

DOUBLE ROW ANGULAR CONTACT BALL BEARINGS IN CENTRIFUGAL PUMPS

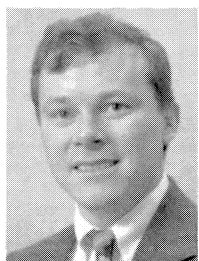
by

Keith E. Meyers

Manager, Applications Engineering, General Machinery Segment

SKF USA Inc.

King of Prussia, Pennsylvania



Keith Meyers is Manager, Applications Engineering, for SKF USA Inc., General Machinery Segment, King of Prussia, Pennsylvania. He is responsible for providing technical assistance for the use of rolling bearings to the major manufacturers of pumps, compressors, and other general machinery in the USA. He has held various positions within SKF, including a two year assignment at the SKF Engineering & Research Centre, The

Netherlands. He is a registered Professional Engineer in the Commonwealth of Pennsylvania. Prior to joining SKF in 1985, he was a Senior Product Engineer for Allis-Chalmers Corp., Hydroturbine Division, York, PA. He is a graduate BSME from the University of Maryland (1978). He has provided a tutorial at a previous Pump Symposium and has been a Discussion Group Leader for the Symposium's Bearing and Lubrication Discussion Groups.

ABSTRACT

Double row angular contact ball bearings are used extensively in ANSI type end suction centrifugal pumps and other fluid machinery. The double row angular contact ball bearing supports combined axial and radial loads, provides high shaft stiffness and limits the movement of the pump impeller, shaft, and seal. Recent case studies, tests, and analysis of double row ball bearings operating in various conditions have both confirmed and contradicted some long held opinions, regarding the application of these bearings in centrifugal pumps.

The studies indicate that Conrad type (e.g., without filling slot) double row angular contact ball bearings operate at lower temperatures than the maximum capacity filling slot type double row bearings at 3,600 rpm rotational speed. These lower operating temperatures result in longer bearing and lubricant life and greater pump reliability. The filling slot of the modern design maximum capacity double row bearing has been redesigned so that it seldom has direct influence on the bearing life and performance when correctly applied in the pump. Double row angular contact ball bearings having moderate to high contact angle and normal axial internal clearance operate at lower temperature and have better internal motion than bearings having lower contact angles and greater clearances in typical pump application conditions. The results and conclusions of the studies made with the double row angular contact ball bearings are discussed. The presentation also provides specific recommendations for obtaining the best performance and longest life of double row angular contact ball bearings in centrifugal pump applications.

INTRODUCTION—DOUBLE ROW ANGULAR CONTACT BALL BEARINGS

The double row angular contact ball bearing (Figure 1) is commonly used in the American National Standard Institute (ANSI) B73.1M-1984 chemical process pump (Figure 2), double suction pump, and submersible pump to support radial and axial loads. The double row angular contact ball bearing is similar to two single row angular contact bearings mounted side by side in a back-to-back arrangement. Formerly, the bearing was more common with a face-to-face arrangement. The bearing is made in the Conrad type (Figure 1(a)) and the maximum capacity filling slot type (Figure 1(b)). Owing to the two ball rows and angular contact construction the bearing is suitable to support axial load in either direction or combinations of radial and axial loads. The bearings have high radial and axial stiffness and small axial and radial endplay for support of the shaft and pump shaft seal. The bearing ring construction allows it to be factory lubricated and shielded (Figure 1(c)) or sealed (Figure 1(d)), for simplified installation onto the pump shaft, and into the housing.

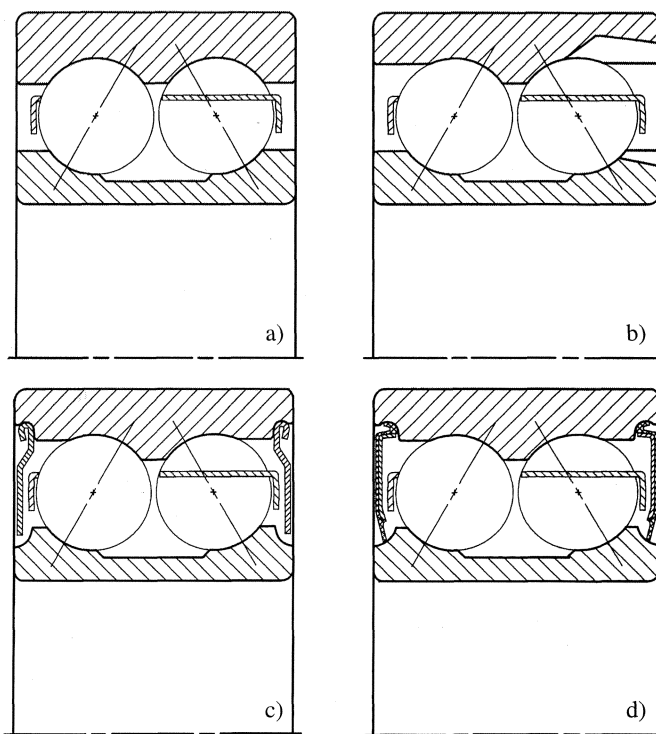


Figure 1. Double Row Angular Contact Ball Bearings. a) Conrad type; b) filling slot; c) shielded; d) sealed.

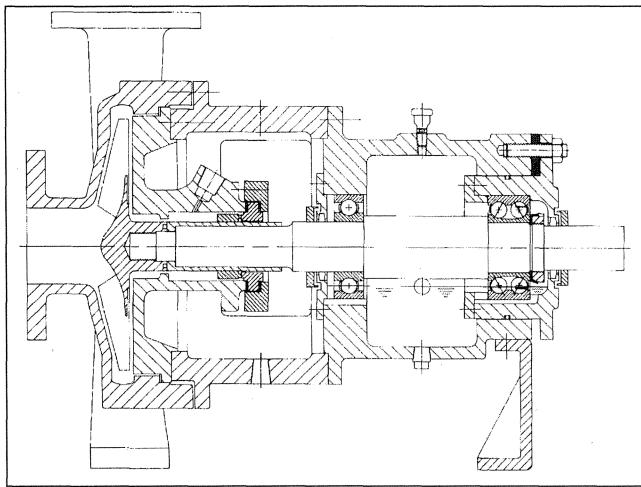


Figure 2. ANSI Centrifugal Pump.

Approximately 30,000 new ANSI centrifugal pumps are produced each year and, for the most part, all use the double row angular contact ball bearing. Additionally, many double row bearings are installed each year during maintenance of existing pumps. The reliability of the pumps (new and rebuilt) depend on the correct selection and use of the bearings. It is important for the pump manufacturer (OEM) and end user, industrial bearing distributor, and bearing manufacturer to recognize the differences in bearing designs and the significance of their features. This is particularly important, since the designs vary and there are no definitive International Standards Organization (ISO) or ANSI/American Bearing Manufacturers Association (ABMA) standards for the nomenclature or internal clearances of double row angular contact ball bearings.

There are "understandings" regarding the use of double row bearings that have developed over the years. One of these "understandings" is that the filling slot double row bearing should not be used in centrifugal pumps. Another is that double row bearings having greater than normal (C3 suffix) internal clearance perform better in pump applications. These "understandings" have been studied and are not necessarily correct. The results are discussed of these studies and a background is provided for the use of the double row angular contact ball bearing in centrifugal pump applications.

DOUBLE ROW BEARING DESIGN

The double row angular contact ball bearing is currently designated with two basic nomenclatures. The Dimensions Series: 5200 and 5300 by the ABMA, and the 3200 and 3300 by the ISO. These bearings are all dimensionally interchangeable. Some manufacturers use one or both nomenclatures depending on the country of manufacture to identify the two basic types (Conrad or maximum capacity) (Table 1). In some cases a suffix code is used to denote the Conrad or filling slot type. The boundary dimensions of the double row bearings are in accordance to ISO 15-1981: the bore and outer diameter dimensions of the bearings are to metric dimensions while the widths are generally to in dimensions (to the nearest 1/16 in). The double row bearing is one of the few types having its width made to nominal in dimensions. Previously, the bearings having seals or shields were an additional 1/16 in wider than the current bearings. The modern design bearings can accommodate the seals and shields within the standard bearing widths. The shields are a nonrubbing type made of sheet steel. The seals are a steel backed, nitrile contact lip type. Bearings having two seals or shields are factory greased with a volume of grease

generally equal to 25 to 35 percent of the bearing's free internal volume. The exact grease type depends on the manufacturer.

Table 1. Comparison of Bearing Nomenclature and Designs.*

Manufacturer	Bearing	Type	Standard		
			Contact angle (degrees)	Cage Material	Clearance definition (axial or radial)
A	5000	Conrad	20	steel	unpublished
A	5000	filling slot	20	steel	unpublished
B	5000	Conrad	25	steel	radial
C	3000	Conrad	25	nonmetallic	axial
D	5000	Conrad	30	steel	radial
D	3000	filling slot	30	nonmetallic	radial
E	5000	Conrad	30	steel	axial
E	5000	filling slot	30	steel	axial

* pump bearing sizes.

The double row bearing is available with a number of different internal contact angles.

The contact angles generally range from 20 to 30 degrees (Table 1). The low contact angle bearings have the best capability to support a predominant radial load such as in a double suction centrifugal pump. The low contact angle double row bearing is also used in automotive clutch and belt tensioner applications. The axial or thrust capability of the bearing increases with increase in contact angle. There is no ISO or ABMA Standards for the internal contact angle in double row bearings. The bearing manufacturers each have their own standard for contact angle. The contact angle in the double row bearing can generally only be identified by contacting the manufacturer or by studying their catalogs. It will be discussed later that the design contact angle is an important feature for the selection of the bearing in centrifugal pump applications.

The double row bearing is available with a number of cage options; i.e., steel, nonmetallic, and machined brass in some limited bearing sizes. The steel cage is the most common of the options and is usually the pressed snap-in type, one for each row. The nonmetallic cages are molded of glass reinforced polyamide 6.6 material. The polyamide material has a recommended temperature limit of 100°C (212°F) in centrifugal pump applications. This temperature limit is based on the use of mineral oils and greases. Prolonged use of the material above this temperature causes aging, a drying of the material, which reduces its elasticity and structural strength. The limit is reduced for instance to 80°C (176°F) when phosphate ester lubricants are used. The temperature limit is based on the oil temperature. Tests and experience have shown that all the cage types perform equally well in normal operating conditions, although the double row bearing with a steel cage is perceived to last longer in poor lubrication conditions. The bearing with polyamide cage is quieter in operation which is an advantage in some applications. A disadvantage of the bearing with polyamide cage is that this quiet operation may not provide warning to the enduser that the bearing is failing and that the bearing and pump should be taken from service. The bearing with pressed steel cage is recommended for the centrifugal pump application.

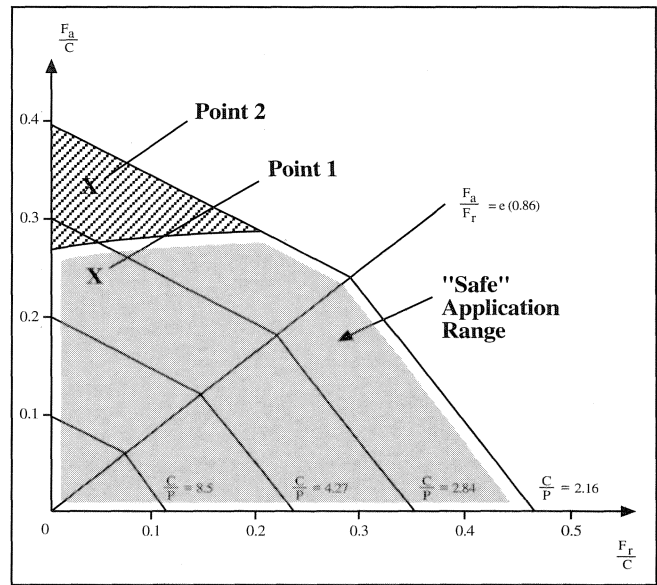
CONRAD AND FILLING SLOT BEARINGS

The double row angular contact ball bearing is available in two designs: Conrad type and maximum capacity filling slot type. The Conrad bearing is constructed of the inner and outer ring snapped together around the balls before assembly of the cages. The filling

slot in the side face of the maximum capacity (from now on referred to as the filling slot type) bearing permits the insertion of a higher number of balls into the rings. The capability of a ball bearing to support load is dependent on the number and size of balls within the rings along with the internal contact geometry. The filling slot type bearing therefore has higher load capacity than the Conrad type according to the bearing industry Standard ISO 281/I-1977, and a theoretically longer rating life for similar load conditions.

The slot milled into the side face of the filling slot double row bearing is slightly larger than the size of the bearing ball and projects into the raceways of the inner and outer rings. The slot is usually in only one side face of the bearing, although in some older designs, it could be in both side faces. For a double row bearing supporting radial load, both rows of balls distribute the load and the contact between the balls and the raceway is low in the ball grooves away from the filling slot. As axial load is applied to the bearing in one direction, the position of the ball contact in the one row supporting the axial load moves further up the ball groove. In the modern filling slot double row bearing, the slot is redesigned to be positioned radially outward slightly in the side face from the bearing mean diameter to minimize the possibility of the ball rolling over the projection of the slot in the raceway. This redesign allows the filling slot bearing to support axial load in both axial directions with reduced risk of damage from the filling slot. A large application range where the modern filling slot double row angular contact ball bearings can be safely applied without risk of damaging contact between the balls and the filling slot can now be defined (Figure 3). The "safe" application range depends on the bearing dynamic load rating, C and the magnitude of the applied radial, F_r and axial loads, F_a . For instance, a 5306 filling slot double row bearing ($C = 45,700 \text{ N}$) can be safely used in a pump having an axial load of 10867 N (2440 lbf) and radial load of 2173 N (490 lbf) without regard to orientation and without risk of damage from the filling slot, see Point 1 in the "safe" zone of Figure 3. For the bearing supporting very high axial load, Point 2 in the "unsafe" zone of Figure 3, damage from the ball contacting the filling slot is possible, resulting in reduced bearing life. Endurance tests [1] of these two points confirmed the function of this "safe" application range. The tests further suggest that the low geometry factor allowed by the ISO 281/I-1977 Standard is not necessarily justified and that the filling slot bearing could have 18 percent higher ISO (and ABMA) load rating than indicated by the present bearing catalogs [2], so long as it is applied in the "safe" range. In all cases, however, the installation and orientation of the filling slot bearing in a pump should be made in accordance with the instructions of the pump OEM.

Tests and experience have shown that Conrad double row bearings operate at much cooler temperatures than filling slot double row bearings. One case study examines the operation of a 5312 bearing in an ANSI centrifugal pump operating at 3,600 rpm. The bearing originally operated in the pump was a 5312 filling slot bearing having greater than normal axial clearance that was "greased for life" with two shields. Operating temperatures of the bearing outer rings were measured to be in the range of 99° to 104°C (210° to 220°F). Substitution of the 5312 Conrad bearing with two shields and greater than normal clearance resulted in a 11° to 17°C (20° to 30°F) reduction in bearing operating temperature. The bearing operating temperature was reduced another 28°C (50°F) when a 5312 bearing (open Conrad bearing, without shields and normal axial clearance), hand packed with grease, was used instead. This became the OEM's standard bearing. The lubricant adjusted rating life of the Conrad bearing was 35 percent longer than the original filling slot type bearing due to the reduced operating temperature and resulting improved lubrication. The grease life (relubrication interval) was increased by a factor of six by the reductions in operating temperature.



A  B 

Figure 3. Safe Application Range for Filling Slot Double Row Bearings.

The lower operating temperatures in the Conrad double row bearing can be explained by examining the components of friction within the bearing. The total frictional moment in a rolling bearing is the sum of the load-independent moment, M_0 , and the load-dependent moment, M_1 . Seal friction also can contribute to high bearing operating temperature. In pump applications, the most dominant friction comes from the load-independent friction, M_0 , due to the high speed motion of the balls moving through the lubricant. The more balls and lubricant in the bearing, the greater the M_0 friction. This explains why bearings lubricated by oil-mist have the lowest friction and operating temperature since the quantity of oil is low. The load-dependent moment, M_1 is generally low due to the relatively low load in the pump bearing. The M_0 friction is proportional to the number (Z) and size of balls (D_w) in the bearing, the bearing mean diameter (dm), and the quantity of lubricant, K . This relationship is shown in Equation (1). The viscosity of the lubricant and bearing rotational speed also influences the M_0 friction.

$$M_0 \propto K Z (D_w/dm)^{1/3} \quad (1)$$

A Conrad double row bearing has fewer balls ($Z = 8 - 9$ per row) compared to a filling slot bearing ($Z = 11 - 12$ per row) and, therefore, has generally less load-independent friction moment, M_0 , and lower operating temperature. This increases the life of the bearing and the lubricant. At 100°C (212°F), the life of a good quality mineral oil is three months. At 80°C (176°F), the life of an oil is one year. This information is used in computer programs to estimate the operating performance of the Conrad and filling slot bearings.

The filling slot double row bearing performs very well, at satisfactory low operating temperatures in pumps having lower speeds, predominant radial loads, or where the quantity of the oil is low (e.g., oil-mist, oil-ring lubrication). Examples of this are the submersible type and the double suction type centrifugal pumps.

BEARING INTERNAL CLEARANCE

There is no industry standard for the internal clearance in double row angular contact ball bearings, radial or axial. The different bearing manufacturers have their own standards and definitions of clearance (Table 1). Some define the clearance in the radial

direction and use the ISO and ABMA designations for radial clearance: normal, greater than normal (C3 suffix), etc. Other manufacturers define the clearance in the axial direction, but use the ISO and ABMA radial clearance designations. The axial clearance in a double row bearing can be estimated by dividing the radial bearing clearance by the tangent of the bearing contact angle.

A key function of the double row angular contact ball bearings in the ANSI centrifugal pump is to limit and control the position of the pump shaft, impeller, and mechanical seal. The performance of the pump and reliability of the mechanical seal depends on this positioning. The ANSI Standard B73.1 specifies that the shaft axial end play should be minimized, depending on the pump clearances and mechanical seal requirements. Most pump manufacturers specify that the axial play of the shaft should be less than 0.05 mm (0.002 in) to minimize the axial movement of the mechanical seal. It is most logical, therefore, for the bearing internal clearance to be provided and defined in the axial direction, although the bearing nomenclature should have other designations to avoid confusion with the radial clearance in bearings.

Historically, double row bearings having both normal and greater than normal internal clearance have been used in centrifugal pumps. The American Petroleum Institute (API) 610 Standard for General Refinery Service Pumps specifies that bearings other than angular contact bearings shall have greater than normal (C3 suffix) radial clearance. It is likely that this practice for deep groove ball bearings has also been applied to the double row angular contact ball bearing. Tests and case studies have shown that double row bearings having normal clearance operate at the same or at lower temperatures than bearings having greater clearance in pump conditions. The results of tests which measured the operating temperature rise in bearings having different clearances as a function of applied radial and axial load are shown in Figure 4. The 5306 Conrad bearing having normal clearance operated at 10°C (18°F) cooler than the 5306 Conrad bearing having greater clearance.

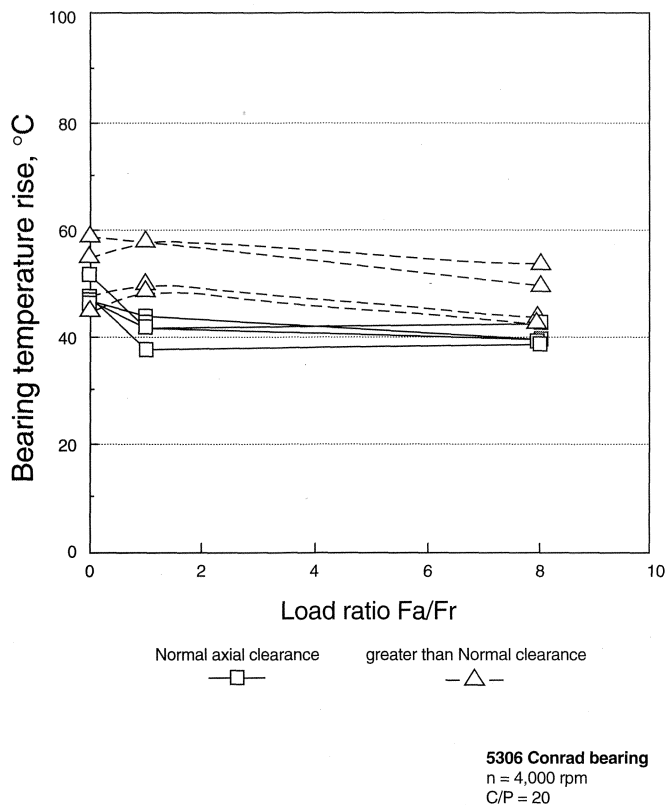


Figure 4. Temperature Rise in Double Row Bearings-Different Internal Clearances.

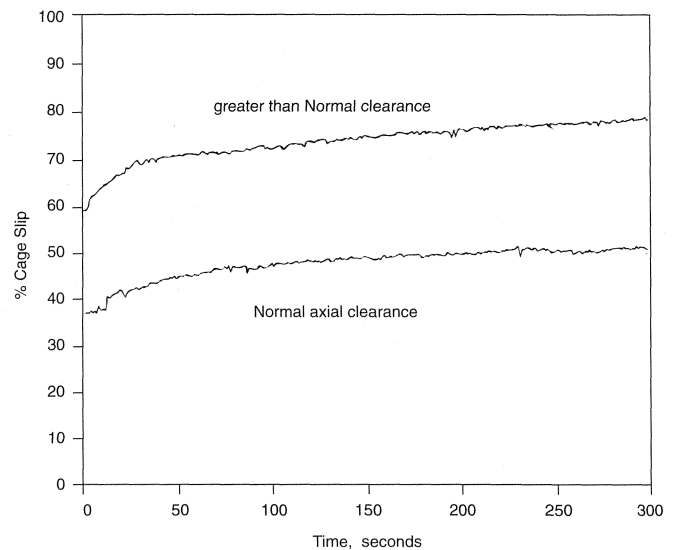


Figure 5. 5206 Cage Slip vs Time.

Tests were also made to examine the motion of the cage in the inactive (unloaded) row of the double row bearing operating at 3600 rpm and with light axial load. The tests showed that the cage in the inactive row of the 5206 bearing having normal clearance moved with considerably less slip than the cage in the 5206 bearing having greater than normal clearance. The test results are shown in Figure 5. Cage slip is an indication of how well the cage is moving within the bearing compared to its expected motion. The greater the slip of the cage, the greater the sliding friction in the bearing resulting in cage distress and higher operating temperatures. The higher cage slip observed in the tests indicates that the bearing should have normal clearance.

Based on these results, the following recommendations for the selection of clearance in double row angular contact ball bearings are provided:

- use normal internal axial clearance, unless the pump shaft speed is high, $n > 75$ percent of the bearing speed rating in oil, or the shaft temperature is high ($>80^{\circ}\text{C}$ (176°F)) due to heat conducted from the pump
- use the ISO k5 shaft fit and H6 housing fit.

The shaft and housing fits must be specified since the bearings internal clearance in the bearing is reduced when mounted on the shaft and in the housing. Consult the pump OEM for their recommended bearing clearance and shaft and housing fits. Many OEMs provide laminated cards for their pumps that define both the recommended bearings and fits. Bearings having greater than normal clearance may be necessary, if the housing is water cooled, or the ambient conditions are very cold.

BEARING SERVICE LIFE AND PERFORMANCE

Bearing "service life" is the actual life achieved by a specific bearing before it fails or is no longer suitable for continued use. Usual causes for the end of a bearing's service life are contamination and ineffective lubrication (these two causes combined are considered to be responsible for approximately 50 percent of all bearing replacements), raceway damage, excessive operating temperature, wear, etc. Bearing fatigue caused by the stressing of the

loaded raceways is a well understood cause of bearing failure. The fatigue life of a bearing is statistically estimated by the ISO 281/I-1977 (and ABMA) as L_{10h} rating life. This is the life that 90 percent of a large group of similarly operated bearings can be expected to survive before raceway fatigue is observed. The bearings in the ANSI centrifugal pump are specified to have a minimum L_{10h} rating life of 17,500 hrs at maximum load and rated speed conditions by the B73.1 Standard. To consider the influences of lubrication and contamination, the basic rating life is adjusted by the bearing manufactures by factors to better estimate the bearing service life. Bearing rating life and adjusted rating life is calculated according to Equations (2) and (3).

$$L_{10h} = (C/P)^3 16667/n \quad (2)$$

$$L_{10aah} = LF L_{10h} \quad (3)$$

where

L_{10h} = basic rating life, hrs

L_{10aah} = adjusted rating life considering contamination, stress limit, lubrication

LF = life adjustment factor based on contamination, stress limit, lubrication

C = basic dynamic load rating, N

P = equivalent dynamic bearing load, N

n = bearing rotational speed, rpm

The basic dynamic load rating, C is proportional to the number and size of balls and the contact angle in the bearing. The adjustment factor, LF, for ball bearings, including double row angular contact ball bearings is shown in Figure 6. Bearings must be provided with clean and dry lubricant of sufficient quantity and viscosity. The bearing should ideally be provided with a lubricant having a minimum viscosity of 13 cSt (70 SUS) at the bearing operating temperature. The recommended oil viscosity grade changes with the change in bearing operating temperature (Table 2). For instance, a typical ISO VG 68 oil has a viscosity of 13 cSt at a temperature of approximately 80°C (176°F). The use of the oils having 13cSt viscosity provide a lubrication Kappa, κ value of approximately 1.5, the recommended minimum value.

The overrolling of solid particle contamination by the balls can cause stress concentrations on the raceways which reduce the fatigue life of the bearing. The contamination is considered by the factor, η_c . The moisture level in the lubricant should not exceed 200 to 500 ppm depending whether it is mineral or synthetic type. Bearing fatigue life is greatly reduced with only a small amount of moisture in the lubricant. Cases of extreme cage wear in double row bearings have been attributed to operation in contaminated lubricants and operation with insufficient quantity of lubricant. The bearing housing should be provided with a sight glass or bullseye target glass for correct setting of the oil level at the center of the lower most ball for oil-bath lubrication. The constant level oiler can be used to ensure sufficient oil is supplied to the bearings. But, it can be difficult to correctly set the oil level in the bearing housing using only the oiler. The pump user can be misled to believe that the bearing is adequately lubricated when the bulb of the constant level oiler is full. Bearing failures have been attributed to incorrect setting of the constant level oiler. Bearing temperatures as much as 3°C (5°F) higher have also been observed in tests of bearings lubricated with constant level oiler. This is due to excessive oil fill in the housing. It is recommended not to depend only on the bulb of the constant level oiler for correct setting of the oil level in the bearing.

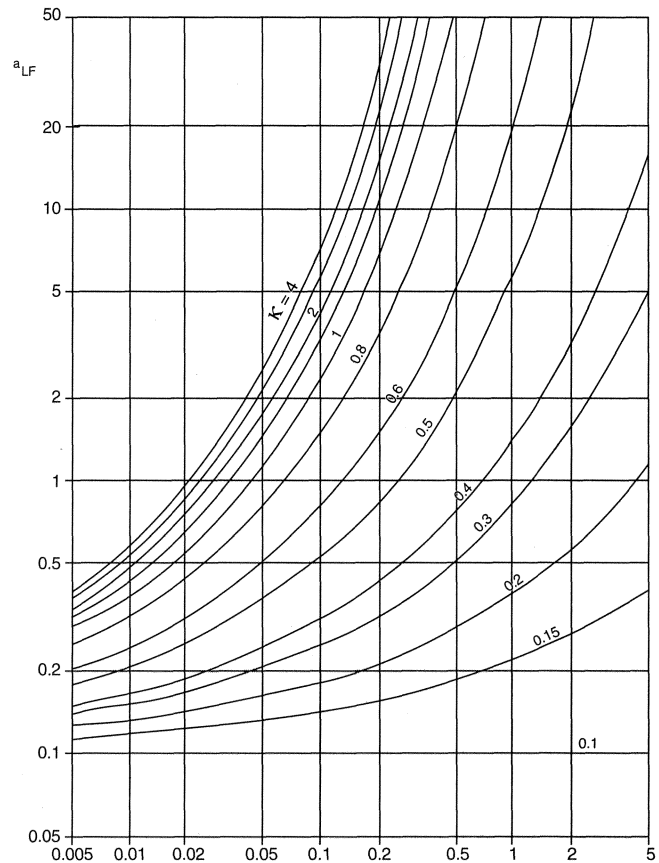


Figure 6. Life Adjustment Factor for Radial Ball Bearings.

Table 2. Recommended ISO Viscosity Grades.

Bearing operating temperature°C (°F)	Recommended ISO Viscosity Grade
70 (156)	46
80 (176)	68
90 (194)	100

The equivalent dynamic bearing load, P, is calculated according to Equation (4).

$$P = X Fr + Y Fa \quad (4)$$

where

X = radial load factor for the bearing

Fr = radial bearing load, N

Y = axial load factor for the bearing

Fa = axial bearing load, N

The X and Y factors can be obtained from the bearing manufacturer's catalog. The axial load factors, Y for double row ball bearings having different contact angles are shown in Table 3. Since in most end suction centrifugal pumps the axial hydraulic load is the most predominant, it is important to select the double row angular contact ball bearing on its capability to support axial load. The axial load capability of the bearing increases with an increase in contact angle or decrease in axial load factor, Y. The capability of the different double row bearings to support axial

load can be determined by comparing the ratio of the bearing dynamic load rating, C , and the axial load factor, Y . An example is given in Table 4.

Bearing B, having a 30 degree contact angle, has better capability to support axial load as indicated by its higher C/Y factor. The ratio C/Y can be used to compare the suitability of different bearings for a pump application when the load conditions are unknown but the axial load is thought to be high.

Table 3. Axial Load Factors for Angular contact Ball Bearings.

Contact angle (degree)	Axial load factor, $Y @ Fa/Fr > e$
20	1.63
25	1.41
30	1.24

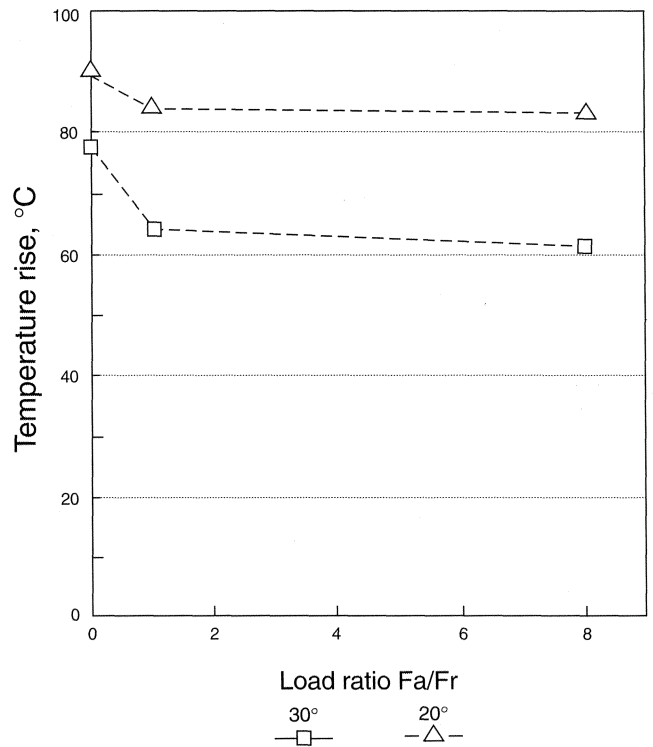
Table 4. Comparison of Load Rating/Axial Load Factor Ratio.

Bearing	Contact angle (degree)	Dynamic load rating, C (N)	Y	C/Y
A	20	64,000	1.63	39,300
B	30	60,500	1.24	48,700

Another aspect of bearing service life is its operating performance. A bearing will have longest life if it and its lubricant have low operating temperature. The life adjustment factor, LF and bearing life increases with a increase in oil viscosity (e.g., as temperature decreases). As already discussed, the life of a typical mineral oil is also increased with decrease in temperature. Tests were performed on double row bearings having different contact angles. The tests operated bearings having 20 degree and 30 degree contact angles at different values of axial and radial load at 4,000 rpm. The temperature rise of the bearings was measured as a function of radial and axial load. The results are shown in Figure 7. The tests indicate that the operating temperature of the 30 degree double row bearing decreases with an increase in axial load. This is attributed to the reduced sliding in the hertzian contacts between the balls and raceways. The double row bearing having a moderate to high contact angle will perform the best in the ANSI centrifugal pump application because of the predominant axial load and high speed.

"GREASED FOR LIFE" CENTRIFUGAL PUMPS

An increasing number of centrifugal pumps are now specified to be "greased for life," meaning that no grease relubrication of the pump bearings is to be made during the life of the pump and bearings. The bearings are sealed within the mechanical end of the pump and no grease fittings are provided. The pump housing seals protect the bearings from contamination and the bearings cannot be incorrectly relubricated with incompatible grease or excessively greased, both causes of bearings failure and overheating. In these pumps the "service life" of the bearings depends not only on the L_{10aah} rating life of the bearing but also on the life of the grease, which is dependent on the type and quality of the grease and the operating temperature. For these pumps, bearings having two shields are recommended because they provided the lowest friction and operating temperature compared to bearings having two seals. For pumps in which the bearings are to be periodically relubricated with grease, bearings without shields or bearings having only one shield are recommended. It is recommended to orient the one shielded face of the bearing towards the grease fitting [3]. Excess grease can pass into and out of the open bearing or through the shielded face of the bearing and out the open face. This avoids



5309 Conrad bearing
 $C/P = 20$
 $n = 4000$ rpm

Figure 7. Temperature Rise in Double Row Bearings-Different Contact Angles.

overheating the bearing with excessive grease (high M_0) and ensures that the bearing is supplied with fresh grease at each relubrication.

DOUBLE ROW VS SINGLE ROW ANGULAR CONTACT BALL BEARINGS

For the thrust bearing in General Refinery Service Pumps, the API 610 Standard requires the use of two 7000 series single row angular contact bearing having 40 degree contact angle, mounted back-to-back. The 8000 series bearing set is also used. The bearing set is a 40 degree and 15 degree single row angular contact bearing combined to have the same boundary dimensions as the 7000 series bearings. The bearing can be used when the direction of the axial load is oriented in one direction and only momentarily reverses axial direction. Both the double row and other bearings are allowed for use in the API refinery pump if approved by the purchaser. The ANSI centrifugal pump is also available in some cases with pairs of single row angular contact ball bearings in place of the double row bearings.

Two single row angular contact bearings mounted together have greater width than the same series double row bearing. This greater width and the design of the single row bearing rings allows a large number ($Z = 11-17$) and size of balls to be placed in the bearing without the use of a filling slot. The single row angular contact ball bearing therefore has high dynamic load rating, C , and because of the 40 degree contact angle has low axial load factor ($Y = 0.93$) for high axial load capability (high C/Y). The double row bearing shaft and housing design must be changed to accommodate a pair of single row bearings. The single row angular contact ball bearing has higher axial stiffness compared to the double row bearing

owing to the large ball complement (Z and D_w) and contact angle. Comparisons of the axial deflection for a 5308 (30 degree contact angle) Conrad double row bearing and 7308 (40 degree contact angle) single row bearing as a function of axial load are shown in Figure 8. The single row angular contact bearing has approximately 35 percent less axial deflection than the double row bearing. The high stiffness is an advantage for controlling the position and running accuracy of the pump shaft and mechanical seal.

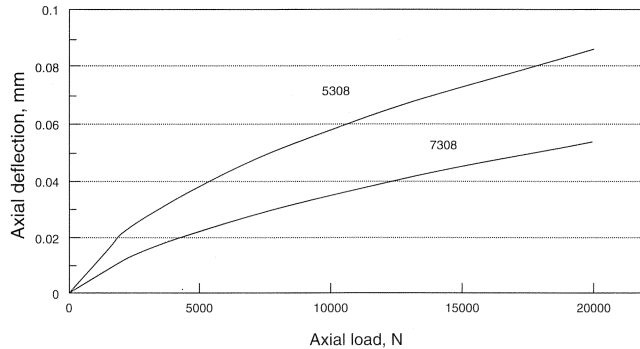


Figure 8. Axial Load-Deflection Diagram for Angular Contact Ball Bearings.

Tests were made of double row and pairs of single row angular contact bearings in an ANSI centrifugal pump operating at 3,600 rpm. The bearings were oil-bath lubricated with an ISO VG 68 mineral oil. The measured operating temperatures for the different bearings tested are shown in Table 5.

Table 5. Measured Operating Temperature of Bearings in an ANSI Pump.

Bearing	Bearing type	Operating temperature, °C (°F)*
5311	filling slot double row	87 (189)
5311	Conrad double row	72 (161)
(2) 7311	preloaded, single row pair	90 (194)
8311	bearing set	81 (177)

* temperature measured at housing surface. Bearing outer ring temperature can be 2 to 11°C (5 to 20°F) hotter than the housing surface.

The Conrad double row angular contact ball bearing performed at the lowest temperature. The high temperatures in the other bearings are attributed again to their higher M_0 friction. The temperatures in all the bearings could be reduced by the use of oil-mist or oil-ring lubrication. The particular low temperature in the 8311 bearing set is attributed to the reduced friction in the 40 degree/15 degree contact angle bearing combination, specifically reduced skidding in the 15 degree bearing. The 7311 bearings likely operated at the highest temperature because of their large number and size of balls. The increased load capability of the 7000 series bearing allows the use of smaller size bearings for still satisfactory reliability at reduced operating temperature (lower M_0). The internal axial clearance or preload in the 7200 and 7300 series bearings can be varied to suit the needs of the application. This is an additional advantage for the pump application.

The double row bearing has a moderate price compared to two single row angular contact ball bearings. The Conrad and filling slot double row bearings have, on average, 50 percent and 25 percent lower price, respectively than a pair of single row angular contact ball bearings. The filling slot double row bearings have higher price than the Conrad bearings because of the cost to carefully add the filling slot to the rings of the bearing.

The API 610 Standard for General Refinery Service pumps specifically does not allow the use of filling slot bearings. This specification is directed towards the pump inboard radial bearing, most commonly a deep groove ball bearing.

SUMMARY

Experience has shown that the Conrad double row angular contact ball bearing is very suitable for use in the ANSI chemical process and other centrifugal pumps. Clearly, there is a need to rationalize and standardize the internal clearances and nomenclature of double row angular contact ball bearings. The nomenclature should identify for the pump OEM, industrial bearing distributor, and end user the internal contact angle and clearance in the bearing. The ISO and ABMA should lead this development. In the meantime, it is important to recognize that there are double row angular contact ball bearings having contact angles and internal clearances that make them best suited for the centrifugal pump application.

The Conrad type is the preferred double row angular contact ball bearing in centrifugal pumps because of its good operating performance. The modern filling slot double row bearing is redesigned and can be successfully used in the centrifugal pump. The "safe" application range for its use is well understood and predictable. The cause of poor filling slot bearing performance is not likely the filling slot itself, but likely the high operating temperature due to the friction within the bearing. The filling slot bearing is best suited for lower speed, radial load conditions.

The Conrad double row angular contact ball bearing with moderate to high internal contact angle and normal axial clearance provides lowest operating temperature and long service life for the ANSI centrifugal pump and other pumps operating at high speed. The double row bearing in pumps should be selected to provide the highest possible C/Y ratio. The bearing should be mounted carefully on the shaft and in the housing using the recommended shaft and housing fits to ensure correct internal clearance in the bearing when mounted. The bearings should be provided with clean and dry lubricant having sufficient viscosity and quantity. The double row bearing provides a well performing, reliable and economical bearing solution for the centrifugal pump. The pump end user and OEM should contact the industrial bearing distributor or bearing manufacturer for technical assistance if needed when selecting or replacing double row angular contact ball bearing bearings in centrifugal pump applications.

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