Lubrication management

An overview of best practices

Summary
This article is not designed to make the reader a lubrication expert. The purpose of this article is to provide a balanced start in the investigation into lubrication management. It would be impossible to cover everything one needs to know about managing your plant's lubrication issues in one article. Instead, the intention here is to provide an understanding of lubrication management through the use of terms and definitions, current techniques and practices, and many resources.

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1. Introduction

We start with a few definitions.

- Friction: The rubbing of one object or surface against another.
- Lubricant: A substance that reduces friction when applied as a surface coating to moving parts.

All throughout history, many have looked for ways to reduce friction. Certainly, ancient armies used grease as a weapon whereby they would ignite the oil and wield it at their foe. Grease and oil was used for medicinal purposes as applied to the body. On a more industrious note, while building the pyramids, ancient Egyptians used crude types of greases to lubricate the axels of pharaoh's chariots.

Time has passed since the introduction of lubrication in industry; the sophistication of machinery has changed as well. The different materials used in combination to increased loads and speeds have forced lubrication manufacturers to meet growing needs. But what has really changed?

Lubrication still performs the same function as before: friction reduction, but what is different about the lubricants of today? With all the different lubricants to choose from for each application, a better question might be, "what do I need to know in order to ensure I am getting the most out of the lubrication used in my plant?"

This article is not designed to make the reader a lubrication expert. The purpose of this article is to provide a balanced start in the investigation into lubrication management for an equipment end-user. It would be impossible to cover everything one needs to know about managing your plant's lubrication issues in one article. Instead, the intention here is to provide an understanding of lubrication management through the use of terms and definitions, current techniques and best practices, and other resources. The article is set-up as follows:

Why; lubrication strategy
What; grease and oil lubrication, (system) selection
How; storage/handling, contamination control, data handling, training

2. Lubrication Strategy

2.1. Why Bearings Fail

Some still valid statistics regarding the failure of bearings are provided by SKF. Certain industries of course vary from the statistics quoted, but in general the percentages are a sound indicator of the different failure modes. These reasons are:

- 36 % Lubrication problems
- 14% Contamination, e.g., dirt, water, particles
- 16% Poor fitting
- 34% Abuse, e.g., overload, temperature too low/high, alignment, mounting

Notice that lubrication and contamination accounts for half of the failures. Lubrication problems include wrong lubricants, insufficient lubrication, too much lubrication, and contaminated lubrication. Sources listed for contamination problems include contaminated environment, contaminated lubricants, ineffective seals, damaged seals, and wear.

Enough reason to have a closer look into the lubrication strategy. Let's consider various components of a lubrication strategy, including possible improvement actions.

2.2. Manual and Automatic Lubrication

The manual and automatic lubrication practices can suffer by various reasons. For example, lack of dedicated resources, low competence levels, bad understanding of lubrication effects on reliability, antiquated lubrication systems, inaccessible lubrication points, lack of defined lubrication schedules, and undesired mixing lubricants. In order to improve, lubrication training, modern automatic systems, implementation of a lubrication management program compatible to the relevant computerized maintenance management system (CMMS), and appropriate lubrication coding and identification could be included in the lubrication strategy.

2.3. Lubrication Knowledge

Low or lack of knowledge on the effects of contamination on component and asset performance, grease/oil lubricant selection, and use of automated lubrication systems, may be the reason of unnecessary lubrication problems. This could be a reason to educate the in-house resources on contamination effects, lubricant selection, use of lubrication systems, etc., or partnering with competent lubrication services providers. Also crucial is to make management aware of the effects of lubrication on asset performance/availability.

2.4. Data Management Processes

The lubrication (data) management processes and databases may suffer due to incomplete content (lubrication types, quantities per point, routing schedule, and machine requirements), lack of dedicated resources to manage the data, or lack of interface with work activity systems like CMMS. Possible improvements include completing the information in professional and accessible databases per lubrication point, training dedicated resources, implementing Lubrication Management Systems with status information and connection to CMMS.

2.5. Cleanliness Control

Contamination definitely could be a major driver for improvements due to various reasons. Examples include lack of closed lubrication systems, limited structure to eliminate lubricant mixing, poor filtration systems, lack of dedicated flushing of equipment, contamination ingress during sampling, poor follow-up of lubrication analysis reports, and contaminated filling points. In the lubrication strategy, improvements could be included like closed lubrication systems, clearly marked and coded lubricants per point, effective filtration systems, dedicated flushing, clean sampling, dedicated follow-up of lubrication analysis reports, and protection of filling points and closed systems and filling cans.

2.6. Safety and Environment

Special administrative processes are generally required for potential environmental damaging products, i.e., collection and disposal of lubricant waste, cleaning rags, spillage of cleaning material, empty packaging and drums, cleaning chemicals, etc. Special safety and environmental arrangements are also required for the storage of lubricants, unless removed from the site after lubrication activities. Spillage reduction, e.g., during relubrication, and its safety and environmental consequences, needs to be addressed by appropriate procedures, training, and tools.

2.7. Warehousing and Supply

Various inventory issues may drive desired improvements activities. Identified problem may include high lubricant inventories compared to consumption, many different lubricant types, excessive inventories due to available pack sizes, high lubrication logistics administration cost, aging lubricants in stock and unsuitable for use, and damages packaging due to excessive storage periods. An extensive audit and planning on the lubrication plan for all lubrication points can improve the situation considerably. Further, an inventory analysis could be done together with the lubricant suppliers.

Lubricants consolidation aims to reduce overall maintenance costs, extend equipment life, and simplify the lubricant purchasing process. Typical lubrication consolidation targets include reduce stock of lubricants, reduce consumption of lubricants, and reduce number of different lubricants on stock.

2.8. Lubrication Monitoring

Monitoring the status of the lubrication practices could indicate various problems. For example, repetitive failures dues to inadequate lubrication, no follow-up of lubrication analysis reports, poor maintenance of lubrication systems (dirty points and ineffective pipes), incorrect lubricants used, lack of reporting processes of the lubrication activities. This can be the reason to improve the preventive maintenance and predictive oil analysis programs, including root cause failure analysis to prevent problems from occurring, and coordination of follow-up on analyses done. Further improvements include closer monitoring of lubrication systems, clear identification of filling points, and an open lubrication management system for lubrication reports, routes, and analysis reports.

2.9. Maturity Stages

Depending on current lubrication practices, a plant can grow from a "stabilizing" basic requirements stage, a lubrication processes implementation stage, a proactive stage with continuous improvements, towards an integrated stage with the overall asset maintenance strategies. Analyzing the current lubrication practices and comparing with targets depending on business objectives, an overall lubrication strategy and roadmap can be derived covering the various activities to improve. Figure 1 provides a graphic representation of the four phases of maintenance maturity, helping thus to identify the characteristics of each stage from drivers behaviours and rewards point of view.

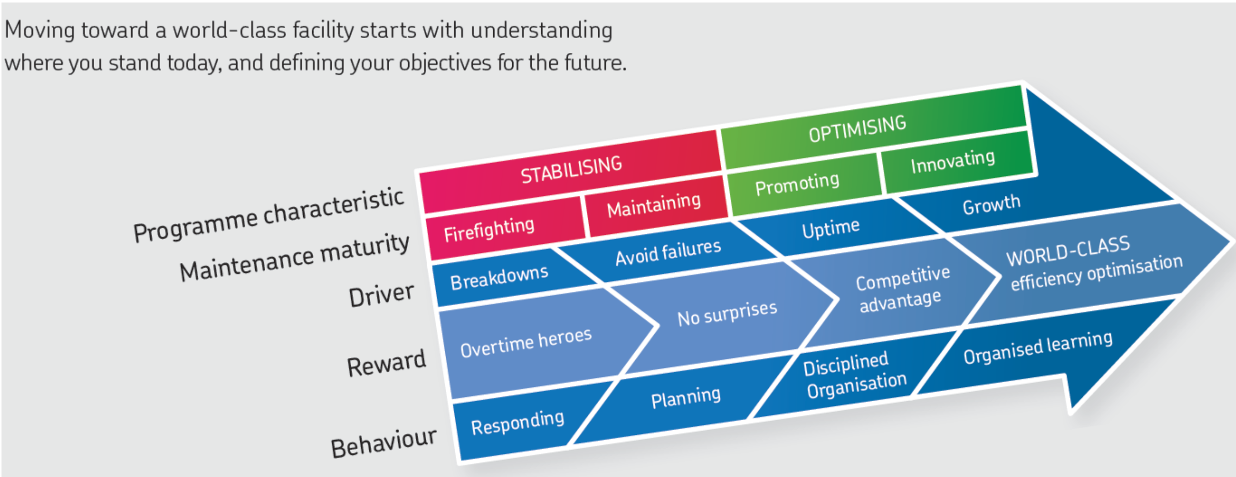


Figure 1 The four phases of maintenance maturity

SKF Clients Needs Analysis – Lubrication Management (CNA-LM) analyzes four major components of a lubrication programme: Strategy, work identification, work control and work execution. Figures 2 and 3 illustrate the kind of output obtained. The spider chart gives a quick overview of the major improvement areas from the strategy point of view, while the maturity matrix provides a reading of the level of maturity the programme has. Combined, these two elements conform the starting point for any strategy adjustment.

SKF Lubrication Audit, on the other hand, dives deep into the components of a lubrication programme identifying specific actions that require to be executed in order to improve, once the strategy has been defined. Figure 4 illustrates a spider chart analyzing all the major components of a given lubrication programme.

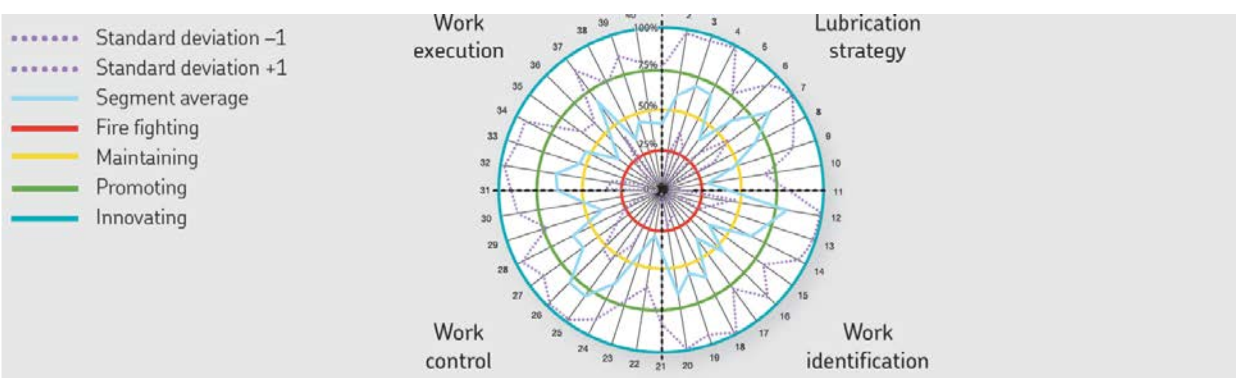


Figure 2 Spider Chart output from an SKF CNA-LM

Main facet / Maturity	Absent	Fire fighting	Maintaining	Promoting	Innovating	Not applicable	Not understood	Totals
Maintenance Strategy	3,97	5,31	3,51	4,91	6,78	0,38	0,16	25,0
Work Identification	5,6	3,74	2,44	3,39	8,42	1,3	0,12	25,0
Work Control	4,33	2,87	4,41	5,78	6,68	0,83	0,09	25,0
Work Execution	5,02	6,79	3,46	3,61	5,36	0,71	0,06	25,0
Subtotals per choice of response	18,91	18,71	13,82	17,69	17,23	3,21	0,43	100,0

Figure 3 Maturity Matrix Summary from a CNA-LM

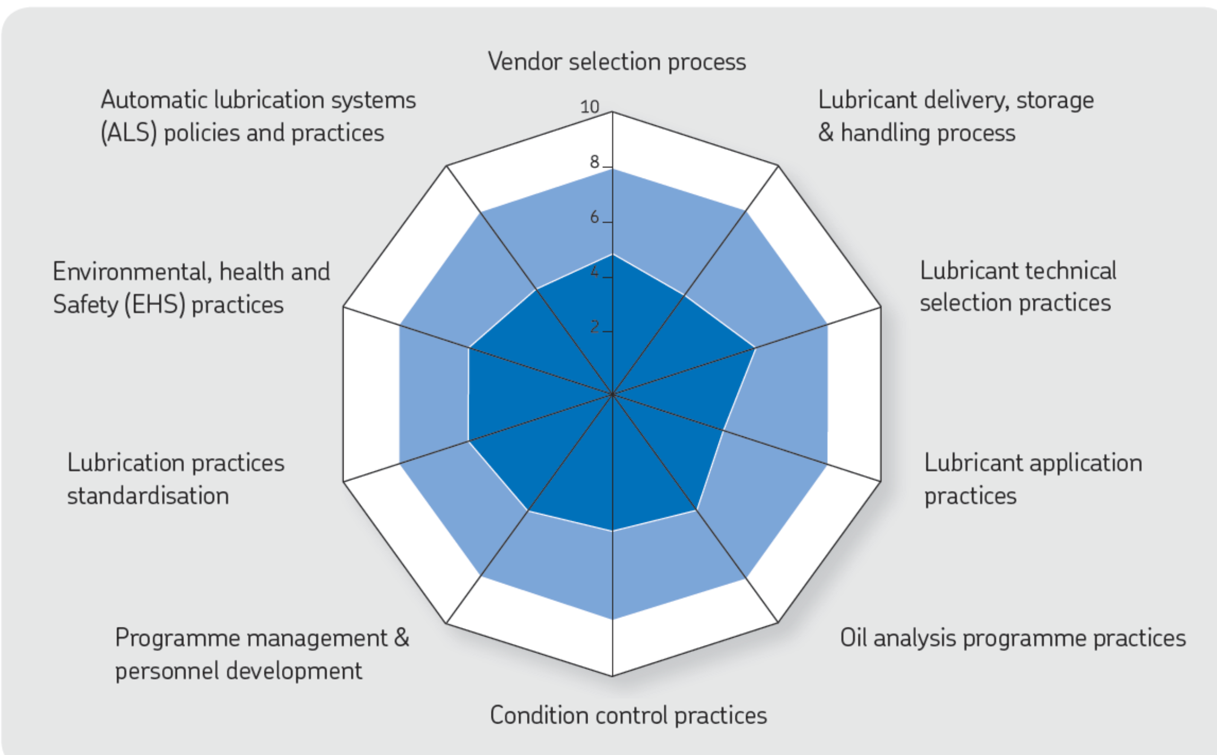


Figure 4 Spider Chart from an SKF Lubrication Audit

2.10. Management Responsibilities

Responsibilities of the manager include, but are not limited to, the following:

- Establishing a lubrication strategy "where to go, in what period."
- Planning for improvement "projects."
- Resource planning: people, tools, software, etc.
- Establishing lubrication plan: lubrication selection, schedules, routes, intervals, quantities, etc.
- Establishing appropriate contamination control, including oil analysis, filters, etc.
- Establishing recording database and reporting system.
- Establishing health, environmental, and safety procedures.
- Optimizing supply and storage.
- Implementation – ensuring the plan and operating procedures are followed.

3. Oil Lubrication

Understanding key properties of lubricants is useful for, choosing lubricating oils, diagnosing lubrication, friction and wear problems, and designing lubrication systems. Some of them are summarized below.

3.1. Viscosity

Viscosity is the property of a fluid that causes it to resist flow, which mechanically is the ratio of shear stress to shear rate. Most base oil viscosities used for mechanical applications lie between 15 and 500 mm2/sec at 40º C (104º F). Generally speaking, high-speed applications need a lower viscosity, while low-speed applications need high viscosity base lubricants. Viscosity is by far the most significant property for establishing the thickness, pressure, and temperature of the oil film. Oil film thickness generally increases with viscosity.

Viscosity of industrial lubricants is commonly classified using the International Standard Organization Viscosity Grade (ISO VG) system, which is the average viscosity in centiStokes (cSt) at 40 degree Celsius. For example, ISO VG 32 is assigned to oils with viscosity between 28.8 and 35.2 cSt at 40°C. Regarding viscosity guidelines for the lubrication of rolling element bearings, several charts are provided by SKF. For a quick selection, use the Internet based programs “LubeSelect" and "LuBase", found at http://www.skf.com/group/knowledge-centre/index.html.

3.2. Oxidation Inhibitors

Resistance to oxidation is a critical property for all machines, but especially critical for machines requiring extended life at elevated temperatures, such as turbines, aircraft engines, and hydraulic systems. Also, good oxidation resistance prolongs storage life. Oxidation resistance may be due to natural inhibitors or commercial additives. Metal surfaces and soluble metal salts, especially copper, usually promote oxidation. Another approach to inhibiting oxidation is to reduce the catalysis by deactivating the metal surfaces.

3.3. Rust Inhibitors

Since water is a common contaminant in oil lubricated systems used on earth, anti-rust additives are used. Rust inhibitors prevent the formation of rust (hydrated iron oxide) on iron surfaces by the formation of protective films, or by the neutralization of acids. The rusting of ferrous parts in a lubricated system is undesirable. The rust contributes to sludge, causes loss of metal, sticking of metal parts, and the formation of solid particles of rust that are abrasive.

3.4. Detergent

These additives may be described as “cleaning” additives. They work in such a way that reaction products from high-temperature zones are kept floating in the oil. Without these additives such reaction products may adhere to and discolor the surfaces in contact with the oil. These additives are normally used in engine oils for cars but sometimes feature in paper machine oils as well.

3.5. Dispersant

One way to avoid sedimentation of contaminant particles inside long pipes and large reservoirs of machine lubrication systems is to use an oil with dispersant additives. These additives can keep the particles floating in the oil until they enter the oil filter. One drawback of these additives is that they can keep small drops of water floating as well. This may cause corrosion in the bearings and clogging of the oil filters. Another drawback is that these additives can neutralize the effect of anti-wear additives.

3.6. Load Carrying Ability

Component life is shortened if the lubricant film thickness is not sufficient to prevent metal to metal contact of the asperities on the contact surfaces. One option to overcome this is to use so-called EP (Extreme Pressure) additives. High temperatures induced by local asperity contact, activate these additives promoting mild wear at the points of contact. The result is a smoother surface, lower contact stresses and an increase in service life.

Many modern EP additives are of the sulphur/phosphorus type. Unfortunately these additives may have a negative effect on the strength of the bearing steel matrix. If such additives are used then the chemical activity may not be restricted to the asperity contacts. If the operating temperature and contact stresses are too high, the additives may become chemically reactive even without asperity contact. This can promote corrosion/diffusion mechanisms in the contacts and may lead to accelerated bearing failure usually initiated by micro pitting. SKF recommends the use of less reactive EP additives for (bearing) operating temperatures above 80 °C. Lubricants with EP additives should not be used for bearings operating at temperatures higher than 100 °C.

AW (Anti-Wear) additives have a function similar to that of EP additives, i.e. to prevent severe metal-to-metal contact. Therefore EP and AW additives are very often not differentiated between. However, the way they work is different. The main difference is that an AW additive builds a protective layer that adheres to the surface. The asperities are then shearing over each other rather than through each other. The roughness is not reduced by mild wear as in the case of EP additives. Here too special care has to be taken; AW additives may contain elements that, in the same way as the EP additives, can migrate into the (bearing) steel and weaken the structure.
If the lubricant film thickness is sufficient, SKF does not generally recommend the use of EP and AW additives. However there are circumstances where EP/AW additives may be useful. If excessive sliding between the rollers and raceways is expected they may be beneficial.

3.7. Friction modifiers

Friction modifiers are defined as those additives with the ability to reduce friction, by other means than by oil viscous properties. These additives reduce friction below that of the base oil alone under conditions of boundary lubrication. The additives are adsorbed on, or react with the metal surface or its oxide to form monolayers of low shear strength material.

4. Grease Lubrication

Grease can be used to lubricate rolling bearings under normal operating conditions in the majority of bearing applications. Grease has the advantage over oil that it is more easily retained in the bearing arrangement, particularly where shafts are inclined or vertical, and it also contributes to sealing the arrangement against contaminants, moisture or water.

Excessive amounts of grease will cause the operating temperature within the bearing to rise rapidly, particularly when running at high speeds. As a general rule, when starting up only the bearing should be completely filled, while the free space in the housing should be partly filled with grease. Before operating at full speed, the excess grease in the bearing must be allowed to settle or escape during a running-in period. At the end of the running-in period the operating temperature will drop considerably indicating that the grease has been distributed in the bearing arrangement. However, where bearings are to operate at very low speeds and good protection against contamination and corrosion is required, it is advisable to fill the housing completely.

Lubricating greases consist of a mineral or synthetic oil combined with a thickener. The thickeners are usually metallic soaps. However, other thickeners, e.g. polyurea can be used for superior performance in certain areas, i.e. high temperature applications. Additives can also be included to enhance certain properties of the grease. The consistency of the grease depends largely on the type and concentration of the thickener used and on the operating temperature of the application. When selecting a grease, the consistency and mechanical stability, operating temperature range, viscosity of the base oil, rust inhibiting properties and the load carrying ability are the most important factors to be considered.

4.1. Base Oil Viscosity

The base oil viscosity of the greases normally used for rolling bearings lies between 15 and 500 mm2/s at 40 °C. Greases based on oils having higher viscosities than 1 000 mm2/s at 40 °C bleed oil so slowly that the bearing will not be adequately lubricated. Therefore, if a calculated viscosity well above 1 000 mm2/s at 40 °C is required because of low speeds, it is better to use a grease with a maximum viscosity of 1 000 mm2/s and good oil bleeding properties or to apply oil lubrication.

4.2. Consistency

Greases are divided into various consistency classes according to the National Lubricating Grease Institute (NLGI) scale. The consistency of grease used for bearing lubrication should not change drastically when operated within its specified temperature range after mechanical working. Greases that soften at elevated temperatures may leak from the (bearing) arrangement. Those that stiffen at low temperatures may restrict rotation of the bearing or have insufficient oil bleeding.

Metallic soap thickened greases, with a consistency of 1, 2 or 3 are used for rolling bearings. The most common greases have a consistency of 2. Lower consistency greases are preferred for low temperature applications, or for improved pumpability. Consistency 3 greases are recommended for bearing arrangements with a vertical shaft, where a baffle plate is arranged beneath the bearing to prevent the grease from leaving the bearing.

NLGI no.	ASTM Worked Penetration	Appearance at room temperature	Typical use
000	445-475	very fluid	gears
00	400-430	fluid	gears
0	355-385	semi-fluid	gears
1	310-340	very soft	bearing
2	265-295	soft	bearing
3	220-250	medium hard	bearing
4	175-205	hard	seals
5	130-160	very hard	seals
6	85-115	extremely hard	seals

In applications subjected to vibration, the grease is heavily worked as it is continuously thrown back into the bearing by vibration. Higher consistency greases may help here, but stiffness alone does not necessarily provide adequate lubrication. Therefore mechanically stable greases should be used instead. Mechanical stability can be defined as ability of a given grease of maintaining its consistency after being subjected to working conditions.

4.3. Temperature Range

The temperature range over which a grease can be used depends largely on the type of base oil and thickener used as well as the additives. The relevant temperatures are schematically illustrated in Figure 5 in the form of a “double traffic light”, as introduced in [1]. The extreme temperature limits, i.e. low temperature limit and the high temperature limit, are well defined.

- The low temperature limit (LTL), i.e. the lowest temperature at which the grease will allow the bearing to be started up without difficulty, is largely determined by the type of base oil and its viscosity.
- The high temperature limit (HTL) is determined by the type of thickener and for soap base greases it is given by the dropping point. The dropping point indicates the temperature where the grease loses its consistency and becomes a fluid.

Operation below the low temperature limit and above the high temperature limit is not advised as shown in Figure 5 by the red zones. Although grease suppliers indicate the specific values for the low and high temperature limits in the product information, the really important temperatures for reliable operation are given by the SKF values for

- Low temperature performance limit (LTPL)
- High temperature performance limit (HTPL)

It is within these two limits, the green zone in Figure 5, where the grease will function reliably and grease life can be determined accurately. Since the definition of the high temperature performance limit is not standardized internationally care must be taken when interpreting suppliers’ data.

At temperatures above the high temperature performance limit (HTPL), grease will age and oxidize with increasing rapidity and the by-products of the oxidation will have a detrimental effect on lubrication. Therefore, temperatures in the amber zone, between the high temperature performance limit and the high temperature limit (HTL) should occur only for very short periods.

An amber zone exists for low temperatures. With decreasing temperature, the tendency of grease to bleed decreases and the stiffness (consistency) of the grease increases. This will ultimately lead to an insufficient supply of lubricant to the contact surfaces of the rolling elements and raceways. In Figure 5, this temperature limit is indicated by the low temperature performance limit (LTPL). Values for the low temperature performance limit are different for roller and ball bearings. Since ball bearings are easier to lubricate than roller bearings, the low temperature performance limit is less important for ball bearings. For roller bearings, however, serious damage will result when the bearings are operated continuously below this limit. Short periods in this zone e.g. during a cold start, are not harmful since the heat caused by friction will bring the bearing temperature into the green zone.

The SKF traffic light concept is applicable for any grease; however, the temperature zones differ from grease to grease and can only be determined by functional bearing testing. The limits for grease types normally used for rolling bearings are shown in Figure 6. The values shown in this figure are based on extensive tests conducted in SKF laboratories and may differ from those quoted by lubricant manufacturers. The values shown in figures are valid for commonly available NLGI 2 greases without EP additives. The temperatures relate to the observed self-induced bearing temperature (usually measured on the non-rotating ring).

Since the data for each grease type is a summary of many greases of more or less similar composition, the transitions for each group are not sharp but fall within a small range.

4.4. Protection Against Corrosion

Grease should protect the bearing against corrosion and should not be washed out of the bearing arrangement in cases of water penetration. The thickener type solely determines the resistance to water: lithium complex, calcium complex and polyurea greases offer usually very good resistance. The type of rust inhibitor additive mainly determines the rust inhibiting properties of greases. At very low speeds, a full grease pack is beneficial for corrosion protection and for the prevention of water ingress.

4.5. Load Carrying Ability

The similar discussion as in the oil section on AW and EP additives applies to greases. Certain grease thickeners (e.g. calcium sulphonate complex) also provide an EP/AW effect without chemical activity and the resulting effect on bearing fatigue life. Therefore, the operating temperature limits for EP additives do not apply for these greases.

Again, if the lubricant film thickness is sufficient, SKF does not generally recommend the use of EP and AW additives [1]. However there are circumstances where EP/AW additives may be useful. If excessive sliding between the rollers and raceways is expected they may be beneficial.

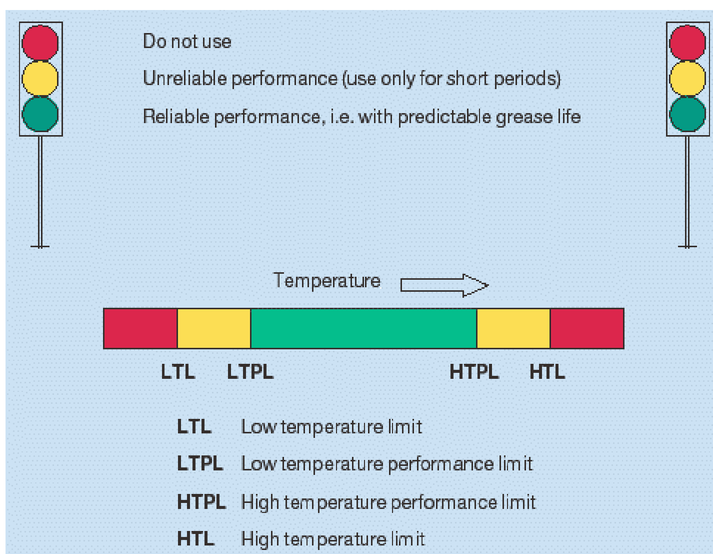
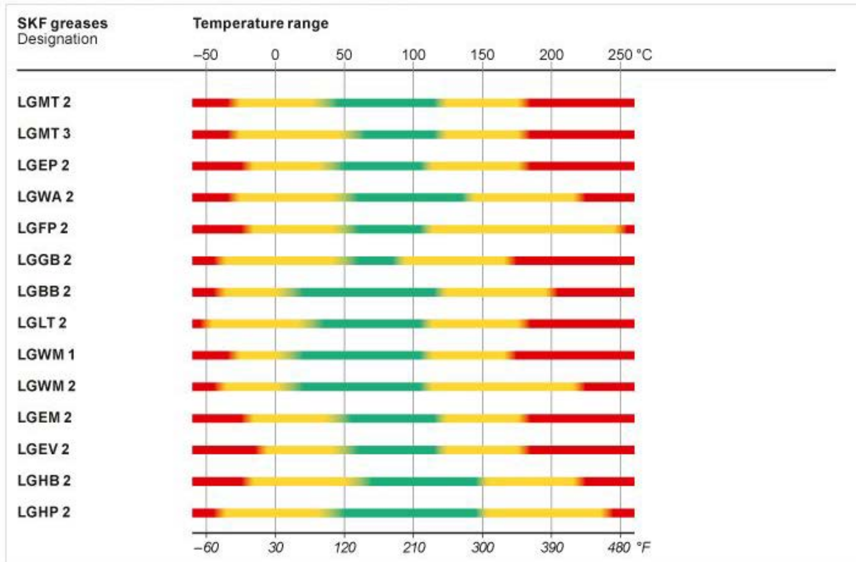


Figure 5: The SKF traffic light concept.



For operating temperatures > 150 °C (300 °F), SKF recommends SKF LGET 2 grease.

Figure 6: The SKF traffic light concept – SKF greases.

4.6. Miscibility

If it becomes necessary to change from one grease to another, the miscibility or the ability to mix greases without adverse effects should be considered. If incompatible greases are mixed, the resulting consistency can change dramatically so that bearing damage e.g. due to severe leakage, could result.

Greases having the same thickener and similar base oils can generally be mixed without any detrimental consequences, e.g. a lithium thickener/mineral oil grease can generally be mixed with another lithium thickener/mineral oil grease. Also, some greases with different thickeners e.g. calcium complex and lithium complex greases, are miscible with each other.

In bearing arrangements where a low grease consistency might lead to grease escaping from the arrangement, the next relubrication should involve purging all the old grease from the arrangement rather than replenishing it.

5. Lubricant Selection

5.1. Oil or Grease?

Some advantages of oil lubrication are [2]:

- Oil is easily drainable and refillable. For frequent changes of lubrication this can lead to time / cost savings.
- The amount of lubricant placed in the system is more easily controlled.
- Oil flows through the system more easily, and therefore reaches most areas of the machine.
- The characteristics of oil better lend themselves to high temperature and high-speed applications. Particularly at high speeds, an excess of grease lubricant can cause the operating temperature to rise rapidly.
- The advantages of grease lubrication are:
- Grease systems are more easily maintained from an “amount of time spent on the system” standpoint. They do not require visual inspection and the addition of lubricant occurs less frequently.
- Grease, in proper quantity, is more easily contained within the system, thus allowing a simpler designed system.
- Excess leakage from the bearing is rare so grease is effective in applications where contamination must be avoided. However, in the case of central grease lubrication system, leakage could be higher than for oil circulation systems, due to the fact that there is no recirculation. Grease improves the sealing efficiency of enclosures.

5.2. General Purpose

It is common to select a family of greases that account for most applications and then order additional lubricants for specific applications that are not covered [1].

However, care must be taken with so called “General Purpose” greases. Applications of modern facilities are subjected to higher stress and are demanded higher reliability. Therefore, it is advisable to verify whether an improvement towards a grease with better performance could provide savings by means of extended relubrication intervals, less interventions and higher reliability. Still, some high performance greases can cover a wide variety of “general purpose” applications.

5.3. Special Purpose

Special circumstances may ask for a special lubricant, for example, in the case of high rotational speeds, low/high temperatures, vibration, vertical shafts, water contamination, etc. Selecting the correct lubrication is a crucial step to live up to design expectations of the application.

Regarding rolling element bearing lubrication, SKF engineers have considerable experience and knowledge of greases and oils in association with bearing operation [1-2]. This knowledge has been encapsulated into the SKF lubricants range (http://www.skf.com/group/products/lubrication-solutions/lubricants/index.html)

5.4. Relubrication Intervals

The frequency with which it is necessary to change the oil depends mainly on the operating conditions and the quantity of oil.

With oil bath lubrication it is generally sufficient to change the oil once a year, provided the operating temperature does not exceed 50 °C (120□F) and there is little risk of contamination. Higher temperatures call for more frequent oil changes, e.g. for operating temperatures around 100 °C (220□F), the oil should be changed every three months. Frequent oil changes are also needed if other operating conditions are arduous.

With circulating oil lubrication, the period between two oil changes is also determined by how frequently the total oil quantity is circulated and whether or not the oil is cooled. It is generally only possible to determine a suitable interval by test runs and by regular inspection of the condition of the oil to see that it is not contaminated and is not excessively oxidized. The same applies for oil jet lubrication. With oil spot lubrication the oil only passes through the bearing once and is not re-circulated.

In case of contaminated environments or heavy wear (e.g. in a gearbox) more frequent changes may be necessary. In ISO 4406, a classification oil contamination is given. See Chapter 9 Contamination

Regarding grease, rolling bearings have to be relubricated if the service life of the grease is shorter than the expected service life of the bearing. Relubrication should always be undertaken at a time when the condition of the existing lubricant is still satisfactory.

The time at which relubrication should be undertaken depends on many related factors. These include bearing type and size, speed, operating temperature, grease type, space around the bearing and the bearing environment. It is only possible to base recommendations on statistical rules; the SKF relubrication intervals are defined as the time period, at the end of which 99 % of the bearings are still reliably lubricated. This represents the L1 grease life. SKF recommends using experience based on data from actual applications and tests, together with the estimated relubrication intervals provided in [1].

6. Oil Supply Systems

When dealing with liquid lubricating systems it is important to have a suitable enclosure that aids in preventing leakage. Careful consideration needs to be taken when selecting the proper system [1].

6.1. Oil Bath

The simplest method of oil lubrication is the oil bath. A simple oil bath method is satisfactory for low or moderate speed machinery. The oil, which is picked up by the rotating components of the bearing, is distributed within the bearing and then flows back to the oil bath. The oil level should be such that it almost reaches the center of the lowest rolling element when the bearing is stationary. The use of oil levelers is recommended to provide the correct oil level. When operating at high speed the oil level can drop significantly and the housing can become overfilled by the oil.

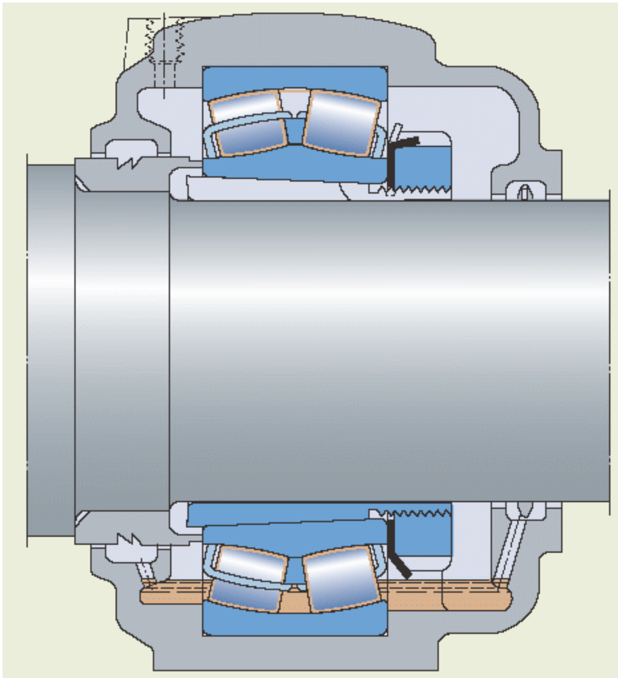


Figure 7 An oil bath system displaying proper oil level when the system is stationary

6.2. Oil Pick-up Ring

For bearing applications where speeds and operating temperature are such that oil lubrication is necessary and high reliability is required the oil pick-up ring lubrication method is recommended. The pick-up ring serves to bring about oil circulation. The ring hangs loosely on a sleeve on the shaft at one side of the bearing and dips into the oil in the lower half of the housing. As the shaft rotates, the ring follows and transports oil from the bottom to a collecting trough. The oil then flows through the bearing back into the reservoir at the bottom.

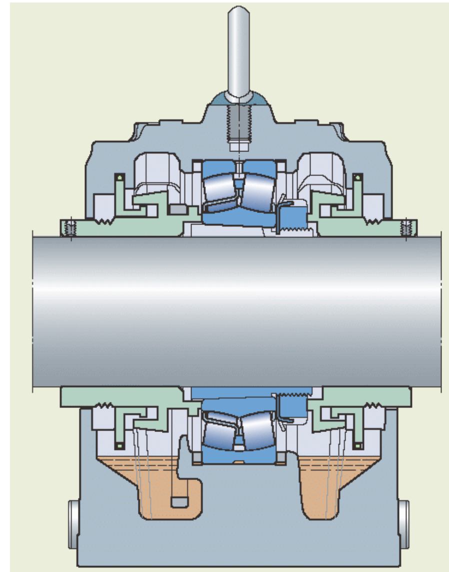


Figure 8: Oil pick-up ring method.

6.3. Wick Feed

Wick feed is suitable for extreme speeds as a small quantity of filtered oil is supplied to the bearing. Moreover, there is no risk of the lubricant being churned inside the housing. However, some attention must be given to the wicks and they have to be replaced occasionally. They should be dried and thoroughly saturated with oil before mounting, in order to prevent absorption of moisture, which would impair their ability to convey lubricant. Figure 8 shows a wick feed where the wick siphons the oil into the bearing. With this arrangement, no wear takes place but the wicks will continue to feed oil when the machine has stopped.

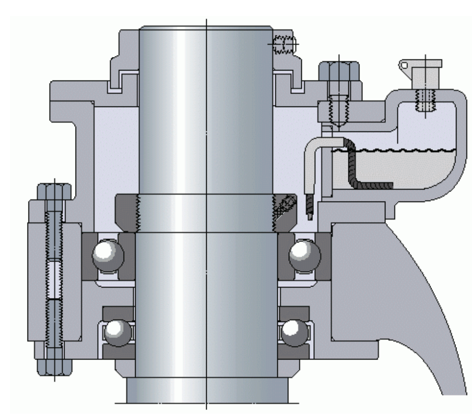


Figure 9: Vertical milling machine spindle. Note the simplicity of design. A small quantity of oil is fed to the bearing by wicks, which syphon the oil from the oil reservoirs.

Figure 10 shows an arrangement whereby oil is conveyed by a wick by means of capillary attraction to a rotating collar or flinger, where it is thrown off by centrifugal force (see also oil ring method). This system has the advantage of delivering oil only when it is needed. However, to function, the wick must be in contact with the rotating collar.

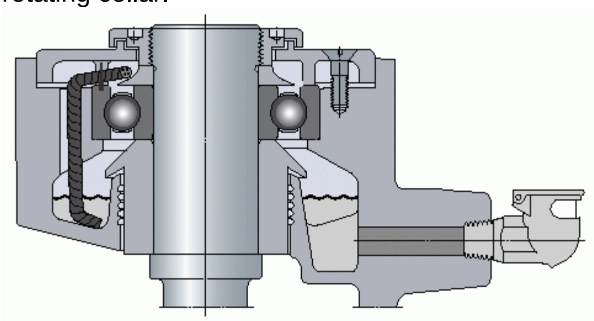


Figure 10: Wick feed on vertical shaper Spindle. The wick conveys the lubricant to a rotating collar, from which it is thrown off and drains back through the bearing. This method circulates and filters the oil, so that clean lubricant is delivered to the bearing.

6.4. Circulating System

Operation at high speeds will cause the operating temperature to increase and will accelerate ageing of the oil. To avoid frequent oil changes and to achieve a fully flooded condition, the circulating oil lubrication method is generally preferred (Figure 11). Circulation is usually produced with the aid of a pump. After the oil has passed through the bearing, it generally settles in a tank where it is filtered and, if required, cooled before being returned to the bearing. Proper filtering leads to long bearing service life. Cooling the oil enables the operating temperature of the bearing to be kept at a low level.

Entry of oil is best at the center plane of the bearing, near the top of the housing. When CARB bearings are applied, lubrication must be taken in from the side. Drain for the center feed is best done by two drains, one on each sidewall of the housing, which leads downward outside the housing. Horizontal drains must be avoided. An alternate method is to have the inlet on one side, below the horizontal center, and drain from the opposite side of the bearing. The outlet should be larger than the inlet to prevent accumulating too much oil in the bearing housing.

The amount of oil retained in the housing is controlled be the location of the outlet. For “wet sump” the oil level at a standstill must not be higher than the center of the lowest ball or roller. A reliable sight-glass gauge should be provided to permit an easy check. Where there is extreme heat, the lubricant will last longer if the “dry sump” design is used, which permits oil to drain out immediately after it passes through the bearing. The outlets are then located at the lowest point on both sides of the housing. With this arrangement, the bearing remains cleaner as there is little chance of carbonized oil being retained in the housing. When the outlets or drains are located at the lowest point on both sides of the housing, an arrangement is necessary to indicate when oil flow is impaired or stopped.

A key parameter to consider is the required oil flow for cooling. A minimum oil flow for lubrication is necessary. For additional cooling, the oil flow must be higher. There are complex calculations based on heat transfer between the bearing components, oil, and environment.

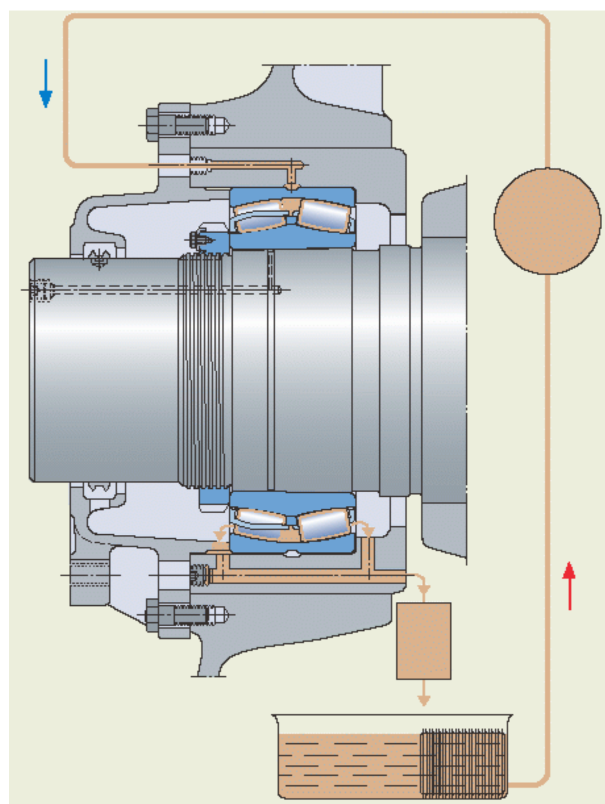


Figure 11 Circulating System

6.5. Oil Jet

For very high-speed operation a sufficient but not excessive amount of oil must be supplied to the bearing to provide adequate lubrication without increasing the operating temperature more than necessary. One particularly efficient method of achieving this is the oil jet method (Figure 12) where a jet of oil under high pressure is directed at the side of the bearing. The velocity of the oil jet must be sufficiently high (at least 15 m/s) to penetrate the turbulence surrounding the rotating bearing. A dry sump should always be used in addition to a drainage hole to alleviate the accumulation of extemporaneous oil.

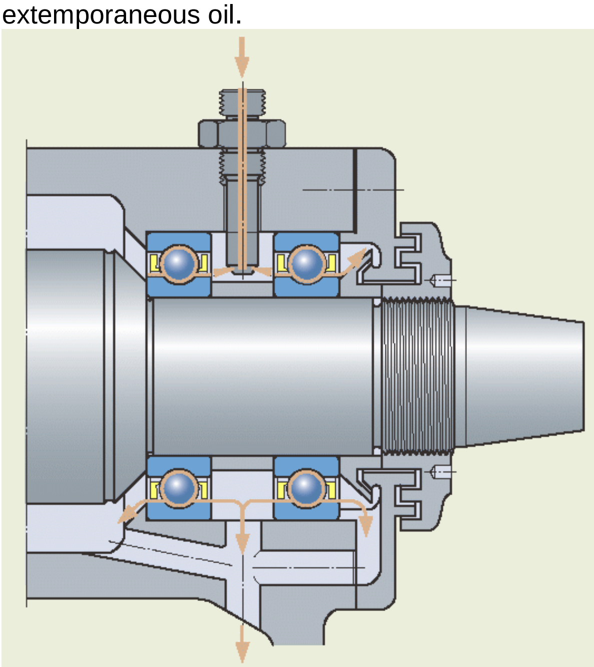


Figure 12: Oil jet method.

6.6. Oil-Spot

With the oil-spot method (Figure 13) – also called the oil-air method – very small, accurately metered quantities of oil are directed at each individual bearing by compressed air. This minimum quantity enables bearings to operate at lower temperatures or at higher speeds than any other method of lubrication. The oil is supplied to the leads by a metering unit, at given intervals. The oil is transported by compressed air; it coats the inside of the leads and "creeps" along them. It is projected to the bearing via a nozzle or it just flows to the bearing raceways by a surface tension effect. The compressed air serves to cool the bearing and also produces an excess pressure in the bearing arrangement to prevent contaminants from entering.

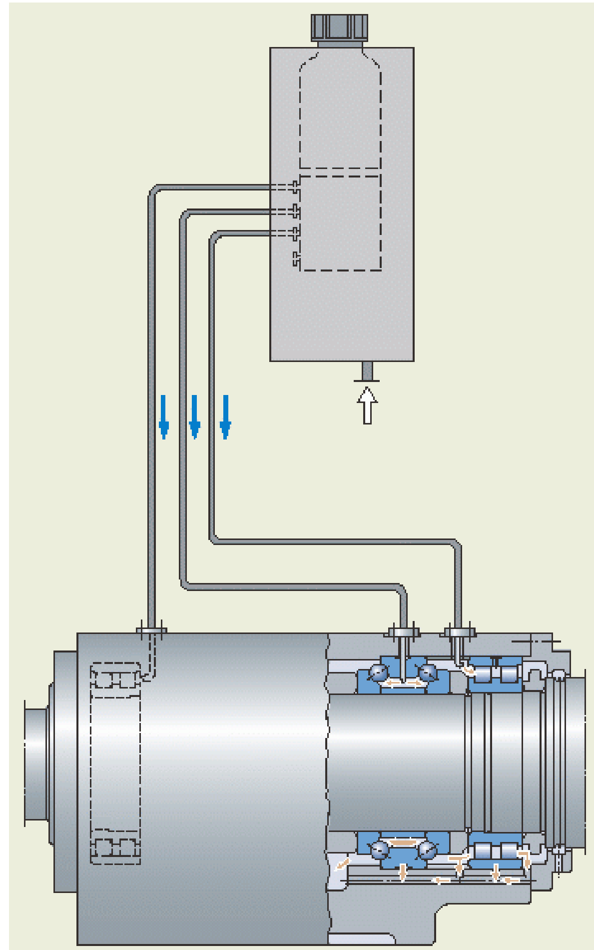


Figure 13: Oil-spot method.

6.7. Oil Mist from Separate Mist Generator

The oil mist method consists of a mixture of air and atomized oil that is supplied to the bearing housing under suitable pressure. The oil mist is formed in an atomizer. Several manufacturers offer suitable designs and can recommend systems, capacities, and operating temperature and pressure to assure the required oil viscosity is maintained.

In an oil mist system, air is charged with mist oil and then introduced in the housing between the bearings before escaping through the housing enclosure or vents. The air from the supply line first passes through a filter then through a reduction valve, which reduces the line pressure to a suitable value. It is important that the air be sufficiently dry, which sometimes requires the use of a dehumidifier.

This method of lubrication has proven effective in reducing the operating temperature, as the flow of air prevents excess oil from accumulating in the bearing. Since the air under pressure in the housing escapes through the housing enclosure or vents, the entrance of moisture and grit is retarded. In addition, oil mist lubrication continuously supplies only clean, fresh oil to the bearings. In an oil mist system, the bearings require very little lubricant, thus oil consumption is comparatively small.

Oil mist lubrication has not been recommended for some time due to possible negative environmental effects. The oil spot method offers significant advantages. For example, higher base oil viscosity can be more effectively used with the oil spot system. Also, the system does not vent oil mist into the environment. Finally, it uses a lower volume of oil, so it is more cost-efficient. A new generation of oil mist generators permits to produce oil mist with 5 ppm. oil. New designs of special seals also limit the amount of stray mist to a minimum. In case synthetic non-toxic oil is used, environmental effects are even further reduced. Oil mist lubrication today is used in very specific applications, like the petroleum industry.

7. Grease Supply

The choice of the relubrication procedure for bearings generally depends on the application and on the relubrication interval obtained.

- Replenishment is a convenient and preferred procedure if the relubrication interval is shorter than six months. It allows uninterrupted operation and provides, when compared with continuous relubrication, a lower temperature.
- Renewing the grease fill is generally recommended when the relubrication intervals are longer than six months. This procedure is often applied as part of a bearing maintenance schedule e.g. in railway applications.
- Continuous relubrication is used when the estimated relubrication intervals are short, e.g. due to the adverse effects of contamination, or when other procedures of relubrication are inconvenient because access to the bearing is difficult. Continuous relubrication is not recommended for applications with high rotational speeds since the intensive churning of the grease can lead to very high operating temperatures and destruction of the grease thickener.

When using different bearings in a bearing arrangement it is common practice to apply the lowest estimated relubrication interval for both bearings.

7.1. Replenishment

The bearing should initially be completely filled, while the free space in the housing should be partly filled. Depending on the intended method of replenishment, the following grease fill percentages for this free space in the housing are recommended:

- 40 % when replenishing is made from the side of the bearing (Figure 14);
- 20 % when replenishing is made through the annular groove and lubrication holes in the bearing outer or inner ring (Figure 15).

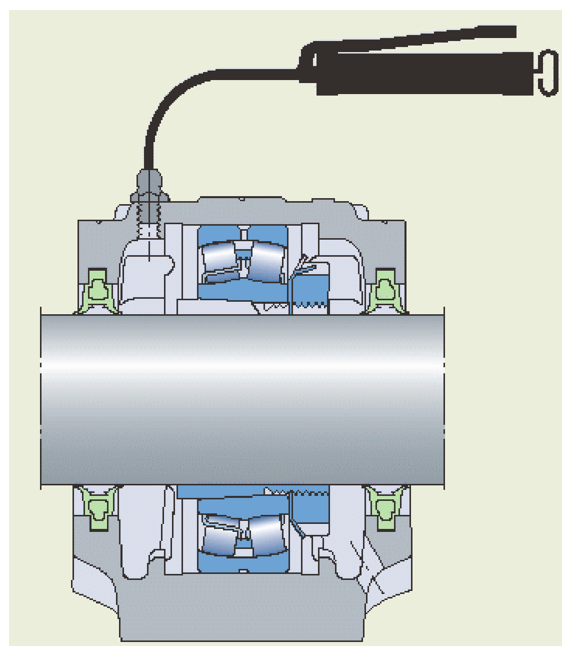


Figure 14: Replenishing made from the side of the bearing.

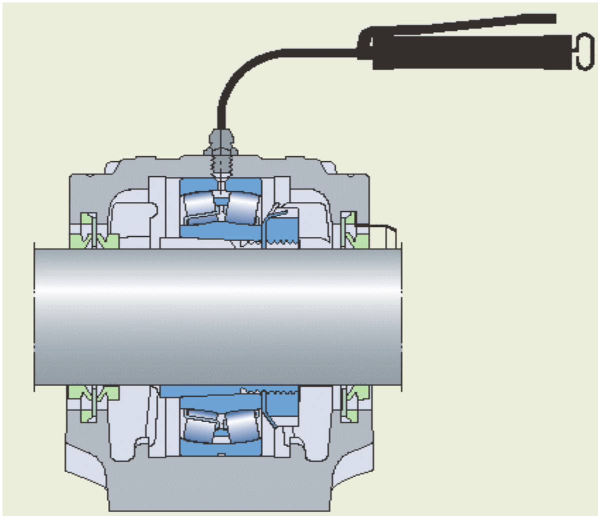


Figure 15: Replenishing made through the annular groove and lubrication holes.

Suitable quantities for replenishment from the side of a bearing can be obtained from

$G_p = 0{,}005\ D\ B$

and for replenishment through the bearing outer or inner ring from

$G_p = 0{,}002\ D\ B$

where: Gp is the grease quantity (g)

D is the bearing outer diameter

B is the total bearing width (mm).

(For thrust bearings use height (H))

To facilitate the supply of grease using a grease gun, a grease nipple must be provided on the housing. If contact seals are used, an exit hole in the housing should also be provided so that excessive amounts of grease will not build up in the space surrounding the bearing as this might cause a permanent increase in bearing temperature. The exit hole should be plugged when high-pressure water is used for cleaning. The danger of excess grease collecting in the space surrounding the bearing and causing temperature peaks, with its detrimental effect on the grease as well as the bearing, is more pronounced when bearings operate at high speeds. In these cases it is advisable to use a grease escape valve rather than an exit hole. This prevents over-lubrication and allows relubrication to be performed while the machine is in operation.

To be effective in replacing old grease, it is important that grease is replenished while the machine is operating. In cases where the machine is not in operation, the bearing should be rotated during replenishment. When lubricating the bearing directly through the inner or outer ring, the fresh grease is most effective in replenishment; therefore, the amount of grease needed is reduced when compared with relubricating from the side. It is assumed that the lubrication ducts were already filled with grease during the mounting process. If not, a greater relubrication quantity during the first replenishment is needed to compensate for the empty ducts.

Where long lubrication ducts are used, check whether the grease can be adequately pumped at the prevailing ambient temperature.

The complete grease fill should be replaced when the free space in the housing can no longer accommodate additional grease, e.g. approximately above 75 % of the housing free volume. When relubricating from the side and starting with 40 % initial fill of the housing, the complete grease fill should be replaced after approximately five replenishments. Due to the lower initial fill of the housing and the reduced topping-up quantity during replenishment in the case of relubricating the bearing directly through inner or outer ring, renewal will only be required in exceptional cases.

7.2. Renewing Grease Fill

When renewal of the grease fill is made at the estimated relubrication interval or after a certain number of replenishments, the used grease in the bearing arrangement should be completely removed and replaced by fresh grease. Filling the bearing and housing with grease should be done in accordance with the guidelines given under “Replenishment”.

To enable renewal of the grease fill the bearing housing should be easily accessible and easily opened. The cap of split housings and the covers of one-piece housings can usually be removed to expose the bearing. After removing the used grease, fresh grease should first be packed between the rolling elements. Great care should be taken to see that contaminants are not introduced into the bearing or housing when relubricating, and the grease itself should be protected. The use of grease resistant gloves is recommended to prevent any allergic skin reactions.

When housings are less accessible but are provided with grease nipples and exit holes, it is possible to completely renew the grease fill by relubricating several times in close succession until it can be assumed that all old grease has been pressed out of the housing. This procedure requires much more grease than is needed for manual renewal of the grease fill. In addition, this method of renewal has a limitation with respect to rotational speeds: at high speeds it will lead to undue temperature increases caused by excessive churning of the grease.

7.3. Continuous Relubrication

This procedure is used when the calculated relubrication interval is very short, e.g. due to the adverse effects of contamination, or when other procedures of relubrication are inconvenient, e.g. access to the bearing is difficult. Due to the excessive churning of the grease, which can lead to increased temperature, continuous lubrication is only recommended when rotational speeds are low, i.e. at speed factors

- A < 150 000 for ball bearings and
- A < 75 000 for roller bearings.

In these cases the initial grease fill of the housing may be 100 % and the quantity for relubrication per time unit is derived from the equations for Gp under "Replenishment" by spreading the relevant quantity over the relubrication interval. When using continuous relubrication, check whether the grease can be adequately pumped through the ducts at the prevailing ambient temperature.

7.4. SKF Automatic Lubricators

When lubrication points are too many or difficult to reach, tasks imply safety risks, or continuous lubrication is advised. SKF Automatic lubrication systems can be an ideal choice. The portfolio offers from easy to install and cost effective single point lubricators up to tailored designed centralized lubrication systems. Among the single point devices, three technologies can be identified: Gas driven, electromechanical and dispenser. The first one is designed for installation directly on the lubrication point, and is suitable for explosive atmospheres. When remote installation or larger reservoirs are required, electromechanical units are more advised. Dispensers are most suitable when ample temperature ranges and harsher environment are expected. In some cases, these units can handle several points by means of a progressive distributor. For more complex applications, SKF offers a comprehensive range of centralized lubrication systems. Further details can be found at http://www.skf.com/group/products/lubrication-solutions/lubrication-systems/index.html

Figure 16: Gas driven automatic lubricator SYSTEM 24.

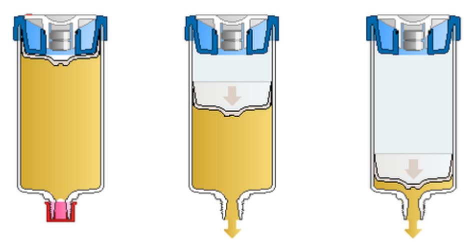


Figure 17: The working of SYSTEM 24: the amount of grease supplied is set beforehand.

Figure 18: Electro mechanical Automatic lubricator SKF TLSD .

Figure 19: Lubricant Dispenser SKF TLMR .

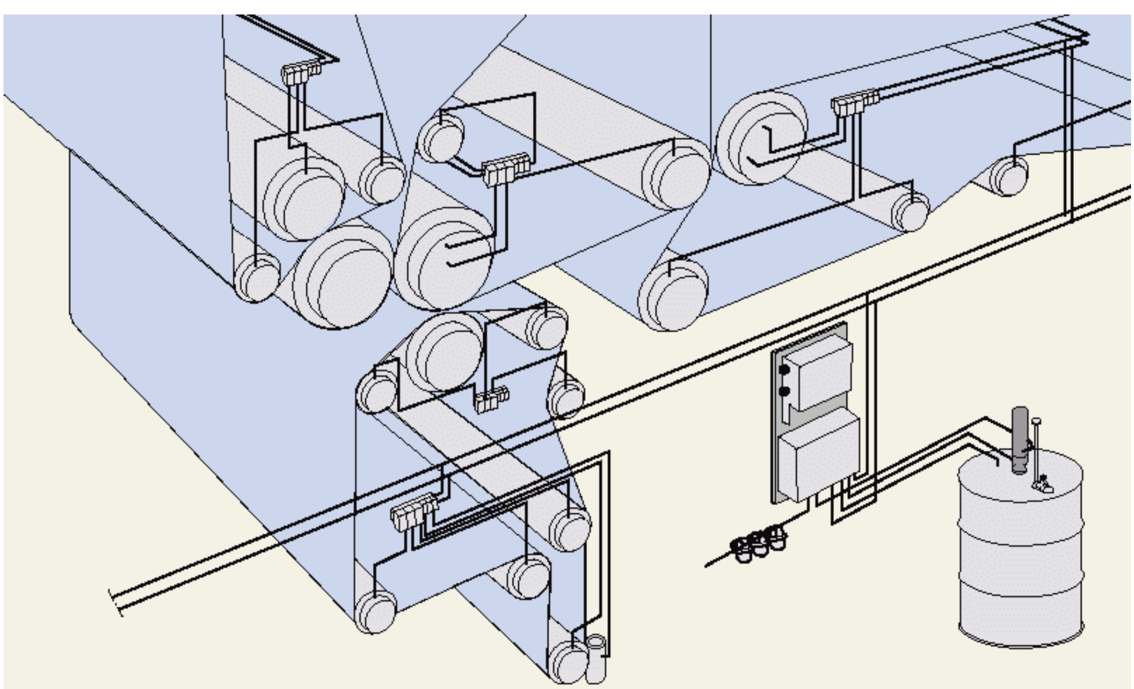


Figure 20: Automatic grease system in paper machine.

8. Storage and Handling

The method of storage is directly related to the longevity and quality of the lubricant over a period of time. Given that the lubricant is free from contamination and still holds its original properties, the storage container is the single most important way to ensure the lubricant is not compromised by external influences.

When selecting the pack size of a given lubricant, several factors should be taken into account, such as the consumption rate, delivery times, available space and storage conditions.

8.1. Storage Transfer

Assuming the lubricant is stored properly, the other potential for compromise comes from the transfer. The transfer from a storage container to the machinery can take many forms, but should be considered an extension of the overall plant storage lubricant system. It does little good to store a lubricant in a contamination free container, only for the lubricant to be compromised during transfer. Tools like SKF LAOS Series are of great help in achieving this goal. Figure 21 provides some examples on useful tools that help to avoid cross contamination while keeping cleanliness codes according with the targets.
Oil storage stations, for example help to reduce the contamination level by means of continuous filtration while the oil remains in storage and the colour coding system helps to avoid cross contamination.

8.2. Storage Life

Lubricant storage life will vary dependant upon many factors; all of which are specific to the individual plant, location, and operating environment. The manufacturer of the plant's many lubricants will be best suited to recommend proper storage and handling procedures. It is important that the specific manufacturer makes the recommendations, other than the competitive brand, due to the fact that they will know the specific ingredients to their own product.

In addition to the manufacturer's recommendations, there are some common sense storage rules that will add to the longevity of the lubricant being stored.

- Rotate lubricants, ensuring that the first lubricant into storage is the first lubricant to be used.
- Monitor date codes, to guarantee lubricant shelf life has not been exceeded.
- Avoid lubricant storage in extreme temperatures if possible.
- Avoid lubricant storage in areas where the temperatures fluctuate drastically.
- Avoid a humid environment.
- Keep the storage container in a clean and dry place.
- The lubricant container should be stored whereby the bung (the plug to the container opening) can be easily accessed.
- Also, keep in mind that the containers should be easily moved, allowing proper first in, first out rotation.


Figure 21 SKF LAOS oil transfer reservoirsand oil Storage stations

While these suggestions may be difficult to follow as listed, the task of keeping lubricants in contamination free status becomes even more difficult once the container is opened. A standard operating procedure (SOP) is a must when multiple people are accessing the same storage container. The SOP is simple and should be posted in written form near the lubrication storage containers (or where everyone can see it).

1. Ensure hands are free from lose particles which could possibly fall into the storage or transfer container.
2. Confirm that the area surrounding the storage and transfer container opening are clean.
3. After removing the bung, place it in a common place (where it is not easily lost), and that that place is clean.
4. Use a clean screen when transferring lubricant from one container to the next.
5. After transfer is complete, clean areas around both storage and transfer containers.
6. Replace bung (ensuring it is clean)

Simple in approach and form, the SOP can be adapted to meet the specific needs of the users and specific transfer equipment. The basic idea is to ensure that the transfer is completed with a minimal loss of lubricant, and that no contamination took place in the process.

8.3. Labeling

It is impossible to ensure proper lubrication management when it is unknown exactly what lubricant is used in what application and machine. Obviously, there would be no problems with mixing lubricants if every machine in the plant used the exact same lubricant. But, since this is not the case, it is imperative to not only know what lubricant goes into each specific machine but you know what lubrication you have in each container.

Proper labeling begins with proper understanding within the organization. A basic understanding of the rules of lubrication is an excellent place to start. For example, if everyone involved understands that lubricants are not to be mixed, then the process of proper identification is credible. From this basis, any clearly marked lubrication identification system will work well.

The physical act of marking the storage and transfer devices to coincide with the associated machine is simple. Yet, conditions of the environment may make one method or combination of methods more practical.

Text based identification systems are by far the easiest to utilize from the perspective of ordering, reordering, inventorying, and dating. Unfortunately, labels become lose and fall off; text is easily worn off, faded, or scratched; and mistakes are made when lubricant designations are similar (prompting the user to accidentally use the wrong lube). Upgraded, or lubricants carrying different designations cause a great deal of confusion. Ultimately, some companies may experience lubrication identification problems due to language barriers.

Color-coding seems an excellent solution to these potential problems. In the color-coding scheme, all affiliated lubricants are designated a specific color or color combination. Accordingly, the bulk and transfer containers share the same color designation as that of the equipment. Paint, colored bands, or stickers are placed on each container/machine to set it apart. Standard Operating Procedures (SOP) will dictate, for example, that red painted transfer containers are to be used only with red colors bulk containers and machines. Assuming that the proper lubricant assessment has been made for each machine, and as long as the initial lubricant is labeled properly and placed into the correct bulk container, the likelihood of misapplication is minimal.

A good example of appropriate storage and labeling are the tools shown in Figure 21 and the grease fitting caps and tags TLAC 50 shown in Figure 22

Figure 22 SKF Grease fitting caps and tags TLAC 50

8.4. Lubricant Maintenance

In conjunction with manufacturer recommendations per specific lubricant, periodic agitation of the storage container may be needed. The purpose behind this action is to re-suspend the additives that may have settled during its long storage period. When an Oil Storage Station (as in Figure 21) is in place, this process together with continuous filtration is done automatically by the equipment

8.5. Disposal

Proper lubricant disposal is outlined by governmental regulations. It is recommended that proper lubricant disposal be addressed in the planning phase of the lubrication plan.

8.6. Recycling/Reclamation

Under the right circumstances, reclamation is a wonderful option and can financially benefit both the reclaimer and the user of the oil. Reclaiming also reduces the amount of oil sent for disposal and the cost associated with disposal. Today, it is simply unnecessary to allow these fluids to deteriorate to an extremely contaminated, detrimental condition. However, if they do, many of them can be reclaimed and returned to "suitable for continued use" condition. “This practice has very positive environmental impact and economic significance for both the oil manufacturers and the oil users.” [3].

Apart from lubrication disposal, many municipalities and manufacturers offer recycling services. While the municipality may charge for recycling, manufacturers may offer these services as part of their overall sales package.

8.7. Biodegradable Greases

Recycling and reclaiming lubricants are excellent for handling once they have been used and are in a container. But what about lubricants that find their way out of the equipment, or storage container, and onto the ground? Pumps and absorbent materials are excellent for cleaning up larger spills – that is if the spill is noticed at all. But what happens to the lubricants that are not noticed?

Overcoming the limitations of biodegradable lubricants has been a goal of SKF for many years. Thanks to its specialist knowledge of bearing behavior and the effects of lubrication, the company has now launched its first “green grease,” which is believed to be the first of its kind on the open market. Developed to meet a range of bearing applications, the new grease, called LGGB 2, meets the strict criteria that SKF places on bearing greases. It has been tested and approved for steel-on-steel spherical plain bearings, ball and roller bearings. The new grease is part of the continued commitment to the environment and the adoption of sound environmental practices within the bearing industry [4].

9. Contamination

9.1. Sources

Compatibility of Greases
If a system is changed for a particular reason, lubrication compatibility is of utmost importance. It can be detrimental to system operation to mix incompatible greases. Greases with the same base oil and thickener properties can generally be mixed without a great effect on the system. For example, calcium and lithium based greases are usually miscible. However, they are not miscible with sodium-based grease. Always consult the manufacturer for properties and suggestions when combining grease.

Solids
Solids contamination is any particulate, which is hard in nature. Dirt, rocks, and metal particles are examples of solids. While solids may have adverse effects on the physical properties of the lubricant, of greater concern is the wear damage done to the machinery.

Fluids
Fluid contamination includes anything that is liquid in form. Water, chemicals, process byproducts, and solvents are all considered fluid contamination. As such, vents, seals, and any other kind of opening, which allows access to the lubricant, should be taken into consideration.

Air/Gas
Dependent upon the specific application, gasses, when mixed with the lubricant will change the lubricant's characteristics. Whether it is mineral, synthetic, or animal and vegetable based, among other characteristics, gases will reduce viscosity, increase foaming, and possibly increase the flashpoint.

Foam
"Foam may be a result of a variety of problems including air leaks, contamination, and over-filling of sumps. Foaming can cause loss of oil out of vent and serious operational problems in most lubricated systems." [1].

9.2. Cleanliness Level Requirements

Lubricating oil should be continuously cleaned of impurities. It is important to remove both water and solid particles from the oil. When selecting suitable water extractors and filters the following cleanliness guidelines should be aimed for, applicable for rolling element bearings [5]:

a) Water content should be below 200 ppm.
b) Particle content should be according to ISO 4406 cleanliness class –/15/12 (using a microscope) or 18/15/12 (using automatic particle counter) or better.

9.3. Water Removal

SKF has found water to be one of the major reasons for short service live of bearings. The recommendation for water content to be below 200 ppm gives a good balance between the cost of water removal and increased bearing service life. The recommended water content level can easily be obtained by using ordinary extractors available on the market. The most common extractors work according to two basic principles, using vacuum or centrifugal forces. The advantage of the centrifugal extractors is that they normally remove more water per minute than the vacuum extractors. On the other hand, vacuum extractors have the advantage that they take air out as well.

The final result of water removal depends very much on the amount of water entering the system. Therefore, the main question when selecting equipment is the estimation of the risk of water entering into the lubrication system. The most common reasons for the entry of water are inefficient housing sealings and high-pressure cleaning, but accidental leakage from oil coolers etc. has to be considered as well.

The bearings should never be exposed to oil that has higher water content than that recommended. This is especially important during standstill. If this does happen there is a great risk that the free water in the oil can start the corrosion process. Therefore, it is very important to keep water content low just before machine stoppages and to prevent entry of water during standstill.
Other causes of high water content in machine oils are so-called dispersant additives. The main task of these additives is to keep all contaminant particles floating in the oil until they enter the oil filters. Unfortunately, these additives sometimes have the same effect on water molecules. This is one of the reasons for the clogging of oil filters. In such cases the continuous use of a water extractor is required. From the bearing point of view, oil lubrication systems should have equipment for continuous water removal. Without such equipment, machine oils may have water content higher than the 200 ppm.

9.4. Oil Filters

Different types of oil filters have been used for many years in the lubrication systems. The first replaceable filters were so-called mesh elements made of woven steel wire. These filters were efficient when it came to very large particles but research at SKF has proved that even particles smaller than 10 µm should be removed from the oil because they may have a detrimental effect on bearing surfaces.

Normally there is a connection between fine filters and clean oil. However, the most important thing is to have clean lubricating oil. Therefore, SKF's recommendation is based on oil cleanliness instead of filter ratings. This recommendation is based on the optimized filter cost as well as on the bearing service life obtained. When selecting filters, the filterability of the current oil should also be considered.

The filter rating should give an indication of the filter efficiency. Unfortunately, in the case of so-called "nominal" filters there is no definition of the efficiency. Efficiency of the filters is defined as a reduction factor β which is related to one particle size. The higher the β value, the more efficient the filter is for the specified particle size. Therefore both the β value and the specified particle size have to be considered. The reduction factor β is expressed as the relationship between the number of specified particles before and after the filter. This can be calculated as follows:

$\beta x = n1/n2$

n1 = number of particles per volume unit (100 ml) larger than x µm upstream the filter

n2 = number of particles per volume unit (100 ml) larger than x µm downstream the filter

Note! The β value is connected to only one particle size in µm, which is shown as the index e.g. β3 , β6, β12, etc. For example, a complete rating β6 = 75 means that only 1 of 75 particles of 6 µm or larger passes the filter.

Figure 23 Filtration system.

9.5. Particle Counting

The simplest procedure for particle counting is to filter the oil on to a membrane and look at it through an optical microscope. The size of a particle is established by measuring the longest dimension. The particle size distribution can be estimated by comparing the sample membrane with reference membranes of different cleanliness levels. A skilled operator should do this as it is a subjective method.

Automatic Particle Counting (APC analysis) is a method more commonly used. Particles are passed in front of a light source coupled to a sensor. The amount of light passing through a window depends on the size of the particle passing that window. The particle size is derived from its cross-sectional area. Calibration of the equipment is most important. A drawback of using a sensor is the necessity of removing air bubbles, which would otherwise be counted as particles.

Yet another method for particle analysis is Spectro-metric Oil Analysis Program, also called SOAP. This method is very good for the analysis of small particles e.g. from abrasive wear. Wear particles are in most cases smaller than 5 to 10 µm.

There are a number of additional methods and equipment on the market today and new products are launched all the time in this growing field of condition monitoring. For example, Pacific Scientific Instruments introduced an on-line particle counter that outputs in terms of ISO 4406 classes. (see http://www.particle.com). Whatever the method used the results should be presented as a development trend. Errors are to be expected if the results of an analysis show that there are very big differences between the different particle size ranges. If there are too many large particles the filter may be damaged or by-passed.

Another reason could be that the oil has not been correctly sampled. It may include sediment particles. The presence of too many particles results in a “step” in the distribution curve. This “step” shows the performance limit of the filter.

9.6. ISO Contamination levels

Standards establish information as to allow comparison and interpretation of contamination (cleanliness) levels and hence enabling control of particle contamination to ensure system performance and reliability. The method for coding the contamination level in a lubrication system is according to ISO 4406:1999 [6]. In order to simplify the reporting of particle count data, the quantities counted are converted in a code using scale numbers. These are allocated according to the number of particles counted per millilitre of the fluid sample.

The code for contamination levels using automatic particle counters (APC) comprises three scale numbers relating to the number of particles ≥ 4 μm (c), ≥ 6 μm (c) and ≥ 14 μm (c), where (c) refers to APC. The three numbers are written one after the other separated by oblique strokes (slashes). Example: 18/15/12. APC calibration is according to ISO 11171.

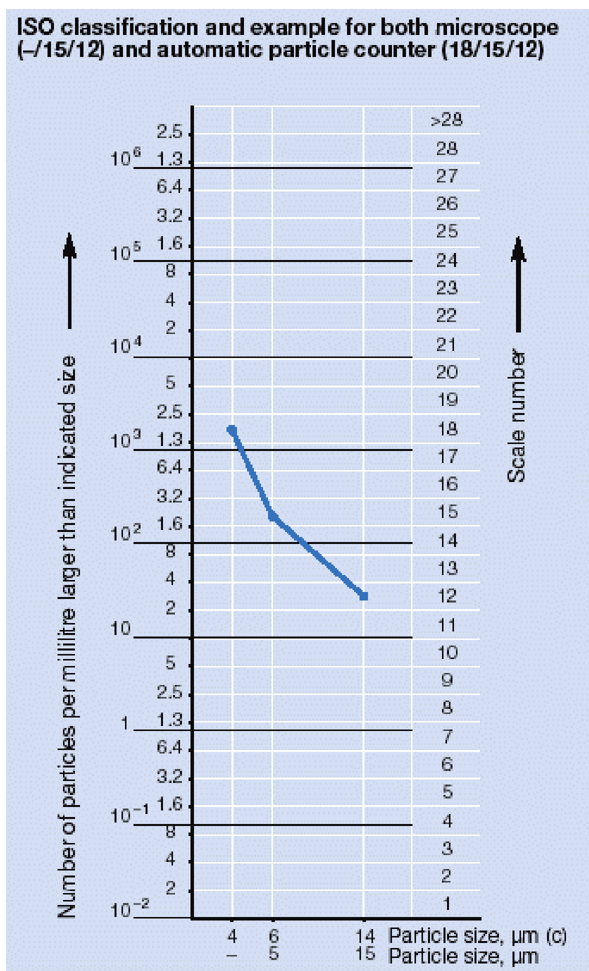


Figure 24: ISO 4406 Cleanliness code.

For example, the ISO class "-/15/12" (microscope) or better for rolling element bearings, serves as a guideline. Counting is undertaken in accordance with ISO 4407. This corresponds to less than 320 and 40 particles per ml that are larger than 5 and 15 µm, respectively. The ISO class "18/15/12" (APC) refers to less than 2500, 320, and 40 particles per ml that are larger than 4, 6, and 14 µm.

The number of abrasives, such as metallic particles or sand, should be lower. Serious concerns for *abrasive wear* arise for the following classes (according the different hardness types):

- Soft particles (< 500 Hv): class 15/12 (320/40 particles per ml > 5/15 µm)
- Hardened steel (600-800 Hv): class 13/10 (80/10 particles p ml > 5/15 µm)
- Hard particles (> 850 Hv): class 10/7 (10/1 particles p ml > 5/15 µm)

For rolling element bearings with bore diameter > 100 mm, somewhat higher values are allowed.

9.7. Oil Sampling

An adequate oil sampling procedure has to consider port location, design of the test port , and a procedure that provides clear instructions.

The ideal oil sample should be representative, i.e. identical to the lubricant in contact with the rolling bearing [5]. Sampling from the pressurized side of the circulating oil system can be done either with a simple ball valve or with more sophisticated equipment. The main requirement is to flush the valve and the sample bottle so much that no additional contamination will enter the oil sample. When taking oil samples from non-pressurized systems like oil baths and oil reservoirs it is important that the sample is taken at a certain distance above the bottom sedimentation. In these cases some kind of syringe or pump has to be used. The results are not as accurate as those obtained when sampling from pressurized pipes.

On the other hand, oil samples from return pipes can be used when analyzing the source of the wear particles. The best way to analyze the cleanliness level of the oil is to install an online automatic particle counter. However, all oil lubrication systems should be provided with good sampling points because additional testing of the oil for viscosity, water content, oxidation etc is required. For this purpose some equipment is available on the market. This equipment uses sampling points integrated in the pressurized side of the lubrication system. When the sampler is connected to a sampling point it is easy to flush the sample bottle with the pressurized lubricating oil. This ensures that the oil sample will be representative.

9.8. Checking Water Content

Today there are some products on the market for continuous on-line measurements, but the method most widely used is to take an oil sample and carry out a Carl-Fischer analysis. Irrespective of the method, the results are usually presented in ppm, because the actual quantities are very small. Maximum water content depends on the application but in all cases it is advised to be below 200 ppm.

9.9. Checking Oil Condition

As certain properties change during operation, regular condition checks should be carried out. For example, the degradation of the oil is mainly determined by how often the oil passes through heated areas in the system, like bearings, pumps etc. Contamination also influences the oil “life”. The greater the number of steel particles in the oil, the faster the oxidation of the oil. Suitable oil change intervals can be determined by regular checks of the oil condition. Such an analysis should include checking the following properties:

- Viscosity
- Oxidation
- Particle distribution by size
- Microscopic examination of particle type and shape
- Water content
- Loss of additive content

These properties dictate the life of the oil in oil baths, but in circulation systems oil life can be extended by removing particles and water from the oil. The main advantage of regular checking is the possibility of following up the results of maintenance activities, such as changes of filter elements.

9.10. On-Site Testing

Typical parameters to be measured for oils at the plant include viscosity, water in oil, ISO cleanliness code, etc. Likewise, with the help of the SKF TKGT 1, analysis of the consistency, oil content and contamination level of given grease can be assessed.

Figure 25 SKF TKGT 1 Grease Test Kit

9.11. Checking New Lubricants

Although people believe that new oil equals clean oil, unfortunately it is not uncommon to find ISO cleanliness codes in the range of 21/18. It should not be assumed new lubricant delivered from the manufacturer is completely contamination free. While ISO 4406 sets standards for lubrication cleanliness, not all manufacturers follow ISO standards. It is always advisable to perform a quick patch test in the field when receiving the oil from the supplier, unless the manufacturer specifically guarantees their specification for cleanliness.

To be clear, new lubricant contaminants may not be the fault of the manufacturer. The time it takes for a lubricant to reach the end user can be lengthy, and could experience many different environmental changes along its way. This is due in part to the many different handlers of the lubricant: from the shipping companies through the distributors, and then eventual storage at the end user’s facility. Consequently, the probability of the lubricant being contaminated should at least be considered.

To offset the possibility of contaminated lubricant, a sample should be taken and analyzed. While oil sample analysis can be costly, both for the service itself and the overhead costs involved the proactive approach to lubricant cleanliness before utilization could save time and even greater expenses later.

10. Data Management and Reporting

There are various ways how to manage all the information and lubrication tasks within a plant, for example, integrated with the plant's Computerized Maintenance Management System (CMMS).

The objective is to run a program to register and follow-up lubrications tasks. The software should have functions like:

- Report lubrication process with routes and done tasks date.
- Follow status of the tasks.
- Select a person responsible.

- Detection and report of failures and problems in machines.

For small and medium plants, when no specific software is in place, SKF Lubrication Planner can be of great help. The software as available for free and it has been developed to help in the administration of a lubrication plan, thereby bridging the gap between the need for a software platform vs. administration by a simple spreadsheet.

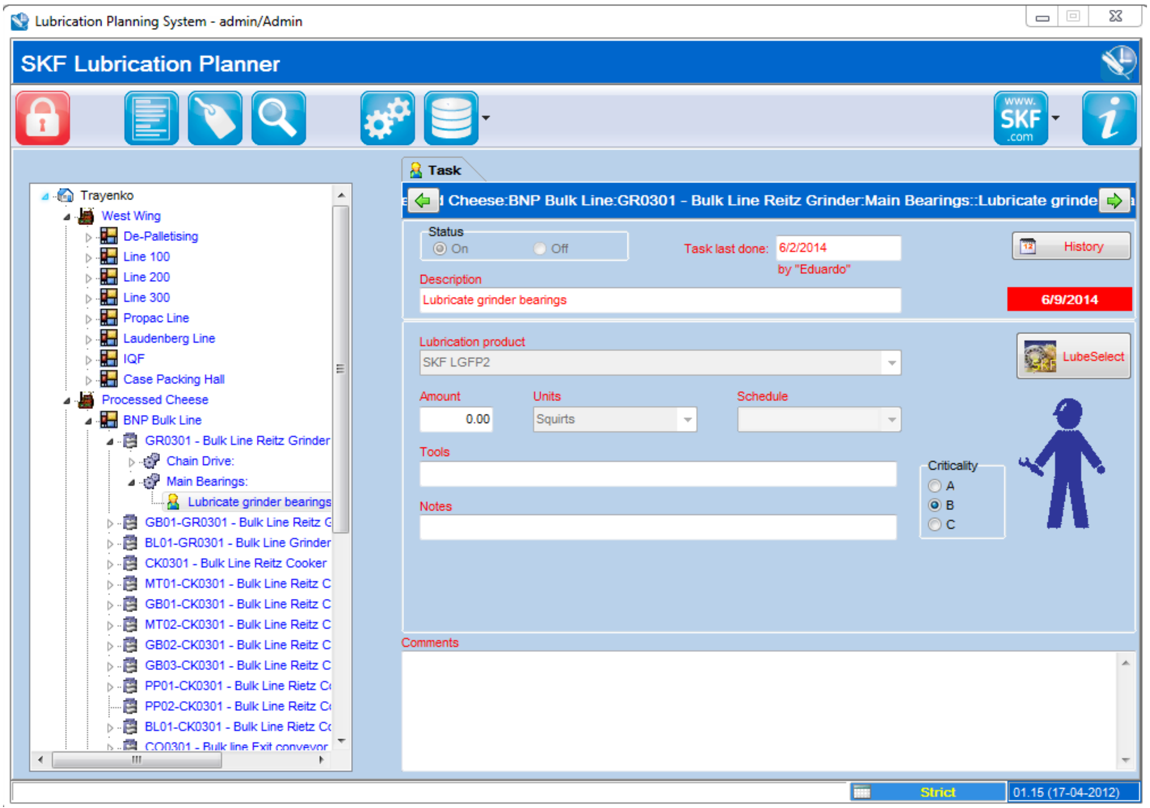


Figure 26 SKF Lubrication Planner

11. Training

Anyone can provide training to a group of individuals, but what guarantees that the attendees absorbed the information? Even more relevant is the line of questioning:

- What was the purpose of the training?
- Were the right people in the training?
- Was the training directly related to the needs of the individuals in attendance?
- Was the training conducted with the overall maintenance objective in mind?
- Was the training conducted with the intention of completing personnel training hour requirements?

Lubrication management, as a part of the overall maintenance program, rests upon the entire maintenance staff not only understanding, but also actively participating in the program’s upkeep.

While traditional education on lubrication and lubrication systems include: lubrication fundamentals, contamination control, and lubrications storage and inspection (all of which are very important), training the staff for true lubrication management is much more comprehensive.

To begin with, plant management must make the commitment to the expertise of those who deal with lubrication. This costs money and may require resources to be shifted away from other functions.

While it is beneficial to begin with skills mapping of the employee, a much more concise solution to personnel competence is certification.

Certification assures a specific level of quantifiable knowledge and skill in an employee. The International Council for Machinery Lubrication (ICML) is one such entity offering certification.

The ICML's mission is to be “organized to serve the needs of the lubrication end user on a global basis. The activities of ICML include standards development, scholarships, skill certification and curriculum development. ICML certification shows that you are a professional with the ability to successfully lubricate machinery and utilize oil analysis. You get worldwide industry recognition of your knowledge and proficiency in oil analysis/machinery lubrication techniques [10].

12. Conclusion

While this article has provided a great deal of best practices relating to lubrication management, there is still a lot more to know. It is suggested that anyone conducting investigations for their plant, that they contact a reputable lubrication service to assist in assessing plant needs.

13. Acknowledgements

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[9] SKF Lubrication Planner http://www.skf.com/group/products/lubrication-solutions/lubrication-management-tools/skf-lubrication-planner/index.html

[10] International Council for Machinery Lubrication (ICML) http://www.lubecouncil.org

15. Additional Resources

American Petroleum Institute (API) http://www.api.org

American Society of Mechanical Engineers (ASME), http://www.asme.org.

American Society for Testing and Materials (ASTM), http://www.astm.org