7 Lubrication

Lubrication

This part of the handbook provides lubrication guidelines for almost all the bearing positions in the paper machine. By following these guidelines, the user should be able to reduce many common bearing failures related to lubrication.

Why lubricate?

Lubrication in earlier times

Lubricants are products that predate the industrial age. They have been used in one form or another for several thousand years to fight friction or for as long as man has needed to move bulky objects.

The first great civilisation evolved in the Middle East some six thousand years ago. Trade, construction and war necessitated the transport of heavy goods, but it was not always an easy matter.

An Egyptian illustration from some four thousand years ago demonstrates the point.

What was in the jar, shown in **fig 1**? It could have been water that lubricated the runners of the stone sledge as it was pulled along a roadway of clay or Nile mud.

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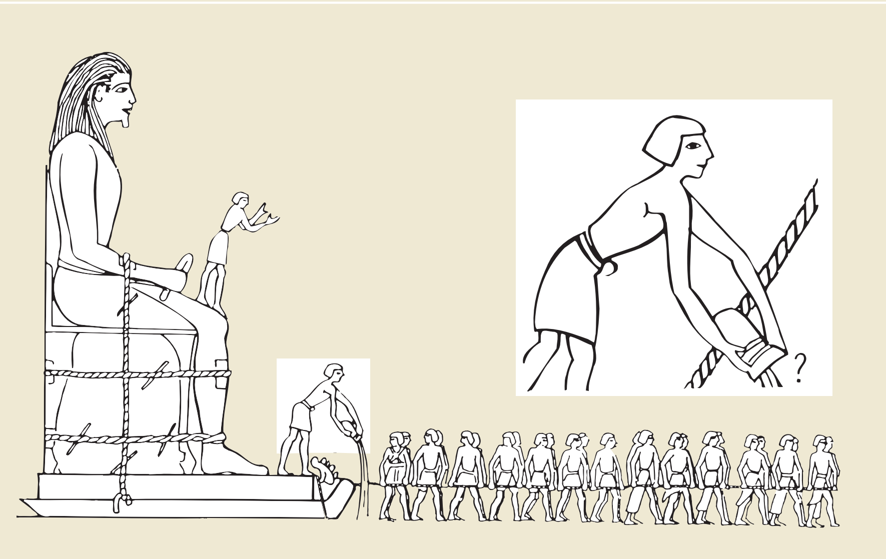
Fig. 1



Early use of lubricants

It was also in Egypt that an ingenious man is said to have discovered that when he stuffed animal fat between the axle and the wheel hub, the cart moved much more easily and wear was also reduced.

Olive oil was the general-purpose fat for the Mediterranean peoples. They also used it when they needed a lubricant. Analyses of remains show that the lubricating "grease" used by the ancient Egyptians consisted of olive oil mixed with lime.

Mineral oil was also known in very early times, but it was not used for lubrication. The Indians employed oil in medicines and to make their canoes watertight.

The story of lubrication began with these modest experiments using nature's various products, but it was not until the 19th century that the fight against friction really got into its stride.

1859 is the year usually stated for the birth of the oil industry. It was then that the first oil well was drilled in Pennsylvania, USA.

Oil films

Lubrication plays a major role in rolling bearing performance. The main task of the lubricant is to build up an oil film between the rolling elements and the raceways. The oil film should be thick enough to separate these mating surfaces completely.

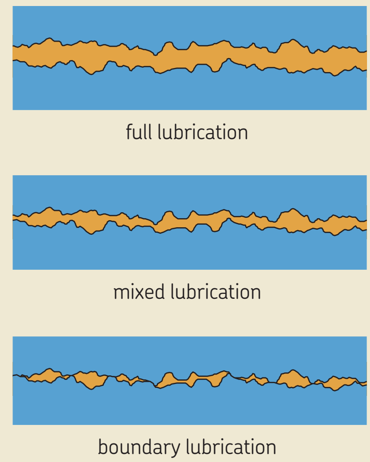
Sometimes the question is asked whether the radial internal clearance in the bearing can be too small to allow an oil film to form. This is not the case as even bearings with zero clearance can build up an oil film. For example, an average oil film has a thickness of only 0,3 µm. By way of comparison, a sheet of printing paper has a thickness equal to about 200 oil films.

The film thickness in a rolling bearing is dictated by the bearing size, the operating speed and the viscosity at the operating temperature of the oil used. The higher the speed, the thicker the oil film. Three different terms are used to describe the lubrication conditions: full, mixed or boundary lubrication (→ **fig 2**).

The bearings for high-speed suction rolls are an example of paper machine bearings with full lubrication. Unfortunately, there are also some disadvantages with increased speed. One is the risk of sliding between the rolling elements and the raceways. If the sliding speed of rolling elements is too high in relation to the rolling speed, the oil film can be broken. This normally leads to serious damage to the bearing. In such cases, NoWear bearings can solve the problem (→ *chapter 1, General requirements and recommendations*, **page 18**)

Fig. 2

Lubrication conditions



Felt roll bearings in the dryer section are examples of bearings with mixed lubrication. These bearings do not suffer much lubrication-related damage because the lubrication conditions are still relatively good and the speed is moderate.

The bearings for drying cylinders without insulation are examples of bearings with boundary lubrication. Whether insufficient lubrication in this case leads to serious damage or to just mild wear and running-in of the surfaces depends on the actual operating conditions.

General notes on lubrication

Basic terms

When selecting suitable lubrication for rolling bearings, there are some basic terms that need to be known.

Kinematic viscosity ν

The kinematic viscosity ν describes the resistance to flow of the oil at a certain temperature. Low values mean that the oil flows easily, high values mean that the oil flows sluggishly. The unit for viscosity is mm²/s (previously known as Centistoke).

Table 1 lists the ISO classification of oils used in paper machines. The four classes in bold text are commonly used for circulating oil systems.

κ value

κ is a viscosity ratio which shows the relation between the operating viscosity of the oil ν and the required viscosity ν_1 both at operating temperature, i.e.

$$\kappa = \frac{\nu}{\nu_1}$$

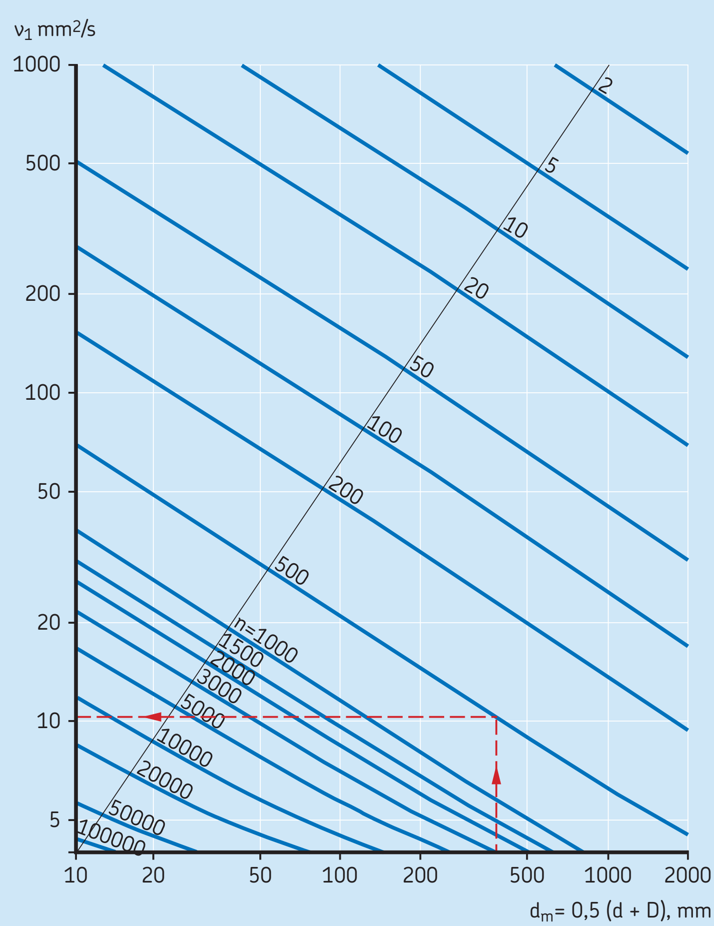
Diagram 1 is used to determine ν_1. When ν_1 is known, **diagram 2**, **page 4**, is used to select an oil that gives the required viscosity at the operating temperature. κ = 1 is in-

Table 1

Viscosity classes according to ISO	Kinematic viscosity mm²/s at 40 °C (*104 °F*) min	mean	max
ISO VG 68	61,2	68	74,8
ISO VG 100	90,0	100	110
ISO VG 150	**135**	**150**	**165**
ISO VG 220	**198**	**220**	**242**
ISO VG 320	**288**	**320**	**352**
ISO VG 460	**414**	**460**	**506**
ISO VG 680	612	680	748
ISO VG 1 000	900	1 000	1 100
ISO VG 1 500	1 350	1 500	1 650

Viscosity class according to ISO standards

Diagram 1



ν_1 diagram with an example

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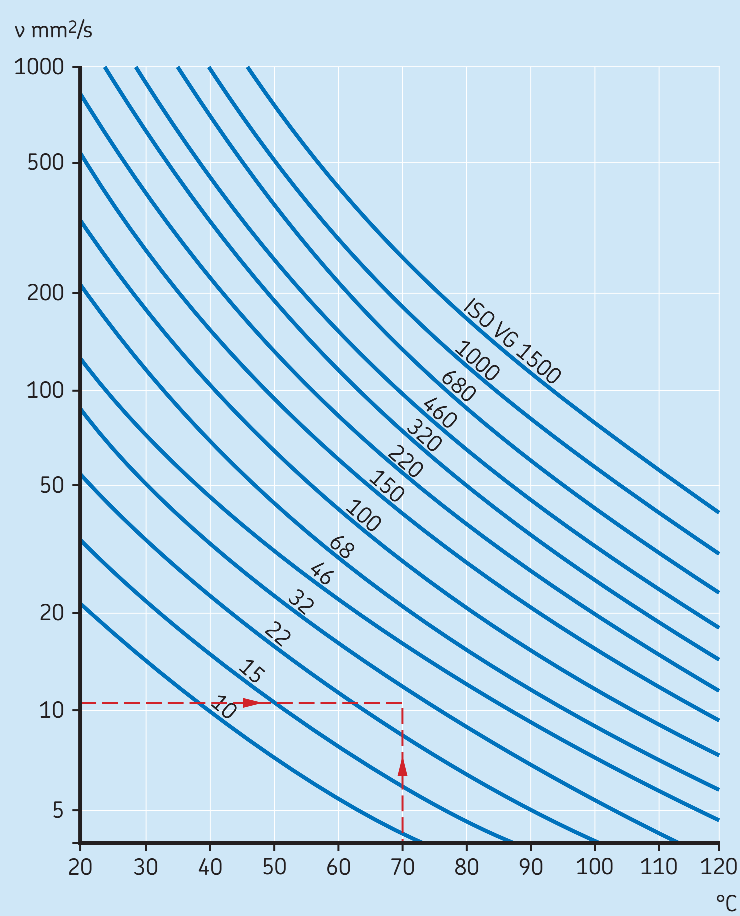
tended for general applications and there are special recommendations for paper machine bearings (→ *Chapter 9, Maintenance*, **pages 28–29**). Example: A bearing having bore diameter d=340 mm and an outside diameter D=420 mm is required to operate at a speed n=500 rpm. Since d_m = 0,5 (d+D), d_m = 380 mm from **diagram 1**, the minimum rated viscosity ν_1 required to provide adequate lubrication at the operating temperature is approximately 11 mm²/s. If the bearing runs at 70 °C and an oil with a viscosity of 32 mm²/s at 40 °C is selected, the obtained κ value is 1 (→ **diagram 2**). For paper machine bearings, a κ between 2 and 4 is recommended. This means that the oil, or the base oil of the grease, to be chosen would be either an ISO VG 68, an ISO VG 100, or an ISO VG 150.

Viscosity index (VI)

The viscosity of an oil changes with the temperature. The viscosity index is a way to describe the magnitude of the change for a specific oil. Synthetic oils normally have a much higher viscosity index than mineral oils, i.e. their temperature dependence is less.

Diagram 2 is used when the viscosity at the operating temperature is converted into the reference viscosity at 40 °C. Tests at SKF show that the oil film thickness at 100 °C, i.e. at the "normal" bearing temperature in the dryer section, is the same for both mineral and synthetic oils if both have the same viscosity at 40 °C. Therefore, the diagram can be used for both mineral and synthetic oils. It is based on the viscosity index VI = 85. However, at temperatures above approximately 130 °C, the advantage of the high viscosity index of synthetic oils is significant and should therefore be taken into consideration.

Diagram 2



Viscosity/temperature diagram with an example of κ calculation

Bearing life factors a_{23} and a_{SKF}

When the κ value is known, **diagram 3** can be used to find out the value of the a_{23} factor. Bearing life adjustment factor a_{23} will either increase or decrease the calculated bearing life (except when κ = 1).

This diagram can be used for all common paper machine lubricants with EP or AW additives provided the additives are not aggressive to steel, see remarks in section *Different types of additives*, **pages 5–6**. Higher values may be obtained (shaded area) if lubricants containing additives of the EP or AW type are used, the water content is below 200 ppm and the contamination level is low.

In the SKF Life Method, the life factor a_{23} is replaced by a life adjustment factor, called a_{SKF}. The advantage with this factor is that it takes both the viscosity ratio κ and the lubricant cleanliness into account. The cleanliness in this case means the representative particle concentration in the lubricating oil during continuous operation (→ *chapter 1*, *General requirements and recommendations*, **page 4**).

The number of “clean” lubrication systems is increasing every year as more efficient filters are introduced. However, continuous monitoring of the cleanliness is still uncommon.

When dimensioning the bearing arrangements for paper machines, SKF recommends the use of the SKF Life Method (a_{SKF}).

For further information, see *chapter 1*, *General requirements and recommendations*, *Selection of bearing size*, **pages 2–4**.

Diagram 3

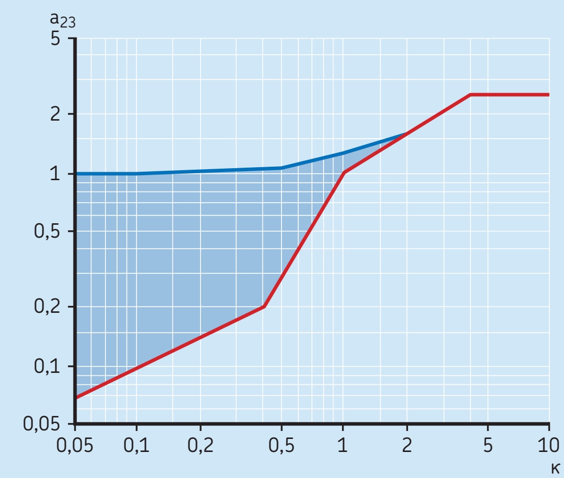


Diagram for bearing life adjustment factor a_{23}

Different types of additives

Production of all different lubricating oils begins with a straight base oil, i.e. an oil without any additives. The difference between hydraulic, gear, engine and paper machine oils is the additive package, i.e. the combination of different additives. Gear oils, for example, may very well be used in paper machines if the additive package is suitable.

The function of additives is an area of very intensive development. New products are presented as replacements for products found to be toxic. For example, the use of products containing lead and chlorine is prohibited in most countries. Below are explanations of the functions of some common additives in paper machine oils.

Anti-corrosion

There are in principle two types of additives which offer protection. They are either water-soluble or oil-soluble chemicals, e.g. sodium nitrite. Such additives normally give sufficient protection in damp operating conditions. However, they cannot give complete rust protection if the water content in the lubricant is too high. This is perhaps the biggest problem for the bearings in the forming and press section.

Anti-foam

The foam-damping action can be obtained, for example, by adding small quantities of silicone fluid. Such additives cause the bubbles to burst when they come in contact with the surface of the oil in the reservoir. Air in the oil gives shorter oil and bearing life.

Anti-oxidant

Oil exposed to high temperatures and air oxidizes, i.e. chemical compounds are formed. These compounds can increase the viscosity of the oil and also cause corrosion. Viscosity increase is normally used as one criterion for oil change because these oxidation compounds have a negative influence on the lubrication effect. Anti-oxidants improve the oxidation stability of the oil by 10 to 150 times. The performance of the oil is maintained longer, which also means that the cost of the oil will decrease because it will last longer. Furthermore, these additives have an anti-corrosive effect, but it is relatively limited.

EP (extreme pressure)

If the oil film in the rolling contact is not thick enough to fully separate the surfaces, there will be an interaction between the mating surfaces causing very high local temperatures. The temperature can be so high in these hot spots that asperities are welded together. This creates high friction and heavy adhesive wear like smeared surfaces in the bearing (*Chapter 9*, *Maintenance*, **pages 25–26**).

EP additives cause a chemical reaction in any hot spots so that the asperities shear off instead of being welded together. The result is a smoothing effect which reduces the size of surface irregularities. As the calculated κ value is based on the surface finish of the raceways before the bearing has been in operation, this smoothing effect will lead to an increase in κ value in operation when lubricants with good EP additives are used. After some time, the surfaces should be fully separated by the oil film.

Many common modern EP additives are of the sulphur/phosphorus type. These additives tend to be aggressive to bearing steel at elevated temperatures and therefore reduce bearing life. As such, SKF generally recommends that lubricants with EP additives should not be used for bearings with operating temperatures above 80 °C. Of course, this can be discussed with your oil supplier.

In lightly loaded bearings where the rollers have a risk of extensive sliding during operation, EP additives normally do not work. For these applications, SKF recommends NoWear bearings with coated rollers (L5DA) (→ *chapter 1*, *General requirements and recommendations*, **page 18**).

AW (anti-wear)

At temperatures above 80 °C where EP additives should not be used, we recommend AW additives to reduce the risk of wear and smearing in the bearing. Additives of the AW type form a surface layer with certain beneficial properties such as a stronger adhesion to the surfaces. This surface layer causes the asperities of the mating surfaces to slide over each other instead of shearing off.

Also, EP additives are sometimes called wear-prevention additives, because they prevent adhesive wear. This is perhaps why some markets do not distinguish between AW and EP additives. Both of them are called EP.

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 discolour 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.

Dispersant

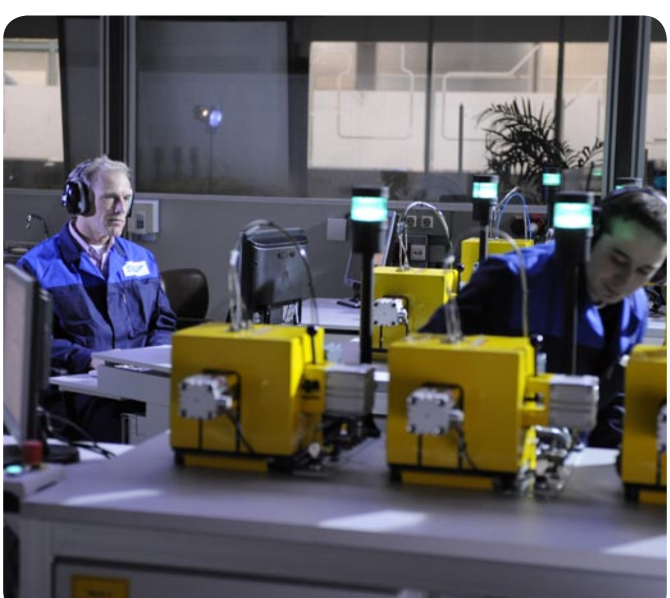
One way to avoid sedimentation of contaminant particles inside the long pipes and large reservoirs of paper machine lubrication systems is to use an oil with dispersant additives. These additives can keep the particles floating in the oil until they enter the oil filter. One drawback of these additives 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.

VI-improvement

These viscosity index (and sometimes viscosity) with increasing additives are often made up of large-molecule polymers. Experience with high-viscosity oils shows that these additives can be sheared to smaller molecules, i.e. the viscosity of the oil will decrease. If that happens, the thickness of the oil film in the bearings will also decrease. Therefore, additives of this type are not recommended for paper machine oils. These additives are very common in engine oils for cars, but paper machine oils must have a much longer service life without any change of basic properties like viscosity.

These additives may influence the filterability of the oil.

Lubricant test



Grease or oil lubrication?

Whether a rolling bearing is to be lubricated with grease or oil depends on a number of factors.

Grease has the advantage over oil of being easier to retain inside the bearing housing. It can also be retained in the sealing labyrinths where it protects the bearing against damp and impurities. A disadvantage when relubricating with large amounts of grease, is that the used grease must come out through the labyrinths. This may cause contamination of the wire and the paper web.

Oil lubrication is used when the operating temperature with grease lubrication (due to high speed and/or heating) would be too high. A common maximum operating temperature for medium temperature greases in the forming and press section is 75 °C and for high-temperature greases in the dryer section is 120 °C.

However, SKF recommends circulating oil for all bearings in the dryer section to enable cooling and cleaning of the oil. Unfortunately, circulating oil lubrication is not possible for all the bearing positions, e.g. rope pulleys, spreader rolls, doctors and steam joints. Grease is used for all these positions. In old machines, the felt rolls are grease lubricated too.

To select an appropriate lubricant, it is necessary to know the operating temperature of the bearing. The temperature can either be calculated by SKF with the help of computer programs or by measuring in the machine.

Grease lubrication

Grease lubrication system

Traditionally, most of the forming and press section bearings, as well as rope pulley and doctor bearings in the dryer section, have been grease lubricated. There are a number of reasons for this but, today, the main consideration is cost. SKF does not recommend grease lubrication in the dryer section. For the rope pulley, doctor and spreader roll bearings, where it is very difficult to apply oil, grease lubrication is used as a compromise.

Previously, when production speeds were low, relubrication was carried out manually during maintenance stops i.e. once or twice per month. More frequent relubrication is necessary today due to increasing speeds, high-pressure cleaning of the machine and increased demand for machine reliability.

Therefore, the use of automatic lubrication is becoming increasingly popular. Automatic lubrication systems consist of a number of components (→ **fig 3**) which can all be supplied by SKF.

The aim of both automatic and manual lubrication is to supply the right amount of fresh grease to the bearing arrangement.

Examples of disadvantages with grease lubrication are the difficulties in selecting grease quality, initial charge, relubrication quantity and method of grease supply into the bearing.

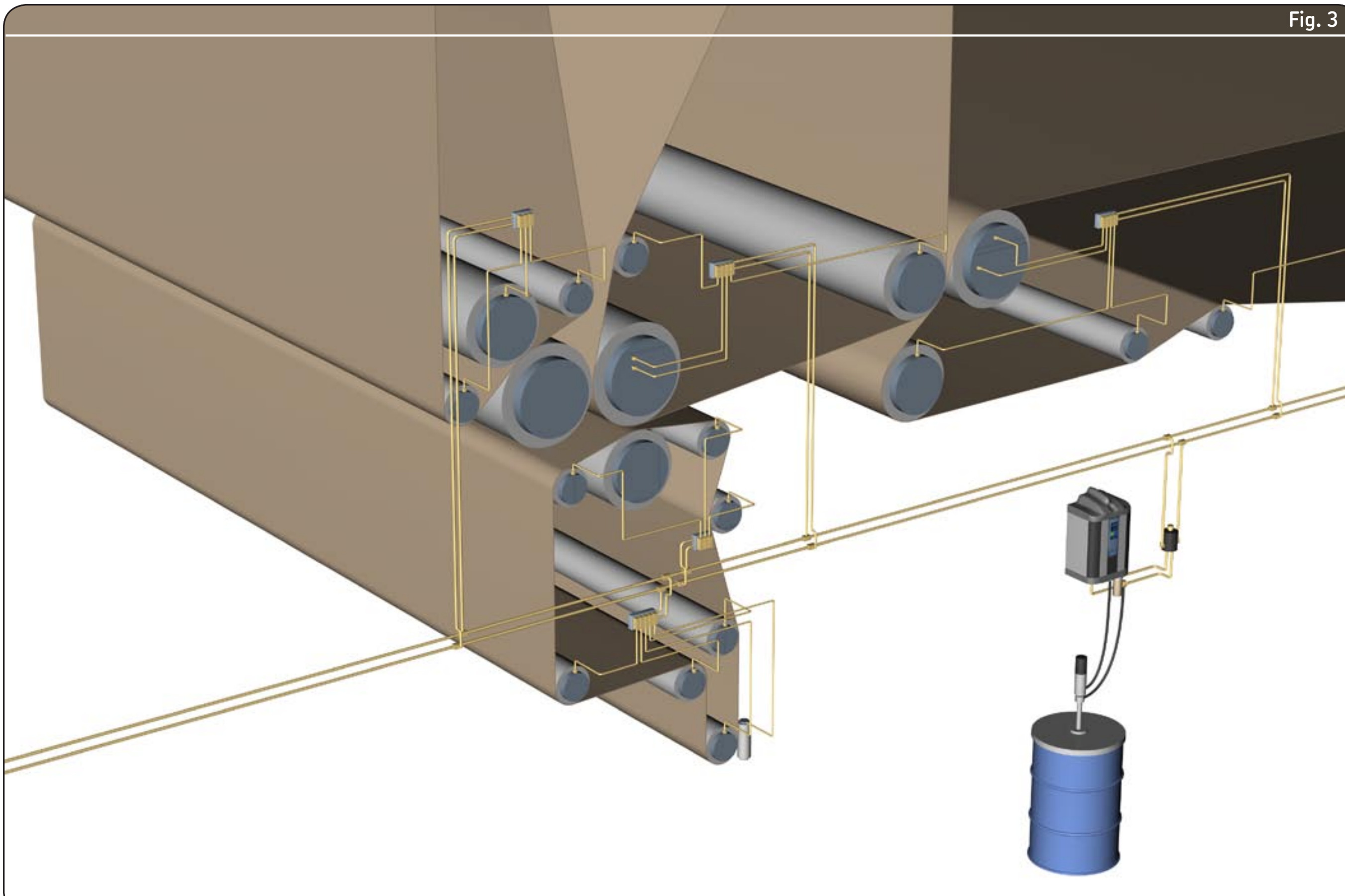
Selection of grease type

Lubricating grease is made up of a so-called base fluid which is mixed with a thickener. The base fluid is normally either a mineral or a synthetic oil, often referred to as the base oil.

The thickener in the majority of cases is a metal soap, e.g. calcium, lithium, sodium, or non-soap, e.g. clay (bentonite), silica gel, polyurea. The consistency of the grease depends on the type and quantity of the thickener used. The consistency is measured as the penetration depth of a standardized cone into the grease during a certain time. **Table 2** shows three consistency classes according to NLGI (National Lubricating Grease Institute), which are used for bearing applications.

Automatic grease lubrication

Fig. 3



Consistency classes

Table 2

NLGI index	Penetration mm/10
1	310–340 (very soft)
2	265–295 (soft)
3	222–250 (medium hard)

When selecting greases for paper machines, it is necessary to take all operating conditions into consideration. Unfortunately, there has been a trend, mainly in response to end-user requirements, to minimize the number of different greases. That may lead to an unsatisfactory compromise. For example, it may be hard to find a grease that has all the properties required for both the forming and press section as well as the dryer section.

SKF lubricating grease range

With the improvements in bearing lubrication technology, higher operating speeds and temperatures, the demands made on lubricating greases have become more severe. SKF, in conjunction with major grease manufacturers, has developed a range of lubricating greases to satisfy these demands.

Depending on operating conditions, seal efficiency, bearing type and how the bearing is fed, SKF LGMT 2, SKF LGHB 2, SKF LGHP 2, SKF LGWM 2, SKF LGWA 2, or SKF LGLT 2 grease may be suitable. There is no grease existing on the market that is suitable for all bearing positions. As an example of this, SKF might recommend the following greases for a specific paper machine:

- SKF LGWA 2 for the roller bearings of the wet section and spreader rolls in the dry section.
- SKF LGHB 2 for the doctor bearings in the wet and dry ends and rollers bearings in the dryer section
- SKF LGHP 2 for the ball bearings of the rope sheaves
- SKF LGLT 2 for the spreader rolls in the wet section

Testing the performance of fresh grease

The operating conditions of the bearings dictate the priorities given to the individual performance properties of lubricating greases. As a general guideline, this chapter gives required characteristics for a grease to meet for a paper machine bearing application. It is a guideline only and the choice of grease should be made based on the exact operating conditions, if possible. The operating conditions for papermaking machine bearings can be said to fall into three basic groups represented in the test programme by positions **a**, **b** and **c** (→ **table 3**, **page 10**).

For more information, please contact SKF. SKF can undertake all of the above tests to determine whether a lubricant is suitable for known bearing operating conditions. As lubricant manufacturers might change the formula of their product in the future, an infrared analysis is done on the sample tested so that it is possible to tell if the lubricant used to lubricate the bearings is still the same as the one tested.

The bearing should be completely filled with fresh clean grease during the initial mounting. Furthermore, 30 to 50% of the free space in the housing should be filled with grease.

In addition, to ensure sealing efficiency, the labyrinth seals should be completely filled with grease from the beginning.

Table 3

Testing the performance of fresh grease

Position **a** represents all the grease lubricated ball and roller bearing positions in the wet section.
Position **b** represents rope pulleys, doctors and felt roll grease lubricated ball and roller bearing positions in the dryer section.
Be aware that some bearing positions in the lowest part of the dryer section might fail due to insufficient oil bleeding if they are lubricated with some high temperature grease.
Position **c** represents spreader rolls in the dryer section with ball bearings and an operating temperature of 100 to 140 °C.

1.1 Kinematic viscosity of the original oil including additives
Type of test: DIN 51562/1, ISO 3448 or ASTM D 2422
Required result for **a**: Min 175 mm^2/s at 40 °C
Required result for **b**: Min 400 mm^2/s at 40 °C
Required result for **c**: Min 220 mm^2/s at 40 °C

1.2 Consistency
Type of test: DIN ISO 2137 or ASTM D 217
Required result for **a**: NLGI 2
Required result for **b**: NLGI 2
Required result for **c**: normally NLGI 2 but sometimes NLGI 3

1.3 Mechanical stability 100 000 strokes
Type of test: DIN ISO 2137 or ASTM D 217
Required result for **a**:
Worked penetration value should not change more than +/–40
Required result for **b**:
Worked penetration value should not change more than +/–30
Required result for **c**:
Worked penetration value should not change more than +/–30

1.4 Mechanical stability (shear stability in a roller test)
Type of test: DIN 51804/2 or ASTM D1831, 50 g grease, 50 h at 80 °C
Required result for **a**:
Worked penetration value should not change more than +/–40
Required result for **b**:
Worked penetration value should not change more than +/–30
Required result for **c**:
Worked penetration value should not change more than +/–30

1.5 Mechanical stability (vibrations)
Type of test: SKF V2F
Required result for **a**: M
Required result for **b**: M
Required result for **c**: M

1.6 Water resistance
Type of test: DIN 51807/1
Required result for **a**: 1 max at 90 °C
Required result for **b**: 1 max at 90 °C
Required result for **c**: –

1.7 Water washout
Type of test: DIN 51807/2
Required result for **a**: Washout less than 10%
Required result for **b**: Washout less than 10%
Required result for **c**: Washout less than 20%

1.8 Rust inhibition with artificial process water or with customer's process water
Type of test: SKF EMCOR, IP 220 or DIN 51802 or ISO 11007
Required result for **a**: 0–0
Required result for **b**: 1–1
Required result for **c**: 1–1

1.9 Rust inhibition with 0.5% NaCl
Type of test: SKF EMCOR, IP 220 or DIN 51802 or ISO 11007
Required result for **a**: 0–0
Required result for **b**: 1–1
Required result for **c**: 1–1

1.10 Rust inhibition with 3% NaCl
Type of test: SKF EMCOR, IP 220 or DIN 51802 or ISO 11007
Required result for **a**: 0–0
Required result for **b**: –
Required result for **c**: –

1.11 Copper compatibility, 24 h at 90 °C
Type of test: DIN 51811, IP 112 or ASTM D4048
Required result for **a**: 1
Required result for **b**: –
Required result for **c**: –

1.12 Copper compatibility, 24 h at 120 °C
Type of test: DIN 51811, IP 112 or ASTM D4048
Required result for **a**: –
Required result for **b**: 1
Required result for **c**: 1

1.13 4 ball weld load
Type of test: DIN 51350/4
Required result for **a**: equal or higher than 2 800 N
Required result for **b**: equal or higher than 2 800 N but grease must pass the EP reaction test
Required result for **c**: equal or higher than 2 800 N but grease must pass the EP reaction test

1.14 4 ball wear test
Type of test: DIN 51350/3 (1400 N) or ASTM D2266
Required result for **a**: 0,8 mm max
Required result for **b**: 0,8 mm max
Required result for **c**: 1,0 mm max

1.15 Dropping point
Type of test: DIN ISO 2176 or ASTM 2265
Required result for **a**: 180 °C min
Required result for **b**: 250 °C min
Required result for **c**: 250 °C min

1.16 Oil bleeding[1)]
Type of test: DIN 51817 or IP121
Required result for **a**: min 1% at 40 °C and max 10% at 80 °C
Required result for **b**: min 3% at 80 °C and max 12% at 120 °C
Required result for **c**: min 3% at 100 °C and max 15% at 140 °C

Note, if the real operating conditions are known, oil bleeding for roller bearings should be at least 3% at operating temperature. For b, operating temperature can be very different depending on the bearing position. The bearings in the lowest position might be better lubricated with a grease for a.

1.17 Spherical roller bearing lubricating ability
Type of test: SKF R2F
Required result for **a**: rating 1 with procedure A (unheated)
Required result for **b**: rating 1 with procedure B (at 120 °C)
Required result for **c**: –

1.18 Pumpabilty (feedability)
Type of test: SKF test, to be published

1.19 Cleanliness
Type of test: DIN 51831
Required result for **a**: max. 5 mg/kg
Required result for **b**: max. 5 mg/kg
Required result for **c**: max. 5 mg/kg

1.20 EP additives reaction test
Type of test: SKF test 24 h at 160 °C (to be published)
Required result for **a**: –
Required result for **b**: rating 0
Required result for **c**: rating 0

1.21 Grease service life
Type of test: SKF ROF at 140 °C
Required result for **a**: –
Required result for **b**: –
Required result for **c**: min. 1 000 h

1.22 Evaporation loss
Type of test: SKF test.
Required result for **a**: –
Required result for **b**: TBD
Required result for **c**: TBD

The above requirements are general guidelines. Real operating conditions and seal efficiency might make a grease suitable even if it does not meet all of these requirements.

Relubrication

There are some important issues to consider when relubricating. One basic rule is to use the same grease quality for relubrication as was used when the bearing was mounted.

Another important point to consider is the method of relubrication. In most cases, there is a need of regular relubrication. Therefore, the housing must be supplied with a lubricant duct and grease nipple. For the fresh grease to penetrate effectively into the interior of the bearing, and for the old grease to be pushed away, the duct should open so that the grease is supplied immediately adjacent to the outer ring face or directly into the lubrication groove (W33 feature). Evacuation holes should be considered for the excess or old grease that cannot be pushed out.

The bearing housings in most paper machine applications with grease lubrication are provided only with labyrinth seals. These labyrinths have to be filled with grease to obtain an efficient sealing function. Therefore, the recommended relubrication intervals and quantities are selected to secure both good lubrication and efficient sealing function.

The grease in the labyrinths can easily be washed out if the housings are hosed down under high pressure. Therefore, never direct high-pressure sprays towards the sealing gap. The housing sealing should be protected e.g. with splash covers (→ *chapter 2*, *Forming section*, **fig. 8**, **page 5**).

Sometimes extra relubrication is carried out during a standstill in order to push the water-contaminated grease out from the labyrinth. This extra relubrication should instead be carried out under operating conditions just before standstill. More details are given in *chapter 9*, *Maintenance*, *Standstill precautions* (→ **page 17**).

Relubrication intervals and quantities

As the bearing arrangements in the forming and press section of the paper machines have a "wet" environment, there is a need for shorter relubrication intervals than those indicated in the *SKF General Catalogue*.

There are basically three factors to consider when selecting relubrication intervals and quantities. These are the lubrication and sealing functions and the grease leakage from the housing. From a lubrication point of view, the amount of grease in the bearing should be just sufficient to supply an adequate quantity of base oil to the raceways, rollers and cages.

From a sealing point of view, it is important that the labyrinth seals are always completely filled with grease.

From a leakage point of view, the grease quantity should not be too large. Large quantities of grease generate heat in the bearing, especially at high speeds, when the bearing attempts to pump out most of the grease. When relubrication has been carried out a number of times, all the free space inside the housing can be filled with grease. From then on, the grease leakage will be equal to the relubrication quantity. Therefore, with large regreasing quantities, there is a risk that the leakage is so great that some grease may come out on the wire.

As the environment and the bearing housing design vary widely from machine to machine, the relubrication quantities should always be adjusted according to practical experience. Thus, the recommended values for relubrication intervals and quantities listed in **tables 4** and **5** should be used as guidelines only.

Manual lubrication

Table 4

Forming and press section
Relubrication once a week is recommended for bearings in wet positions, as in the wire and press parts.

Once a month is recommended for bearings in damp positions, e.g. calenders, reelers, winders.

Quantities according to

$$G = K\,D\,B$$

where
G = quantity of grease, g
D = bearing outside diameter, mm
B = bearing width, mm
K = 0,002 (weekly relubrication)
0,003 (monthly relubrication)

Dryer section
Manual grease lubrication is not to be recommended in the dryer section because of the difficulty in reaching all the positions during operation.

Automatic lubrication

Table 5

Forming and press section
Automatic grease lubrication systems are becoming increasingly common, The advantage with these systems is better protection of the bearings because of shorter relubrication intervals.

Quantities according to the equation below are valid for bearings in the forming and press sections.

$$G = 0{,}00001\,H\,D\,B$$

where
G = grease quantity after H hours, g
D = bearing outside diameter, mm
B = bearing width, mm
H = relubrication interval, hours

Dryer section
SKF normally recommends oil lubrication for the bearings in the dryer section. However, there are some positions where circulating oil is difficult to apply. For these positions, SKF recommends a high-temperature grease with the same quantities as above.

Oil lubrication

Oil lubrication systems

Most of the bearings in old machines were grease lubricated. Originally, only the bearings for drying cylinders had oil lubrication. These first oil lubrication systems were of the oil bath type.

Increased operating speeds and steam temperatures soon made improved lubrication necessary. The higher the operating temperature of the bearing, the more rapidly the lubricating oil would degrade.

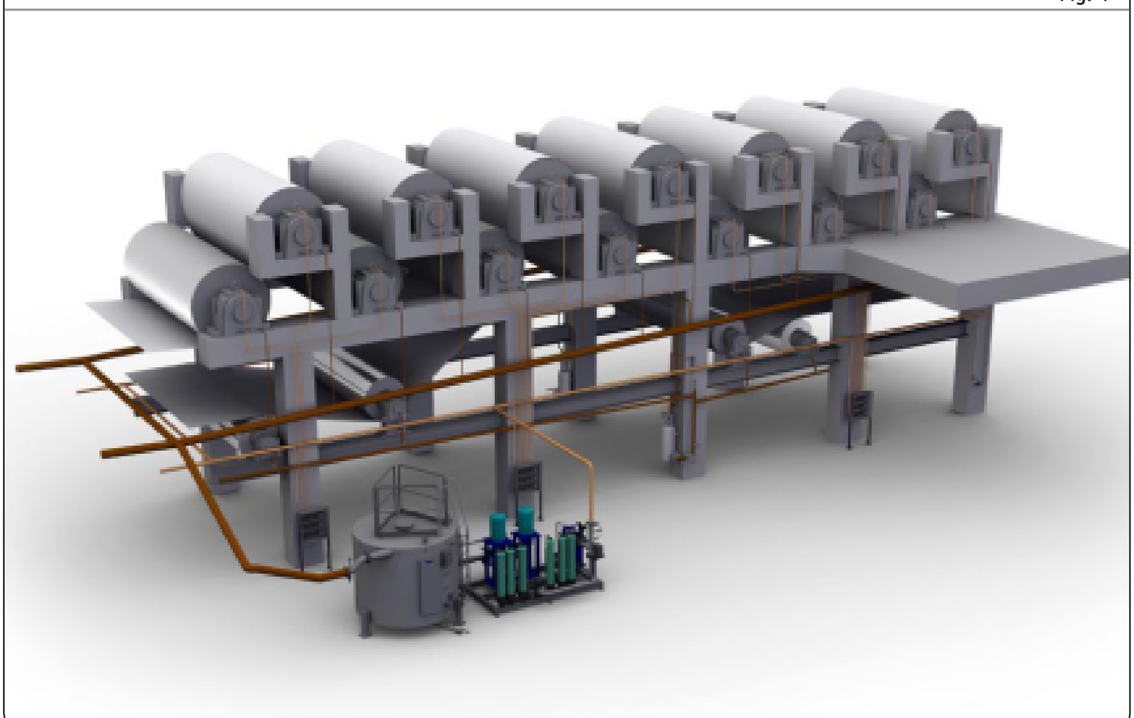
The next step in improved lubrication was the introduction of oil drip lubrication. With this method, it was possible to extend the life of the oil. However, the continuous increase in paper speeds and steam temperatures and the introduction of hooded dryer sections very soon resulted in bearing operating conditions that required even better lubrication. This was obtained by introducing circulating oil lubrication.

Modern circulation systems make it possible to cool and clean the oil (→ **fig 4**). These are the main reasons why circulating oil lubrication is used for most bearings in new machines.

Over the years, the speed increase has been so great that other parts of the machine also have to be lubricated with circulating oil. Note that the speed rating in the *SKF General Catalogue* is not the maximum permissible speed for the bearing. With oil circulation it is possible to operate at higher speeds. Some bearings in modern high-speed machines operate above limiting speed.

Modern paper machines are often very large and the bearing operating conditions differ in the various parts of the machine. Therefore, the bearing lubrication system is split up into several smaller systems. For example, the forming and dryer sections usually have their own lubrication systems, as do the Yankee cylinders and deflection-compensating rolls (→ **fig 5**, **page 14**).

Fig. 4



SKF Flowline circulating oil lubrication system for a paper machine

Selection of oil quality

When selecting oils for paper machines it is necessary to take into consideration a great number of factors, including:

- Lubrication method (oil bath/circulation)
- Operating conditions for all the bearings connected to the same lubrication system
- Design and performance of the seals
- Pipe dimensions

The most common operating conditions usually result in two or three different oils in one machine. This represents a good compromise between the different lubrication requirements and what is practical.

Unfortunately, there has been a trend, mainly in response to end-user requirements, to minimize the number of different oils. That may lead to an unsatisfactory compromise. For example, it may be hard to find an oil that has all the properties required for both the forming and dryer sections.

Mineral oils

In most cases, good-quality mineral oils are suitable as lubricants for paper machine bearings at operating temperatures up to 100 °C. However, some mineral oils (developed for paper machines) perform well up to 120 °C.

Synthetic oils

There are a number of different types of synthetic base oils such as synthetic hydrocarbons, esters and polyglycols.

These products have different properties regarding their influence on rubber seals, evaporation and miscibility with polar and non-polar additives etc. Another difference is that the density of polyglycols is very close to that of water at 50 °C. This is a disadvantage since the water will not separate in the reservoirs which normally have a temperature of about 50 °C.

Poly-alpha-olefin (PAO) oils (often mixed with small amounts of other synthetic base oils) have been the most popular synthetic oil type in paper machines. This is perhaps due to the fact that these oils do not have the above-mentioned drawbacks.

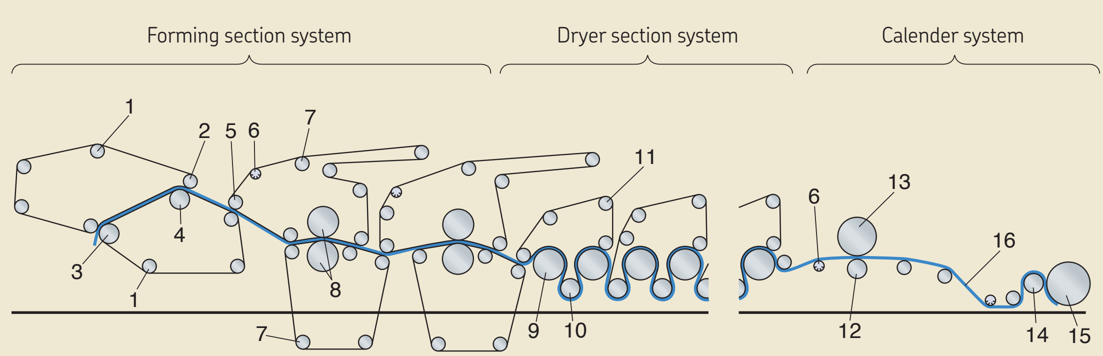
Synthetic oils have a number of advantages compared with mineral oils. The most valuable property of synthetic oils is perhaps their better performance at high operating temperatures. Therefore, these oils are often used at operating temperatures above 100 °C, but they can of course be used at lower temperatures as well.

Oils for the forming section

The selection of oil for the forming section should be based on operating conditions for press and suction roll bearings because these are the most demanding positions.

When large bearings with heavy rollers rotate at high speeds the rollers may slide as they enter the loaded zone. The interior surfaces of such bearings may be damaged severely by smearing. That is why these bearings need a thick oil film containing EP additives. If these additives are of the sulphur-phosphorus type, the bearing operating temperature should not exceed 80 °C as such additives act aggressively at higher temperatures. Therefore, the oil flows should be large enough to keep the bearing temperature below 80 °C. Oils with EP additives that are stable at higher temperatures

Fig. 5



Basic layout of a paper machine including a common division in different oil lubrication systems.

1 *Wire roll*
2 *Forward drive roll*
3 *Forming roll (suction roll)*
4 *Suction couch roll*
5 *Pick-up roll*
6 *Spreader roll*
7 *Felt roll*
8 *Shoe press*
9 *Drying cylinder*
10 *Vacuum roll*
11 *Guide roll (wire roll)*
12 *Deflection compensating press roll (soft calender)*
13 *Thermo roll (soft calender)*
14 *Reel drum*
15 *Reel spool*
16 *Paper web*

or with AW additives should be used at operating temperatures above 80 °C.

Effective rust-inhibition and rapid water separation are the most important properties of oils for the forming section, but EP additives are also of top priority for high-speed press and suction rolls.

An oil suitable for the forming section should have the following basic properties:

- Viscosity class ISO VG 150 to 320, depending on machine
- EP additives up to 80 °C
- Anti-wear additives above 80 °C
- Rust inhibiting additives

The operational limits for the oil are specified in the section *Cleanliness control* (→ **pages 17–23**).

Oils for the dryer section and machine calenders

The selection of oil for the dryer section should be based on operating conditions for drying and Yankee cylinder bearings because these are the most demanding positions.

EP or AW additives are also recommended for oils in the dryer section because the high bearing operating temperatures, in combination with the viscosity of commonly used oils, leads to metal-to-metal contact between rollers and raceways. If the EP additives are of the sulphur-phosphorus type, the bearing operating temperature should not exceed 80 °C as these additives act aggressively at higher temperatures. Oils with EP additives that are stable at higher temperatures or with AW additives should be used at operating temperatures above 80 °C.

Good thermal and chemical stability are the most important properties of oils for the dryer section and machine calenders. Effective rust inhibition is desirable here as well. An oil suitable for the dryer section should have the following basic properties:

- Viscosity classes
  ISO VG 220 to 320 for drying cylinders etc.
  ISO VG 320 to 460 for Yankee cylinders
  ISO VG 460 to 1500 for oil baths
- EP additives up to 80 °C
- AW additives above 80 °C
- Rust inhibiting additives

Oils for off-line calenders

Off-line calenders are often made up of ordinary press rolls. Therefore, the requirements for calender oils are the same as for forming section oils, if the bearing operating temperature is below 80 °C. However, in some off-line calenders, bearings are operating at the same temperatures as dryer section bearings. In these cases, the oils should fulfil the requirements for dryer section oils.

Calender development is very rapid. Heating oil in so-called hot calenders may have temperatures up to 350 °C. Special oils and lubrication systems are required if the temperatures of the press roll bearings in these hot calenders are much higher than those of the bearings in the dryer section.

The operational limits for the oil are specified in the section *Cleanliness control* (→ **pages 17–23**).

Testing the performance of fresh oil

The operating conditions of the bearings dictate the priorities given to the individual performance properties of lubricating oils. The operating conditions for paper machine bearings can be said to fall into two basic groups represented in the test programme by positions **a** and **b** (→ **table 6**, **page 16**)

For more information, please contact SKF. SKF can also do all the above tests to determine if a lubricant is adequate or not, for known bearing operating conditions. As lubricant manufacturers might change the formula of their product in the future, an infrared analysis is done on the sample tested so that it is possible to tell if the lubricant used to lubricate the bearings is still the same as the one that was tested.

The operational limits for the oil are specified in the section *Cleanliness control* (→ **pages 17–23**).

Table 6

Testing the performance of fresh oil

Position **a** represents all oil lubricated bearing positions in the wet section.
Position **b** represents all oil lubricated bearings in the dryer section including machine calenders.
(N.B. : The use of so-called hot calenders is increasing, but lubrication requirements for the bearings in these applications are not considered in this test programme).

The limits listed for the various properties are of a general nature and therefore refer to most exacting requirements. Naturally, some of these restrictions can be eased if the operating conditions so permit.

1.23 Kinematic viscosity
Type of test: DIN 51562/1 or ASTM D 445
Required result for **a**:
to meet viscosity recommendation given on **page 15**
Required result for **b**:
to meet viscosity recommendation given on **page 15**

1.24 Rust inhibition with artificial process water or with customer's process water
Type of test: SKF EMCOR, IP 220 or DIN 51802
Required result for **a**: 0–0
Required result for **b**: 1–1 (0–0 if oil bath)

1.25 Rust inhibition with distilled water
Type of test: SKF EMCOR, IP 220 or DIN 51802
Required result for **a**: 0–0
Required result for **b**: 0–0

1.26 Copper compatibility, 48 h at 80 °C
Type of test: DIN EN ISO 2160
Required result for **a**: 2
Required result for **b**: –

1.27 Copper compatibility, 48 h at 120 °C
Type of test: DIN EN ISO 2160
Required result for **a**: –
Required result for **b**: 2

1.28 4 ball weld load
Type of test: DIN 51350/4
Required result for **a**: equal or higher than 2 800 N
Required result for **b**: max. 2 000 N if the EP activity has been obtained by phosphorous and sulphur compounds. Other EP-additives with higher welding loads may be used if the oil passes the other required tests.

1.29 4 ball wear test
Type of test: DIN 51350/3 under 600 N
Required result for **a**: 1 mm max
Required result for **b**: 1 mm max

1.30 Water separation ability
Type of test: ISO DIN 6614
Required result for **a**: max. 20 minutes
Required result for **b**: max. 20 minutes

1.31 Filterability
Type of test: SKF method: at 800 mbar absolute pressure, 12 μm laboratory filter
Required result for **a**: max 15 minutes
Required result for **b**: max 15 minutes

1.32 Chemical reaction on bearing steel
Type of test: SKF roller test, part 1
Required result for **a**: –
Required result for **b**: max. 2
(mineral oils at 120 °C, synthetic oils at 120 °C and 140 °C)

1.33 Change of viscosity
Type of test: SKF roller test, part 2
Required result for **a**: –
Required result for **b**: +/– 20% kinematic variation from fresh oil after ageing (mineral oils at 120 °C, synthetic oils at 120 °C and 140 °C)

1.34 Sludge formation
Type of test: SKF roller test, part 3
Required result for **a**: –
Required result for **b**: traces, visual
(mineral oils at 120 °C, synthetic oils at 120 °C and 140 °C)

1.35 Incrustation
Type of test: SKF roller test, part 4
Required result for **a**: –
Required result for **b**: No incrustations
(mineral oils at 120 °C, synthetic oils at 120 °C and 140 °C)

1.36 Dye number
Type of test: DIN ISO 2049
Required result for **a**: –
Required result for **b**: max 6,5
(mineral oils at 120 °C, synthetic oils at 120 °C and 140 °C)

1.37 Oil film ageing (first test)
Type of test: SKF film stability test
Required result for **a**: –
Required result for **b**: rating max 2
(mineral oils at 120 °C, synthetic oils at 120 °C and 140 °C)

1.38 Oil film ageing (second test)
Type of test: SKF weight loss (evaporation test)
Required result for **a**: –
Required result for **b**: max. 20%
(mineral oils at 120 °C, synthetic oils at 120 °C and 140 °C)

1.39 Compatibility with elastomers
Type of test: SKF method, 200 h: FPM seal at 150 °C, NBR seal at 120 °C
Required result for **a** and **b**: NBR seal: max 10% change in weight, FPM seal: max 5% in weight. Less than 5 shore A hardness change for NBR and FPM.

The above requirements are general guidelines. Real operating conditions and seal efficiency might make an oil suitable even if does not meet all these requirements.

Cleanliness control

Lubricating oil should be continuously cleaned of impurities. It is important to remove both water and solid particles from the oil.

Cleanliness recommendation

When selecting suitable water extractors and filters, the following cleanliness guidelines should be aimed for:

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 SAE class 6B/6C, or better.

Water extractors

As mentioned earlier, SKF has found water to be one of the major reasons for the short service life of bearings. The recommendation of a water content below 200 ppm provides a good balance between the cost of water removal and increased bearing service life.

The recommended water content level can 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 sealing and high-pressure cleaning, but accidental leakage from oil coolers etc. has to be considered as well.

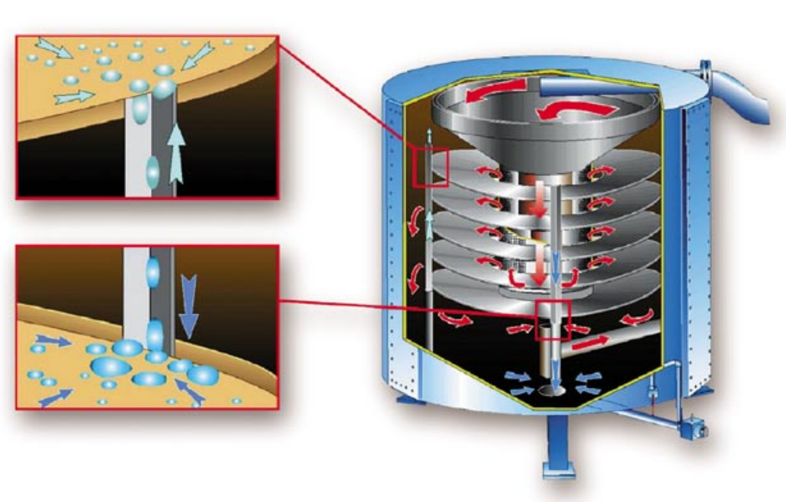
The bearings should never be exposed to oil that has higher water content than that recommended. This is especially important during standstill. If this does happen, there is a greater risk that the free water in the oil can start the corrosion process. Therefore, it is very important to keep water content low just before machine stoppages and to prevent entry of water during standstill.

Other causes of high water content in modern paper 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.

SKF recommends the use of the SKF Flowline tank whose design gives superior continuous water and air removal (→ **Fig. 6**). In addition, the oil retention time is much greater than in traditional rectangular tanks, so it is possible to decrease the amount of oil by between 50 to 65%.

Considering the bearing, all oil lubrication systems should have equipment for continuous water removal. Without such equipment many paper machine oils may have water content higher than the recommended 200 ppm.

Fig. 6



SKF Flowline tank
Water condensates on the top surface of the plates, while air condensates on the underneath surfaces of the plates. Air and water are continuously extracted from the oil.

Oil filters

Different types of oil filters have been used for many years in the lubrication systems of paper machines. 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 proven 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, see *Cleanliness recommendation*, **page 17**. 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.

Filter ratings

Filters have developed rapidly in recent years. This means that the "standard" filters of today are many times more efficient than the filters commonly used some years ago.

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 efficiency.

Efficiency of the "standard" 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:

$$\beta_x = \frac{n_1}{n_2}$$

where

n_1 = number of particles per volume unit (100 ml) larger than x µm upstream the filter

n_2 = 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 will pass the filter.

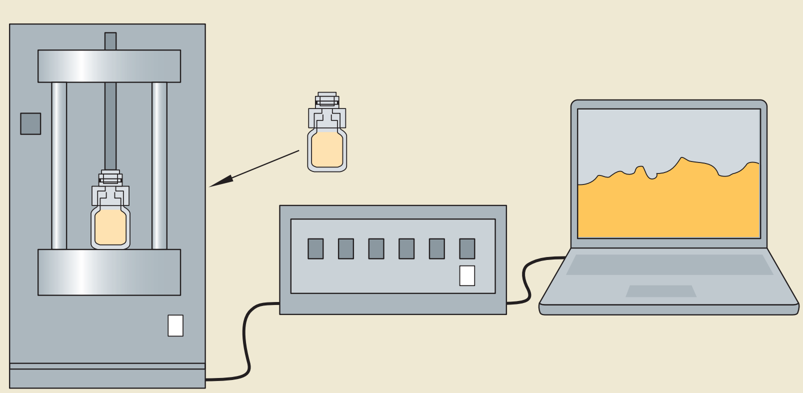
Particle counting

Particle counting can be based on various principles.

The simplest 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 because 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

Fig. 7



Equipment for particle counting

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, (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.

Whatever the method used, the results should be presented as a development trend. **Fig 7** shows how a PC is connected to APC equipment to collect and evaluate the results.

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.

Contamination levels

Standards establish information which allow comparison and interpretation of contamination (cleanliness) levels and hence enabling control of particle contamination to ensure system performance and reliability. Standards have been published by ISO, NAS and SAE (note that the last two are Aerospace Standards).

ISO classification method

The method for coding the contamination level in a lubrication system is according to ISO 4406:1999.

In order to simplify the reporting of particle count data, the quantities counted are converted to a code using scale numbers. These are allocated according to the number of particles counted per millilitre of the fluid sample (→ **table 7**).

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 (slashes). Example: 18/15/12 (→ **diagram 4**). APC calibration is according to ISO 11171.

For comparative results, the code for microscope counting comprises two scale numbers relating to the number of particles ≥ 5 µm and ≥ 15 µm. Counting is undertaken in accordance with ISO 4407. The code is stated in three part form where the first part is given as a "–". Example: –/15/12 (→ **diagram 4**).

NAS classification method

The NAS classification method is according to NAS 1638. The principal means for its development was to count particles with a microscope (according to ARP598). The strength of the method was the ability to provide more details about the particle distribution by considering five size ranges. NAS 1638 is superseded by SAE AS 4059.

ISO classification

Table 7

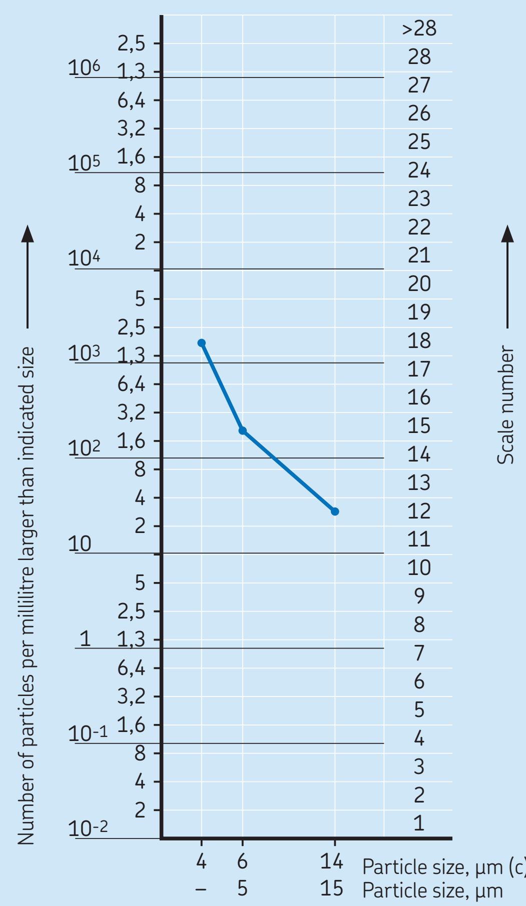
ISO classification – allocation of scale number

Number of particles per ml oil Over including	 Up to and number	 Scale
2 500 000		> 28
1 300 000	2 500 000	28
640 000	1 300 000	27
320 000	640 000	26
160 000	320 000	25
80 000	160 000	24
40 000	80 000	23
20 000	40 000	22
10 000	20 000	21
5 000	10 000	20
2 500	5 000	19
1 300	2 500	18
640	1 300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2,5	5	9
1,3	2,5	8
0,64	1,3	7
0,32	0,64	6
0,16	0,32	5
0,08	0,16	4
0,04	0,08	3
0,02	0,04	2
0,01	0,02	1
0,00	0,01	0

ISO 4406 method

Diagram 4

ISO classification and example for both microscope (–/15/12) and automatic particle counter (18/15/12)



4th Edition SKF

SAE classification method

The classification method is according to SAE AS 4059. The contamination levels selected are an extension of the NAS 1638 levels. However, the SAE standard considers both microscope and automatic particle count.

For reporting, the quantities counted are converted to class codes. These are allocated according to the number of particles counted per 100 millilitre of the fluid sample (→ **table 8**).

The particle distribution considers 6 size ranges (size code by a letter from A to F) and 15 classes.

The SAE cleanliness levels can be identified in different ways, the most important ones being:

- Total number of particles larger than a specific size, example: AS 4059 class 6B
- Designating a class for each size range, example: AS 4059 class 6B/5C/4D/4E where the figure indicates the class and the letter the side code (→ **table 8**).

Flushing of new circulation systems

If there are hard contaminant particles in the system the bearings can be damaged during the first minutes of operation. The best way to avoid this is to flush the complete lubrication system before the very first start-up. Flushing should be continued until the flushing oil has the recommended cleanliness level. This means that there should be a number of cleanliness tests preformed during the flushing period.

The main difficulty during flushing is creating turbulence in the pipes in order to flush out all the contaminant particles attached to the walls of the pipes. SKF recommends the use of the same oil that will be used during operation. To reduce the viscosity, the oil should be heated. The oil pump should give its maximum flow capacity. By doing so, the system is subjected to a higher flushing effect than during subsequent normal operation. In this way, the risk of contaminants being dislodged from the pipe walls during normal operation will be minimized.

ISO 4406 method

Table 8

Size code			**Cleanliness classes** (based on maximum number of particles per 100 ml oil)														
(1)	(2)	(3)	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12
A	**>1**	**>4**	195	390	780	1 560	3 120	6 250	12 500	25 000	50 000	100 000	200 000	400 000	800 000	1 600 000	3 200 000
B	**>5**	**>6**	76	152	304	609	1 220	2 430	4 860	9 730	19 500	38 900	77 900	156 000	311 000	623 000	1 250 000
C	**>15**	**>14**	14	27	54	109	217	432	864	1 730	3 406	6 920	13 900	27 700	55 400	111 000	222 000
D	**>25**	**>21**	3	5	10	20	39	76	152	306	612	1 220	2 450	4 900	9 800	19 600	39 200
E	**>50**	**>38**	1	1	2	4	7	13	26	53	106	212	424	848	1 700	3 390	6 780
F	**>100**	**>70**	0	0	0	1	1	2	4	8	16	32	64	128	256	512	1 020

(1): size code (letter)
(2): size, microscope count (ISO 4402 calibration) – particle size based on longest dimension
(3): size, automatic particle count (ISO 11171 calibration or Electron Microscope) – particle size based on projected area equivalent diameter

Oil sampling

The ideal oil sample should be representative, i.e. identical to the lubricant entering the rolling bearing.

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, e.g. the sampler shown in **fig. 8**. 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. There is of course other similar equipment on the market.

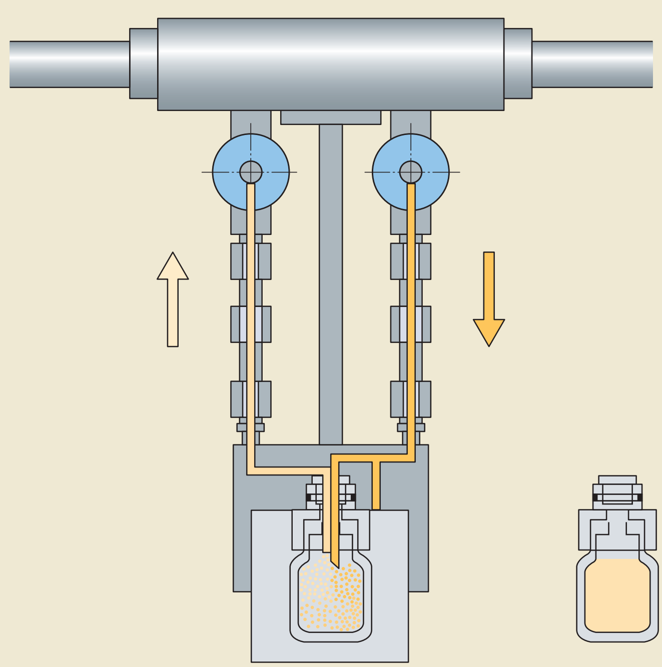
Checking water content

Today, there are some products on the market for continuous online measurements, but the method most widely used is to take an oil sample and carry out a Karl Fischer analyzis. Irrespective of the method, the results are usually presented in ppm, because the actual quantities are very small. Maximum water content should be 200 ppm.

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

Fig. 8



Equipment for oil sampling

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 being able to follow up the results of maintenance activities with such things as changes of filter elements.