

Tribology: the science of keeping bearings running

Correct and efficient lubrication is essential for the satisfactory function of rolling element bearings and to attain maximum service life. It is therefore advisable for both design engineers and maintenance technicians to thoroughly understand the basics of tribology and its effects on the proper function of rolling element bearings. Roland Gruber of bearing specialist NKE Austria explains the issues.

Each rolling element bearing represents a 'tribological system' consisting of the bearing and an adequate lubricant. In this system – namely, in a rolling element bearing – the lubricant primarily separates the metallic surfaces and thereby reduces friction, as well as preserving the steel parts and preventing or neutralizing the effects of contamination.

In many cases, the bearing life is determined by the service life of the lubricant: the failure of the lubricant will definitely terminate the life of the bearing. In the case of oil lubrication, the lubricant may also act as a coolant, actively taking part in the heat dissipation and thereby supporting the thermal equilibrium in bearings operating at high speeds.

Lubrication types

Generally three types of lubrication are used in rolling element bearings – grease, oil and solid or dry lubricants. The selection of a suitable lubrication method should be made in the early stages of design. The operating conditions – such as operating speeds, temperature and environment – have to be carefully evaluated.

The latest state-of-the-art lubricants feature special agents – additives – to enhance specific lubricant properties, i.e. high-pressure characteristics, temperature stabilization, etc.

Grease lubrication

Grease is by far the most common form of lubrication; in fact, about

90% of all rolling element bearings are grease lubricated. Simple application, minimal maintenance, easy sealing, a wide spectrum of lubricants and the availability of pre-greased and greased-for-life bearings are some of the main advantages of grease lubrication.

Grease consists of a soap structure, which in most cases is a metal soap based on lithium soap with a base oil and additives.

Oil lubrication

Oil is usually used for bearing lubrication if an oil supply system is already incorporated into the design of a machine for other purposes (e.g. gearbox lubrication, etc.).

Oil lubrication is also used for special operating conditions that require effective heat dissipation. In certain high-speed applications, the use of oil allows for a highly accurate and easily dosed application, for example via oil jet or oil mist.

Solid and dry lubrication

Where applications do not allow the use of oil or grease, for example, due to heat, several other materials can be used, such as graphite powder or pressed graphite cages, polytetrafluoroethylene

Table 1. Typical $n \cdot d_m$ values of different lubricant types

Lubricating method	$n \cdot d_m$
Grease lubrication	
Standard bearing greases	500 000
Special greases	1 000 000
Oil lubrication	
Oil bath lubrication	500 000
Circulating oil lubrication	750 000
Splash oil lubrication	800 000
Oil mist lubrication*	1 500 000
Minimum quantity lubrication*	3 000 000

* For $n \cdot d_m$ values of >1 000 000 practical experience is of major importance as special appliances such as oil coolers, additional pumps or a separate compressed air system for oil and air lubrication may become necessary.

(PTFE) powder, metallic coatings, sliding varnish and various other surface treatments.

should be contacted for detailed and accurate values for a specific lubricant.

Speed ability

Different lubricants and lubrication methods have different abilities for operating under given speeds. The most important factor for evaluating the 'speed ability' of a certain lubrication method is the speed characteristic ($n \cdot d_m$); where n is the bearing operating speed (rpm) and d_m the bearing pitch diameter (mm):

$$d_m = (d + D)/2$$

where d = bearing bore diameter and D = outer diameter.

Table 1 shows some typical $n \cdot d_m$ values of various lubricating methods. All values are for guidance only. The lubricant supplier

Characteristic parameters

Viscosity (ν)

This is one of the most important features for selecting an oil or grease. The term viscosity describes the ability of oil to flow under given conditions and temperatures. A low figure indicates thin oil; higher figures denote thicker oils. In the case of grease, the viscosity of the respective base oil is indicated.

Since the viscosity of a lubricant depends considerably on its temperature, the nominal viscosity of a lubricant is typically indicated with a defined reference temperature, usually 40°C (ν_{40}).

Table 2. NGLI consistency grades of greases

NLGI consistency grades (DIN 51818)	Worked penetration (0.1 mm)
000	445 to 475
00	400 to 430
0	355 to 385
1	310 to 340
2	265 to 295
3	220 to 250
4	175 to 205
5	130 to 160
6	85 to 115

Table 3. Relationship between speed ratios and grease filling volumes

Speed ratio (%)*		Grease filling (%)**
>	≤	
-	20	80 to 90
20	75	30 to 50
75		25

* In % of the speed ratings with grease lubrication given in the bearing product tables
 ** In % of bearing housing cavity volume

Consistency

The consistency indicates the 'stiffness' of a grease. It is classified by the NLGI (National Lubrication Grease Institute) scale according to DIN 51818 where the penetration depth of a standardized test cone into a grease specimen at a standardized test temperature and after a standardized time is measured. The deeper the test cone penetrates, the softer the grease

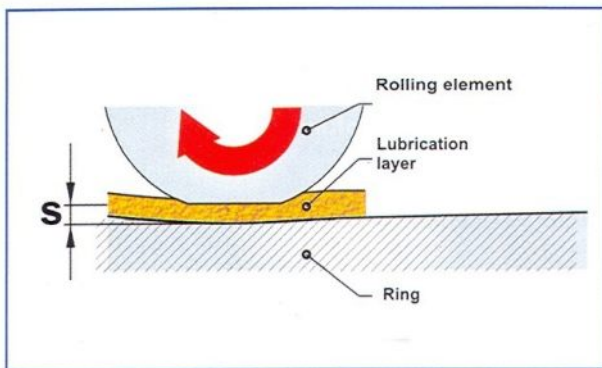


Figure 1. The lubricant film separates the metal parts of a bearing.

is and hence the lower the NLGI grade (see Table 2).

Stiffer lubricants have higher consistency and therefore higher NLGI grades. For lubricating rolling bearings, grease lubricants of NLGI grades 2 and 3 are widely used. For certain high-speed applications, for example spindle bearings, grade 0 and grade 1 greases may be used.

Soft greases are optimal for small and miniature bearings, low temperatures, high speeds or when a central lubrication system is installed. Stiffer greases are suitable for large bearings running at low speeds or for high-temperature applications. Stiffer greases also provide a better sealing effect.

Viscosity selection

The most significant function of any lubricant is to separate the metallic surfaces in the 'load zone'. As shown in Figure 1, optimum separation in rolling bearings is achieved when the thickness (S) of the lubricating film that builds up in the contact area between the rolling element surface and the bearing rings is large enough to separate them completely. In most applications only an incomplete separation, the so-called 'mixed' lubrication, is achieved.

The actual operating viscosity and thus the actual film thickness under given operating conditions is determined by the nominal viscosity of the lubricant, the bearing size, the speed and the operating temperature.

Grease volume

The lubricating grease fill volume in bearing housings is determined mainly by the bearing design and its actual operating speed. The free space within the bearing itself has to be fully filled with grease in all cases. The grease fill volume for bearing housing cavities should be chosen according to Table 3.

Grease service life

Bearing lubricants undergo permanent mechanical stress as they are over-rolled

continuously by the rolling elements. Additionally, lubricants change their characteristics, particularly when operating at high temperatures, in the presence of humidity, pollution and chemical agents. The service life of lubricants is therefore limited; its length depends on the individual operating conditions, particularly the operating temperature and the speed.

In the case of greased-for-life bearings, mainly with shields or seals on both sides, the service life of the lubricant is expected to be longer than the required bearing life rating. When considering the maintenance of bearings, it is essential to estimate the service life of the lubricant realistically and schedule regular re-lubrication.

Re-lubrication intervals

Re-lubrication intervals are very much related to the actual operating conditions and the individual characteristics of the lubricant in question. Modern high-performance lubricants allow for much longer service life due to the progress in lubricant research, development and manufacturing. For accurate figures on specific lubricants the grease vendor should be consulted; for standard lubricants the realistic service life in hours, τ_n , can be roughly estimated with the following equation:

$$\tau_n = (a \cdot 10^6 / n \cdot \sqrt{d}) - b \cdot d$$

where a and b = bearing type and series coefficients (see Table 4); n = bearing operating speed (in rpm); d = bearing bore diameter (mm).

For safety reasons, the re-lubrication intervals of new machines or plants where no practical experience exists should not exceed 50–60% of the initial calculated service life of the lubricant.

The values obtained from this formula are only valid for standard lithium soap mineral oil greases at consistent operating temperatures not exceeding 70°C (158°F). Above 70°C, the mineral-oil-based lubricants undergo an extremely accelerated ageing

Table 4. Bearing type and series coefficients for calculating lubricant service life		
Bearing types and series	Coefficient	
	a	b
Deep groove ball bearings		
160, 60, 62	75	18
63	65	18
64	55	18
Angular contact ball bearings		
72 B	65	18
73 B	55	18
32	55	18
33	55	18
Four-point contact bearings		
QJ 2	65	18
QJ 3	55	18
Self-aligning ball bearings		
12, 22	75	18
13, 23	65	18
Cylindrical roller bearings		
N. 10, N. 2, N. 2.. E	75	18
N. 3, N. 3.. E	65	18
N. 4	55	18
Taper roller bearings		
302.., 320.., 322..,	20	7
303.., 313	18	7
323..,	15	7
Spherical roller bearings		
222..	20	7
223..	15	7

process. When the lubricant is exposed to constant operating temperatures above 70°C (158°F), the calculated values for re-lubricating intervals must be halved for each 15°C (27°F) increase in operating temperature. The course of this reduction is illustrated in Figure 2.

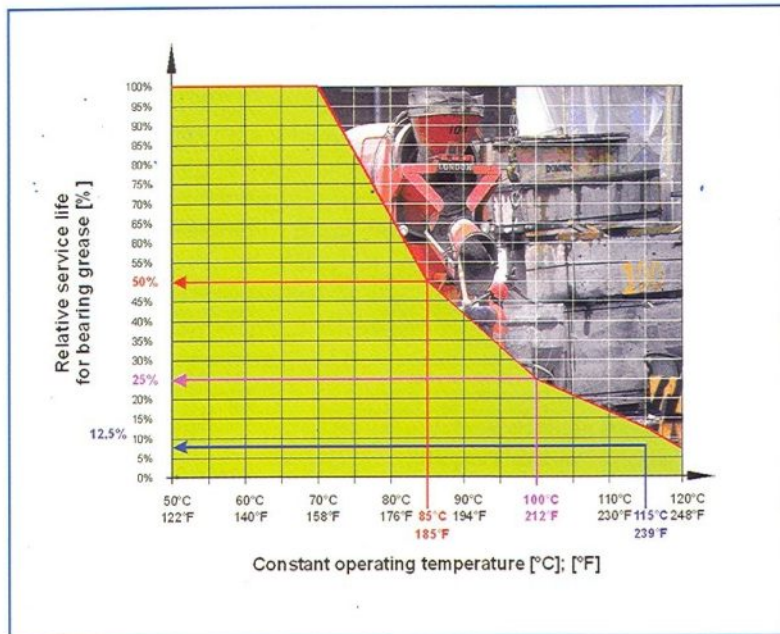


Figure 2. Relationship between operating temperature and re-lubrication interval.

If the grease that is lubricating the bearing also has to act as a seal against the entry of pollution, or when the bearing outer ring rotates, the re-lubrication intervals must be further reduced. This also applies in the presence of moisture, dust, chemicals and vibrations.

Additional and more precise information on specific characteristics of lubricants, their chemical reactions with some elements and the anticipated service life of the lubricant under certain operating conditions are available from the lubricant manufacturer. ■

CONTACT

Roland Gruber
Application Engineering
NKE Austria GmbH
Ennsener Strasse 41a
A 4407 Steyr, Austria.
Tel: +43-7252-86667-615
Fax: +43-7252-86667-59
E-mail: r.gruber@nke.at
www.nke.at