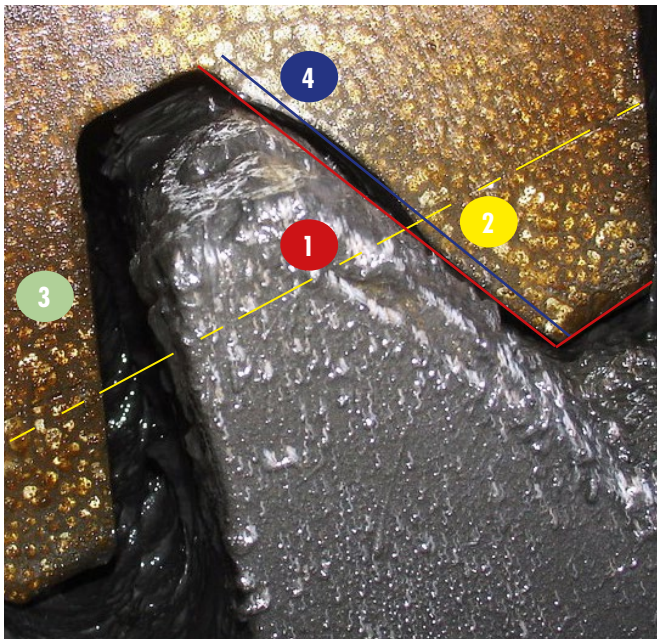
7. C - 2 - LUBRILOG services: teeth repairable damages

Grinding operations are more or less heavy, depending on damages, from burr grinding to complete grinding of the girth gear working flanks, spalling opening, transit of foreign bodies, or tooth-root grinding.
Complete grinding of the working flanks is only done on girth gears: profiles have much larger radiuses than pinions. Pinion(s), on the other hand, will be reversed or replaced depending on their condition.

The most common intervention situations are as follows:

- Surface preparation prior to fast lapping operations (see illustrated description in the previous chapter)
- Normal or abnormal surface wear (working flanks, burrs, tooth-roots)
- Opening of the spalling to prevent spreading
- Transit of foreign bodies





These two images show the normal wear of girth gear working flanks. Figure 1 shows the original profile (like the non-working flank 3). Figure 4 shows the expected profile after grinding.

7. C - 3 - LUBRILOG services: teeth grinding methodology

Grinding operations are only performed by **LUBRILOG** technicians.
They are performed in static form after the gear has been completely cleaned. This cleaning can be done with our LUBRICLEAN EP and finished by hand in a very short time (see chapter titled « In-service cleaning »).
The maximum duration for an intervention is one week.
To make sure the pitch and profile are maintained, control templates are machined specifically for us and with our own data by leading gear set manufacturers in Europe. Through this collaboration, **LUBRILOG** offers its customers incomparable technological mastering.

The grinding steps are the same as those described for repair fast lapping.

Note:
After large grinding operations, short fast lapping is systematically performed to combine on-stop static repair operations with active in-service surface finishing. On-site grinding is a manual operation, even with the best attention, care, and procedural knowledge guaranteed by the operators, profile pairing and working flank quality surface cannot be perfectly obtained without this dynamic finishing.

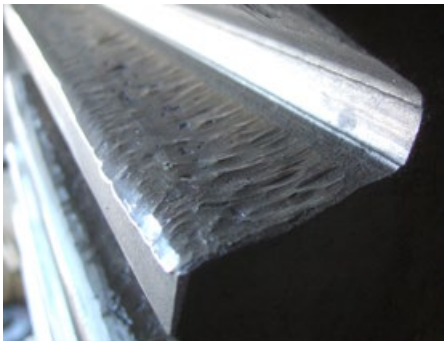
A written technical report with photographic documentation is provided to our customers after each intervention.

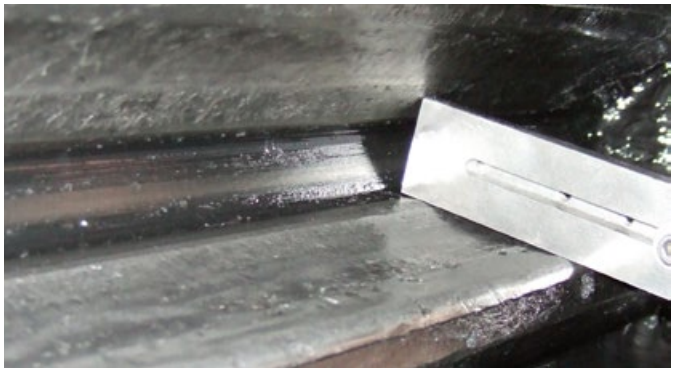
In the gear set's running-in phase, the use of our running-in lubricants is imperative to guarantee the success of the repair operation (priming, running-in lubricant and operational lubricant).

7. C - 4 - LUBRILOG services: teeth grinding examples

Spalling opening on a very good quality working flank. The spalling stopped spreading.
The lubricant is the **GRAFOLOG H 0 +**, graphite grease, sprayed to the pinion.

Ball mill working flank, before and after grinding. The mill is still in service after four years and is still in great condition. The **LUBRILOG** running-in lubrication procedure was applied. The current operational lubricant is our **GEAR FLUID 550 D** oil (17000 mm²/s at 40°C), sprayed to the pinion.





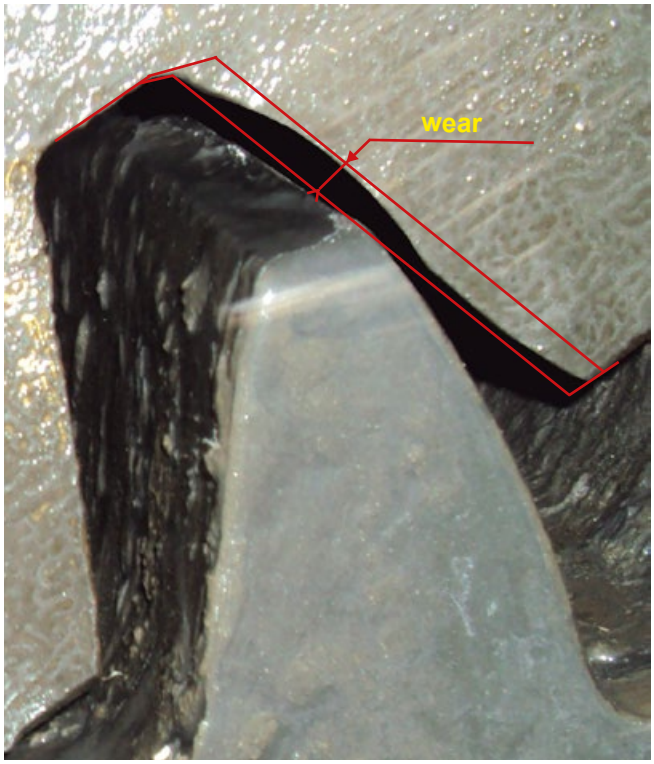
The first thing to do on a girth gear working flanks is to assess profile wear. The measured wear hollow (under the pitch diameter) and the damages present on the working flanks will show the potential need for grinding (normal dynamic controls are also necessary to evaluate the machinery general condition).

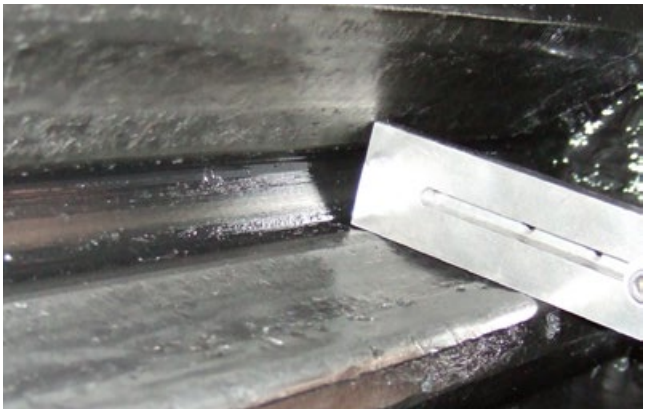
7. D - LUBRILOG services: selecting a repair method for girth gear active flanks

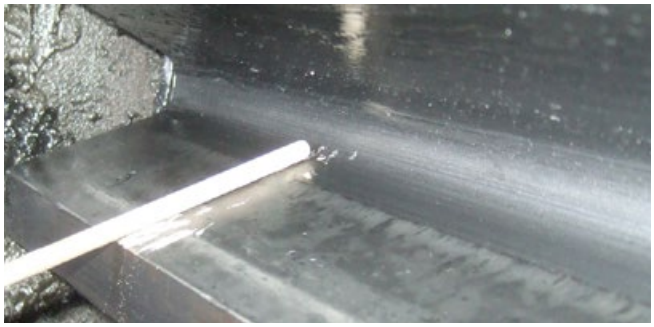
As mentioned above, **LUBRILOG** offers a wide range of repair options, from slow lapping (chemical) to grinding and fast lapping.

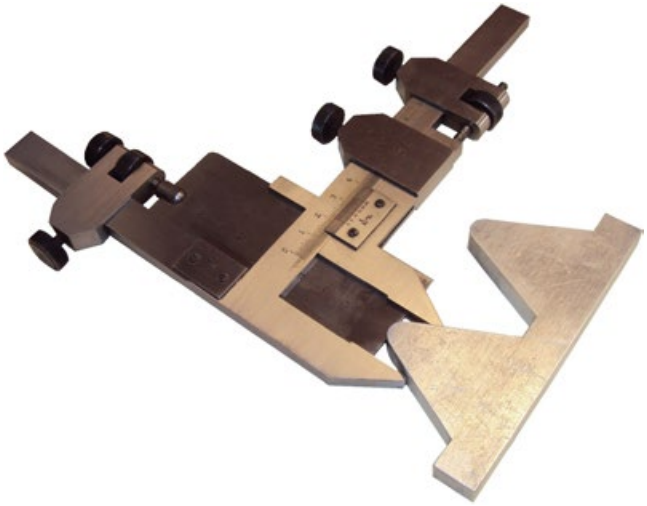
The most important action to determine the appropriate repair method is on-site machinery inspection (in-service and on-stop situations).

Although situations can vary greatly, **LUBRILOG** has developed a set of criteria to help customers define the most appropriate repair operation for the wear observed on their machinery.
The working flanks wear must be normal, evenly spread across flanks, and free of major or deep surface damages.









For the initial evaluation, the wear level on the girth's gear's working flanks can be visualized by placing a straight ruler on the profile (see images). Using a control templates is preferable but rarely available in maintenance services.
An actual and direct profile measure can only be realized with a **gear caliper** (except when both teeth flanks are worn).

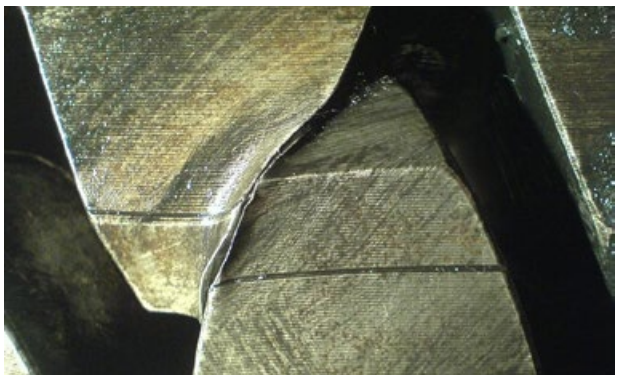
Selecting the appropriate action for optimal operational conditions (the indicated wear percentages are the gear set module percentages):

Situation 1: The gear set drive is new, but a controlled wear is necessary in order to improve load distribution: **slow lapping for a better lubricating film**
Situation 2: Wear is inferior or equal to 2%: fast lapping (in this particular case, reverse or replacement of the pinion(s) is not mandatory)
Situation 3: Wear is superior to 2% and inferior or equal to 7%: **grinding or re-cutting of the working flanks**
Situation 4: Wear is superior to 7% and inferior or equal to 10%: **reversal of the gear set drive**
Situation 5: Wear exceeds 10%: **replacement of the open gear**

The figures mentioned above are approximate and each operation must be considered on a case-by-case basis (combination of wear, working flank surface damages and vibrating level for fast drums).

The re-cutting, reversal and replacement of the girth gear must be done by the installation's manufacturer or by a gear set manufacturer.

Warning: Do not wait too long before reversing an open gear set; in fact except in case of very serious geometrical defects or working flank surface quality damages, the lifespan of a reversed over girth gear is identical to that of a new one.

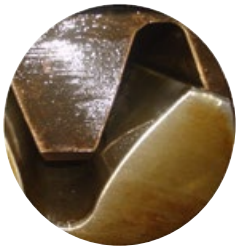
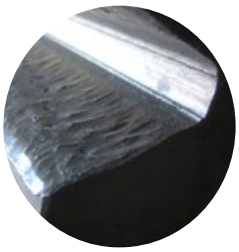


Frequent supervision of the open gear drives and their working flanks allow for better monitoring of their condition. The two examples above show the crucial importance of a proper erection for increased gear set longevity.

	Repair lapping	Grinding	Re-cutting	Reversal
Repair quality	+	-	+	+
Repair speed	+	+	-	+
Repair cost	+	+	-	-

Table showing the strengths and weaknesses of each type of large open gear drive reparation operation (+: advantage; -: disadvantage).

Table: Selecting the appropriate operation

SITUATION	WEAR LEVEL	SUGGESTED OPERATION
1 	new teeth	 RUNNING-IN (ON-SITE)
2 	wear ≤ 2 % of the module	 FAST LAPPING (ON-SITE)
3 	2 % < wear ≤ 7 %	 GRINDING (ON-SITE) OR  RE-CUTTING (IN FACTORY)
4 	7 % < wear ≤ 10 %	 REVERSAL (ON-SITE)
5 	wear > 10 %	 REPLACEMENT OF THE OPEN GEAR

Note: wear figures are expressed in % of the gear set module.

7. E - LUBRILOG services: while operating 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 operating, 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: while operating cleaning objectives

The two major situations in which while operating 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

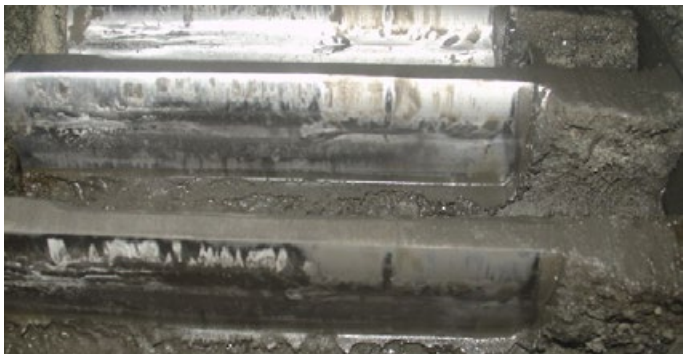
Preparation of an intervention:

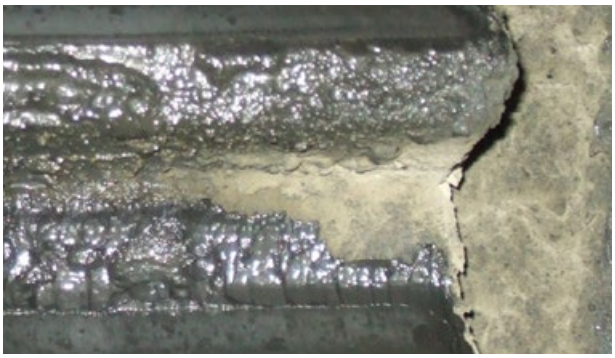
Prior to any intervention on an open gear drive, whether for gear set inspections or for any other mechanical operation (alignment, repair, reverse, replacement), LUBRICLEAN EP can be used to prepare it. This cleaning agent provides a quick and affordable cleaning solution for the lubricant present on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

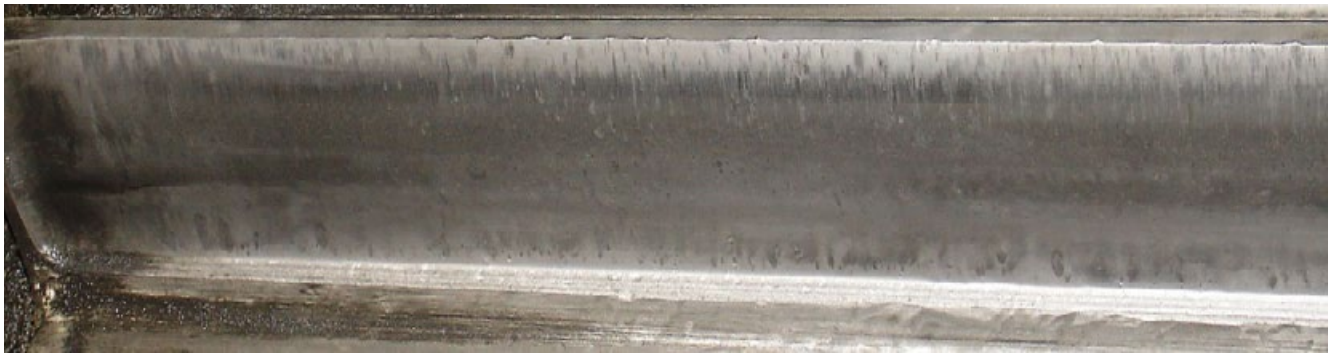
Protection against abrasive wear:

« 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: while operating cleaning advantages

The main advantages of while operating cleaning for large open gear drives are:

- Effective cleaning and associated lubrication (while operating 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: while operating cleaning methodology

While operating 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 customers 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.

Cleaning high-pressure pump example

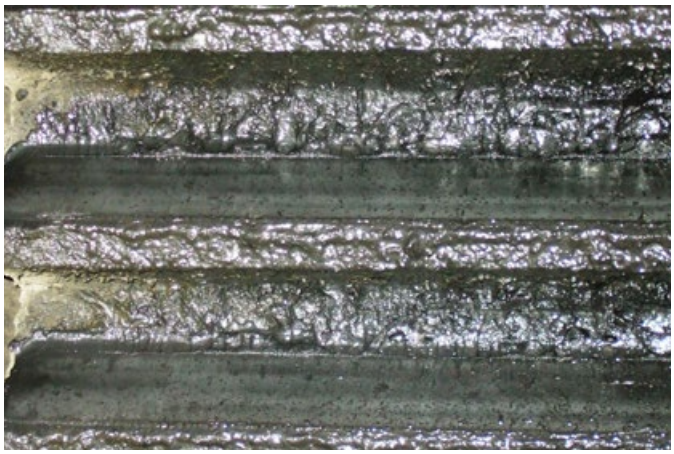
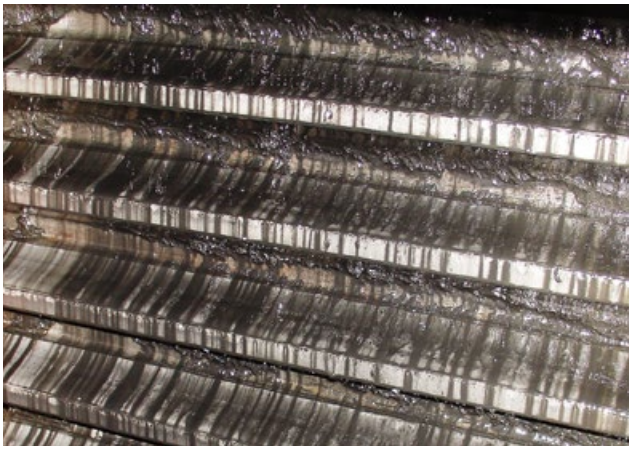
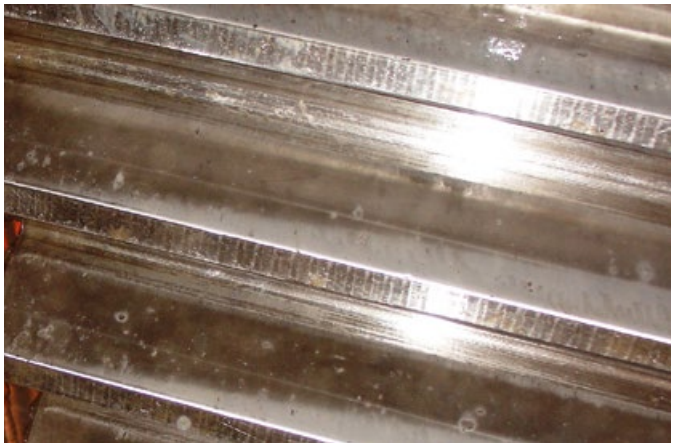
Spray lubrication: steps of while operating cleaning:

- Open the inspection door
- Stop the lubrication system
- Spray LUBRICLEAN EP for 8 minutes at high pressure (200 bars or 2900 psi, at 12 to 16 liters per minute)
- Stop spraying LUBRICLEAN EP for 5 minutes to let it soak in
- Spray LUBRICLEAN EP again at high pressure (200 bars or 2900 psi, at 12 to 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 lubricant **GRAFOLOG H 1 (or GEAR FLUID P)** 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 while operating cleaning.

7. F - LUBRILOG services: training

Although **LUBRILOG** offers short training sessions to customers, through its technical service support it can provide its customers with the basic knowledge of tribology and particularly of open gear drive lubricant.

Various training sessions offered:

- LUBRICANTS: General topics, makeup
- LUBRICANTS: Lubrication regimes and open gear drive lubrication
- TRIBOLOGY: General topics, friction genesis
- TRIBOLOGY: Open gear drive damages, theory and **LUBRILOG** experience
- **LUBRILOG** SERVICES: Preventive maintenance and recommended corrective actions for specific situations

We also customize our training sessions to our customer's specific needs.

LUBRILOG, the only French company specialized in the design and manufacturing of large open gear drive lubricants, offers its expertise to its customers for the protection of surfaces.

The vast majority of damages observed on large gear drive working flanks are avoidable.

/08

INITIAL OPEN GEAR DRIVE RUNNING-IN WORKSHEETS

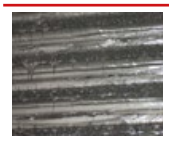
To summarize the information presented in the previous chapters, including chapter 6, **LUBRILOG** has prepared worksheets describing the lubrication operations to be executed in the running-in phase of large rotary drum open gear drives (new or repaired gear drives).
The worksheets correspond to the three industrial lubrication methods:

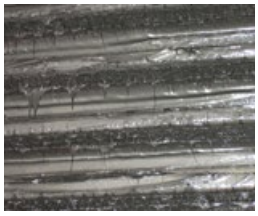
- Splash lubrication (direct or indirect): sheets 1, 2 and 5
- Circulation lubrication: sheets 1, 3 and 5
- Automatic spray lubrication: sheets 1, 4 and 6

For manual lubrication we recommend contacting our Technical Department.

Note:
For any additional information please refer to the previous chapters or contact our Technical Department.

Initial running-in worksheets:

	1 - Open gear drive running-in - Priming
	2 - Open gear drive running-in - Splash
	3 - Open gear drive running-in - Circulation
	4 - Open gear drive running-in - Automatic spray
	5 - Switching to the operational lubricant - Splash and Circulation
	6 - Switching to the operational lubricant - Spray



1 - Open gear drive running-in: Priming

Priming lubricants: GRAFOLOG H 1 or GEAR FLUID P

LUBRILOG PRIMING LUBRICANTS					CHARACTERISTICS			
name	nature of oil basis	thickener	solid lubricant	structure	40°C viscosity (mm^2/s) / consistency	4 ball welding (daN)	color	operational temperatures
GRAFOLOG H 1	mineral	aluminium complex	25% graphite	grease	1,000 / 1	> 500	black	- 20 to + 120 c.
GEAR FLUID P	half-synthetic	-	-	oil	25,000	> 800	brown	0 to + 120 c.

Lubrication procedure:

Step	Gear set position	Action	Note
1	Stop & auxiliary drive	Full cleaning of the open gear drive (girth gear and pinions)	Full cleaning of oxidation, greases and dust marks, etc…
2	Stop & auxiliary drive	Manual application of GRAFOLOG H 1 or GEAR FLUID P Quantities to order: **Quantity = 6 x b x Dp** with the quantity in kg and the dimensions, the girth gear pitch diameter (Dp) and working flanks facewidth (b), in meters	Application method: with a brush, avoiding any air inclusion, especially on working surfaces (risk of damage by cavitation); lubricant will be applied in thick layers on the girth gear and pinions working flanks (about 2 mm) and in thin layers on all other teeth surfaces (protection against corrosion). Application duration: Priming lubricants are very adherent: about one hour and half for a girth gear of 5500 mm diameter. Application conditions: the lubricant will be applied before loading (for mills) in order to protect the working flanks and, if possible, before installing the housing (for easier access).

Conditioning:
GRAFOLOG H 1 and GEAR FLUID P are available in 50 kg drums, 12.5 kg and 5 kg pails.

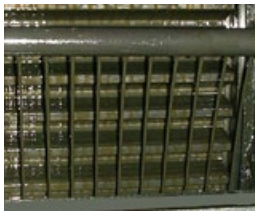
2 - Open gear drive running-in: Splash

Running-in splash lubricants: GRAFOLOG R FLUID or GEAR FLUID R

LUBRILOG RUNNING-IN SPLASH LUBRICANTS					CHARACTERISTICS			
name	nature of oil basis	thickener	solid lubricant	structure	40°C viscosity (mm²/s) / consistency	4 ball welding (daN)	color	operational temperatures
GRAFOLOG R FLUID	mineral	aluminium complex	>10% graphite	grease	2,000 / < 000	> 800	black	- 10 to + 120 c.
GEAR FLUID R	half-synthetic	none	none	oil	680	> 800	brown	- 15 to + 100 c.

Lubrication procedure:

Step	Gear set position	Action	Note
3	Stop	Full cleaning of the splashing bath	Full cleaning of the splashing bath in order to avoid any lubricant pollution during set up.
4	Stop	Fill splashing bath with GRAFOLOG R FLUID or GEAR FLUID R	Lubricant quantity: the lubricant quantity is determined by the splashing bath capacity and the quantity of circulating lubricant on the gear set, based on the gear set size. The in-service level must reach half of the teeth height. Adjust the initial lubricant level in-service. Operational lubricant may be added if needed. Check lubricants miscibility with our technical department.
5	In-service	Start-up of the machinery, in accordance with manufacturer's recommendations in case of a new gear set **Check the clamping of the housing seals:** seals too clamped will cause high temperatures, which are dangerous for the girth gear's working flanks	For ball and rod mills (mills with grinding elements): the load must be increased progressively (see example p. 41). In case of running-in in full load, we recommend fast lapping. Contact our technical department. Warning: the working flank condition, the contact quality and the splashing lubrication quality must be monitored daily. See chapter « 6. B - 2 - 3 » for the necessary controls to execute. A temperature increase on the working flanks may be observed on very solicited teeth, even with good mechanical erection settings.



3 - Open gear drive running-in: Circulation - 1/2

Running-in circulation lubricants: LUBRILOG L CC 680 R or GEAR FLUID R

LUBRILOG RUNNING-IN CIRCULATION LUBRICANTS					CHARACTERISTICS			
name	nature of oil basis	thickener	solid lubricant	structure	40°C viscosity (mm^2/s) / consistency	4 ball welding (daN)	color	operational temperatures
LUBRILOG L CC 680 R	mineral	none	none	oil	680	> 750	brown	- 0 to +120 c.
GEAR FLUID R	half-synthetic	none	none	oil	680	> 800	brown	- 15 to +100 c.
GRAFOLOG R FLUID	mineral	aluminium complex	> 10% graphite	grease	2,000 / < 000	> 800	black	- 10 to +120 c.

Lubrication procedure:

Step	Gear set position	Action	Note
3	Stop	Full cleaning of the circulation system	Full cleaning of the circulation system in order to avoid any lubricant pollution during set up.
4	Stop	Fill circulation oil tank with LUBRILOG L CC 680 R or GEAR FLUID R or GRAFOLOG R FLUID	In all cases, it is necessary to contact our technical department to check the miscibility of our running-in lubricants with the operational oil. In case of operational lubrication with fluid grease, such as GRAFOLOG M FLUID, our running-in GRAFOLOG R FLUID grease will be used. Check the miscibility and the circulation system's capacity for the treatment of viscous lubricants.
5	Stop	Start lubrication system by circulation of the open gear set	*Lubricant heating:* if the lubricant can be heated, set the temperature to maximum 40-50°C.

3 - Open gear drive running-in: Circulation - 2/2

Running-in circulation lubricants: LUBRILOG L CC 680 R or GEAR FLUID R

Lubrication procedure (continued):

Step	Gear set position	Action	Note
6	In-service	Start-up of the machinery, in accordance with manufacturer's recommendations in case of a new gear set Check the clamping of the housing seals: seals too clamped will cause high temperatures, which are dangerous for the girth gear's working flanks	For ball and rod mills (mills with grinding elements): the load must be increased progressively (see example p. 41). In case of running-in in full load, we recommend fast lapping. Contact our technical department. Warning: the working flank condition, the contact quality, the circulation lubrication quality, the cover of working flanks by lubricant and the oil flow on the manifold must be monitored daily. See chapter « 6. B - 2 - 3 » for the necessary controls to execute. A temperature increase on the working flanks may be observed on very solicited teeth, even with good mechanical erection settings. The lubricant circuit filters must be controlled and cleaned frequently.

4 - Open gear drive running-in: Automatic spay - 1/3

Running-in automatic spray lubricants: GRAFOLOG H 00 R or GEAR FLUID R

LUBRILOG RUNNING-IN SPRAY LUBRICANTS					CHARACTERISTICS			
name	nature of oil basis	thickener	solid lubricant	structure	40°C viscosity (mm^2/s) / consistency	4 ball welding (daN)	color	operational temperatures
GRAFOLOG H 00 R	mineral	aluminium complex	graphite	grease	320 / 00	> 800	black	- 10 to + 200 c.
GEAR FLUID R	half-synthetic	none	none	oil	680	> 800	brown	- 15 to + 100 c.

Lubrication procedure:

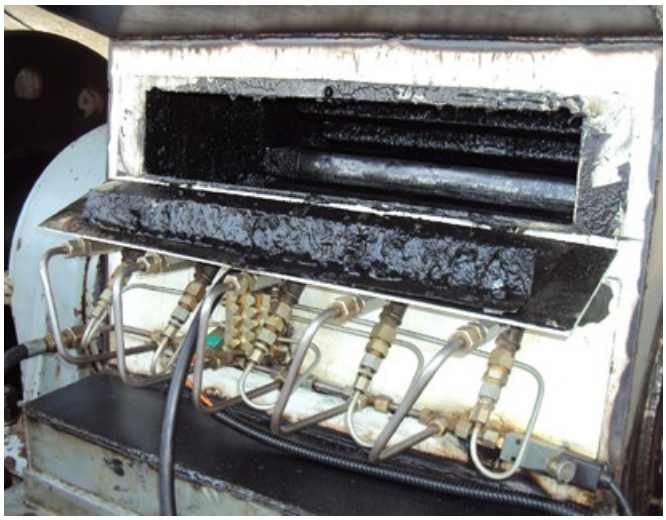
Step	Gear set position	Action	Note
3	Stop	Full cleaning of the spraying system	Full cleaning of the spraying system from the nozzles to the lubricant feeding system.
4	Stop	Calculation of the lubricant quantity to be sprayed and the lubrication times (pause and spray times)	Lubricant quantity: the required lubricant quantity for correct running-in varies between 180 to 540 kg, depending to the type of machinery and the open gear drive's capacity. The spraying system must also be taken into account. the quantity to be applied is determined by the method described in chapter « 6. B - 1 », recalled below.
5	Stop	Fill lubrication system with GRAFOLOG H 00 R or GEAR FLUID R Generally an intermediary tank or a drum, or container, direct feeding system	Pollution: avoid polluting the lubricant and spraying circuit when inserting the lubricant.

4 - Open gear drive running-in: Automatic spay - 2/3

Running-in automatic spray lubricants: GRAFOLOG H 00 R or GEAR FLUID R

Lubrication procedure (continued):

Step	Gear set position	Action	Note
6	Stop	Set and test the spraying system	Set the automatic spraying system according to parameters defined in step 4; test the spraying system, lubricant and air pressure, alarms, spray pattern and applied lubricant weight measure. For the first 24 hours of service, set continuous spraying. Then spread lubricant according to instructions provided in chapter « 5. C - 8 ». Consult our technical department if necessary.
7	In-service	Start-up of the machinery, in accordance with manufacturer's recommendations in case of a new gear set **Check the clamping of the housing seals:** seals too clamped will cause high temperatures, which are dangerous for the girth gear's working flanks	For ball and rod mills (mills with grinding elements): the load must be increased progressively (see example p. 41). In case of running-in in full load, we recommend fast lapping. Contact our technical department. Warning: the working flank condition, the contact quality, the spraying lubrication quality and the cover of working flanks by lubricant must be monitored daily. See chapter « 6. B - 2 - 3 » for the necessary controls to execute. A temperature increase on the working flanks may be observed on very solicited teeth, even with good mechanical erection settings.



4 - Open gear drive running-in: Automatic spay - 3/3

Running-in automatic spray lubricants: GRAFOLOG H 00 R or GEAR FLUID R

Lubrication procedure (continued): lubricant quantities to apply

TYPE OF OPEN GEAR DRIVE		GRAFOLOG H 00 R or GEAR FLUID R QUANTITY TO APPLY **(in grams . mm . service hour)**
Q1 -	Single drive (one pinion) for kiln, dryers, cooler	0.50
Q2 -	Single drive (one pinion) for mill	0.70
$Q3_1$-	Double drive (two pinions) for kiln	0.80
$Q3_2$-	Double drive (two pinions) for mill	1

The indicated quantity of our GRAFOLOG H 00 R running-in grease or our GEAR FLUID R running-in oil for spray lubrication is expressed in grams per working flank millimeter (facewidth) and per service hour.

For double drives (two pinions), the quantity of calculated lubricant is global and must be spread evenly between both pinions.

For new open gear drives we recommend referring to the machine manufacturer's instructions.

Example:

Calculating the grease quantity to spray on a ball mill open gear drive.

Hypotheses:
Single drive (one pinion)
Working flanks facewidth, b = 500 mm

Calculating the running-in lubricant quantity to apply: Qr = Qn x b (with n = 1, 2, 3_1 or 3_2)

Qr = 0.7 x 500 = **350 grams per service hour** (8.4 kg per 24 service hours)

5 - Switching to the operational lubricant: Splash & Circulation

For all types of open gear lubrication: **splash, circulation or automatic spraying**, the end of the initial running-in operation or slow lapping is reached when both of the following criteria have been met:

- Working flanks good quality surface and
- Contact percentage between the teeth superior to 80%.

Warning: For new open gear drives, manufacturer's agreement is required prior to stopping the running-in phase.

Splash lubrication: switching to operational lubricant

Operational lubricant setup procedure:

Service time	Action	Note
2500 to 4000 hours depending on the operational conditions	Emptying splashing bath and insert operational lubricant Verify that the predefined splash lubricant level is applied	We recommend cleaning splashing bath and housing interior surfaces to get rid of all remaining polluting particules. For kilns, the emptying can be done in-service and the running-in duration can be increased (in this case check lubricant quality). Contact our Technical Department for this operation and to define intervals for emptying of the operational lubricant.

Circulation lubrication: switching to operational lubricant

Operational lubricant setup procedure:

Service time	Action	Note
2500 to 4000 hours depending on the operational conditions	Emptying lubricant tank and insert operational lubricant Verify that the predefined tank lubricant level is applied	We recommend cleaning lubricant tank, lubricant circuit, filters and housing interior surfaces to get rid of all remaining polluting particules. Contact our Technical Department for any additional information and to define intervals for emptying of the operational lubricant.

6 - Switching to the operational lubricant: Spray - 1/2

For all types of open gear lubrication: **splash, circulation or automatic spraying**, the end of the initial running-in operation or slow lapping is reached when both of the following criteria have been met:

- Working flanks good quality surface and
- Contact percentage between the teeth superior to 80%.

Warning: For new open gear drives, manufacturer's agreement is required prior to stopping the running-in phase.

Automatic spray lubrication: switching to operational lubricant

Operational lubricant setup procedure:

Service time	Action	Note
After 720 to 1080 hours (30 to 45 days) depending on the operational conditions & For about 168 hours (7 days)	Replace running-in lubricant with operational lubricant Do not modify spray lubrication system settings	Pollution: Avoid polluting lubricant and spray circuit when inserting operational lubricant. Spray quantity: The operational lubricant quantity to spray is identical to the defined quantity for the previous running-in phase. Two intermediary steps must be executed for not quickly reduce the quantity of lubricant on the working flanks (see diagram below).
After 888 to 1248 hours (37 to 52 days) depending on the operational conditions & For about 168 hours (7 days)	Reduce the quantity of sprayed operational lubricant Modify spray lubrication system settings	Spray quantity: This second intermediary step involves reducing the quantity of operational lubricant sprayed on the working flanks (see diagram below). A balanced distribution between pause and spray times is crucial during this intermediary spraying phase. Set the automatic spray system (PLC). Check spray quality: flow, spray pattern, etc.. and spray cycles.

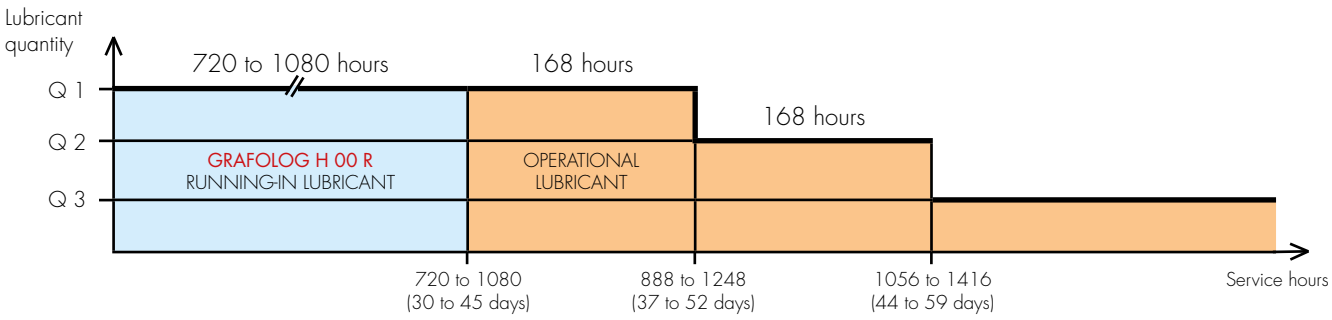
6 - Switching to the operational lubricant: Spray - 2/2

Automatic spray lubrication: switching to operational lubricant

Operational lubricant setup procedure(continued):

Service time	Action	Note
After 1056 to 1416 hours (44 to 59 days) depending on operational conditions	Reduce the quantity of sprayed operational lubricant Modify spray lubrication system settings Set spray system lubricant quantity to the calculed and approved quantity Test spray lubrication system before starting up the open gear drive	Spray quantity: This last step consists of setting the operational lubricant quantity sprayed on the working flanks while verifying the actual operational parameters (including the working flank temperature). Set the automatic spray system according to previously defined operational spraying cycles (PLC). Check spray quality: flow, spray pattern, etc.. and spray cycles.

The diagram below shows the evolution of lubricant quantities to apply to the open gear drive according to operational duration.



Q 1 = running-in lubricant quantity: GRAFOLOG H 00 R or GEAR FLUID R (see page 39 or 72)
Q 2 = intermediary operational lubricant quantity
Q 3 = operational lubricant quantity (see pages 28, 29 and 30)

with Q 2 = (Q 1 + Q 3) / 2

/09

SUMMARY TABLES SHOWING THE LUBRILOG OPERATIONAL LUBRICANTS

LUBRILOG offers a complete range of lubricants designed for large rotary drum open gears drives, which correspond to the industrial lubrication methods described in chapter « 5 - Typology of lubrication methods ».

Our operational lubricants tables allow you to select the most appropriate lubricant for you existing open gear drive lubrication method.

Warning:
Specific priming or running-in lubricants are described in our running-in procedure worksheets
(see pages 66, 67, 68 and 70).

LUBRILOG operational lubricants tables:

	1 - Permanent lubrication - Splash
	2 - Permanent lubrication - Circulation
	3 - Sequential lubrication - Spray

1 - Permanent lubrication: Splash

2 - Permanent lubrication: Circulation

The lubricants mentioned in the following table can be used for both permanent lubrication methods: direct or indirect splash lubrication or circulation lubrication.

However, although the splash lubrication tolerates the use of the highest viscosities, the circulation lubrication method involves a limited choice in viscosity (lubricant feeding pump capacity). In this case, knowing the characteristics of the circulation system is necessary in order to select the appropriate lubricant.

Our Technical Department will assist you in this crucial process to help you establish the most efficient lubrication.

LUBRILOG SPLASH & CIRCULATION LUBRICANTS				CHARACTERISTICS		
name	graphite or MoS_2 ●	non graphite ○	structure	40°C viscosity (mm^2/s) / Consistency	4 ball welding (daN)	color
GRAFOLOG M FLUID	●		grease	3,000 / < 000	> 800	black
GRAFOLOG MT FLUID	●		grease	7,500 / < 000	> 800	black
LUBRILOG L CC 1200 M	●		oil	1,200	400	black
LUBRILOG L CC 1500 M	●		oil	1,500	400	black
LUBRILOG L CC 2200 M	●		oil	2,200	400	black
LUBRILOG L CC 3200 M	●		oil	3,200	400	black
GEAR FLUID 180		○	oil	4,600	> 980	brown
GEAR FLUID 550		○	oil	17,000	> 980	brown
GEAR FLUID 1000		○	oil	25,000	> 980	brown

LUBRILOG biodegradable technology, ECOLABEL respect

ECOBIOL OG FLUID		●	grease	20,000	> 650	amber

Available conditioning:
25 kg pail
50 kg drum
180 kg drum
1000 kg container

Our very high viscosity « **GEAR FLUID** » oils and our biodegradable oils are available in several viscosities.

Our lubricant technical and safety data-sheets are available upon request by contacting our Sales Department: « contact@lubrilog.fr ».

3 - Sequential lubrication: Spray

Lubricants in the table below can be used for both industrial sequential lubrication methodes: automatic spray lubrication and manual spray lubrication.

Warning:
You must make sure that the spraying system matches the selected lubricant especially in cold temperatures and in the machinery start-up phase and that the automatic spraying system can sustain the calculated lubrication cycle.

Our Technical Department will assist you in this crucial process to help you establish the most efficient lubrication.

LUBRILOG SPRAY LUBRICANTS				CHARACTERISTICS		
name	graphite or MoS_2 ●	non graphite ○	structure	40°C viscosity (mm²/s) / Consistency	4 ball welding (daN)	color
GRAFOLOG H 0	●		grease	500 / 0	> 620	black
GRAFOLOG H 0 +	●		grease	1,100 / 0 - 1	> 700	black
GRAFOLOG H 1500	●		grease	1,500 / 0 - 1	> 700	black
GRAFOLOG H 2200	●		grease	2,200 / 00 - 0	> 700	black
GRAFOLOG H 3000	●		grease	3,200 / 0	> 700	black
INVERTA RUN PLUS		○	oil	1,000 / 0 - 1	> 700	brown
INVERTA RUN HT		○	oil	460 / 00* 12,500 / 0**	> 800	beige
GEAR FLUID 180		○	oil	4,600	> 980	brown
GEAR FLUID 550 D		○	oil	1,000* 17,000**	> 980	brown
GEAR FLUID 1000 D		○	oil	1,600* 25,000**	> 980	brown

*: before solvent evaporation - **: after solvent evaporation

LUBRILOG biodegradable technology, ECOLABEL respect

ECOBIOL OG FLUID		●	grease	20,000	> 650	amber

Available conditioning:
25 kg pail
50 kg drum
180 kg drum
1000 kg container

Our very high viscosity « GEAR FLUID » oils and our biodegradable oils are available in several viscosities.

Our lubricant technical and safety data-sheets are available upon request by contacting our Sales Department: « contact@lubrilog.fr ».

LUBRILOG Headquarters and Production plant 1 in Romans sur Isère Drôme, FRANCE

LUBRILOG wishes to thank all customers, O.E.Manufacturers, gear set engineers and suppliers for their help in compiling this document.

LUBRILOG

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