VA991 – high-speed spherical roller bearings

For large industrial gearboxes

Contents

Foreword

This document describes the new high-speed spherical roller bearing solution which addresses speed limitation issues in existing large industrial gearboxes and opens up new possibilities when designing new gearboxes.

The document also highlights which points to consider to exploit fully the performance capabilities of the SKF VA991 bearing execution. This document does not replace detailed engineering work when designing the gearbox and selecting the bearing, and should be used more as a checklist.

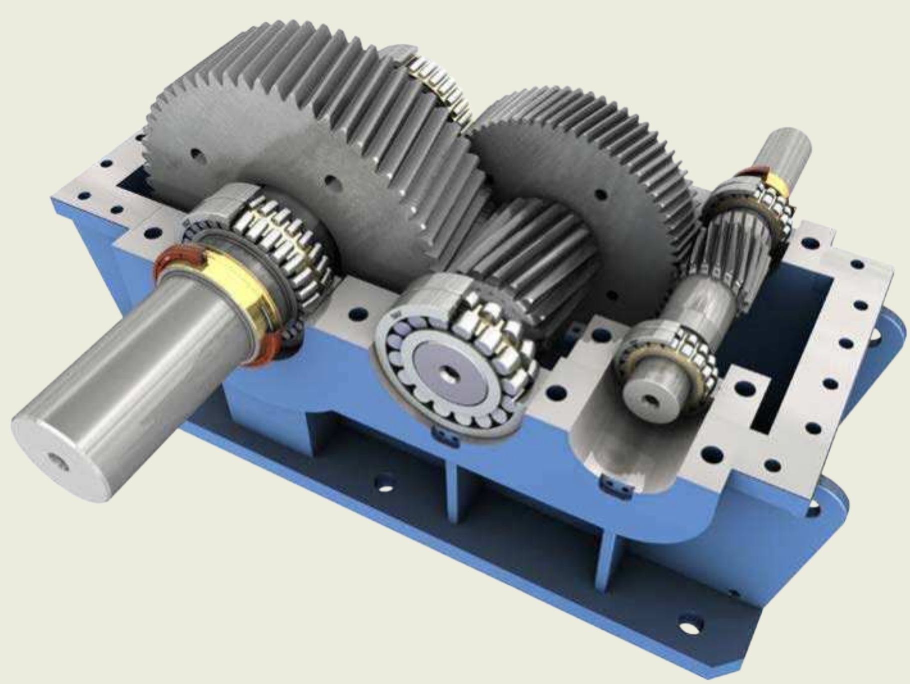
1 Application description

1.1 General description

The SKF Spherical Roller Bearing VA991 range has been designed to overcome design limits reached in large industrial gearboxes, such as grinding mill or conveyor applications. Bearing limiting speed has become a design limiting parameter when users want to combine high power, long life and high speed requirements. The standard bearing execution places severe constraints on the full driveline design, including the choice of motor.

When designing large gearboxes, engineers aim to achieve long rating life up to 100 000 hours. This must be combined with speed capability of the bearing. The bearing speed capability is characterized by three phenomena: heat generation and dissipation, and mechanical properties of the components. Thus, the bearing selection is a combination of these capabilities within the specific gearbox design characteristics. This guide addresses many aspects regarding general engineering of bearings in gearboxes, and highlights speed-specific matters for special attention. However, it is not to be considered as a comprehensive handbook for designing a high-speed gearbox, as there are many other factors beyond the scope of this guide that need to be considered.

Fig. 1



1.2 SKF VA991 design, features and benefits

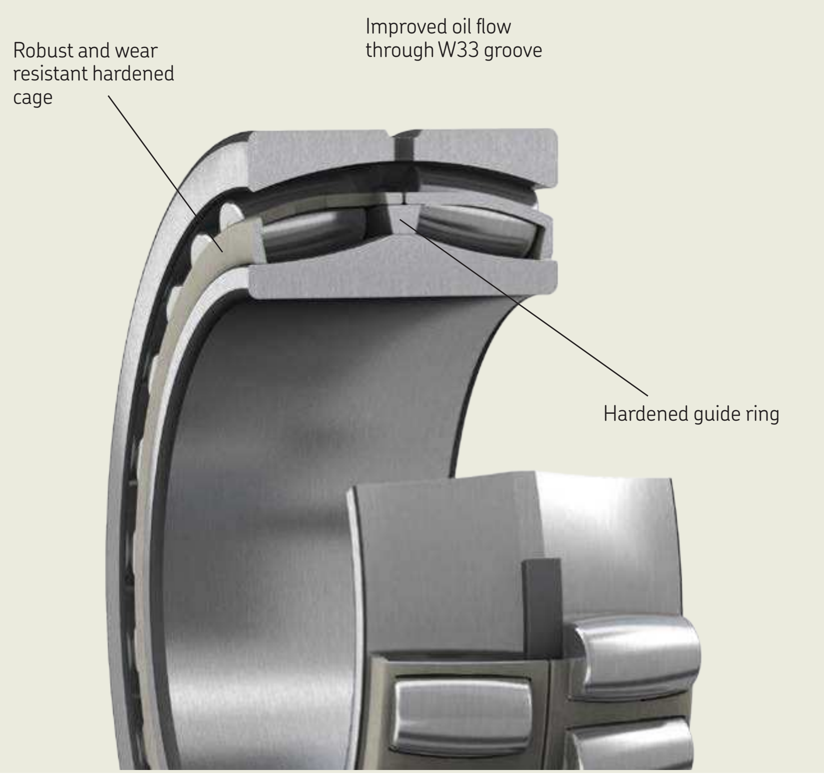
The SKF VA991 spherical roller bearing is available in the shaft size range of 180-360 mm and permits a significant higher limiting speed in comparison to the standard execution. The VA911 design features are:

- SKF Explorer Class
- SKF CC principle having self-guiding rollers that limit roller skew and reduce friction
- Hardened cage
- Hardened guide ring
- Improved oil flow
- Recommended clearance
- Validated performance
- Speed capability matching electric motor technology

Which result in following benefits :

Fig. 2

VA991 bearing



50% higher limiting speed

- Savings in electric motor investment (8-pole → 6-pole → 4-pole)
- Annual savings in electricity (efficiency difference between 8-pole → 6-pole and 4-pole)
- More options and freedom for the gearbox designer
- No longer a need to move away from spherical roller bearings because of the speed limitation
- Savings in R&D and engineering → same design principle can usually be used (throughout a gearbox range)
- Problem solving on speed issues for existing gear units
- Extra safety for unexpected speed conditions (for example, "rushing" water turbine gearboxes).

Table 1

Example of savings

Price of 5 MW motor					**Savings Annual**	**Investment**
4-poles	143 000 €					37 000 €
6-poles	180 000 €					
Efficiency of the 5 MW		**Power loss** [kW]	**El-price** [eur/kWh]	**Cost per year**		
4-poles ~	97,20%	140	0,09	110 376 €	2 000 €	
6-poles ~	97,15%	142,5	0,09	112 347 €		
Additional cost for 2 pcs						
22348 CC/C4W33VA991	700 €					–700 €
					Total savings 1st year	**38 300 €**
					Total savings 5 years	**46 300 €**
					Total savings 10 years	**56 300 €**

Table 2

Example of savings

Price of 10 MW motor					**Savings Annual**	**Investment**
4-poles	312 000 €					44 000 €
6-poles	356 000 €					
Efficiency of the 10 MW		**Power loss** [kW]	**El-price** [eur/kWh]	**Cost per year**		
4-poles	97,5%	250	0,09	197 100 €	7 900 €	
6-poles	97,4%	260	0,09	204 984 €		
Additional cost for 2 pcs						
22356 CC/C4W33VA991	1 000 €					–1 000 €
					Total savings 1st year	**50 900 €**
					Total savings 5 years	**82 500 €**
					Total savings 10 years	**122 000 €**

Robust and wear resistant

- Able to tolerate more acceleration and deceleration
- Advantageous for vibratory application / environment
- Works well in vertical shaft gearboxes.

Reduced total cost of ownership

With the VA991 execution, SKF customers have more possibilities to design large gearboxes with higher motor speed (thus fewer poles), to reach the same output power, as the bearing is no longer a limiting factor.

This can significantly impact the drivetrain investment and potentially energy costs as well. As the motor speed goes up, keeping application specifications constant usually means higher ratio for the gearbox. The tables 1 and 2 show VA991's possible impact by allowing the use of a 4-pole motor instead of 6-pole, on 5 MW and 10 MW sizes. Clearly the additional cost for the VA911 execution is in no time outbalanced by lower motor investment and power consumption.

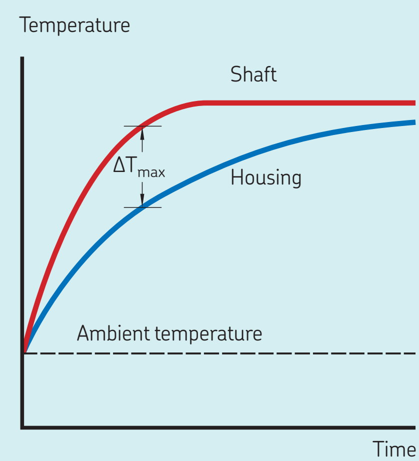
1.3 Technical challenges related to gearbox bearings

Designing a gearbox and selecting bearings often involves compromise. In this process, due to the speed and size of the gearboxes, the following parameters and associated consequences should be carefully considered.

- Selection and use of appropriate fits for shafts and housing.
  - If the shaft fit is too loose, this can result in inner ring fretting corrosion and creeping.
  - If the housing fit is too tight, this can lead to the non-locating spherical roller bearing outer ring becoming stuck. The new higher speed may result in more heat and thus increase the risk of axial preload between the two spherical roller bearings, if the non-locating outer ring is not able to move axially.
- Excessively fast gearbox ramp-up or start-up with cold oil are also potential risks for reduced bearing internal clearance as shown in → **diagram 1**.
  - Ramp-up time should be evaluated case by case and lengthened as needed.
  - In cold ambient conditions pre-heating the oil is typically needed.

Diagram 1

The temperature difference between components



- Load versus speed level
  - Load and speed are interdependent in terms of heat generation. To keep heat generation constant, more load equals less speed and vice versa. This applies to the bearing and the gear mesh.
- Too high viscosity ratio
  - Gearbox lubrication is typically designed more for the gear mesh, meaning the viscosity is unnecessarily high (viscosity ratio κ >4) for the bearings and contrary to the speed requirement.
  - Too high viscosity can lead to greater rolling friction and drag losses, causing higher bearing running temperature.

2 Bearing selection process

Table 3 shows motor compatibility of the different series and sizes of the VA991 execution range, and electric motor speeds with different pole numbers and electric grid frequencies. A 4-pole motor can be used with most of the VA991 range in a gearbox high speed shaft position.

Table 3

VA991 variant limiting speed and motor compatibility

Bearing size	**Shaft diameter**	**Bearing series** 223 Limiting speed	232	240	241
–	mm	r/min			
24	120	3 900			
26	130	3 600			
28	140	3 400			
30	150	3 100			
32	160	2 900			
34	170	2 700			
36	180	2 700			2 400
38	190	2 500			2 300
40	200	2 400	2 500		2 100
44	220	2 100	2 200	2 600	1 900
48	240	1 900	2 000	2 500	1 700
52	260	1 800	1 800	2 200	1 500
56	280	1 600	1 700	2 100	1 300
60	300		1 600	1 900	1 200
64	320		1 400	1 800	1 100
68	340			1 600	
72	360			1 600	

E-motor speed	E-motor type	Electric grid
1 800	4-pole	60 Hz
1 500	4-pole	50 Hz
1 200	6-pole	60 Hz
1 000	6-pole	50 Hz
900	8-pole	60 Hz
750	8-pole	60 Hz

Table 4

Standard spherical roller bearing limiting speed and motor compatibility

Bearing size	**Shaft diameter**	**Bearing series** 223 Limiting speed	232	240	241
–	mm	r/min			
24	120	2 600			
26	130	2 400			
28	140	2 200			
30	150	2 000			
32	160	1 900			
34	170	1 800			
36	180	1 700			1 600
38	190	1 600			1 500
40	200	1 500	1 700		1 400
44	220	1 400	1 500	1 700	1 200
48	240	1 300	1 300	1 600	1 100
52	260	1 100	1 200	1 400	950
56	280	1 100	1 100	1 400	900
60	300		1 000	1 200	800
64	320		950	1 200	700
68	340			1 100	
72	360			1 000	

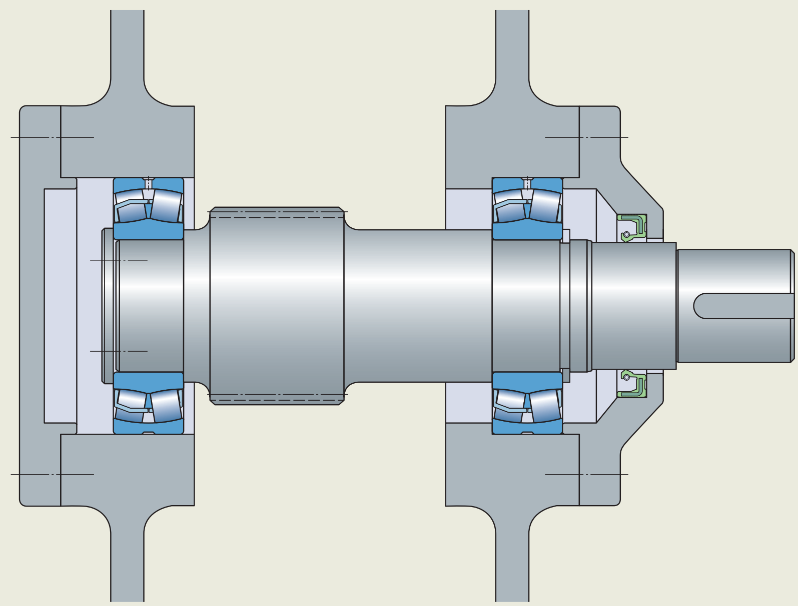
E-motor speed	E-motor type	Electric grid
1 800	4-pole	60 Hz
1 500	4-pole	50 Hz
1 200	6-pole	60 Hz
1 000	6-pole	50 Hz
900	8-pole	60 Hz
750	8-pole	60 Hz

2.1 Bearing type and arrangement

2.1.1 Locating / non-locating arrangement

Fig. 3

Locating / non-locating arrangement



The locating / non-locating arrangement is the recommended setup for the VA991 bearings on helical stage shafts with two bearings per shaft. That means having one bearing outer ring axially locked and the other free to move axially. Both inner rings must be locked. This arrangement has some advantages as compared to a cross-located arrangement:

- Axial force is always taken up by the locating bearing, independent of the direction of the load.
- Displacement of the non-locating bearing outer ring leads to less risk of the axial clamping when the shaft expands (assuming a loose enough outer ring fit is selected).
- When the gear mesh is not in the middle of the distance between the two bearings, axial load can be directed to the bearing with lower radial load.

From a design point of view, the locating / non-locating arrangement is slightly more complicated, as also one of the outer rings must be axially located.

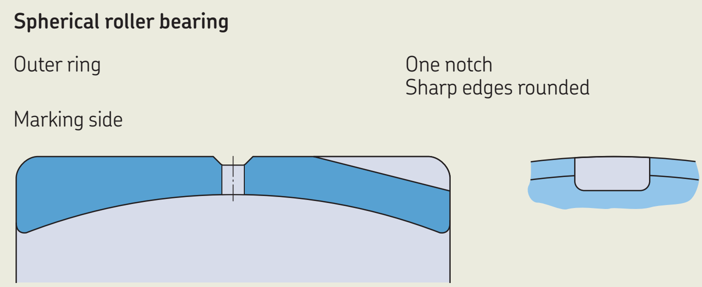
Selecting the motor side bearing as the locating bearing will give an additional advantage. Shaft elongation is less and shaft end movement is reduced which minimizes the axial force towards the input coupling.

For critical applications concerning risk of axial clamping, looser outer ring fit on the non-locating bearing can be selected to facilitate axial movement. Refer to the SKF catalogue, 'Bearing interfaces' section for information.

For critical applications concerning outer ring rotating issues, an anti-rotation slot can be used to reduce the risk of outer ring creeping. The anti-rotation slot can be ordered with suffix VE194.

Fig. 4

VE194 anti-rotation slot



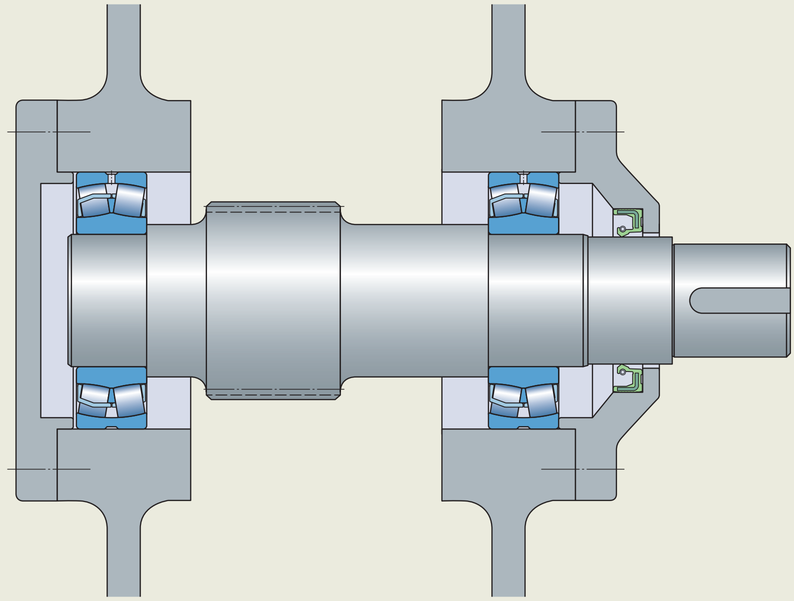
2.1.2 Cross-locating arrangement

The cross-locating arrangement is defined by both bearings being able to move axially and to carry axial load in one direction. This is also a possible solution for VA991, but is not recommended. The main advantage is easier manufacturing of the gearbox housing. Disadvantages as compared to locating / non-locating arrangement are:

- Outer ring of both bearings need to be able to move.
- When the bearing which is at the opposite end from the motor carries axial load, full shaft length elongation must also be compensated in the input coupling.
- Axial force is carried by a different bearing, depending on rotating direction.
- Axial clearance between bearings and covers needs to be adjusted more precisely.

Fig. 5

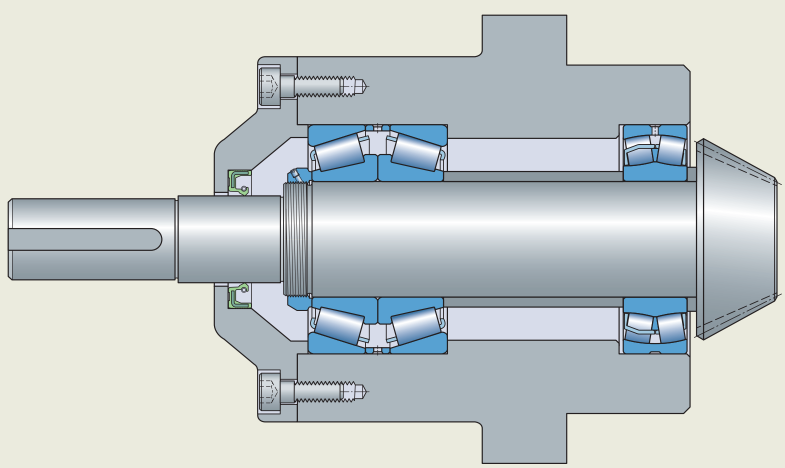
Cross-locating arrangement



2.1.3 Bevel stage arrangement

Fig. 6

Bevel stage arrangement



When using the VA991 variant in bevel stage, special consideration for heat removal and oil flow design is very important. As the bevel mesh is located at the end of the pinion shaft and close to one bearing only, heat distribution differs in comparison to typical helical stage. The bevel pinion housing typically encloses three bearings in a relatively small space. This highlights the need to ensure sufficient oil drainage, especially when there is a long horizontal oil drainage line.

2.2 Bearing size selection

In a large gearbox, typically in high speed shaft position, the fatigue life of the bearing is generally not a limiting factor, due to the load level and favourable lubrication conditions (large viscosity ratio κ). Most operating conditions are located on the top of the a_{SKF} diagram (see **diagram 2**). In such cases, selection of the bearing size and series should be optimised for speed capability, rather than load capability.

Diagram 2

a_{SKF} diagram and common domain for high speed bearing

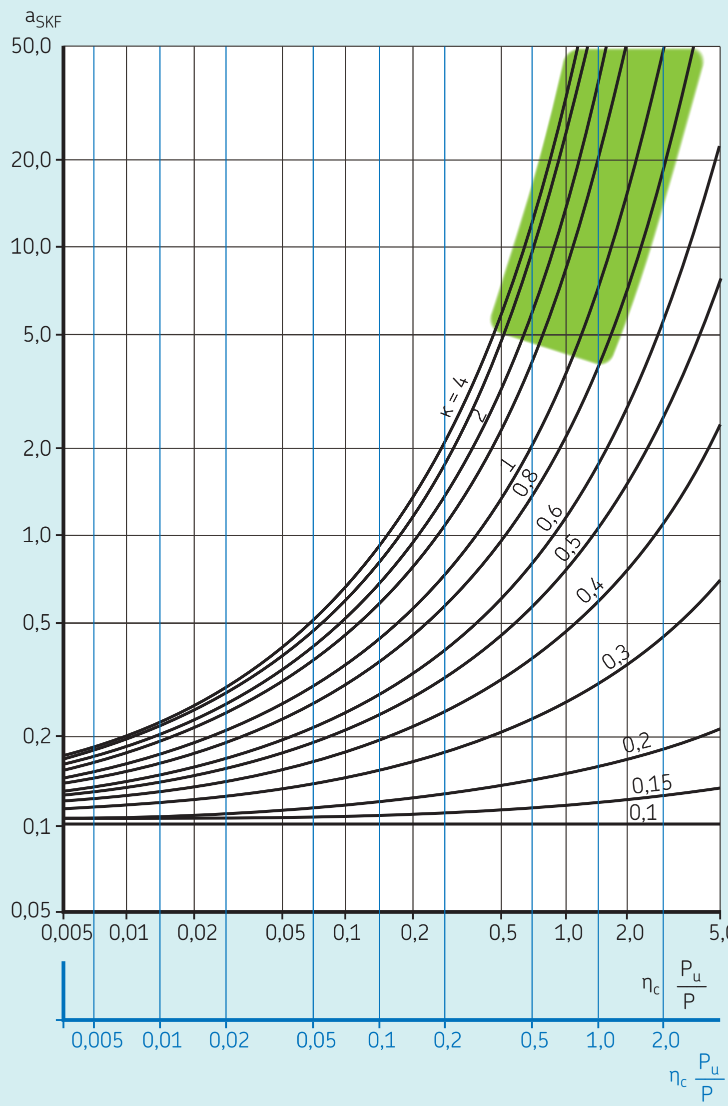


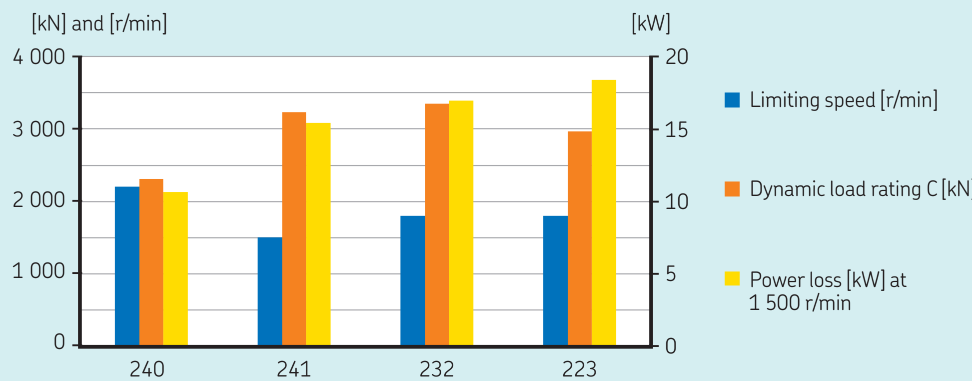
Diagram 3 plots series impact on dynamic load rating, limiting speed capability and power loss at 1 500 r/min. Note that load is not the same for all bearings, but all have same load level C/P = 10, where C is bearing dynamic load carrying capacity and P is equivalent load. It also illustrates how different series can be utilized for different needs. Lack of radial space combined with high load on intermediate shaft could be solved with 241 series. 223 series would be ideal for very high load and limited axial space. Lower power loss and thus lower heat generation would be achieved with 240 series. Selecting the series involves a combination of design considerations where one can optimize selected performance aspects.

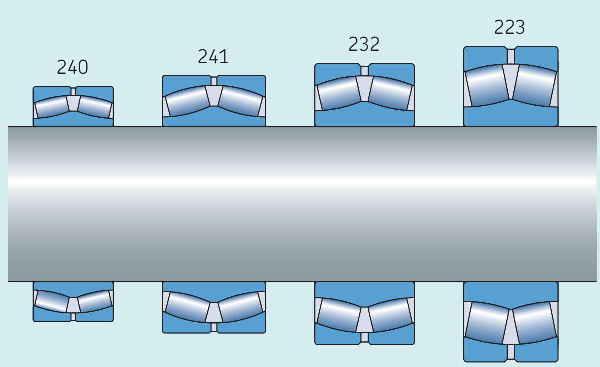
Smearing of rollers during acceleration can also be criteria for selecting the bearing series. Bearings with reduced roller mass and inertia (for example 240 and 241 series which have a smaller roller diameter or shorter roller length), can solve smearing issues.

Diagram 3 shows an example with bearing inner diameter d = 260 mm (bore code 52). Power losses are calculated at C/P = 10 and F_a/F_r = 0,05 and at a temperature of 90 °C with ISO VG 220 oil, where F_a is axial load and F_r is radial load.

Diagram 3

Series' limiting speed and basic dynamic load rating comparison





2.3 Lubrication

2.3.1 Lubrication method

Ensuring adequate lubrication is crucial in high speed gearboxes. Recommendations for the correct levels of oil flow are based on criteria for providing adequate lubrication to the bearing, and sufficient cooling. It is essential to control oil quality and amount and the types of particles present in the oil, which reflect on wear rate.

The optimal amount of oil flow for a high speed bearing application is difficult to predict in general terms, as it is influenced by the complete gearbox thermal equilibrium. To find the optimal amount of oil flow, a thermal simulation model can be used to perform a sensitivity study and to investigate the friction behaviour. Before using such model, it must be calibrated with application testing. A practical way to measure and verify the temperature is to use, for example, PT100 sensors on bearings.

The following guidelines should be considered when selecting the flow level and appropriate method based on application constraints.

2.3.1.1 Lubrication through W33 groove

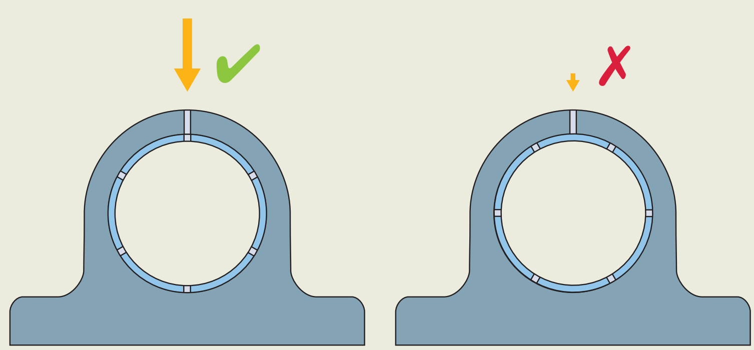
SKF recommends lubricating the bearings through the W33 groove. The advantages are:

- Certainty about all oil going through the bearing.
- Better lubrication of functional contacts inside the bearing.

To facilitate the flow, it is recommended to align the oil inlet with a lubrication hole in the bearing outer ring. Additionally, or alternatively, a groove could be made in the housing bore and used together with the W33 groove.

Fig. 7

Alignment of oil inlet with W33 and additional housing groove

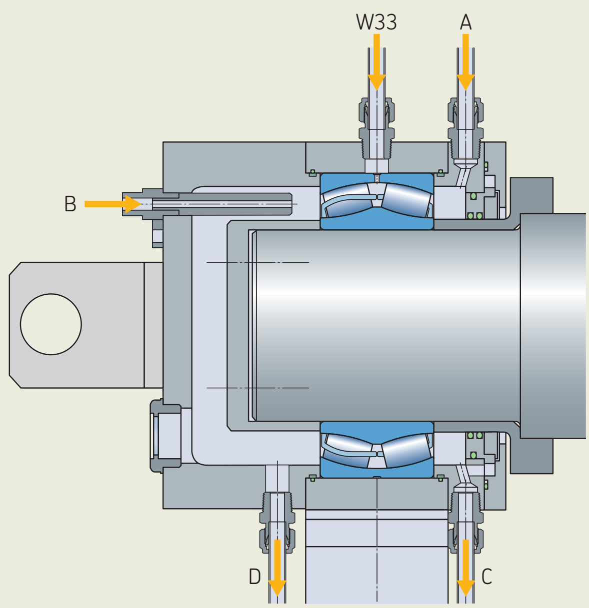


2.3.1.2 Side lubrication

Figure 8 presents a bearing oil flow test rig setup, where B represents side lubrication directed to the rollers, A and B are indirect oil feeds and W33 has oil led directly to the W33 groove in the bearing outer ring. D and C are oil drainages. Test results show that side lubrication is also possible, but appears to be a slightly less efficient cooling method. If side lubrication is used, the flow should be directed preferably between the cage and the outer ring.

Fig. 8

Oil feed and drainage test rig



2.3.1.3 Oil drainage

The flow required to cool the bearing at high speed can be significant. It must be certain that the drainages around the bearings are sufficiently large to allow the flow outlet. If the drainage is too limited, this can result in overheating, as a localised oil bath is created, generating unwanted additional drag losses, and the risk of leakage outside the gearbox.

Drainage is important for W33 and side lubrication.

It is difficult to accurately calculate the required outlet diameter because many variables influence oil drainage, e.g. oil level difference, length and diameter of the drilling or pipe, number of bends, and oil viscosity. Generally, the outlet diameters are selected from experience or by rule of thumb. **Figure 9** shows a drawing of an outlet. An approximate calculation of the required minimum outlet diameter can be performed as follows:

$$d_{min} = 2{,}2 \left(\frac{(2{,}5 + 0{,}2n)\, Q^2 \times 10^3 + 3\nu l Q}{h} \right)^{1/4}$$

where

d_{min} = minimum bore of outlet pipe [mm]

n = number of 90° bends

Q = oil flow [l/min]

ν = kinematic viscosity of oil at lowest operating temperature (mostly at start-up) [mm^2/s]

l = pipe length [mm]

h = oil level difference [mm]

The equation is valid when the outlet from the housing has no restrictions. Practical experience shows that if there are restrictions close to the outlet, e.g. walls in bearing housings, the resistance to the inflow increases considerably. The calculated diameter d_{min} should then be increased by 50%.

Fig. 9

Oil supply and return ducts for oil bath lubrication

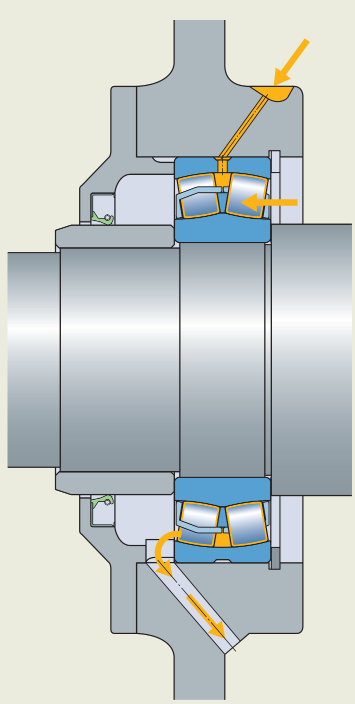


Fig. 10

Oil drainage around bearing

2.3.2 Oil viscosity

The oil viscosity has an important influence on the friction in the bearing and gear mesh, and thus on heat generation. Therefore, the choice of base oil viscosity needs to be selected carefully for high speed application.

In general, oil viscosity choice is driven by the gear mesh lubrication requirements, which often leads to relatively high viscosity ratios for the bearings. It should be noted, that a high oil viscosity will tend to generate higher friction when rotating at high speed, which can lead to higher running temperature of the bearings and the entire gearbox. It is therefore recommended to investigate whether an oil with a lower than usual viscosity can be used, to enable more favourable running conditions.

The following tables illustrate the viscosity ratio (κ) conditions that could be encountered in gearboxes at operating conditions. κ is a ratio of actual operating viscosity of the lubricant and rated viscosity, which depends on the bearing mean diameter and rotation speed. It describes the oil film condition regarding surface separation. For more information, refer to the lubrication chapter in the 'SKF Rolling Bearings catalogue'.

In gearboxes, typical rated viscosity ranges (ν_1) at operating temperature to reach viscosity ratio $\kappa \geq 1$ are listed in **table 5**, for different bearing mean diameters (d_m):

- On high speed shaft bearing (HSS) positions, the typical required viscosity ν_1 is in the range of 4 to 10 mm^2/s
- On intermediate shaft bearing positions (ISS), the typical required viscosity ν_1 is in the range of 9 to 25 mm^2/s.

Table 5

Required viscosity to have κ = 1 at operating temperature for typical gearbox ratio 3,6 per stage

d_m	**Required viscosity, ν_1** HSS speed [r/min] 1 800	1 500	990	ISS speed [r/min] 500	417	275
mm	mm^2/s					
250	5,7	6,1	7,2	13,0	15,2	21,8
350	4,9	5,2	6,1	10,9	12,7	18,2
450	4,5	4,7	5,4	9,5	11,0	15,8

Usually gearbox oils are ISO VG 220, ISO VG 320 and sometimes higher. Operating temperature of a bearing is targeted in the range of 70–90 °C in steady state. **Table 6** illustrates the possible range of κ in such gearboxes. One can observe that HSS bearing position may be in the domain of high-viscosity ratio (κ > 4).

Table 6

Possible κ range examples in gearboxes

Oil viscosity
40 °C, 320 [mm²/s]
90 °C, **33,7** [mm²/s]

	Viscosity ratio, κ					
	HSS speed, [r/min]			ISS speed, [r/min]		
d_m	1 800	1 500	990	500	417	275
mm	–					
250,0	5,9	5,5	4,7	2,6	2,2	1,6
350,0	6,9	6,5	5,5	3,1	2,7	1,9
450,0	7,6	7,2	6,2	3,6	3,0	2,1

Oil viscosity
40 °C, 220 [mm²/s]
90 °C, **25,8** [mm²/s]

	Viscosity ratio, κ					
	HSS speed, [r/min]			ISS speed, [r/min]		
d_m	1 800	1 500	990	500	417	275
mm	–					
250,0	4,6	4,2	3,6	2,0	1,7	1,2
350,0	5,2	4,9	4,2	2,4	2,0	1,4
450,0	5,8	5,5	4,8	2,7	2,3	1,6

Oil viscosity
40 °C, 220 [mm²/s]
70 °C, **52,1** [mm²/s]

	Viscosity ratio, κ					
	HSS speed, [r/min]			ISS speed, [r/min]		
d_m	1 800	1 500	990	500	417	275
mm	–					
250,0	9,2	8,6	7,2	4,0	3,4	2,4
350,0	10,6	10,0	8,5	4,8	4,1	2,9
450,0	11,7	11,2	9,7	5,5	4,7	3,3

Diagrams 4 and **5** show the impact of the initial oil viscosity on power loss for different speeds. They include two bearing sizes with a fixed temperature of 90 °C. One can notice that switching from the standard execution to the VA991 execution with the higher limiting speed, power loss will increase 50–60% for the considered load cases.

Power loss in a HSS bearing is not the driving parameter for the complete gearbox design. For example, reliability expressed by a good κ at low speed shaft bearings and good lubrication film at gears, are usually more important factors. Nevertheless, in some cases it is possible to limit power loss increase by changing to one class lower viscosity oil, e.g. 5–10% can be obtained by switching from ISO VG 320 to ISO VG 220 . The horizontal arrows in **diagrams 4** and **5** indicate the change to new limiting speed, and vertical arrows indicate the change in power loss between different viscosity oils.

Diagram 4

Example of viscosity impact on power losses on 22336 size with load cases C/P = 10 and F_a/F_r = 0,05

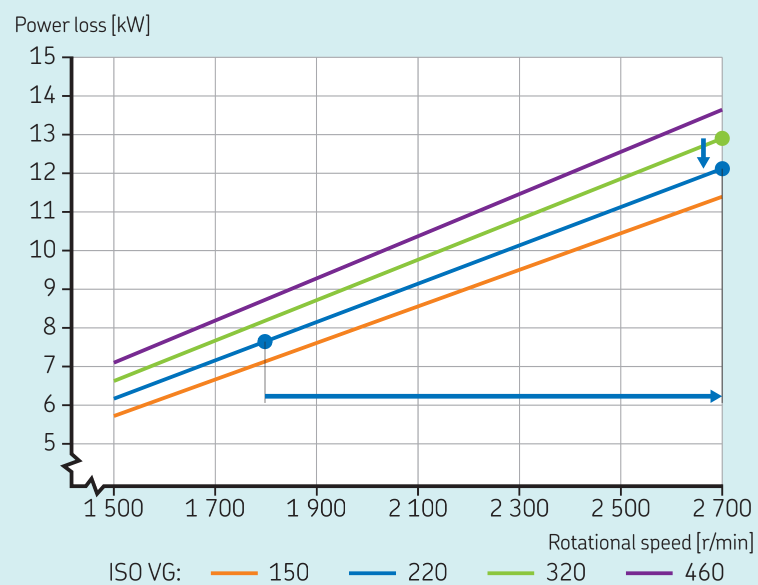
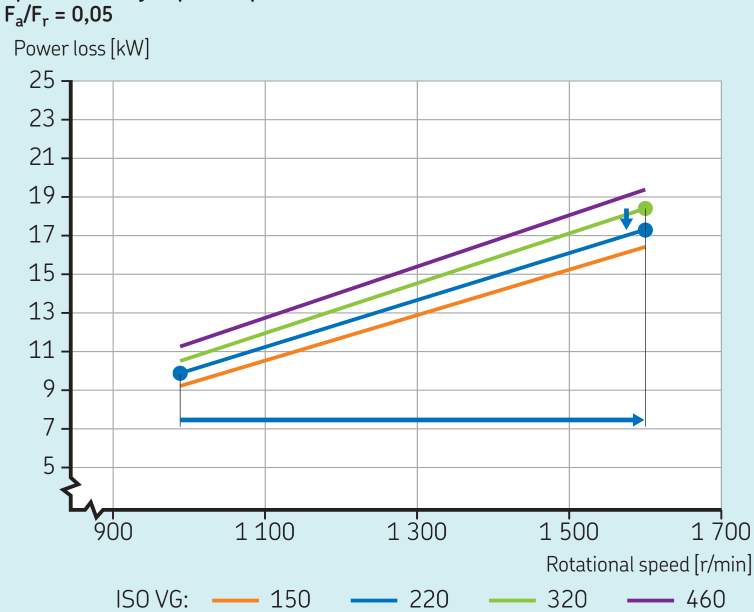


Diagram 5

Example of viscosity impact on power losses on 22356 size with load cases C/P = 10 and F_a/F_r = 0,05



2.4 Thermal analysis

2.4.1 Thermal equilibrium and lubrication flow requirement

Arranging appropriate cooling is especially important. At full speed and full load, the VA991 variant will naturally generate more heat compared to a standard bearing running at its limiting speed. Depending on the speed, load and the maximum allowable operating temperature, the potential requirement for extra cooling needs to be achieved by increasing cooling capacity and/or oil circulation with cooled oil.

2.4.2 Oil preheating

SKF recommends the circulating oil to be heated to a temperature range of 40–50 °C prior to start-up, in order to ensure that the bearings are heated to the same temperature. If the ambient temperature is especially cold, it is recommended to increase the pre-heating time, and to lenghten ramp-up time during the start-up.

The objective is to have the oil heated and circulating to warm up the gearbox components. This will minimize the unfavourable temperature gradient during start-up, and will also allow more favourable viscosity domain in start-up situations.

2.4.3 Oil flow

The oil flow required to cool the bearing is primarily dependent on the operating conditions (speed, load and lubricant), excluding the effect of other gearbox components. **Table 7** and **8** indicate the typical power loss level that can be expected in gearbox operating condition at VA991 limiting speeds and at 1 500 r/min. Remember that the values can change for different operating conditions.

Table 7

Bearing power loss [kW] with load cases C/P = 10 and F_a/F_r = 0,05, at limiting speed and 90 °C with ISOVG 220 oil

Bearing	**Bearing series**							
	223		232		240		241	
Bore code	Power loss	Speed	Power loss	Speed	Power loss	Speed	Power loss	Speed
–	kW	r/min	kW	r/min	kW	r/min	kW	
24	7	3 900						
26	8	3 600						
28	9	3 400						
30	9	3 100						
32	10	2 900						
34	10	2 700						
36	12	2 700					10	2 400
38	12	2 500					11	2 300
40	13	2 400	14	2 500			11	2 100
44	14	2 100	16	2 200	14	2 600	13	1 900
48	16	1 900	19	2 000	15	2 500	14	1 700
52	18	1 800	20	1 800	17	2 200	16	1 500
56	19	1 600	20	1 700	18	2 100	15	1 300
60			23	1 600	21	1 900	17	1 200
64			24	1 400	21	1 800	19	1 100
68					24	1 600		
72					25	1 600		

Table 8

Power loss at 1 500 r/min for most of the range, with load cases C/P = 10 and F_a/F_r = 0,05 and 90 °C with ISO VG 220 oil

Power loss Bore code	**Bearing series** 223 Power loss	Speed	232 Power loss	Speed	240 Power loss	Speed	241 Power loss	Speed
–	kW	r/min	kW	r/min	kW	r/min	kW	r/min
24	2	1 500						
26	3	1 500						
28	3	1 500						
30	4	1 500						
32	5	1 500						
34	5	1 500						
36	6	1 500					6	1 500
38	7	1 500					7	1 500
40	8	1 500	8	1 500			8	1 500
44	10	1 500	10	1 500	7	1 500	10	1 500
48	12	1 500	14	1 500	8	1 500	12	1 500
52	14	1 500	16	1 500	11	1 500	16	1 500
56	17	1 500	17	1 500	12	1 500	15	1 300[1)]
60			22	1 500	16	1 500	17	1 200[1)]
64			24	1 400	17	1 500	19	1 100[1)]
68					22	1 500		
72					23	1 500		

1) Limiting speeds of the particular bearing size which are below 1 500 r/min

The following tables display flow requirement, assuming all heat is transferred by the oil (although heat dissipation inside the gearbox is dependent on the gearbox design). Note that the oil flow requirement also depends on the temperature gradient between oil inlet and outlet.

Tables 9 and **10** can be used as a starting point when designing gearbox oil flow. **Table 9** displays oil flow requirement at each bearing limiting speed with load case of C/P = 10 and F_a/F_r = 0,05. **Table 10** has the same load case, but speed is set to 1 500 r/min for the bearings that have the appropriate limiting speed.

Table 9

Flow requirement with load cases C/P = 10 and F_a/F_r = 0,05, at limiting speed and 90 °C with ISOVG 220 oil, assuming 50° C gradient between inlet and outlet.

Bearing Bore code	**Bearing series** 223 Oil flow	Speed	232 Oil flow	Speed	240 Oil flow	Speed	241 Oil flow	Speed
–	l/min	r/min	l/min	r/min	l/min	r/min	l/min	r/min
24	5	3 900						
26	5	3 600						
28	6	3 400						
30	6	3 100						
32	7	2 900						
34	7	2 700						
36	8	2 700					7	2 400
38	9	2 500					8	2 300
40	9	2 400	10	2 500			8	2 100
44	10	2 100	11	2 200	10	2 600	9	1 900
48	11	1 900	13	2 000	10	2 500	10	1 700
52	12	1 800	14	1 800	12	2 200	11	1 500
56	13	1 600	14	1 700	12	2 100	10	1 300
60			16	1 600	14	1 900	12	1 200
64			17	1 400	15	1 800	13	1 100
68					16	1 600		
72					18	1 600		

Table 10

Flow at 1 500 r/min for most of the range, with load cases C/P = 10 and F_a/F_r = 0,05 and 90 °C with ISO VG 220 oil, assuming 50 °C gradient between inlet and outlet.

Bearing Bore code	Bearing series 223 Oil flow	Speed	232 Oil flow	Speed	240 Oil flow	Speed	241 Oil flow	Speed
–	l/min	r/min	l/min	r/min	l/min	r/min	l/min	r/min
24	2	1 500						
26	2	1 500						
28	2	1 500						
30	3	1 500						
32	3	1 500						
34	4	1 500						
36	4	1 500					4	1 500
38	5	1 500					5	1 500
40	5	1 500	5	1500			5	1 500
44	7	1 500	7	1 500	7	1 500	7	1 500
48	8	1 500	10	1 500	8	1 500	9	1 500
52	10	1 500	11	1 500	11	1 500	11	1 500
56	12	1 500	12	1 500	12	1 500	10	1 300[1)]
60			15	1 500	16	1 500	12	1 200[1)]
64			17	1 400	17	1 500	13	1 100[1)]
68					22	1 500		
72					23	1 500		

1) Limiting speeds of the particular bearing size which are below 1 500 r/min

For quick estimation of flow requirement, the following formula can be used. Note that this formula does not consider heat dissipation inside the gearbox (which would require a thermal study).

Oil flow quantity:

$$Q = \frac{P}{29\,(T_{out} - T_{in})}$$

where

Q = oil flow [l/min]

P = power loss [kW]

T_{out} = oil outlet temperature [°C]

T_{in} = oil inlet temperature [°C]

2.5 Bearing interfaces

2.5.1 Shaft and housing seat tolerances

For the high speed bearing VA991 solution in gearboxes, it is recommended to follow the guidelines set out below.

Shaft seat tolerances

The rotating inner ring load condition means an interference fit is needed.

- To avoid inner ring creep in steady state and transient conditions considering a load of P > 0,1 C
- To minimize fretting corrosion risk.

The recommended shaft tolerance is r6 Ⓔ as compromise between required interference fit fit and hoop stress.

Table 11

Fits for solid steel shafts
Shaft fits recommended for VA991 spherical roller bearing for P > 0,1 C

Bearings	Fit tolerance class	Ra [µm]
22324 to 22356	r6 Ⓔ	1,6
23240 to 23264	r6 Ⓔ	1,6
24044 to 24072	r6 Ⓔ	1,6
24136 to 24136	r6 Ⓔ	1,6

Housing seat tolerances

The stationary outer ring load allows to use a loose fit in the housing which is required to allow the outer ring of the non-locating bearing or the cross located bearings to move axially in their housing seat to compensate shaft thermal expansion. The housing recommendation is G7Ⓔ, owing to the temperature difference between outer ring and housing during start-up and normal operation. H7Ⓔ may result in interference fit, particularly during start-up transient conditions which could lead to axial preloading of the bearings.

K7Ⓔ can be used as the locating bearing for limiting the risk of the outer ring rotating. Tolerance class 6 is preferred but not compulsory.

Table 12

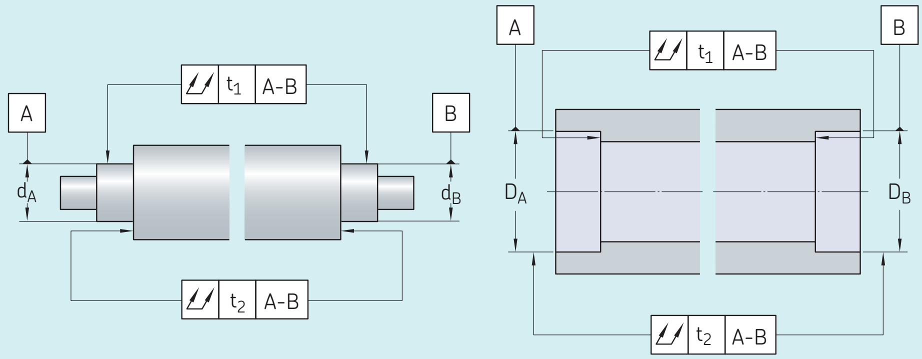
Fits for cast iron and steel housings (for radial bearings)
Housing fits recommended for VA991 spherical roller bearing

Bearings	Fit tolerance class non-locating cross-locating	locating	Ra [µm]
22324 to 22356	G7Ⓔ	K7Ⓔ(**) or G7Ⓔ	3,2
23240 to 23264	G7Ⓔ	K7Ⓔ(**) or G7Ⓔ	3,2
24044 to 24072	G7Ⓔ	K7Ⓔ(**) or G7Ⓔ	3,2
24136 to 24136	G7Ⓔ	K7Ⓔ(**) or G7Ⓔ	3,2

* K7 is recommended for limiting the risk of OR rotating (and to improve thermal contact between OR and housing)
** K7 is maximum interference fit with a split housing

Table 13

Tolerance grades for bearing seats



Shaft seat | Housing seat

Application requirements	Dimensional tolerance grade	Geometrical tolerance grades		Dimensional tolerance grade	Geometrical tolerance grades	
		Radial run-out t_1	Axial run-out t_2		Radial run-out t_1	Axial run-out t_2
Bearing to Normal tolerances	IT6	IT5/2	IT5	IT7	IT6/2	IT6

2.5.2 Bearing tolerance class

Bearing internal radial clearance is defined as the total distance through which one bearing ring can be moved radially relative to the other. It is necessary to distinguish the difference between initial clearance prior to mounting, and operating clearance, which applies to a bearing in operation that has reached a stable temperature, having also transient conditions, for example at start-up. Sufficient internal clearance in a bearing during operation is extremely important. For more information, refer to the chapter 'Bearing internal clearance' of the SKF Rolling Bearings catalogue.

Based on SKF knowledge and studies on typical gearbox conditions, the basic clearance class should be C4 for VA991 and high speed conditions. The choice is a result of fits, speeds and temperature gradient; remembering that:

- Target is steady state operating clearance
- Safety margin for transient conditions like start-up situation
- A specific detailed evaluation can be performed to optimize choice between C3 and C4 for a specific gearbox.

The Normal bearing tolerance class is typically appropriate for usage in gearboxes. Spherical roller bearings of standard SKF Explorer design or VA991 execution have:

- Normal tolerance class for d >300 mm
- P5 run-out tolerances for d < or = 300 mm.

The narrower run-out tolerances of P5 are particularly advantageous when running at the high speeds of the VA991 execution. When combined with a shaft seat tolerance of IT5 and housing seat tolerance of IT6 this results in:

- less vibration and noise
- smoother running
- less risk of critical imbalance
- less cage forces

For d > 300 mm narrower run-out tolerances can be supplied on request.

The new VA991 execution of the well proven SKF Explorer spherical roller bearing for high speed applications was designed and validated for industrial gearboxes using:

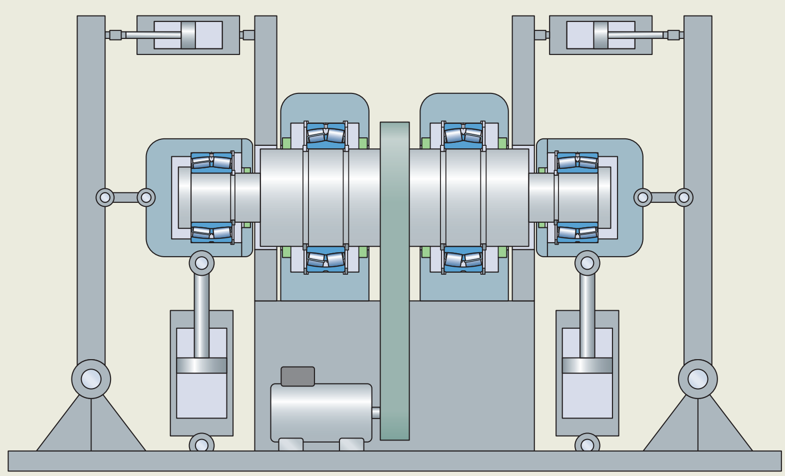
- Advanced modelling
  - SKF Beast for component design
  - SKF SimPro Expert for gearbox thermal and power loss behaviour
- Dedicated testing
  - Bearing functional and comparative tests under gearbox operating conditions.

Dedicated test rig

- Comparing standard and VA991 design
- Running at standard and VA991 limiting speeds
- Under gearbox typical loading (pure radial and combined radial/axial load)
- With various circulating oil lubrication conditions.

Fig. 11

Test bench setup



2.6 Additional design considerations

2.6.1 Mounting

Due to the interference fit and size of bearings, it is recommended to mount the bearings with hot mounting procedure using an induction heater. It is generally not possible to mount larger bearings without heating the bearing, as the force required to mount a bearing rises considerably with increased bearing size.

During mounting, it is important that the bearing rings, cages and rolling elements are never struck directly with any hard object and that the mounting force is never applied through the rolling elements.

For detailed information go to SKF.com/mount.

2.6.2 Gearbox factory test

If a non-loaded gearbox test run is performed after gearbox assembly, the bearing may run below the minimum required load which can lead to roller skidding. To minimize the risk of smearing when running in such conditions, please consider the following recommendations:

- Reduced oil flow
  - To reduce the drag losses
  - To match overall lower heat generation of gearbox
- Target $\kappa > 1$ for all positions, but avoid $\kappa > 4$
  - Use lower viscosity grade oil if needed
- Long ramp-up time is highly recommended
  - 10–20 min
- Gearbox should not be driven from the low speed shaft
- Sudden load changes are to be avoided in all situations.

skf.com

PUB BU/P2 17857 EN · Mars 2018