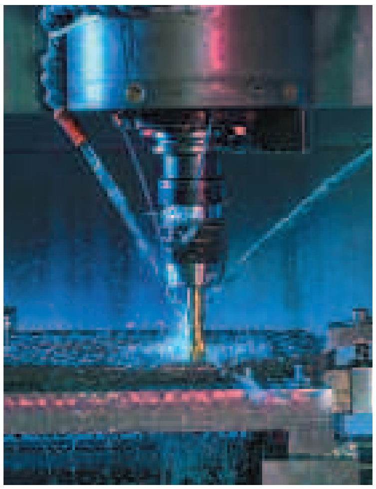
TIMKEN

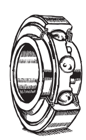
Where You Turn



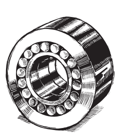
Timken® Bearing Damage Analysis

with Lubrication Reference Guide

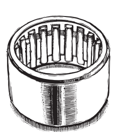
Featuring:



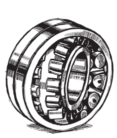
Ball



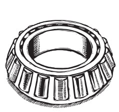
Cylindrical



Needle



Spherical



Tapered

Introduction

Timken stands behind its products and the customers it serves. Whether training a team of maintenance personnel on proper bearing installation in the Powder River Basin area of Wyoming or providing application engineering assistance from our technology center in Bangalore, India, Timken friction management knowledge and expertise spans the globe, supporting major industries.

More than 100 years of expertise in material science and tribology — along with our long history of being a quality steel manufacturer — makes Timken uniquely qualified in bearing damage analysis. Our sales and service teams are trained to both assess bearing damage issues on site, as well as work with customers to offer preventive maintenance techniques to improve performance.

The purpose of this reference guide is to help maintenance and operations personnel identify some of the more common types of bearing damage, explain possible causes and discuss corrective actions. In many cases, the bearing damage may be due to a combination of causes. This guide also contains useful bearing references and lubrication guidelines.

For more information on bearing damage analysis, contact your Timken sales or service engineer, or visit www.timken.com.



Table of Contents

For an accurate and complete analysis, the following steps should be taken when investigating bearing damage and system breakdowns. For assistance with bearing damage analysis, contact a Timken sales or service engineer.

1. Obtain operating data from bearing monitoring devices; analyze service and maintenance records and charts; and secure application diagrams, graphics or blueprints.

2. Prepare an inspection sheet to capture all observations. Take photographs throughout the procedure to assist documentation or description of damaged components.

3. Extract used lubricant samples from bearings, housing and seal areas to determine lubricant conditions. Package separately and label properly.

4. Secure a sample of new, unused lubricant. Record any specification or batch information from the container. Obtain technical specifications and any related material safety data (handling, disposal, toxicological) documentation to accompany lubricant shipments.

5. Check bearing environment for external influences, including other equipment problems that preceded or were occurring at the time bearing damage was reported.

6. Disassemble equipment (either partially or completely). Record an assessment of the mounted bearing condition.

7. Inspect other machine elements, in particular the position and condition of components adjacent to the bearing, including locknuts, adapters, seals and seal wear rings.

8. Mark and record the mounted position of bearings and components prior to removal.

9. Measure and verify shaft and housing size, roundness and taper using certified gauges.

10. Following removal — but before cleaning — record observations of lubricant distribution and condition.

11. Clean parts and record manufacturers' information from marking on the bearing rings (part number, serial number, date code).

12. Analyze condition of the internal rolling contact surfaces, load zones and the corresponding external surfaces.

13. Apply a preservative oil and repackage bearings to avoid corrosion.

14. Compile a summary report of all data for discussion with Timken sales or service engineers.

Bearing damage can occur as a result of a number of different operating conditions. Those listed in this section are the most commonly found for anti-friction bearings, including cylindrical, spherical, needle, tapered and ball designs. It is important to remember that proper bearing maintenance and handling practices are critical.

Wear – Foreign Material

One of the most common sources of trouble in anti-friction bearings is wear and damage caused by foreign particles. Foreign particle contamination can cause abrasive wear, bruising and grooving, circumferential lining or debris contamination.

Abrasive Wear

Fine foreign material in the bearing can cause excessive abrasive wear. Sand, fine metal from grinding or machining, and fine metal or carbides from gears will wear or lap the rolling elements and races. In tapered bearings, the roller ends and cone rib will wear to a greater degree than the races. This wear will result in increased end play or internal clearance which can reduce fatigue life and result in misalignment in the bearing. Abrasive wear can also affect other parts of the machine in which the bearings are used. The foreign particles may get in through badly worn or defective seals. Improper initial cleaning of housings and parts, ineffective filtration or improper filter maintenance can allow abrasive particles to accumulate.

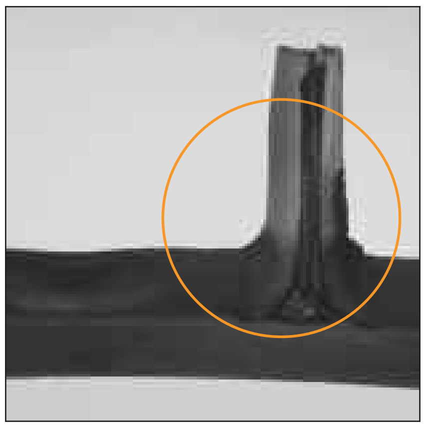


Fig. 1: Fine particle contamination entered this spherical roller bearing and generated wear between the cage surfaces, rollers and races.

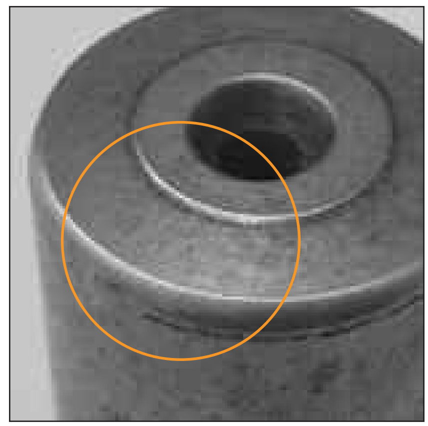


Fig. 2: The roller end wear on this spherical bearing was also caused by fine particle contamination.

Fig. 3: Fine particle contamination caused abrasive wear on this tapered roller bearing.

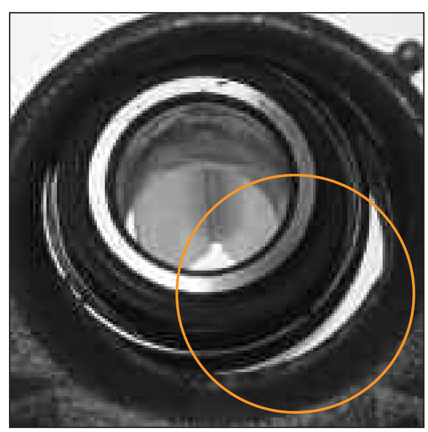


Fig. 4: Exposure to abrasives and water in a severe environment caused extreme wear on this pillow block bearing.

Pitting and Bruising

Hard particles rolling through the bearing may cause pitting and bruising of the rolling elements and races. Metal chips or large particles of dirt remaining in improperly cleaned housings can initiate early fatigue damage.

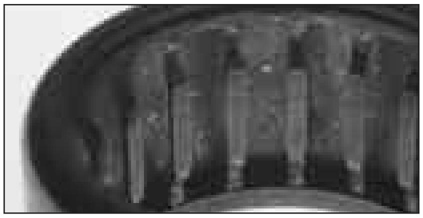


Fig. 5: Contamination bruising on this needle outer ring race resulted from a harsh environment.

Grooving

Grooving is caused by extremely heavy wear from chips or metal particles. These contaminants become wedged in the soft cage material and cause cut grooves in the rolling elements. This condition results in improper rolling contact geometry and can reduce service life.

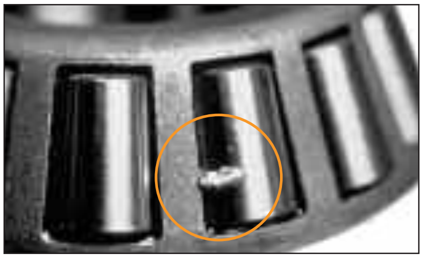


Fig. 6: Large particle contamination imbedded into the soft cage material can result in grooving, as shown here.

Debris Contamination

Common causes of external debris contamination include dirt, sand and environmental particles. Common causes of internal debris contamination include wear from gears, splines, seals, clutches, brakes, joints, housings not properly cleaned, and failed or spalled components. These hard particles travel within the lubrication, through the bearing, and eventually bruise (dent) the internal surfaces. The dents form shoulders that act as surface-stress risers, causing premature surface damage and reduced bearing life.

Fig. 7: A tapered roller bearing inner race (cone) with spalling from debris contamination bruises is shown here.

Fig. 8: Hard particles caused contamination bruising on this spherical roller bearing.

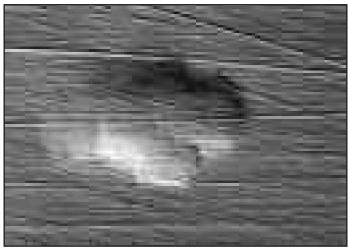


Fig. 9: This photo, taken with a microscope, shows a debris contamination bruise on a bearing race. A corresponding surface map of the dent is shown below in Fig. 11.

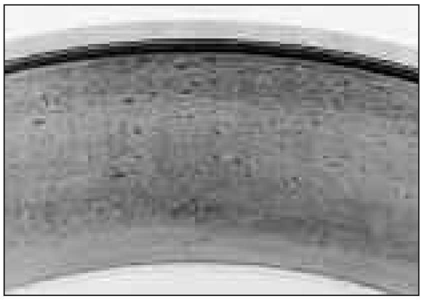


Fig. 10: Debris from other fatigued parts, inadequate sealing or poor maintenance caused bruising on this tapered roller bearing race.

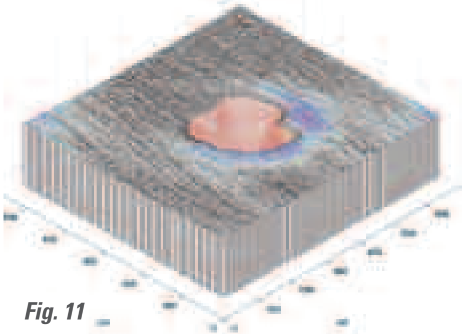


Fig. 11

Etching – Corrosion

Etching or corrosion is one of the most serious problems encountered in anti-friction bearings. The high degree of finish on races and rolling elements makes them susceptible to corrosion damage from moisture and water.

Etching is most often caused by condensate collecting in the bearing housing due to temperature changes. The moisture or water oftentimes gets in through damaged, worn or inadequate seals. Improper washing and drying of bearings when they are removed for inspection can also cause considerable damage. After cleaning and drying or whenever bearings are put into storage, they should be coated with oil or another preservative and wrapped in a protective paper. Bearings, new or used, should always be stored in a dry area and kept in original packaging to reduce risk of static corrosion appearing before mounting.

Fig. 12: This cylindrical bearing inner ring has etching and corrosion.

Fig. 13: Advanced corrosion and pitting on the cone race and rollers makes this bearing unsuitable for further service.

Fig. 14: Heavy water damage is shown on this ball bearing inner ring and cage.

Fig. 15: This cup has heavy corrosion on the race. This type of corrosion may only be a surface stain without pitting. If the staining can be cleaned with a fine emery cloth or crocus cloth, the bearing may be reused. If there are pits that cannot be cleaned with light polishing, the bearing should either be discarded or if practical, refurbished.

Fig. 16: This ball bearing outer race also depicts etching and corrosion.

Inadequate Lubrication

Inadequate lubrication is a term used to describe a broad array of possible damage conditions, in which the lubricant intended for the bearings was not sufficient to separate the bearing's rolling and sliding contact surfaces during service. It is very important that the proper lubricant amount, type, grade, supply system, viscosity and additives be properly engineered for each bearing system based upon history, loading, speeds, sealing systems, service conditions and expected life. Without proper consideration of these factors, less than adequate bearing and application performance may be expected.

Bearing damage from inadequate lubrication varies greatly in appearance, ranging from very light heat discoloration with roller large end scoring (Figure 17), to total bearing lockup with extreme metal flow (Figure 18). It is not uncommon to find a bearing that has experienced a dry start-up in an application to have considerable metal flow, yet still have shiny and polished surfaces. This is because the bearing will quickly experience heat damage from metal-to-metal contact at start-up, then eventually cool off once the lubricant makes its way to the bearings. The bearings may then attempt to "heal" themselves by masking the initial metal flow and heat discoloration.

A second, more pronounced level of damage can occur, which often covers up the initial problem and resultant bearing damage. This bearing damage typically causes high localized heat and metal flow in bearings, thus altering the original bearing geometry and the bearing's material. Any visible signs of metal tearing, scoring, heat, distortion or geometry alteration (Figures 19 and 20) render bearings as scrap and they should never be used again.

Careful inspection of all bearings, gears, seals, lubricants and surrounding parts often sheds light on the primary cause of damage.

See the Lubrication Reference Guide on page 24 to learn more about how lubrication conditions impact bearing performance.

Fig. 17: Heat damage on these tapered rollers was caused by metal-to-metal contact.

Fig. 18: Total bearing lockup is depicted here.

Fig. 19: A misshaped inner ring and torn cage from inadequate lubrication are shown here.

Fig. 20: Excessive heat generation caused metal flow in this ball bearing inner ring.

Fig. 21: Peeling on the race of this spherical plain bearing was caused by thin lubricant film.

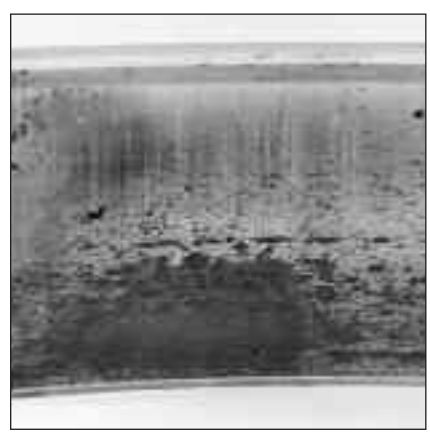


Fig. 22: Micro-spalling or peeling was the result of thin lubricant film from high loads/low RPM or elevated temperatures.

Fatigue Spalling

Spalling is simply defined as the pitting or flaking away of bearing material. Spalling primarily occurs on the races and the rolling elements. It is important to realize that there are many types of "primary" bearing damage shown throughout this reference guide, and they will eventually deteriorate into a secondary damage mode of spalling. Timken classifies three distinct spalling damage modes:

• Geometric Stress Concentration (GSC) Spalling

This mode is the result of misalignment, deflection, or edge loading that initiates high stress at localized regions of the bearing. The damage occurs at the extreme edges of the race/roller paths. It is usually the end result of machining problems with the shaft or the housing, or from high loads.

• Point Surface Origin (PSO) Spalling

This mode is the result of very high and localized stress causing the bearing to prematurely fatigue. The spalling damage is typically from nicks, dents, debris, etching and hard particle contamination in the bearing. PSO spalling is the most common spalling damage, and it often appears as arrowhead shaped spalls.

• Inclusion Origin Spalling

Inclusion Origin Spalling is the result of bearing material fatigue at localized areas of sub-surface, non-metallic inclusions, following millions of load cycles. The damage is observed in the form of localized, elliptically shaped spalls. Bearing steel cleanness has improved over the past two decades to the extent that this type of spalling is seldom encountered.

Fig. 23: High loads resulted in fatigue spalling on this cylindrical roller bearing.

Fig. 24: Heavy spalling and fracturing from high loads on this spherical roller bearing are shown here.

Fig. 25: Misalignment, deflections or heavy loading on this tapered roller bearing caused GSC spalling.

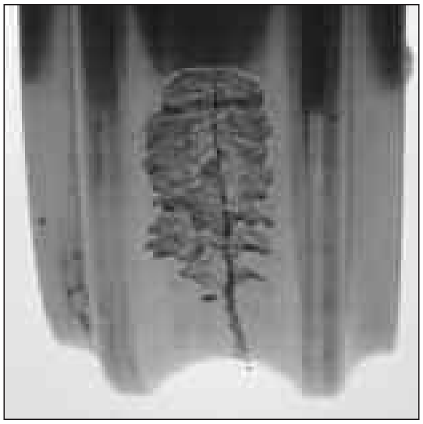


Fig. 26: This ball bearing inner ring depicts fatigue spalling. The fracture is a secondary damage mode.

Fig. 27: PSO spalling resulted from debris or raised metal exceeding the lubricant film thickness on this tapered roller bearing inner ring.

Excessive Preload or Overload

Excessive preload can generate a large amount of heat and cause damage similar in appearance to inadequate lubrication damage. Often the two causes may be confused, so a very thorough check is required to determine the root problem. A lubricant that is suitable for normal operation may be unsuitable for a heavily preloaded bearing, as it may not have the film strength to carry the very high loads. The breakdown of lubricant caused in high preloads can cause the same type of damage as shown in the previous description of inadequate lubrication damage discussed on page 8.

Another type of damage can result from heavy preloads, even if a lubricant, such as an extreme pressure type of oil that can carry heavy loads, is used. Although the lubricant can take care of the loads so that no rolling element or race scoring takes place, the heavy loads may cause premature sub-surface fatigue spalling. The initiation of this spalling and subsequently the life of the bearing would depend upon the amount of preload and the capacity of the bearing.

Fig. 28: Overloading on this cylindrical roller bearing caused roller surfaces to fracture.

Fig. 29: A heavily overloaded tapered roller bearing resulted in premature, severe fatigue spalling on the rollers. The load was so heavy that large pieces of metal broke off the rollers.

Fig. 30: High loads and low speeds caused insufficient lubricant film on this tapered roller bearing cone.

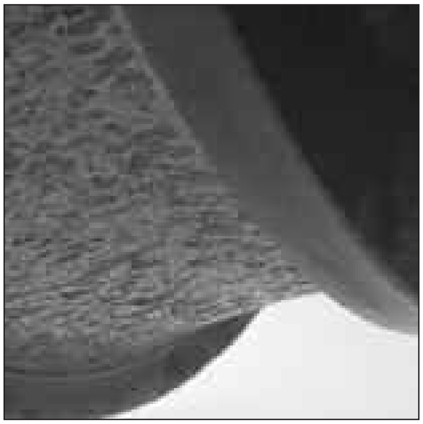


Fig. 31: Severe peeling and spalling is shown on this spherical bearing race.

Fig. 32: High load and low speed conditions caused severe peeling and wear on this needle thrust race.

Misalignment and Inaccurate Machining of Seats and Shoulders

Misaligned bearings will shorten bearing life. The reduction in service will depend on the degree of misalignment. To get full life from the bearing, the seats and shoulders supporting the bearing must be within specified limits set by the bearing manufacturer. If the misalignment exceeds the limits, the load on the bearing will not be distributed along the rolling elements and races as intended, but will be concentrated on only a portion of the rollers or balls and races. In cases of extreme misalignment or off angle, the load will be carried only on the extreme ends of the rolling elements and races. A heavy concentration of the load and high stresses at these points will result in early fatigue of the metal.

Causes of misalignment:

- Inaccurate machining or wear of housings or shafts
- Deflection from high loads
- Out-of-square backing shoulders on shafts or housings

Fig. 33: High edge loads caused Geometric Stress Concentration (GSC) spalling on the inner race of this drawn cup needle bearing.

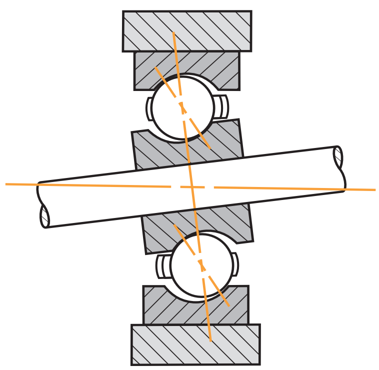


Fig. 34A: Shaft Misalignment

Fig. 35: Deflection, inaccurate machining or wear of bearing seats caused an irregular roller path on this tapered roller bearing outer ring.

Fig. 36: This irregular roller path is 180 degrees opposite of Fig. 35.

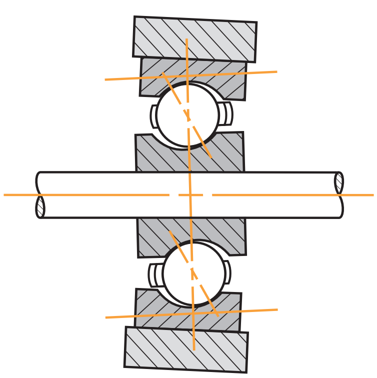


Fig. 34B: Housing Misalignment

Fig. 37: Geometric Stress Concentration spalling on the outer race was the result of a needle bearing installed in an inaccurately machined housing.

Fig. 38: The housing bore was machined with an improper taper, causing the uneven load distribution and GSC spalling in this cylindrical roller bearing outer ring.

Handling and Installation Damage

Care must be taken in handling and assembling bearings so the rolling elements and race surfaces and edges are not damaged. Deep gouges in the race surface or battered and distorted rolling elements will cause metal to be raised around the gouge or damaged area. High stresses will occur as the rolling elements go over these surfaces, resulting in premature, localized spalling. The immediate effect of the gouges and deep nicks will be roughness, vibration and noise in the bearing.

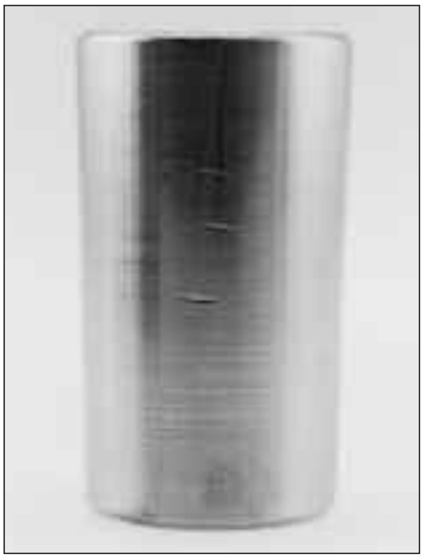


Fig. 39: Rough handling or installation damage resulted in nicks and dents in this tapered bearing roller.

Fig. 40: This spherical roller bearing inner race depicts a fractured toe flange caused by the use of improper installation tools.

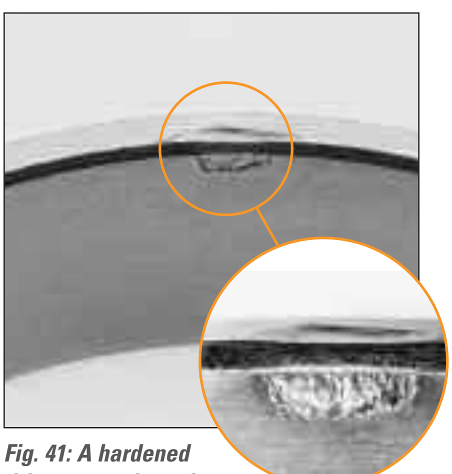


Fig. 41: A hardened driver caused cup face denting on this tapered roller bearing.

Fig. 42: A hardened driver caused a broken rib on this needle roller bearing.

Fig. 43: A hardened punch caused indents during assembly.

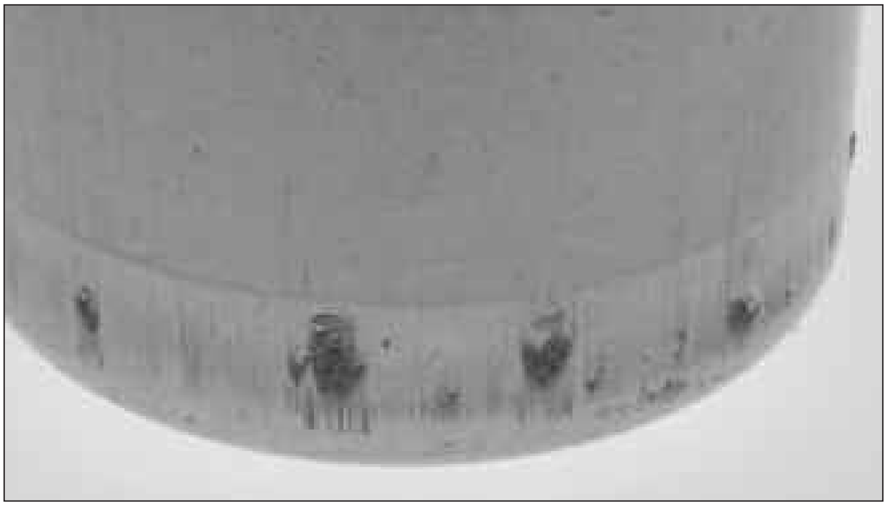


Fig. 44: Inaccurate housing machining caused metal pick-up and galling on this needle roller bearing.

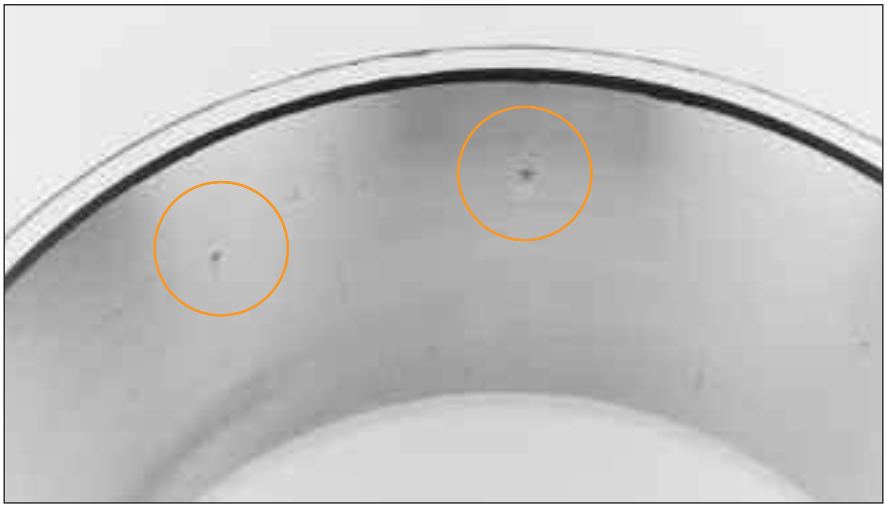


Fig. 45: Tapered roller spaced nicking was caused by the roller edges hitting the race during assembly. These nicks/dents have raised edges that can lead to excessive noise, vibration or act as points of stress concentration.

Damaged Bearing Cages or Retainers

Careless handling and the use of improper tools during bearing installation may cause cage or retainer damage. Cages or retainers are usually made of mild steel, bronze, or brass and can be easily damaged by improper handling or installation, resulting in premature bearing performance problems.

In some applications, fractured cages or retainers may be caused by environmental and operating conditions. This type of damage is too complex to cover in this reference guide. If you experience this problem, contact your Timken sales or service engineer.

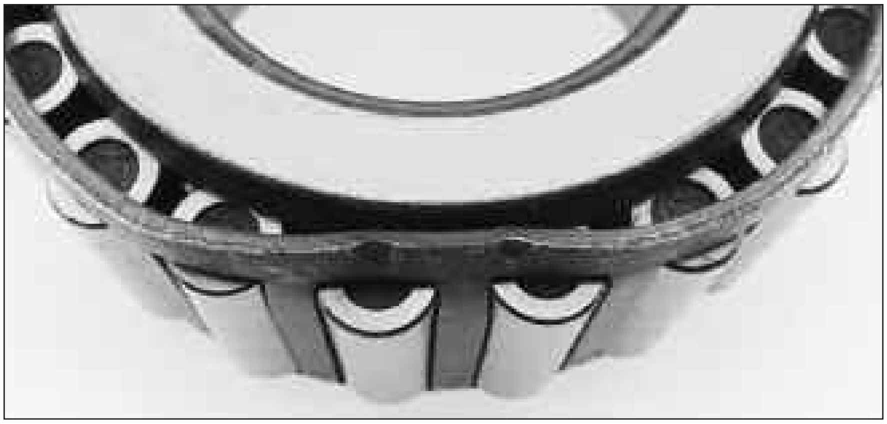


Fig. 46: This cage deformation was caused by an improperly installed or dropped bearing.

Fig. 47: Binding and skewing of these tapered rollers was due to the compression of the cage ring during installation or interference during service.

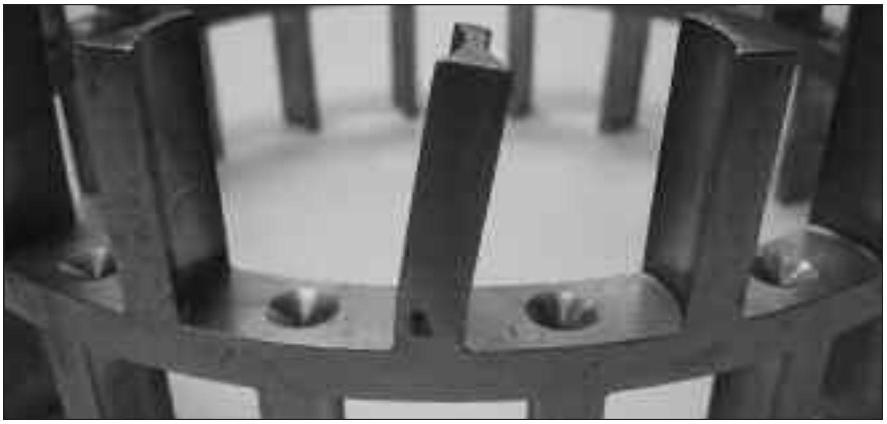


Fig. 48: Rough handling during maintenance caused a bent bridge on this cylindrical roller bearing cage.

Fig. 49: Poor handling practices caused a deep dent on this spherical roller bearing cage bridge. This damage will result in a lack of proper roller rotation, possible roller skidding, increased temperatures and decreased life.

High Spots and Fitting Practices

Careless handling or damage when driving outer races out of housings or wheel hubs can result in burrs or high spots in the outer race seats. If a tool gouges the housing seat surface, it will leave raised areas around the gouge. If these high spots are not scraped or ground down before the outer race is reinstalled, the high spot will transfer through the outer race and cause a corresponding high spot in the outer race inside diameter. As the rolling elements hit this high area, stresses are set up, resulting in early fatigue.

Fig. 50: A worn-out housing caused this bearing to lose fit and fret (move) during service. As a result, metal tearing and wear on this spherical outer ring occurred.

Fig. 51: Classic fretting corrosion from poor fitting practice is depicted here. Relative movement under load between the bearing and its seat caused this worn and corroded condition.

Fig. 52: Inaccurate machining caused a pinch point on this needle roller bearing and grooved the outer ring outside diameter.

Fig. 53: The marks on the outside diameter of this cup are caused by a high spot on the housing. The cup race is spalled at the spot that corresponds to the spot on the outside of the cup marked from heavy contact.

Fig. 54: Localized spalling on this cup race was the result of a stress riser created by a split housing pinch point.

Improper Fit in Housings or Shafts

A manufacturer's recommended bearing fit should be followed to ensure proper bearing performance.

In general, the bearing race where the rotating load exists should be applied with a press or tight fit. An example is a wheel hub where the outer race should be applied with a press fit. The races on a stationary axle would normally be applied with a light or loose fit. Where the shaft rotates, the inner race should normally be applied with a press fit and the outer race may be applied with a split fit or even a loose fit, depending on the application.

Fig. 55: A loose cup fit in a rotating wheel hub (typically tight) caused this bearing race damage.

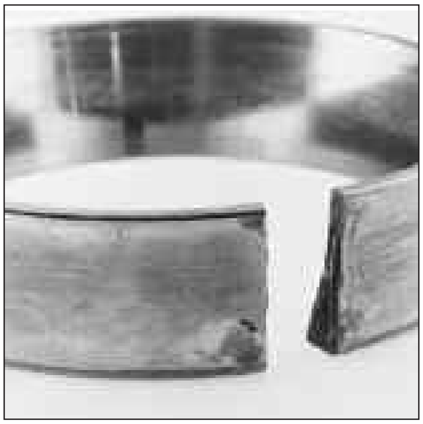


Fig. 56: This tapered roller bearing cup is fractured as a result of the housing cracking during service.

Fig. 57: This ball bearing inner ring fracture is a result of being installed on top of a metal contaminant or raised metal nick.

Fig. 58: An out-of-round or oversized shaft caused this fracture on a tapered roller bearing cone.

Brinell and Impact Damage

Improper mounting practices and/or extremely high operational impact or static loads may cause brinelling.

Brinell due to improper mounting is caused where a force is applied against the unmounted race. When mounting a bearing on a shaft with a tight fit, pushing the outer race will exert an excessive thrust load and bring the rolling elements into sharp contact with the race, causing brinell.

In a needle bearing, typical causes are static overload and shock load, although end loading and geometry defects also play a role.

Figure 63A shows improper removal of a bearing off a shaft, while 63B illustrates the proper mounting procedure.

Extremely heavy impact loads, which may be short in duration, can result in brinell of the bearing races and sometime even fracture the races and rolling elements.

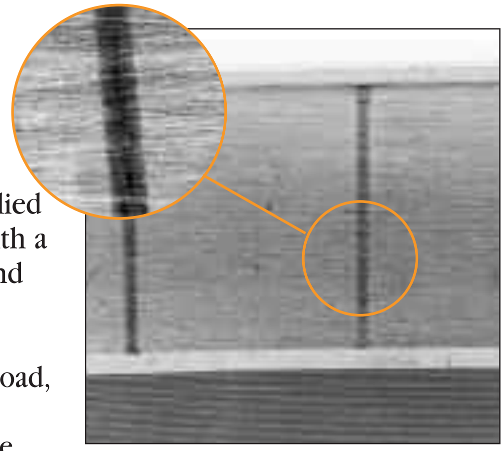


Fig. 59: A heavy impact load on this tapered bearing cup race caused brinell and impact damage. These same indentations are evident on the cone race. This is true metal deformation and not wear as with false brinelling. The close-up view of one of the grooves shows the grinding marks still in the groove.

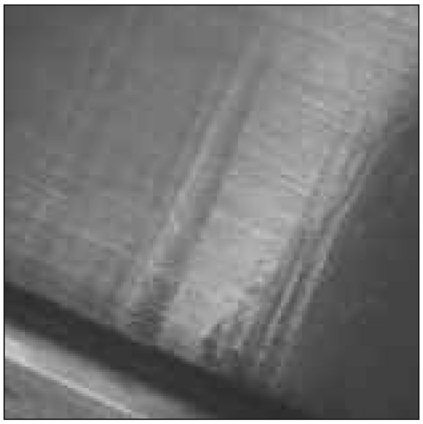


Fig. 60: This inner ring of a spherical roller bearing shows roller impact damage from shock loading.

Fig. 61: This cylindrical roller bearing inner ring is crushed by an application failure during service.

Fig. 62: Impact during installation caused roller spaced indents on this needle roller bearing outer ring.

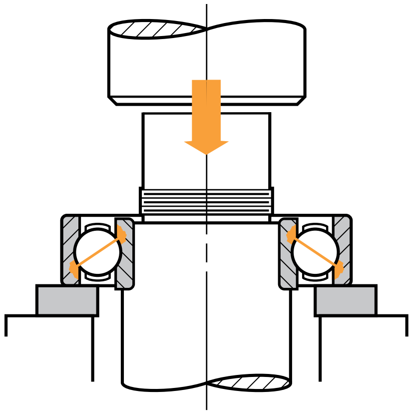


Fig. 63A: Incorrect dismounting of bearing on arbor press.

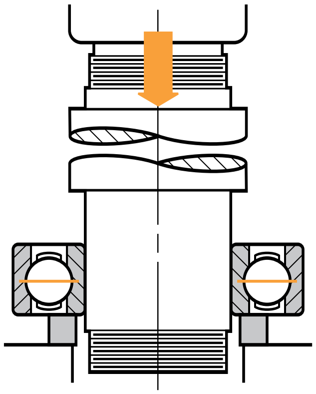


Fig. 63B: Proper mounting procedure on arbor press.

Fig. 64: Shock loading caused brinell damage on this ball bearing inner ring.

False Brinelling

False brinelling is, as the name implies, not true brinelling or denting. False brinelling is actually fretting wear. It is caused by slight axial movement of the rolling elements while the bearing is stationary. A groove is worn into the race by the sliding of the rolling element back and forth across the race. Vibration causes the sliding movement.

There are times when this cannot be prevented, such as when automobiles or other types of equipment are shipped by rail or truck for relatively long distances. It can also occur during shipment by ocean freight. The vibration present may cause enough movement to produce some of this false brinelling. It can be greatly reduced or eliminated by reducing the potential for relative movement and decreasing the static weigh present during shipment or storage.

Rolling element bearings also exhibit false brinnelling when used in positions that encounter very small reversing angular oscillation (less than one complete rotation of the rolling element).

False brinelling can be distinguished from true brinelling by examining the depression or wear area. False brinelling will actually wear away the surface texture whereas the original surface texture will remain in the depression of a true brinell.

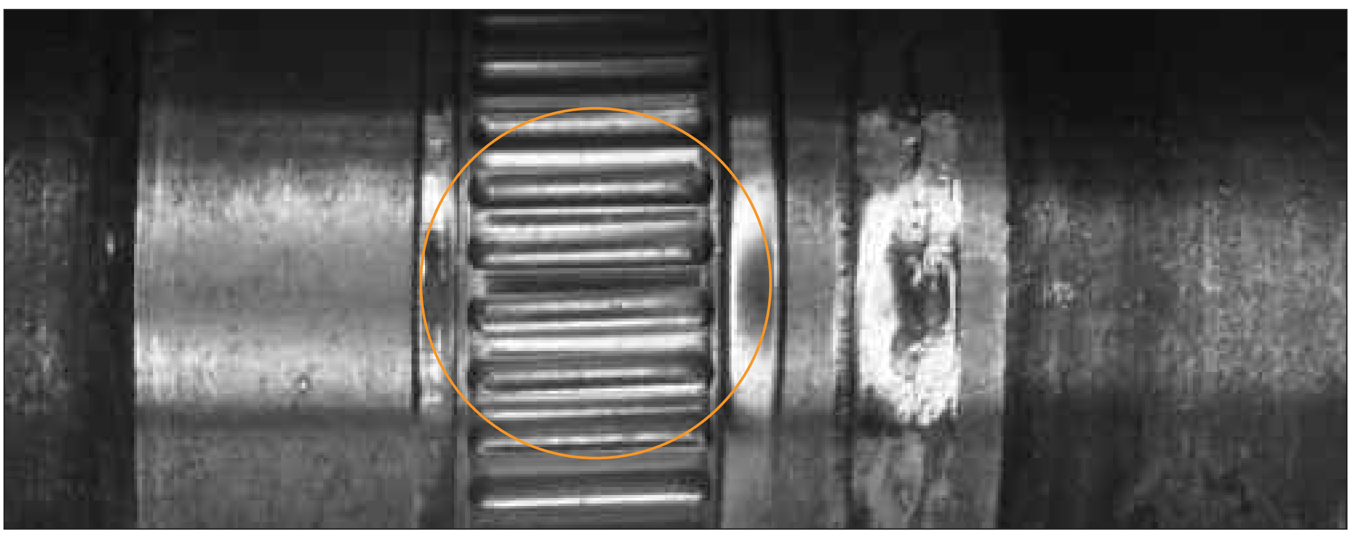


Fig. 65: False brinelling under extreme vibration caused deep roller spaced wear on the inner raceway of this needle bearing.

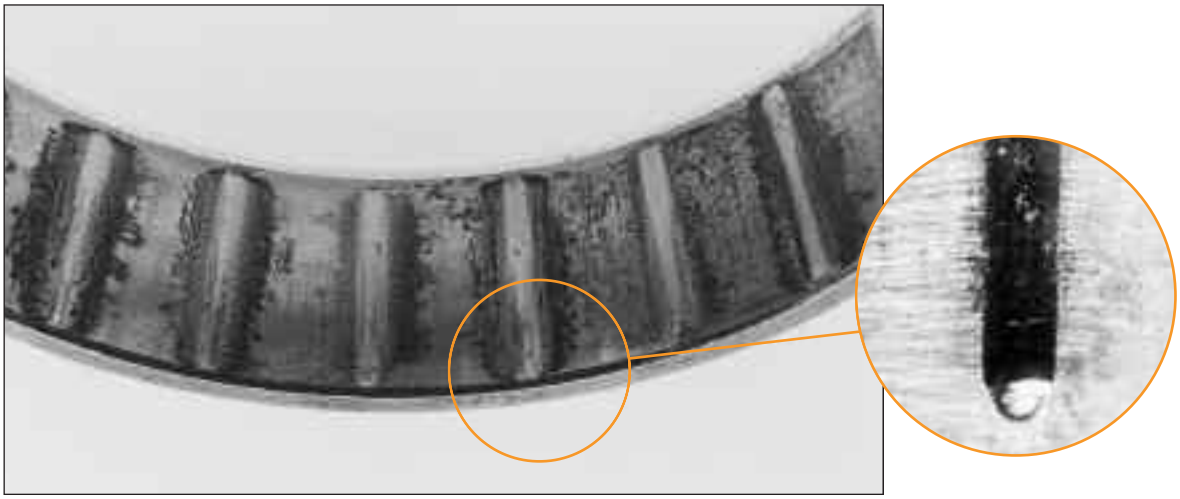


Fig. 66: Wear caused by vibration or relative axial movement between the rollers and races is depicted here in this tapered roller bearing outer ring.

Burns from Electric Current

Arcing, which produces high temperatures at localized points, results when an electric current that passes through a bearing is broken at the contact surfaces between the races and rolling elements. Each time the current is broken while passing between the ball or roller and race, a pit is produced on both parts. Eventually fluting develops. As it becomes deeper, noise and vibration result. A high-amperage current, such as a partial short circuit, will cause a rough, granular appearance. Heavy jolts of high amperage charges will cause more severe damage, resulting in the welding of metal from the race to the ball or roller. These protrusions of metal on the roller will, in turn, cause a crater effect in the race, resulting in bearing noise and vibration.

Causes of arcing include static electricity from charged belts or processes that use calendar rolls, faulty wiring, improper grounding, welding, inadequate or defective insulation, loose rotor windings on an electric motor, and short circuits.

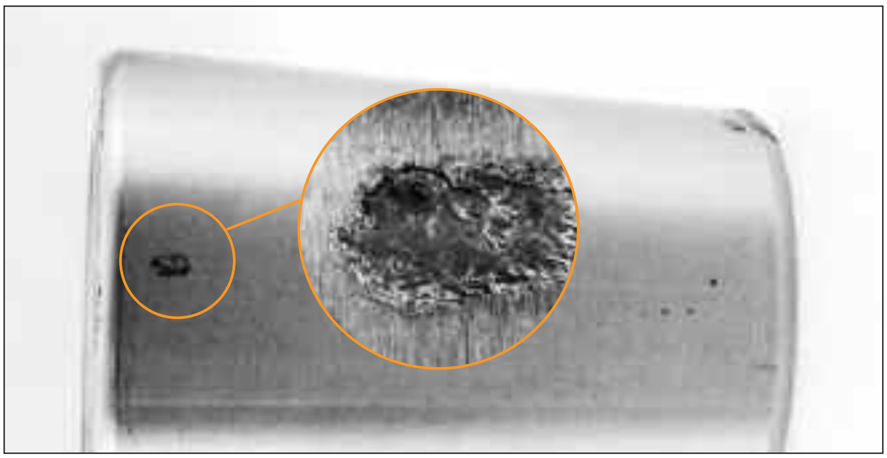


Fig. 67: Electric arc pitting or small burns, magnified 10X here, were created by arcs from improper electric grounding while the bearing was stationary.

Fig. 68: Welding on a machine, while the bearings were rotating, caused electric arc fluting on this spherical roller bearing.

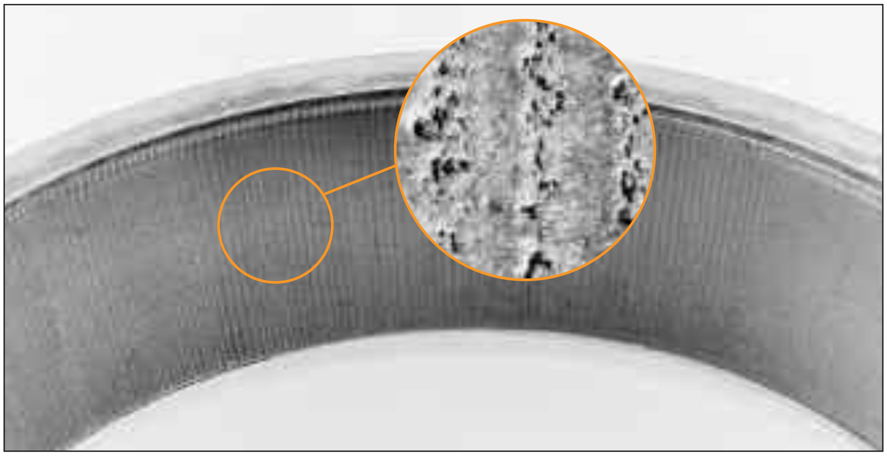


Fig. 69: Magnified by a factor of 10, this fluting, defined as a series of small axial burns, was caused by an electric current passing through the bearing while it was rotating.

Cam Fracture – Wide Inner Ring Ball Bearings

An undersized shaft or an outer ring that cannot be aligned due to the housing may cause a broken cam, a misaligned travel path or bearing wobble.

This type of bearing damage may be prevented by using the correct size shaft and by using the Timken® Fafnir® self-aligning feature, a spherical outer ring to compensate for initial misalignment and correctly mount bearings. The proper mounting procedure is to:

- Align the bearing in its housing and slide unit into position on the shaft;
- Bolt the housing tightly to its mounting support;
- Engage and tighten locking collar and setscrew.

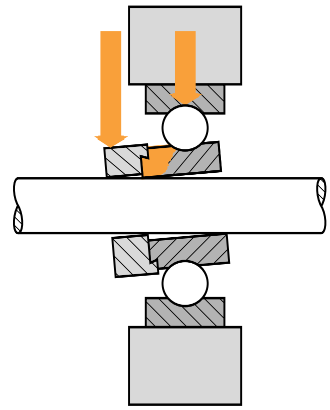


Fig. 70A: Shaft below suggested tolerance levels.

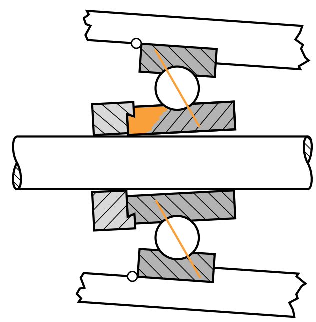


Fig. 70B: Misaligned outer ring.

Roll Out (Sub Case Yielding, Case Crushing)

When a needle bearing is grossly overloaded, the stress is driven deep into the race. If it is a case hardened race, the stress may then exceed the strength of the relatively soft core. When this happens, the race's core will plastically deform in the axial direction (it is constrained in the radial direction by the housing). As the core expands axially, it carries the case with it, causing the case to fracture circumferentially.

If a case hardened race is subjected to severe wear, it can wear away. The stress from a normally loaded bearing will then reach the core and cause roll out.

Fig. 71: High loads and extreme misalignment caused roll out of this needle roller bearing outer ring.

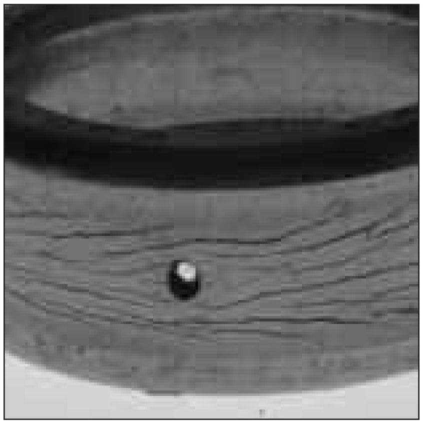


Fig. 72: Roll out and fractures on a needle roller bearing outer ring are depicted here.

Fig. 73: Very high loading resulted in outer ring sub case fracture of this needle roller bearing.

Rollers Locked in Place/Bearing Stamping Lip Fractured Off

Rollers Locked in Place

Bearing failure may also be caused if the pilot in the tool used to install the full complement bearing does not have a functional ball detent. In shipping, a full complement bearing's rollers often settle into a slightly skewed position. If the bearing's rollers are not aligned prior to pressing the bearing into the housing, the rollers will lock into place at installation. The shaft then skids on the locked rollers resulting in smeared flats. The bearing components may be severely discolored (black or blue).

Fig. 74: When the bearing was installed using a pusher without a ball detent to align the rollers, the rollers locked in place as the cup shrunk during installation. The shaft then spun against the locked rollers. (See Fig. 75 right.)

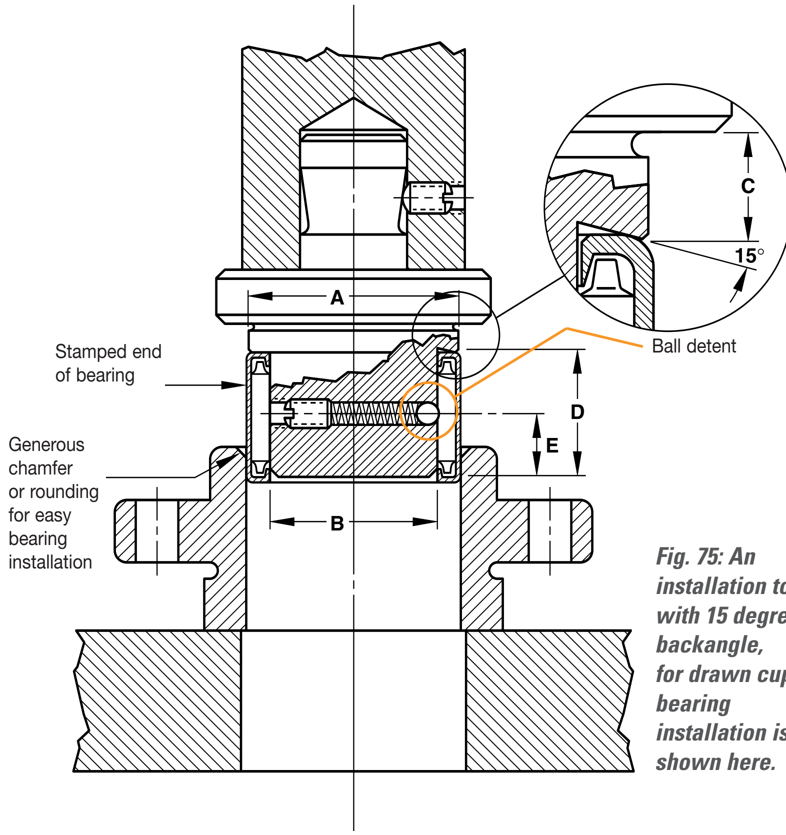


Fig. 75: An installation tool with 15 degree backangle, for drawn cup bearing installation is shown here.

Fig. 75 Key:
A = 1/64 in. (0.4 mm) less than housing bore
B = .003 in. (0.08 mm) less than shaft diameter
C = distance bearing will be inset into housing; minimum of .008 in. (0.2 mm)
D = pilot length should be length of bearing less 1/32 in. (0.8 mm)
E = Approximately one half of D

Bearing Stamping Lip Fractured Off

A bearing's lip may be fractured off if the tool used to install the bearing lacks the required 15 degree backangle. Without this backangle, the installation force is directed through the lip of the cup and will fracture it. Often the lip is only cracked at installation and then breaks in service. With the proper 15 degree backangle, the installation force is directed through the cup's wall, eliminating the possibility of fracturing the cup's lip.

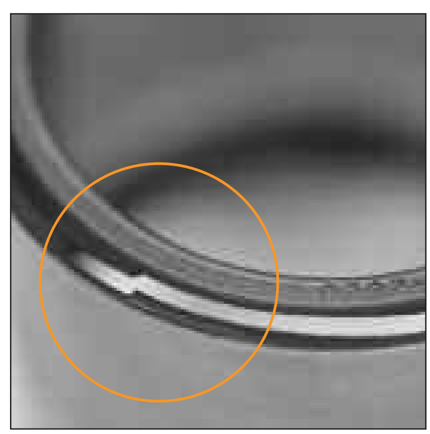


Fig. 76: This needle drawn cup bearing was installed with an improper tool, damaging the lip. Lip damage this severe may lock up the bearing. (See Fig. 75 above.)

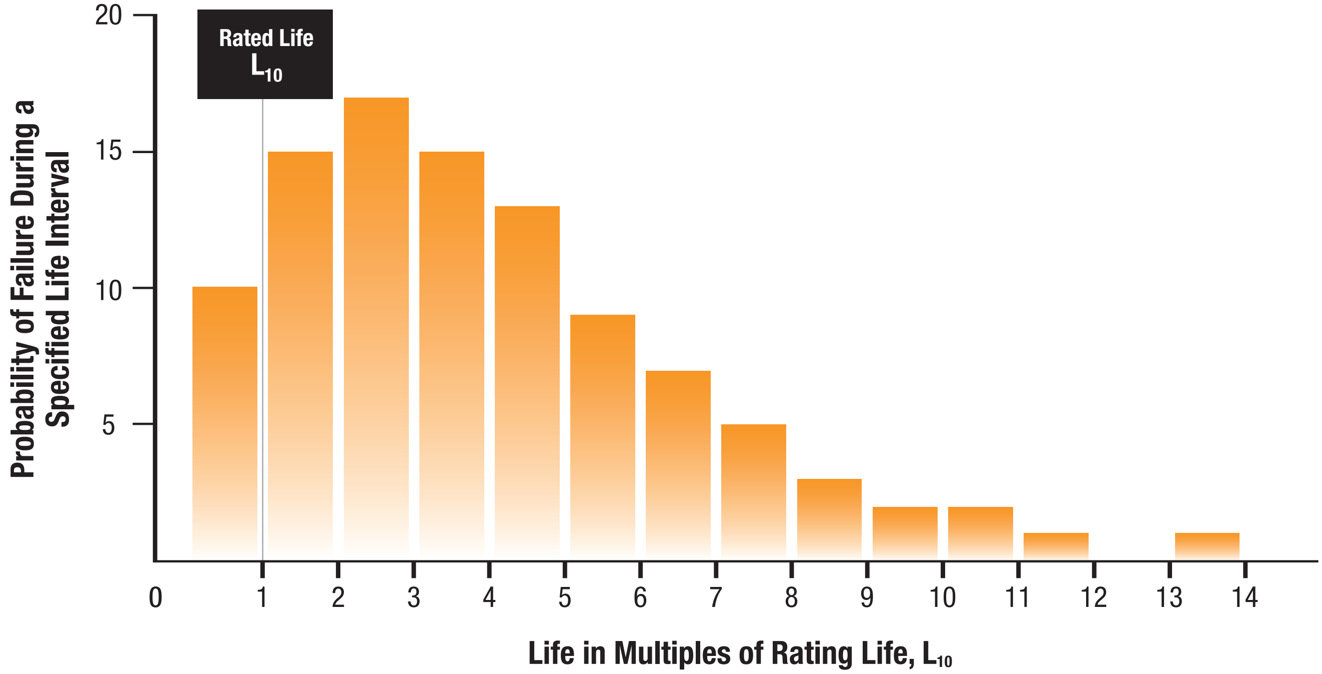


Fig. 77: Theoretical life frequency distribution of a statistically significant group of apparently identical tapered rolling bearings operating under similar laboratory conditions. The same general distribution can be made for other rolling element bearing designs.

We have illustrated many ways that bearings might get damaged. What can you expect from a bearing that is properly handled, installed, adjusted, lubricated and maintained? The following section provides some background on bearing fatigue and service life.

The theoretical bearing life expectancy of a group of bearings can be calculated from the operating conditions and the bearing load rating, based on material fatigue. These calculations must assume that the bearings are correctly mounted, adjusted, lubricated and otherwise properly handled.

Bearing Fatigue Life

Bearings are laboratory examined and tested to verify the basis for bearing load ratings, and to drive enhancements in the performance of parts from global sources. L_{10} life is defined as the theoretical predicted life that 90 percent of a sufficiently large group of bearings would achieve or exceed before an area of spalling or rolling contact surface fatigue damage reaches the defined 6 mm^2 (0.01 $inch^2$) size criterion.

If handled, mounted, adjusted, lubricated, maintained and used in the right way, bearings have the best chance of reaching their predicted life.

Figure 77 shows the typical distribution of theoretical bearing survival at the respective lives. Although tapered roller bearings were used in this illustration, the same general distribution holds true for other rolling element designs.

Bearing Service Life

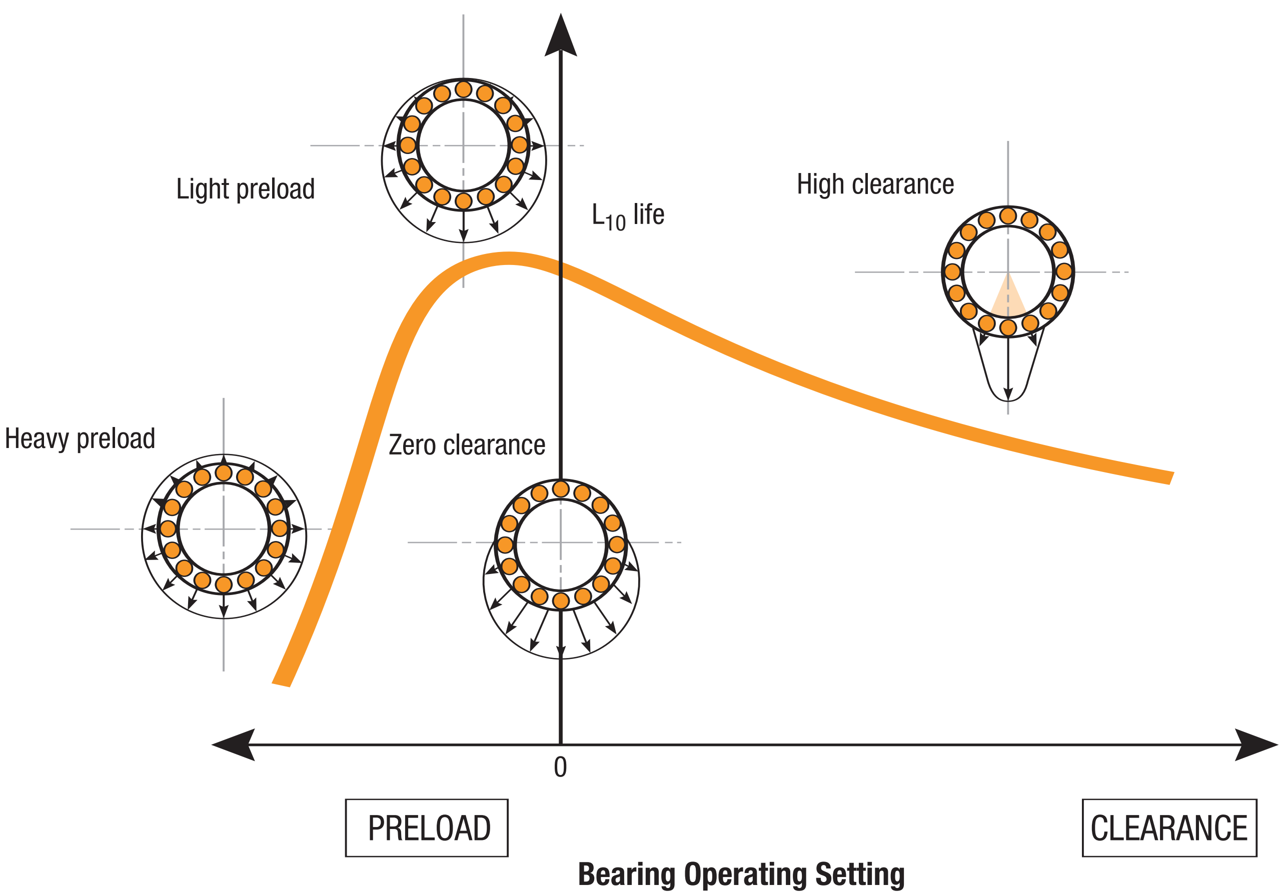
Bearing service life is dependent on many factors other than the calculated L_{10} fatigue life. Depending on the application requirements, the actual service life can vary greatly. For example, a machine tool spindle bearing may be unfit for further service due to minor wear that affects spindle accuracy. In contrast, a rolling mill roll neck bearing may provide satisfactory service life even if the bearing has developed spalling damage, provided the spalls are properly repaired in a timely fashion.

Reduced service life can be caused either individually or by any combination of:

- Faulty mounting
- Improper adjustment
- Insufficient lubrication
- Contamination
- Improper or abusive handling
- Poor housing support
- High static misalignment or shaft and housing deflection
- Poor or inconsistent maintenance practices

The life of your bearing is dependent on the load zone obtained under operating conditions. Generally speaking, the greater the load zone, the longer the life of the bearing under stabilized operating conditions. Figure 78 illustrates this relationship for tapered roller bearings; other roller bearings with radial loads would have a similar performance relationship.

Fig. 78: Bearing life vs. bearing operating setting



Factors that Impact Lubrication Performance

Factors that Impact Lubrication Performance

As noted on page 8, the life of a Timken® bearing depends to a great extent on the proper lubrication of the bearing. Lubricants aid in carrying away heat, protecting bearing surfaces from corrosion, and reducing friction.

A very high percentage of all bearing damage can be attributed to inadequate lubrication. Although a very broad term, inadequate lubrication can be classified into eight basic categories:

- Overfilling
- Underfilling
- Incorrect grease
- Mixing greases
- Incorrect lubrication systems and intervals
- Worn-out grease
- Water contamination
- Debris contamination

Overfilling

Overfilling a bearing with too much grease or oil can cause excess churning during operation and high temperatures, resulting in overheating and excess grease purging* (leaking). Overheating occurs because the heat generated cannot dissipate correctly, continually building until damage occurs. As the operating temperature of the bearing rises, the oxidation (breakdown) rate of the grease sharply increases — doubling every 18 F degrees (10 C degrees).

**NOTE: During initial start-up, it is common for a properly lubricated bearing to purge a small amount of grease. A slight grease purge is often recommended by original equipment manufacturers, as it acts as a barrier seal to help keep out external debris contamination (Figure 80). Always follow original equipment manufacturers' recommendations regarding grease purging and correct replenishment amounts.*

An overfilled bearing may also purge grease during initial start-up. However, over time and as temperature rises, excess grease will continue to purge from an overfilled bearing and have a darkened color (Figure 79).

Fig. 79: This petri dish contains heavily oxidized grease, which purged from an overfilled bearing. Grease undergoing heavy oxidation often has a very distinguishable black color and burned odor. In addition, it gets stiffer in consistency.

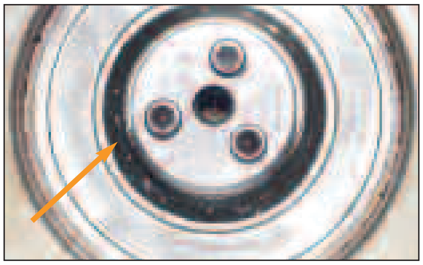


Fig. 80: 'Clean' grease slightly purging (leaking) from a bearing during initial start-up is generally acceptable. The grease is wet and evenly purged. If this slight purge is not causing any problems, leave it alone as it is an effective barrier seal.

Underfilling

Underfilling a bearing with grease can also have adverse consequences. As in overfilling, heat can be generated but for different reasons. When the grease amount is low, a grease starvation condition may be created, causing heat generation or excessive metal wear during operation. If a bearing suddenly becomes noisy and/or the temperature increases, excessive wear may be taking place.

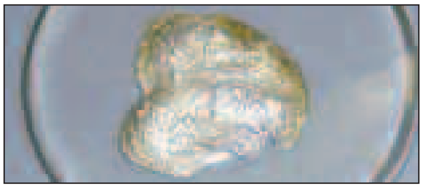


Fig. 81: Grease removed from an underfilled bearing shows shiny bearing metal debris.

Incorrect Grease

The base oil in a particular grease may have a different thickness (viscosity) than what is recommended for your application. If the base oil viscosity is too heavy, the rolling elements may have difficulty in pushing through the grease and begin to skid (Figure 82). If this occurs, excessive grease oxidation (breakdown) (Figure 83) may cause premature grease degeneration and excessive wear of bearing components. If the viscosity is too light, peeling (micro-spalling) and wear (Figure 84) may result due to thin lubricant film from elevated temperatures. In addition, the additives contained in a particular grease may be inappropriate or even incompatible with surrounding components in your system.

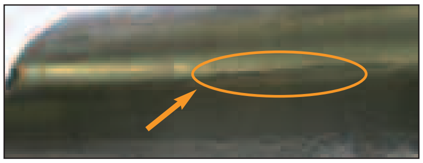


Fig. 82: This cylindrical roller flattened as a result of skidding.

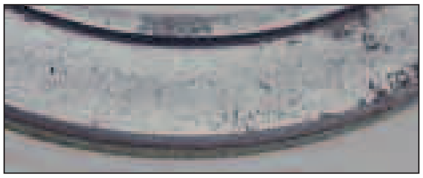


Fig. 83: Peeling (micro-spalling) on this needle thrust bearing inner race was due to a thin lubricant film from elevated temperatures.

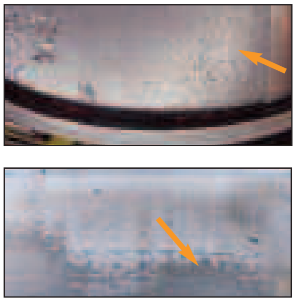


Fig. 84: Micro-spalling in a tapered roller bearing outer race (bottom) and inner race (top) was due to thin lubricant film resulting from elevated temperature.

Mixing Greases

A bearing may be running well with the correct grease. However, while performing routine maintenance, a technician may decide to lubricate the bearing with a different type of grease. If the greases are not compatible, or are an incorrect consistency, the grease mixture will do one of two things: 1) soften and leak out of the bearing due to grease thickener incompatibility, or 2) become lumpy, discolored and hard in composition (Figure 85).

Fig. 85: Grease A and Grease B are not compatible. When mixed together they become lumpy, discolored and hard in composition (Grease C).

Worn-Out Grease

Grease is a precise combination of additives, oil and thickener (Figure 86). Grease acts like a sponge to retain and release the oil. As a result of time and temperature conditions, the oil release properties can become depleted. When this occurs, the grease is worn-out (Figure 87).

Fig. 86: Grease is a precise combination of additives, oil and thickener.

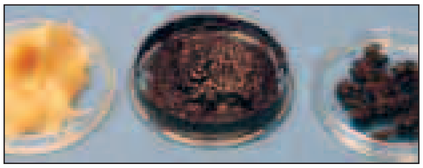


Fig. 87: The above photo shows the same grease at three stages (from left to right): 1) new grease, 2) heavily oxidized grease, and 3) worn-out (failed) grease where the thickener and additives have decomposed and the oil has broken down.

Incorrect Lubrication Systems and Intervals

Maintaining correct bearing lubrication systems and intervals is critical to help prevent premature wear of bearing components.

If maintenance schedules are not followed (Figure 88), lubrication may deteriorate through excessive oxidation. Figure 79 shows excessive bearing grease oxidation.

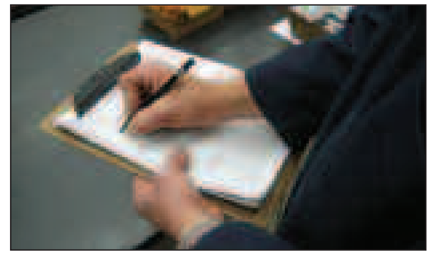


Fig. 88: A technician records key bearing lubrication data on a maintenance sheet.

Water Contamination

Figure 89 shows the effect of water on grease by comparing fresh grease to a grease emulsified with 30 percent water. The fresh grease is smooth and buttery compared to the water laden grease, which is milky white in appearance. As little as one percent water in grease can have a significant impact on bearing life.

Fresh grease — Grease with 30 percent water

Fig. 89: The effect of water on grease is depicted here.

Fig. 90

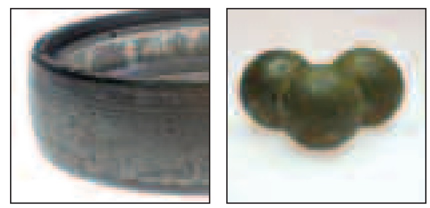


Fig. 91

A tapered roller bearing (Fig. 90) and a ball bearing outer race and balls (Fig. 91) are rusting with pitting and corrosion from moisture/water exposure. This condition is referred to as etching.

Quick & Easy Field Test to Determine Water in Grease

An easy, non-quantified method of determining the presence of water in grease is known as the "crackle test." To perform this test, place a sample of grease on a piece of aluminum foil (Figure 92) and put a flame under the foil (Figure 93). If the grease melts and lightly smokes, the presence of water is minimal. However, if the grease crackles, sizzles and/or pops, the grease contains a considerable amount of water.

Fig. 92: To perform a crackle test, first put the grease sample on a piece of aluminum foil.

Fig. 93: A crackle test determines the presence of water in grease.

Lubrication Guidelines

Lubrication Guidelines – Required Grease Quantity

To avoid the generation of heat, the bearing must not be overgreased. The required quantity of grease is based on the free volume of the bearing calculated as follows:

$V = \approx \pi/4\,(D^2 - d^2)\,(T) - M/A$

Where:

V = free volume in the bearing (cm^3 – $inch^3$)

D = outer race O.D. (cm – inch)

d = inner race bore (cm – inch)

T = overall width (cm – inch)

M = bearing weight (kg – lb)

A = average steel density
7.8×10^{-3} kg/cm^3
0.2833 lb/$inch^3$

$\pi = 3.1416$

Grease should be uniformly distributed over the rollers, raceway, rigs and cages. Special recommendations apply to sealed bearing assemblies. Contact Timken for more information.

Consult the original equipment manufacturer for all lubricant information.

Grease Compatibility Chart

= Best Choice
= Compatible
= Borderline
= Incompatible

	Al Complex	Ba Complex	Ca Stearate	Ca 12 Hydroxy	Ca Complex	Ca Sulfonate	Clay Non-Soap	Li Stearate	Li 12 Hydroxy	Li Complex	Polyurea	Polyurea S S
Aluminum Complex	Best Choice	Incompatible	Incompatible	Compatible	Incompatible	Borderline	Incompatible	Incompatible	Incompatible	Compatible	Incompatible	Compatible
Timken Food Safe	Best Choice	Incompatible	Incompatible	Compatible	Incompatible	Borderline	Incompatible	Incompatible	Incompatible	Compatible	Incompatible	Compatible
Barium Complex	Incompatible	Best Choice	Incompatible	Compatible	Incompatible	Compatible	Incompatible	Incompatible	Incompatible	Incompatible	Incompatible	Borderline
Calcium Stearate	Incompatible	Incompatible	Best Choice	Compatible	Incompatible	Compatible	Compatible	Compatible	Borderline	Compatible	Incompatible	Compatible
Calcium 12 Hydroxy	Compatible	Compatible	Compatible	Best Choice	Borderline	Borderline	Compatible	Compatible	Compatible	Compatible	Incompatible	Compatible
Calcium Complex	Incompatible	Incompatible	Incompatible	Borderline	Best Choice	Incompatible	Incompatible	Incompatible	Incompatible	Compatible	Compatible	Compatible
Calcium Sulfonate	Borderline	Compatible	Compatible	Borderline	Incompatible	Best Choice	Incompatible	Borderline	Borderline	Compatible	Incompatible	Compatible
Timken Premium Mill Timken Heavy Duty Moly	Borderline	Compatible	Compatible	Borderline	Incompatible	Best Choice	Incompatible	Borderline	Borderline	Compatible	Incompatible	Compatible
Clay Non-Soap	Incompatible	Incompatible	Compatible	Compatible	Incompatible	Incompatible	Best Choice	Incompatible	Incompatible	Incompatible	Incompatible	Borderline
Lithium Stearate	Incompatible	Incompatible	Compatible	Compatible	Incompatible	Borderline	Incompatible	Best Choice	Compatible	Compatible	Incompatible	Compatible
Lithium 12 Hydroxy	Incompatible	Incompatible	Borderline	Compatible	Incompatible	Borderline	Incompatible	Compatible	Best Choice	Compatible	Incompatible	Compatible
Lithium Complex	Compatible	Incompatible	Compatible	Compatible	Compatible	Compatible	Incompatible	Compatible	Compatible	Best Choice	Incompatible	Compatible
Polyurea Conventional	Incompatible	Incompatible	Incompatible	Incompatible	Compatible	Incompatible	Incompatible	Incompatible	Incompatible	Incompatible	Best Choice	Compatible
Polyurea Shear Stable	Compatible	Borderline	Compatible	Compatible	Compatible	Compatible	Borderline	Compatible	Compatible	Compatible	Compatible	Best Choice
Timken Multi-Use	Incompatible	Incompatible	Borderline	Compatible	Incompatible	Borderline	Incompatible	Compatible	Best Choice	Compatible	Incompatible	Compatible
Timken All Purpose Timken Premium Synthetic	Compatible	Incompatible	Compatible	Compatible	Compatible	Compatible	Incompatible	Compatible	Compatible	Best Choice	Incompatible	Compatible
Timken High Speed	Incompatible	Incompatible	Incompatible	Incompatible	Compatible	Incompatible	Incompatible	Incompatible	Incompatible	Incompatible	Best Choice	Compatible
Timken Pillow Block	Compatible	Borderline	Compatible	Compatible	Compatible	Compatible	Borderline	Compatible	Compatible	Compatible	Compatible	Best Choice

Abrasive Wear
Usually occurs when foreign particles cut the bearing surfaces.

Adhesive Wear
Caused by metal-to-metal contact, resulting in scuffing or scoring of the bearing surfaces.

Angular Contact Ball Bearing
Ball bearing whose internal clearance and race location result in predetermined angle of contact.

Axial Internal Clearance
In ball or roller bearing assembly, total maximum possible movement parallel to bearing axis of inner ring in relation to outer ring. Also called bearing end play.

Axial Load
Load acting in direction parallel with bearing axis. Also known as "thrust."

Brinelling
A dent or depression in the bearing raceway due to extremely high impact or static loads.

Brinelling – False
Wear grooves in the raceway caused by minute movement or vibration of the rolling elements while the bearing is stationary.

Bruising
The denting or plastic indentation in the raceways and rolling elements due to the contamination of foreign particles in the bearing.

End Play – Internal Clearance
The relative movement of the inner race and rolling elements to the outer race. In single ball and cylindrical bearing, it is the radial movement or the internal clearance. In a tapered bearing it is the axial movement to the two cone assemblies relative to the cups.

Etching – Corrosion
Usually caused by moisture or water contamination and can vary from light staining to deep pitting.

Fatigue
The fracture and breaking away of metal in the form of a spall. Generally, there are three modes of contact fatigue recognized:
- Inclusion origin
- Geometric stress concentration
- Point surface origin

Fillet Radius
Shaft or housing corner dimension which bearing corner must clear.

Fixed Bearing
Bearing which positions shaft against axial movement in both directions.

Floating Bearing
Bearing so designed or mounted as to permit axial displacement between shaft and housing.

Fluting
Electro-etching on both the inner and outer ring.

Fretting Corrosion
Usually occurs on the bores, outside diameters (O.D.) and faces of bearing races due to minute movement of these surfaces and the shaft or housing. Red or black oxide of iron is usually evident.

Housing Fit
Amount of interference or clearance between bearing outside surface and housing bearing seat.

Life
The theoretical bearing life expectancy of a group of bearings can be calculated from the operating conditions and the bearing load rating, based on material fatigue. These calculations must assume that the bearings are correctly mounted, adjusted, lubricated and otherwise properly handled.

Misalignment
A bearing mounted condition whereby the centerline of the inner race or cone is not aligned with the centerline of the outer race or cup. Lack of parallelism between axis of rotating member and stationary member. Some of the causes of misalignment are, machining errors of the housing/shaft, deflection due to high loads, and excessive operating clearances.

Preload
The absence of end play or internal clearance. All of the rolling elements are in contact or in compression with the inner and outer races or cups and cones. Internal load on the rolling elements of bearing, which is the result of mounting conditions or design. Can be intentional or unintentional.

Radial Internal Clearance
In ball or roller bearing assembly, total maximum possible movement perpendicular to bearing axis of inner ring in relation to outer ring. Also called radial play or diametrical clearance.

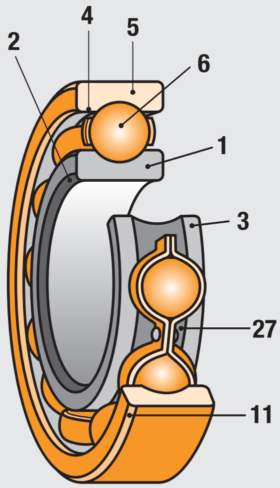
Radial Load
Load acting in direction perpendicular with bearing axis.

Rating Life
L_{10} of group of apparently identical bearings is predicted life in millions of revolutions that 90 percent of group will complete or exceed.

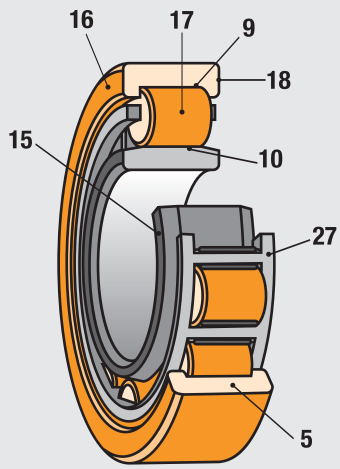
Scoring
Caused by metal-to-metal contact, resulting in the removal and transfer of metal from one component of a bearing to another. Various degrees of scoring can be described as scuffing, smearing, sliding, galling or any other sliding motion.

Shaft Fit
Amount of interference or clearance between bearing inside diameter and shaft bearing seat outside diameter.

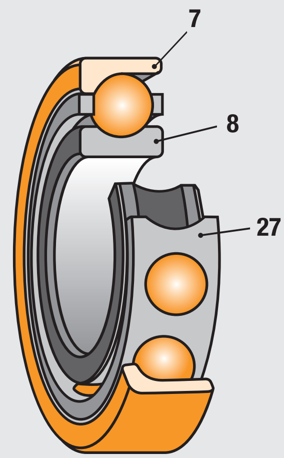
Spalling – Flaking
A breaking away of metal on the raceway or rolling elements in flake or scale-like particles.



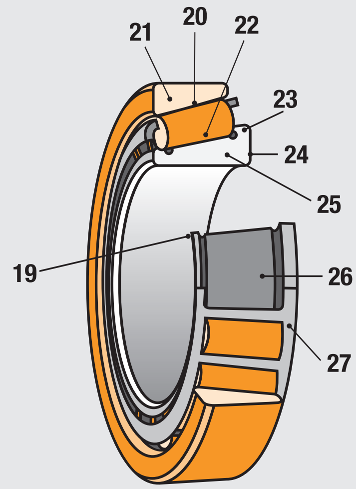
Single Row Deep Groove Ball Bearing



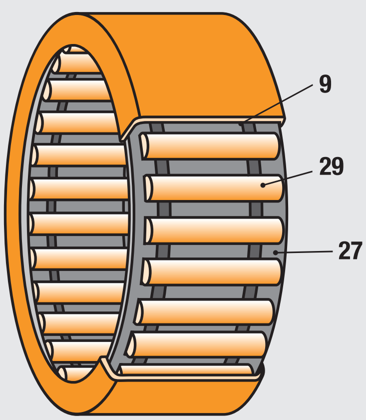
Cylindrical Roller Bearing



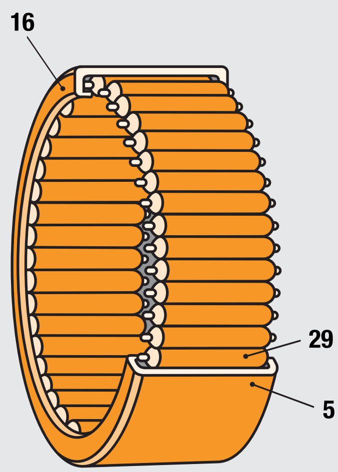
Angular Contact Ball Bearing



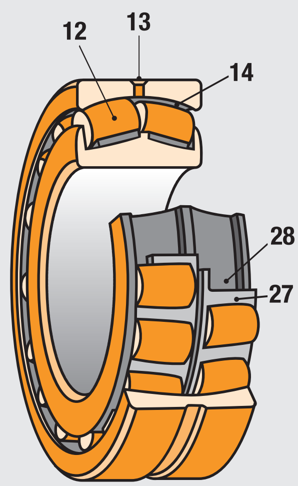
Tapered Roller Bearing



Drawn Cup "J" Bearing



Drawn Cup "B" Bearing



Spherical Roller Bearing

Bearing Nomenclature Key

1. Inner Ring
2. Inner Ring Corner Radius
3. Inner Ring Land
4. Outer Ring Land
5. Outer Ring
6. Ball
7. Counter Bore
8. Thrust Face
9. Outer Ring Race
10. Inner Ring Race
11. Outer Ring Corner Radius
12. Spherical Roller
13. Lubrication Feature (Holes and Groove)
14. Spherical Outer Ring Race
15. Inner Ring Face
16. Outer Ring Face
17. Cylindrical Roller
18. Outer Ring Face
19. Cone Front Face
20. Cup Race
21. Cup (Outer Ring)
22. Tapered Roller
23. Cone Large Rib
24. Cone Back Face
25. Cone (Inner Ring)
26. Cone Race
27. Cage
28. Spherical Inner Ring Race
29. Needle Roller

Speed Capability Guidelines

The usual measure of the speed of a bearing is the circumferential velocity of the midpoint of the inner race large end rib. This may be calculated as:

Rib speed:

$V_r = \pi D_m n/60\,000$ (m/s)
$V_r = \pi D_m n/12$ (ft/min)

Where:

D_m = Inner race rib diameter (mm, in)
n = Bearing speed (rev/min)
$\pi = 3.1416$

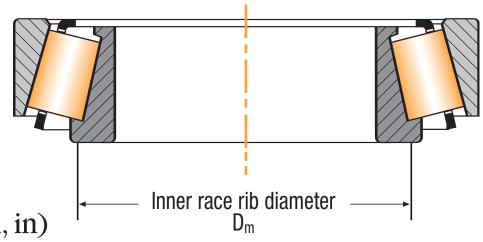


Fig. 94: The inner race rib diameter can be scaled from a drawing or can be approximated as the average of the bearing inner and outer diameter.

Speed capability guidelines for various types of lubrication systems

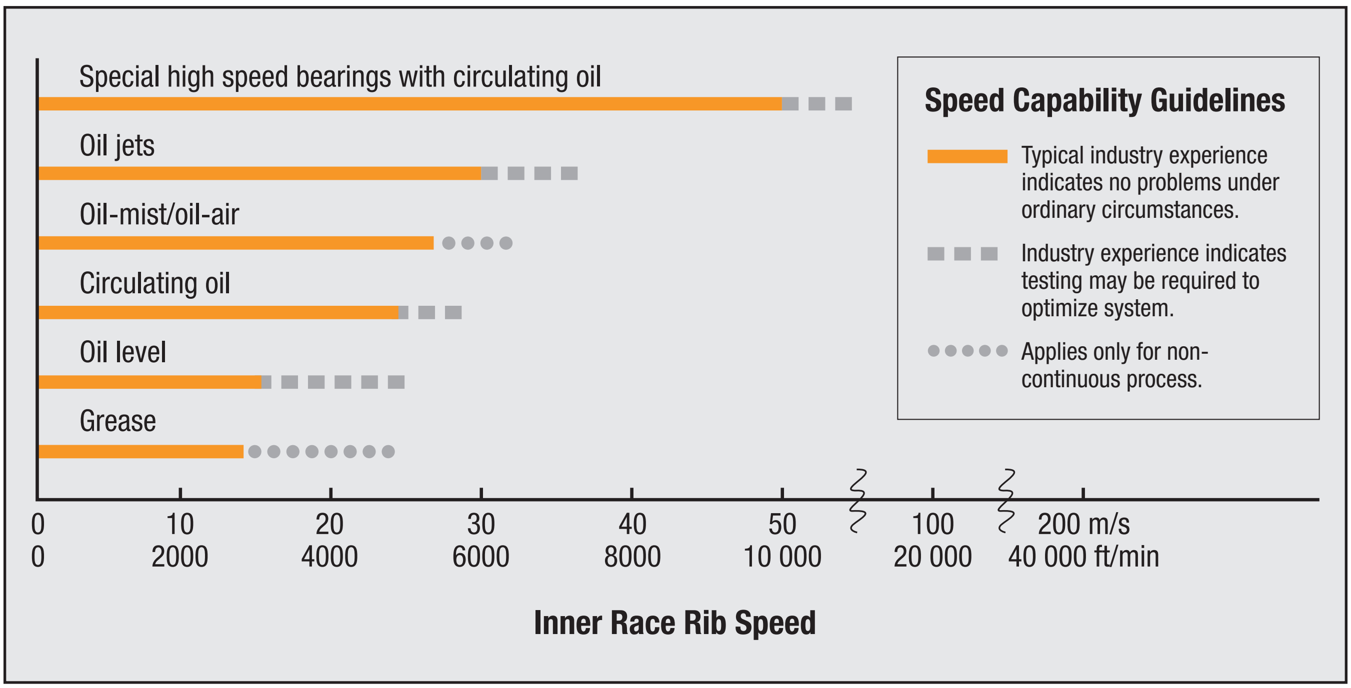


Fig. 95: Here is a summary of guidelines relating to speed and temperature for tapered roller bearings. There are no clear-cut speed limitations for bearings regardless of the bearing design or lubrication systems. The Timken Company recommends that testing be performed for all new high-speed applications, regardless of bearing design.

Conversion Equivalents for U.S. and Metric Measurements

Physical Quantity	When you know	Multiply by	To get an equivalent in
Length	inch (in.)	25.4	millimetre (mm)
	inch (in.)	2.54	centimetre (cm)
	miles	1.609	kilometre (km)
	millimetre (mm)	0.03937	inch (in.)
	centimetre (cm)	0.3937	inch (in.)
	kilometre (km)	0.6214	miles
	kilometre (km)	3280.8	foot (ft.)
Area	square inch (sq. in.)	645.2	square millimetre (mm^2)
	square inch (sq. in.)	6.4516	square centimetre (cm^2)
	square millimetre (mm^2)	0.00155	square inch (sq. in.)
	square centimetre (cm^2)	0.155	square inch (sq. in.)
Volume	inch^3 (in.^{3})	16.387	cubic centimetre (cc, cm^3)
	cubic centimetre (cc, cm^3)	0.061	inch^3 (in.^{3})
	litre (1 1 = 1000 cc, cm^3)	61.0237	inch^3 (in.^{3})
Fluid Volume	quart, U.S. (qt.)	0.946	litre (l)
	gallon, U.S.	3.785	litre (l)
	litre (l)	1.057	quart, U.S. (qt.)
	litre (l)	0.264	gallon, U.S.
	litre (l)	0.22	gallon, U.K.
	gallon, U.K.	4.546	litre (l)
Weight/Mass	pound (lb.)	0.4536	kilogram (kg)
	ounce (oz.)	28.35	gram (gm)
	kilogram (kg)	2.2046	pound (lb.)
	gram (gm)	0.035	ounce (oz.)
	metric ton (1 t = 1000 kg)	2204.6	pound (lb.)
Force	ounce-force	0.278	newton (N)
	pound-force (lb$_f$)	4.448	newton (N)
	newton (N)	3.5969	ounce-force
	newton (N)	0.2248	pound-force (lb$_f$)
Engine Torque	foot-pound (ft.-lb.)	1.3558	newton-metre (Nm)
	newton-metre (Nm)	0.7376	foot-pound (ft.-lb.)
Hardware Torque	foot-pound (ft.-lb.)	0.138	kilogram-metre (kg-m)
	foot-pound (ft.-lb.)	1.3558	newton-metre (Nm)
	inch-pound (in. lb$_f$)	0.113	newton-metre (Nm)
	kilogram-metre (kg-m)	7.23	foot-pound (ft.-lb.)
	newton-metre (Nm)	0.7376	foot-pound (ft.-lb.)
	kilogram-metre (kg-m)	9.807	newton-metre (Nm)
	newton-metre (Nm)	0.102	kilogram-metre (kg-m)
Pressure	pound/inch^2 (PSI)	6.895	kilopascal (kPa)
	kilopascal (kPa)	0.145	pound/inch^2 (PSI)
Power	horsepower (hp)	0.746	kilowatt (kW)
	kilowatt (kW)	1.341	horsepower (hp)
Velocity	miles per hour (mph)	1.609	kilometres per hour (km/h)
	kilometres per hour (km/h)	0.621	miles per hour (mph)
Fuel Usage	miles per gallon (mpg)	0.425	kilometres per liter (km/l)
	kilometres per litre (km/l)	2.353	miles per gallon (mpg)

Conversion Chart Showing Millimetre, Fractional and Decimal Inch Sizes

Fractional	Dec. Equiv.	Millimetre	Fractional	Dec. Equiv.	Millimetre	Fractional	Dec. Equiv.	Millimetre	Fractional	Dec. Equiv.	Millimetre	Fractional	Dec. Equiv.	Millimetre
	.0039	.1		.0689	1.75		.1570	....		.2677	6.8	27/64″	.4219	10.72
	.0059	.15		.0700	....		.1575	4.0		.2716	6.9		.4330	11.0
	.0079	.2		.0709	1.8		.1590	....		.2720	....	7/16″	.4375	11.11
	.0098	.25		.0728	1.85		.1610	...		.2756	7.0		.4528	11.5
	.0118	.3		.0730	...		.1614	4.1		.2770	...	29/64″	.4531	11.51
	.0135	...		.0748	1.9		.1654	4.2		.2795	7.1	15/32″	.4687	11.91
	.0138	.35		.0760	...		.1660	...		.2811	...		.4724	12.0
	.0145	...		.0767	1.95		.1673	4.25	9/32″	.2812	7.14	31/64″	.4843	12.30
1/64″	.0156	.39	5/64″	.0781	1.98		.1693	4.3		.2835	7.2		.4921	12.5
	.0157	.4		.0785	...		.1695	...		.2854	7.25	1/2″	.5000	12.7
	.0160	...		.0787	2.0	11/64″	.1719	4.37		.2874	7.3		.5118	13.0
	.0177	.45		.0807	2.05		.1730	...		.2900	...	33/64″	.5156	13.10
	.0180	...		.0810	...		.1732	4.4		.2913	7.4	17/32″	.5312	13.49
	.0197	.5		.0820	...		.1770	...		.2950	...		.5315	13.5
	.0200	...		.0827	2.1		.1771	4.5		.2953	7.5	35/64″	.5469	13.89
	.0210	...		.0846	2.15		.1800	...	19/64″	.2968	7.54		.5512	14.0
	.0217	.55		.0860	...		.1811	4.6		.2992	7.6	9/16″	.5625	14.29
	.0225	...		.0866	2.2		.1820	...		.3020	...		.5709	14.5
	.0236	.6		.0885	2.25		.1850	4.7		.3031	7.7	37/64″	.5781	14.68
	.0240	...		.0890	...		.1870	4.75		.3051	7.75		.5906	15.0
	.0250	...		.0905	2.3	3/16″	.1875	4.76		.3071	7.8	19/32″	.5937	15.08
	.0256	.65		.0925	2.35		.1890	4.8		.3110	7.9	39/64″	.6094	15.48
	.0260	...		.0935	...		.1910	...	5/16″	.3125	7.94		.6102	15.5
	.0280	...	3/32″	.0937	2.38		.1929	4.9		.3150	8.0	5/8″	.6250	15.88
	.0276	.7		.0945	2.4		.1935	...		.3160	...		.6299	16.0
	.0292	...		.0960	...		.1960	...		.3189	8.1	41/64″	.6406	16.27
	.0295	.75		.0964	2.45		.1968	5.0		.3228	8.2		.6496	16.5
	.0310	...		.0980	...		.1990	...		.3230	...	21/32″	.6562	16.67
1/32″	.0312	.79		.0984	2.5		.2008	5.1		.3248	8.25		.6693	17.0
	.0315	.8		.0995	...		.2010	...		.3268	8.3	43/64″	.6719	17.06
	.0320	...		.1015	...	13/64″	.2031	5.16	21/64″	.3281	8.33	11/16″	.6875	17.46
	.0330	...		.1024	2.6		.2040	...		.3307	8.4		.6890	17.5
	.0335	.85		.1040	...		.2047	5.2		.3320	...	45/64″	.7031	17.86
	.0350	...		.1063	2.7		.2055	...		.3346	8.5		.7087	18.0
	.0354	.9		.1065	...		.2067	5.25		.3386	8.6	23/32″	.7187	18.26
	.0360	...		.1082	2.75		.2086	5.3		.3390	...		.7283	18.5
	.0370	...	7/64″	.1094	2.78		.2090	...		.3425	8.7	47/64″	.7344	18.65
	.0374	.95		.1100	...		.2126	5.4	11/32″	.3437	8.73		.7480	19.0
	.0380	...		.1102	2.8		.2130	...		.3445	8.75	3/4″	.7500	19.05
	.0390	...		.1110	...		.2165	5.5		.3465	8.8	49/64″	.7656	19.45
	.0394	1.0		.1130	...	7/32″	.2187	5.56		.3480	...		.7677	19.5
	.0400	...		.1141	2.9		.2205	5.6		.3504	8.9	25/32″	.7812	19.84
	.0410	...		.1160	...		.2210	...		.3543	9.0		.7874	20.0
	.0413	1.05		.1181	3.0		.2244	5.7		.3580	...	51/64″	.7969	20.24
	.0420	...		.1200	...		.2263	5.75		.3583	9.1		.8071	20.5
	.0430	...		.1220	3.1		.2280	...	23/64″	.3594	9.13	13/16″	.8125	20.64
	.0433	1.1	1/8″	.1250	3.18		.2283	5.8		.3622	9.2		.8268	21.0
	.0452	1.15		.1260	3.2		.2323	5.9		.3641	9.25	53/64″	.8281	21.03
	.0465	...		.1279	3.25		.2340	...		.3661	9.3	27/32″	.8437	21.43
3/64″	.0469	1.19		.1285	...	15/64″	.2344	5.95		.3680	...		.8465	21.5
	.0472	1.2		.1299	3.3		.2362	6.0		.3701	9.4	55/64″	.8594	21.83
	.0492	1.25		.1338	3.4		.2380	...		.3740	9.5		.8661	22.0
	.0512	1.3		.1360	...		.2401	6.1	3/8″	.3750	9.53	7/8″	.8750	22.23
	.0520	...		.1378	3.5		.2420	...		.3770	...		.8858	22.5
	.0531	1.35		.1405	...		.2441	6.2		.3780	9.6	57/64″	.8906	22.62
	.0550	...	9/64″	.1406	3.57		.2460	6.25		.3819	9.7		.9055	23.0
	.0551	1.4		.1417	3.6		.2480	6.3		.3838	9.75	29/32″	.9062	23.02
	.0570	1.45		.1440	...	1/4″	.2500	6.35		.3858	9.8	59/64″	.9219	23.42
	.0591	1.5		.1457	3.7		.2520	6.4		.3860	...		.9252	23.5
	.0595	...		.1470	...		.2559	6.5		.3898	9.9	15/16″	.9375	23.81
	.0610	1.55		.1476	3.75		.2570	...	25/64″	.3906	9.92		.9449	24.0
1/16″	.0625	1.59		.1495	...		.2598	6.6		.3937	10.0	61/64″	.9531	24.21
	.0629	1.6		.1496	3.8		.2610	...		.3970	...		.9646	24.5
	.0635	...		.1520	...		.2638	6.7		.4040	...	31/32″	.9687	24.61
	.0649	1.65		.1535	3.9	17/64″	.2656	6.75	13/32″	.4062	10.32		.9843	25.0
	.0669	1.7		.1540	...		.2657	6.75		.4130	...	63/64″	.9844	25.03
	.0670	...	5/32″	.1562	3.97		.2660	...		.4134	10.5	1″	1.000	25.4

Temperature Conversion Table

This conversion table can be used to convert temperature to Celsius (°C) or to Fahrenheit (°F). The center column is the base temperature. If you want to convert from °F to °C, you would look up the number in the center column and the number in the left column would show the conversion in °C. To convert °C to °F, you would look up the base number and the conversion to °F is shown in the right column.

As an example, to find the °F for 100°C, look up 100 in the base temperature column. The column to the right shows +212°F as the conversion. The shaded portions of the chart represent negative values.

°C	BASE TEMP. °F or °C	°F	°C	BASE TEMP. °F or °C	°F	°C	BASE TEMP. °F or °C	°F	°C	BASE TEMP. °F or °C	°F	°C	BASE TEMP. °F or °C	°F
-73.33	-100	-148.0	1.11	30	86.0	40.56	105	221.0	148.89	300	572	357.22	675	1247
70.55	95	139.0	0.56	31	87.8	41.11	106	222.8	151.67	305	581	360.00	680	1256
67.78	90	130.0	0.00	32	89.6	41.67	107	224.6	154.44	310	590	362.78	685	1265
65.00	85	121.0	+0.56	33	91.4	42.22	108	226.4	157.22	315	599	365.56	690	1274
62.22	80	112.0	1.11	34	93.2	42.78	109	228.2	160.00	320	608	368.34	695	1283
59.44	75	103.0	1.67	35	95.0	43.33	110	230.0	162.78	325	617	371.11	700	1292
56.67	70	94.0	2.22	36	96.8	43.89	111	231.8	165.56	330	626	373.89	705	1301
53.89	65	85.0	2.78	37	98.6	44.44	112	233.6	168.33	335	635	376.67	710	1310
51.11	60	76.0	3.33	38	100.4	45.00	113	235.4	171.11	340	644	379.44	715	1319
48.33	55	67.0	3.89	39	102.2	45.56	114	237.2	173.89	345	653	382.22	720	1328
45.56	50	58.0	4.44	40	104.0	46.11	115	239.0	176.67	350	662	385.00	725	1337
44.44	48	54.4	5.00	41	105.8	46.67	116	240.8	179.44	355	671	387.78	730	1346
43.33	46	50.8	5.56	42	107.6	47.22	117	242.6	182.22	360	680	390.56	735	1355
42.22	44	47.2	6.11	43	109.4	47.78	118	244.4	185.00	365	689	393.33	740	1364
41.11	42	43.6	6.67	44	111.2	48.33	119	246.2	187.78	370	698	396.11	745	1373
40.00	40	40.0	7.22	45	113.0	48.87	120	248.0	190.56	375	707	398.89	750	1382
38.89	38	36.4	7.78	46	114.8	49.44	121	249.8	193.33	380	716	401.67	755	1391
37.78	36	32.8	8.33	47	116.6	50.00	122	251.6	196.11	385	725	404.44	760	1400
36.67	34	29.2	8.89	48	118.4	50.56	123	253.4	198.89	390	734	407.22	765	1409
35.56	32	25.6	9.44	49	120.2	51.11	124	255.2	201.67	395	743	410.00	770	1418
34.44	30	22.0	10.00	50	122.0	51.67	125	257.0	204.44	400	752	412.78	775	1427
33.33	28	18.4	10.56	51	123.8	52.22	126	258.8	207.22	405	761	415.56	780	1436
32.22	26	14.8	11.11	52	125.6	52.78	127	260.6	210.00	410	770	418.33	785	1445
31.11	24	11.2	11.67	53	127.4	53.33	128	262.4	212.78	415	779	421.11	790	1454
30.00	22	7.6	12.22	54	129.2	53.89	129	264.2	215.56	420	788	423.89	795	1463
28.89	20	4.0	12.78	55	131.0	54.44	130	266.0	218.33	425	797	426.67	800	1472
28.33	19	2.2	13.33	56	132.8	55.00	131	267.8	221.11	430	806	429.44	805	1481
27.78	18	0.4	13.89	57	134.6	55.56	132	269.6	223.89	435	815	432.22	810	1490
27.22	17	+1.4	14.44	58	136.4	56.11	133	271.4	226.67	440	824	435.00	815	1499
26.67	16	3.2	15.00	59	138.2	56.67	134	273.2	229.44	445	833	437.78	820	1508
26.11	15	5.0	15.56	60	140.0	57.22	135	275.0	232.22	450	842	440.56	825	1517
25.56	14	6.8	16.11	61	141.8	57.78	136	276.8	235.00	455	851	443.33	830	1526
25.00	13	8.6	16.67	62	143.6	58.33	137	278.6	237.78	460	860	446.11	835	1535
24.44	12	10.4	17.22	63	145.4	58.89	138	280.4	240.56	465	869	448.89	840	1544
23.89	11	12.2	17.78	64	147.2	63.44	139	282.2	243.33	470	878	451.67	845	1553
23.33	10	14.0	18.33	65	149.0	60.00	140	284.0	246.11	475	887	454.44	850	1562
22.78	9	15.8	18.89	66	150.8	60.56	141	285.8	248.89	480	896	457.22	855	1571
22.22	8	17.6	19.44	67	152.6	61.11	142	287.6	251.67	485	905	460.00	860	1580
21.67	7	19.4	20.00	68	154.4	61.67	143	289.4	254.44	490	914	462.78	865	1589
21.11	6	21.2	20.56	69	156.2	62.22	144	291.2	257.22	495	923	465.56	870	1598
20.56	5	23.0	21.11	70	158.0	62.78	145	293.0	260.00	500	932	468.33	875	1607
20.00	4	24.8	21.67	71	159.8	63.33	146	294.8	262.78	505	941	471.11	880	1616
19.44	3	26.6	22.22	72	161.6	63.89	147	296.6	265.56	510	950	473.89	885	1625
18.89	2	28.4	22.78	73	163.4	64.44	148	298.4	268.33	515	959	476.67	890	1634
18.33	1	30.2	23.33	74	165.2	65.00	149	300.2	271.11	520	968	479.44	895	1643
17.78	0	32.0	23.89	75	167.0	65.56	150	302.0	273.89	525	977	482.22	900	1652
17.22	+1	33.8	24.44	76	168.8	68.33	155	311.0	276.67	530	986	485.00	905	1661
16.67	2	35.6	25.00	77	170.6	71.11	160	320.0	279.44	535	995	487.78	910	1670
16.11	3	37.4	25.56	78	172.4	73.89	165	329.0	282.22	540	1004	490.56	915	1679
15.56	4	39.2	26.11	79	174.2	76.67	170	338.0	285.00	545	1013	493.33	920	1688
15.00	5	41.0	26.67	80	176.0	79.44	175	347.0	287.78	550	1022	496.11	925	1697
14.44	6	42.8	27.22	81	177.8	82.22	180	356.0	290.56	555	1031	498.89	930	1706
13.89	7	44.6	27.78	82	179.6	85.00	185	365.0	293.33	560	1040	501.67	935	1715
13.33	8	46.4	28.33	83	181.4	87.78	190	374.0	296.11	565	1049	504.44	940	1724
12.78	9	48.2	28.89	84	183.2	90.56	195	383.0	298.89	570	1058	507.22	945	1733
12.22	10	50.0	29.44	85	185.0	93.33	200	392.0	301.67	575	1067	510.00	950	1742
11.67	11	51.8	30.00	86	186.8	96.11	205	401.0	304.44	580	1076	512.78	955	1751
11.11	12	53.6	30.56	87	188.6	98.89	210	410.0	307.22	585	1085	515.56	960	1760
10.56	13	55.4	31.11	88	190.4	101.67	215	419.0	310.00	590	1094	518.33	965	1769
10.00	14	57.2	31.67	89	192.2	104.44	220	428.0	312.78	595	1103	521.11	970	1778
9.44	15	59.0	32.22	90	194.0	107.22	225	437.0	315.56	600	1112	523.89	975	1787
8.89	16	60.8	32.78	91	195.8	110.00	230	446.0	318.33	605	1121	526.67	980	1796
8.33	17	62.6	33.33	92	197.6	112.78	235	455.0	321.11	610	1130	529.44	985	1805
7.78	18	64.4	33.89	93	199.4	115.56	240	464.0	323.89	615	1139	532.22	990	1814
7.22	19	66.2	34.44	94	201.2	118.33	245	473.0	326.67	620	1148	535.00	995	1823
6.67	20	68.0	35.00	95	203.0	121.11	250	482.0	329.44	625	1157	537.78	1000	1832
6.11	21	69.8	35.56	96	204.8	123.89	255	491.0	332.22	630	1166	565.56	1050	1922
5.56	22	71.6	36.11	97	206.6	126.67	260	500.0	335.00	635	1175	593.33	1100	2012
5.00	23	73.4	36.67	98	208.4	129.44	265	509.0	337.78	640	1184	612.11	1150	2102
4.44	24	75.2	37.22	99	210.2	132.22	270	518.0	340.56	645	1193	648.89	1200	2192
3.89	25	77.0	37.78	100	212.0	135.00	275	527.0	343.33	650	1202	676.67	1250	2282
3.33	26	78.8	38.33	101	213.8	137.78	280	536.0	346.11	655	1211	704.44	1300	2372
2.78	27	80.6	38.89	102	215.6	140.56	285	545.0	348.89	660	1220	732.22	1350	2462
2.22	28	82.4	39.44	103	217.4	143.33	290	554.0	351.67	665	1229	760.00	1400	2552
1.67	29	84.2	40.00	104	219.2	146.11	295	563.0	354.44	670	1238	815.56	1500	2732

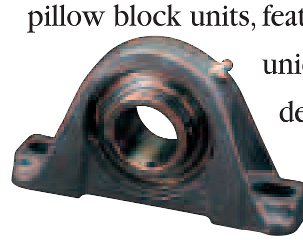
As a Timken customer, you receive an uncompromising standard of quality across the broadest range of bearings and related products. Brands like Timken®, Torrington® and Fafnir® reflect an extensive line of tapered, needle, spherical, cylindrical, ball bearings and mounted units ideal for virtually every industrial application. Complementing our core products is an ever-growing line of friction management solutions including lubricants, single-point lubricators, maintenance tools, safety equipment, condition monitoring systems and repair services that help keep operations running smoothly.

Safety End Caps

These easily installed caps offer a high degree of protection to maintenance personnel as well as to the bearings integrated within a housing.

Housed Units

Ball and spherical roller bearing pillow block units, featuring a



unique sealing design, are easily installed and maintained in heavy-duty environments.

Condition Monitoring Devices

From wireless units to online systems, conditioning monitoring devices give you powerful diagnostic tools to help detect potential bearing failure, while maximizing machine uptime and lowering maintenance costs.

Repair and Replacement Options

By choosing to have bearings and other elements re-manufactured, customers save money in replacement costs and maintain a steady supply of parts instead of purchasing new parts during downtimes. Timken provides bearing repair services for any type of roller bearing design, regardless of manufacturer.

Lubricants

Industrial lubricant formulas have been specifically developed by our tribology experts. These lubricants keep bearings running smoothly in a variety of industrial conditions, including high heat, food processing and high speed. Timken also offers a line of single-point lubricators to simplify the delivery of grease.

Maintenance Handling Tools

Convenient handling devices give technicians the tools they need to install, remove and service bearings. Products include: impact fitting tools, induction heaters and hydraulic pullers.

Industrial Seals

Timken industrial seals are available in small-bore sizes, zero- to 13-inches, as well as in metric and high-temperature varieties. We also provide tools to speed installation, deter seal and bearing damage and prevent premature seal leakage. The seals and tools can be applied in a full range of equipment used in thousands of applications, including manufacturing, off-highway, power transmission and oil refineries.

WARNING:

- **Proper maintenance and handling practices are critical. Failure to follow installation instructions and to maintain proper lubrication can result in equipment failure, creating a risk of serious bodily harm.**
- **Never spin a bearing with compressed air. The rollers may be forcefully expelled creating a risk of serious bodily harm.**

TIMKEN
Where You Turn

www.timken.com

35M 04-06-29 Order No. 5892