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# Roller Contact Bearing Guide

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# **Rolling Contact Bearing Guide**

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## **Table of Contents**

Introduction	3
Types of Rolling Contact Bearings	4
Characteristics of Rolling Bearings	11
Bearing Mounting	13
Bearing Retention	15
Bearing Life	21
Bearing Size	22
Internal Clearance	25
Preloading	27
Cylindrical Bearing Configurations	31
Bearing Material & Manufacture	33
Bearing Lubrication	36
Bearing Closures	38
Bearing Application	41

## **Introduction**

A bearing is a component that is used in machines to support rotating shafts with minimum friction. There are two types of bearings: rolling contact bearings and journal bearings. Rolling contact bearings use balls or rollers that rotate between inner and outer rings to allow shaft rotation. Journal bearings are one-piece static sleeves that are mounted in housings and fit closely to shafts to allow rotational movement. Both have many applications in today's industrial products. For instance, in the automotive industry, rolling contact bearings are used in transmissions while journal bearings are used in engines. This course deals with rolling contact bearings and presents all their important aspects from the basics to machine applications.

## Types of Rolling Contact Bearings

There are two types of rolling contact bearings: ball bearings and roller bearings. Ball bearings, as the name suggests, use balls as the rolling element while roller bearings use rollers.

Ball bearings can be divided into two groups: radial ball bearings and angular contact ball bearings (See Figures 1 and 2). Radial ball bearings support primarily radial loads which act perpendicular to the bearing axis. Angular contact ball bearings support both radial and thrust loads which act parallel to the bearing axis.

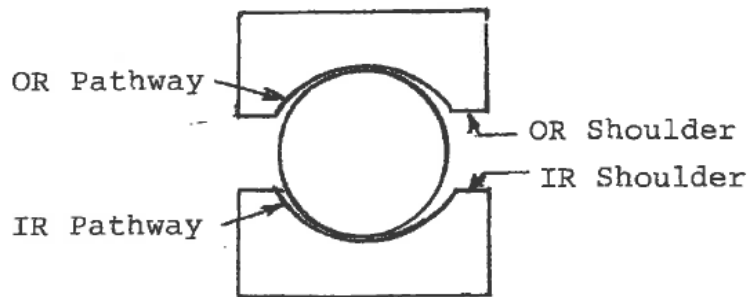
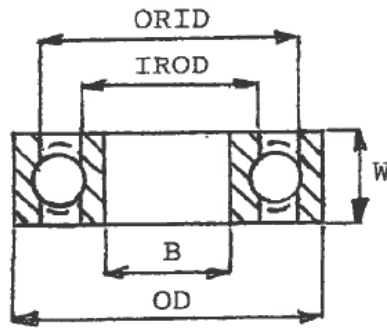
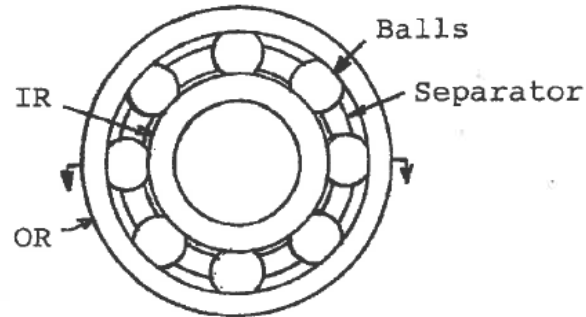
It can be seen from Figure 3 how radial loads act perpendicular to the bearing axis while thrust loads act parallel to the bearing axis. In some instances there are two radial loads acting on a bearing. The Pythagorean Theorem is used to calculate the resultant radial load. The radial load may be located between the two bearings as shown on Figure 3. The simple beam formula can be used to calculate the individual load on each bearing. It can be shown that the bearing located closer to the load supports the greater portion of the load. The load may also be located overhanging the two bearings. In this case, the beam formula will show that the bearing located closer to the load actually supports more than the load itself.

Radial ball bearings are assembled by a method called *Conrad Assembly*. It starts by placing the inner ring off-center inside the outer ring, loading a limited number of balls in the crescent space, centering the balls, and installing the separator (See Figure 4). Adding a loading groove to one or both rings allows the assembly of more balls (as shown later). Radial ball bearings are non-separable. Angular contact bearings have separable rings and can be assembled with a full complement of balls increasing their capacity to support more load than radial ball bearings.

Roller bearings can be divided into two groups: cylindrical roller bearings and tapered roller bearings (See Figures 5 and 6). Cylindrical roller bearings support primarily radial loads while tapered roller bearings support both radial and thrust loads. Cylindrical roller bearings and tapered roller bearings can be assembled with a full complement of rollers maximizing their capacity to support loads.

Figure 1

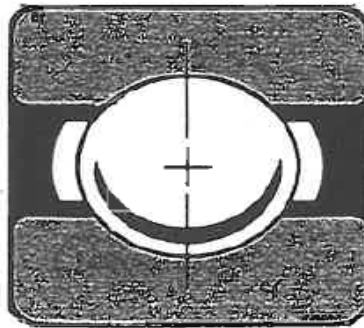
Ball Bearing Terminology



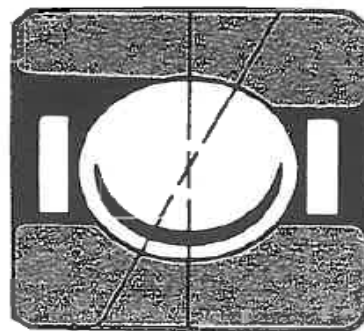
(Exaggerated View)

**Figure 2**

**Ball Bearing Types**



**Radial Ball Bearing**



**Angular Contact Ball Bearing**

Figure 3

Forces Acting on Bearings

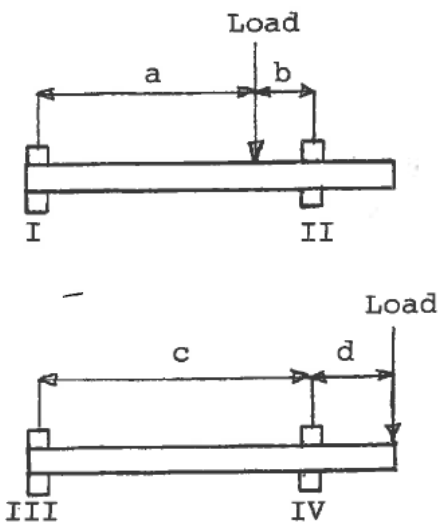
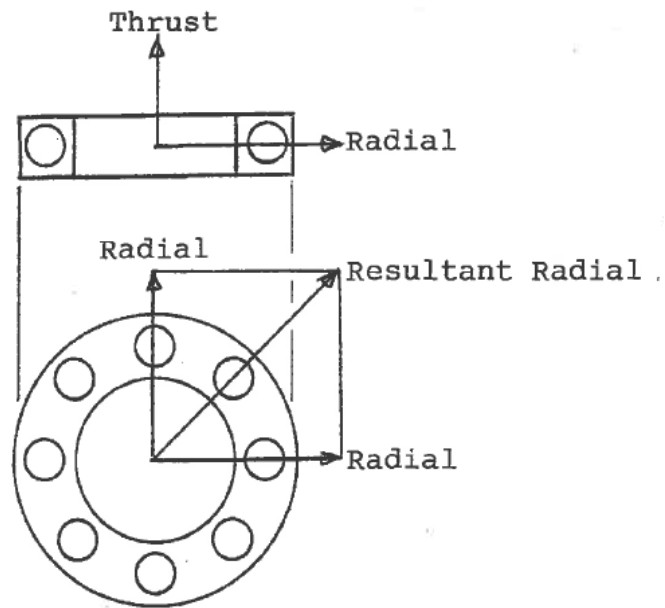
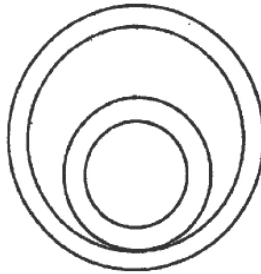


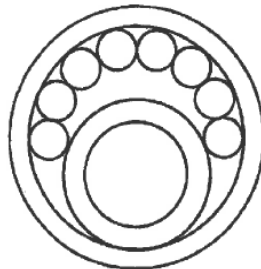


Figure 4

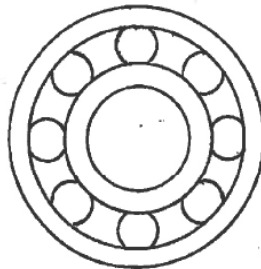
Conrad Assembly



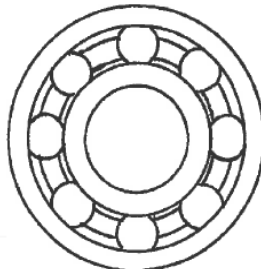
The IR is placed off-center inside the OR.



The balls are placed in the open space.

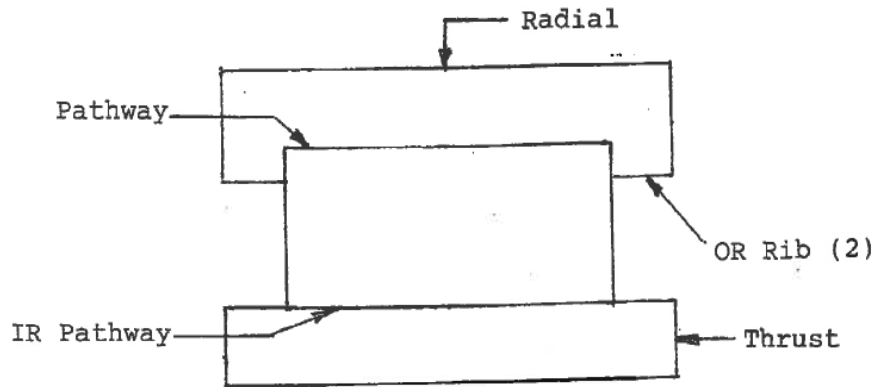
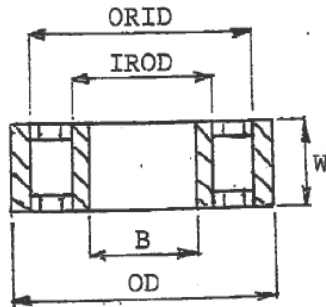
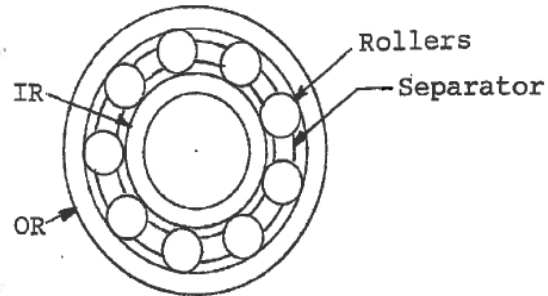


The IR is centered and the balls spaced.



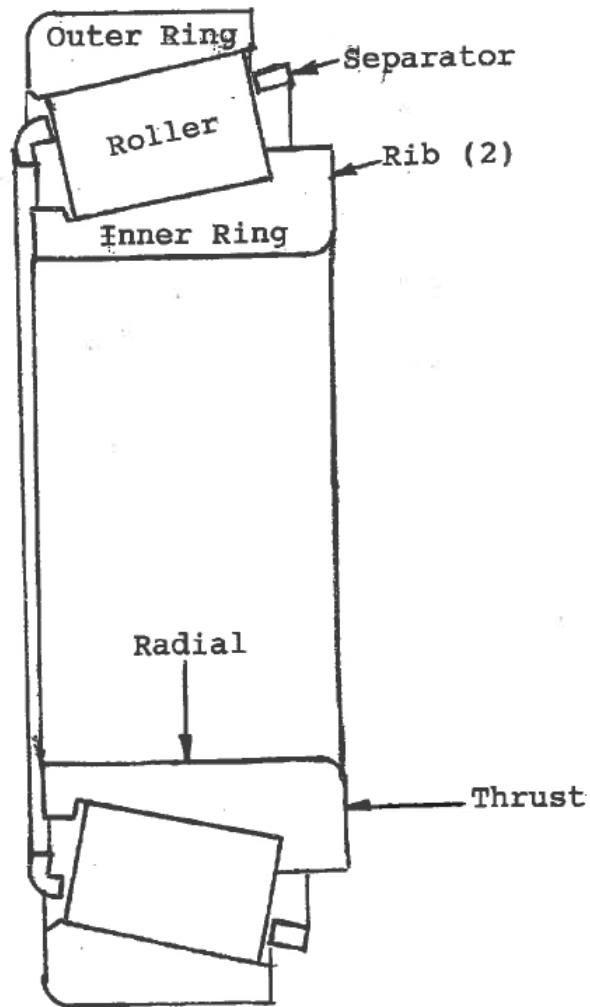
The separator is installed.

Figure 5  
Cylindrical Roller Bearing



(Enlarged Section)

Figure 6  
Tapered Roller Bearing Terminology



## Characteristics of Rolling Contact Bearings

Ball bearings are a common type of rolling contact bearings. Radial ball bearings can support radial loads and a lesser amount of thrust loads in either direction. Angular contact ball bearings can support both radial and thrust loads and are often used in pairs. Because of the much smaller contact between balls and rings, ball bearings cannot support loads as high as equal sized roller bearings; however, ball bearings can operate with lower torque and higher speed and precision than roller bearings. Radial ball bearings can be furnished prelubricated and sealed, and operate for life without maintenance. Ball and roller bearings can be furnished with snap rings installed in grooves in the outer ring for mounting purposes.

Roller bearings are also a common type of rolling bearings. Cylindrical roller bearings can support higher radial loads than similar size ball bearings but lack the capacity to support substantial thrust loads. Tapered roller bearings can support high radial and thrust loads and are often used in pairs.

The following is a summary of the characteristics of ball and roller bearings presented in Figure 7 below:

- Radial ball bearings have fair radial and thrust load carrying capabilities. They are excellent for high speed, high accuracy and low torque. They are also good for shaft misalignment. They can be used together on both ends of a shaft. Angular contact ball bearings have good radial and thrust load carrying capabilities. They are excellent for high speed and high accuracy, fair for low torque, but poor for shaft misalignment.
- Angular contact pairs are good for radial and thrust loads. They are good for high speed and high accuracy but are poor for shaft misalignment. They are commonly used on both ends of a shaft.
- Some forms of cylindrical roller bearings have good radial load and fair thrust load carrying capabilities. Others are excellent for high speed and high accuracy. All are fair for shaft misalignment. Some forms are good for mounting on both ends of a shaft.
- Tapered roller bearings have excellent radial and good thrust load carrying capabilities. They are good for high speed and high accuracy but poor for misalignment. They too are commonly mounted on both ends of the same shaft.

Figure 7

Bearing Characteristics

	<u>Radial Ball Brg</u>	<u>Ang Contact Ball Brg</u>	<u>Cylindrical Roller Brg</u>	<u>Tapered Roller Brg</u>	<u>Double Row Ang. Contact</u>	<u>Double Row Taper Roller</u>
Radial Load)	Fair	Good	Good	Good	Good	Excellent
Thrust Load)	Fair	Good	Fair	Good	Good	Good
Combined Load)	Fair	Good	Fair	Good	Good	Excellent
High Speed)	Excellent	Excellent	Excellent	Good	Good	Good
High Accuracy)	Excellent	Excellent	Excellent	Good	Good	Good
Low Torque)	Excellent	Fair	Good	Fair	Fair	Fair
Misalignment)	Good	Poor	Fair	Fair	Poor	Poor

\*The above ratings may vary somewhat for some forms of some of the bearings.

## **Bearing Mounting**

See Figure 8 for sketches of various bearing mounting arrangements. The first design is a very common arrangement using two ball bearings to support the same shaft. This combination is good for moderate radial loads and a lesser amount of thrust loads. Both bearing inner rings are axially clamped while one outer ring is free to float (move axially) in the housing. This mounting arrangement allows for relative axial motion between the shaft and housing due to manufacturing tolerances and differential thermal expansion between the shaft and housing. This combination is used in transmissions.

The second sketch employs a ball bearing on the shaft's fixed end and a roller bearing supporting the free end. This is a common arrangement especially when there is a heavy off-center load. Both bearing inner and outer rings are axially clamped. The right bearing, having an inner ring with no ribs, allows relative axial movement between the shaft and housing. This arrangement is used in motors and blowers.

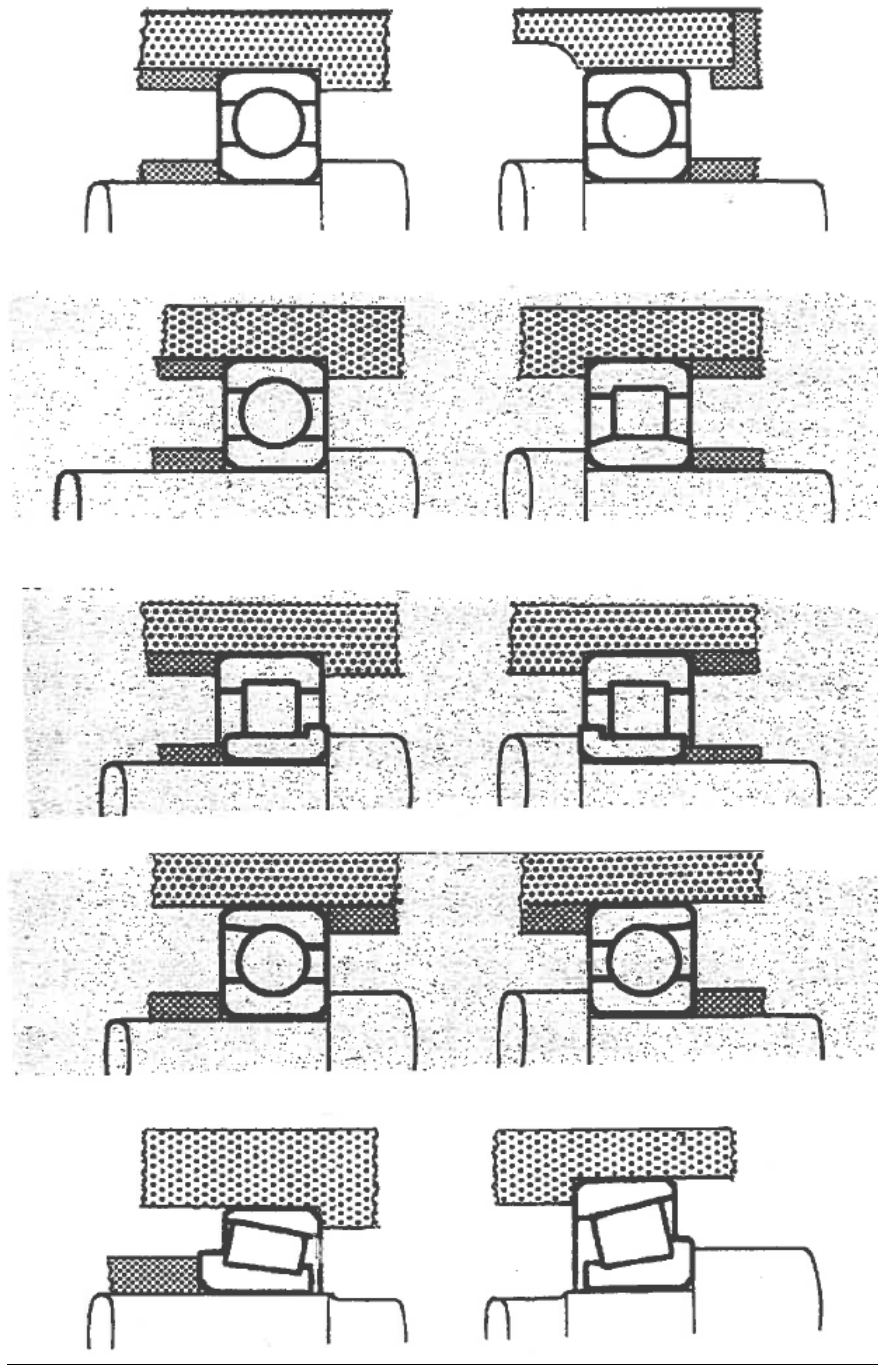
The third schematic has two roller bearings supporting the shaft. This application is used for heavy radial loads with heavy shock loads. Both bearing inner and outer rings are axially clamped. Relative axial movement of the shaft is accommodated by allowing space between both bearing inner ring ribs and roller ends.

The fourth arrangement employs two angular contact bearings mounted back-to-back. They are good for radial and thrust loads and for high speed operation. They are poor for accommodating shaft misalignment but provide good shaft rigidity and resistance to moment loading, and can be preloaded as explained later.

The fifth sketch has two tapered roller bearings mounted back-to-back. They are excellent for radial and thrust loads, and good for high speeds. They are poor for accommodating shaft misalignment but provide excellent shaft rigidity. They can be used on both shaft fixed and free ends. They are used for automotive drive axle pinions and wheel bearings.

Figure 8

Bearing Mounting



## **Bearing Retention**

A commonly used method of retaining bearings is shown on the top sketch of Figure 9. Here a lock washer mounted between the nut and bearing is keyed to the shaft to prevent rotation. The outside diameter of the lock washer has tabs which are designed so that one aligns with one of the slots on the outside diameter of the nut after the nut is torqued. This system is used to retain wheel bearings on some automotive vehicles. It can be used to lock the nut when torqued tight or when the nut is loose allowing some specified end play.

In some circumstances there is insufficient space to lengthen the shaft enough to provide for the thread used on the device above. In this instance, a thick washer is secured against the bearing by means of screws which are threaded into the end of the shaft and lock wired to prevent loosening (as shown on second sketch of Figure 9).

The simplest method is shown on the third sketch of Figure 9 where a snap ring is inserted into a groove on the shaft. Some snap rings are made tapered so that, after installation, pressure is always put on the face of the bearing inner ring to prevent axial movement.

A method of clamping outer rings is shown on the top sketch of Figure 10. Here the retainer is fastened to the housing with screws. An important feature is that the clamp is piloted into the same diameter of the housing as the bearing. This accurately locates the clamp in the radial direction which is important for proper functioning of the seal incorporated in the clamp.

The second sketch of Figure 10 has a two-piece clamp that provides the shoulder for bearing outer ring retainment. This design allows for through-boring the housing for better bearing alignment.

The third sketch on Figure 10 has the bearing outer ring clamped between an outer cap which is fastened to the housing with screws (not shown) and an inner member retained by a wire ring. This design is not recommended where high thrust loads are present in the direction of the wire ring.



There are instances in design when assembly cannot be accomplished because the opening in the housing is too small to allow components to pass through. When this occurs, the opening in the housing is made slightly larger as seen on the upper sketch of Figure 11, where an adapter sleeve is used. This sleeve should be a light tap fit in the housing and should have the bore and outside diameter machined as parallel and concentric as possible.

The second sketch on Figure 11 shows a bearing and sleeve arrangement used on a precision spindle (short shaft). The bearings are a press fit in their respective sleeves. Before this is done, the high points of eccentricity of the bearings are positioned diametrically opposite the high points of eccentricity of the sleeves, thus compensating for the eccentricity of both parts and improving spindle runout.

It is sometimes necessary to mount ball bearings to allow a certain amount of eccentricity between the shaft and housing for various reasons, one of which is for belt tightening. This is accomplished with a sleeve whose outside diameter is sufficiently eccentric with the inside diameter to produce the desired amount of shaft movement. (See the third sketch in Figure 11.)

The first sketch in Figure 12 has a cylindrical roller bearing retained between a housing shoulder and snap ring.

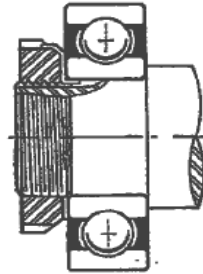
The second sketch has a cylindrical roller bearing outer ring captured between two snap rings. This arrangement allows the housing to be thru-bored for better alignment of the bearings and gears if used.

The third sketch shows bolts and washers retaining a cylindrical roller bearing. This too allows thru-boring the housing.

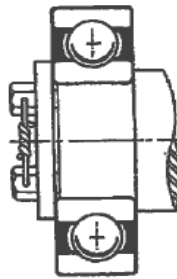
The fourth sketch mounts the bearing between a snap ring and bolted in-place sleeve shoulder. This design increases the housing opening size allowing the installation and removal of larger components such as gears.

**Figure 9**

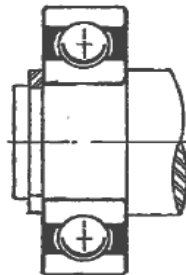
**Bearing Retention**



**Slotted Nut and Tabbed Washer**



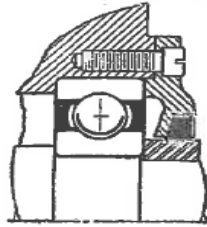
**Thick Washer and Lock Wire**



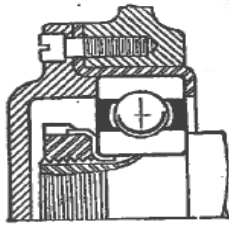
**Snap Ring**

**Figure 10**

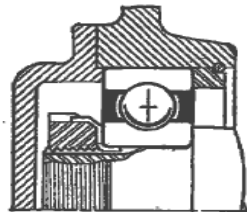
**Bearing Retention**



**Piloted Outer Ring With Clamp  
With Seal**



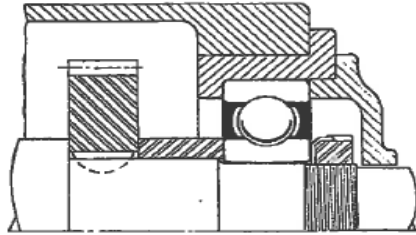
**Two Piece Clamp  
Thru-Bored Housing**



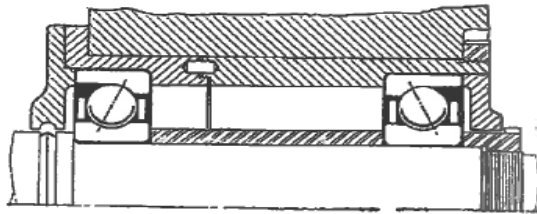
**Wire Ring Retainer  
Thru-Bored Housing**

**Figure 11**

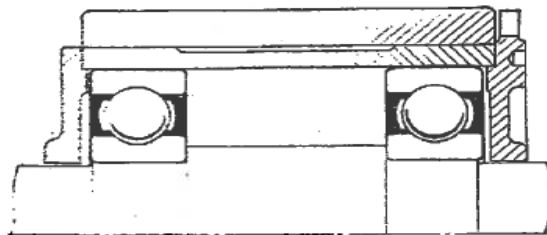
**Bearing Retention**



**Outer Ring Sleeve  
Allows Gear Assembly**



**Precision Sleeve  
Improves Spindle Runout**

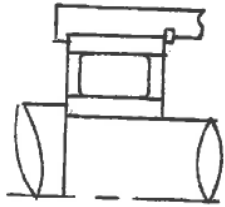


**SLEEVE**

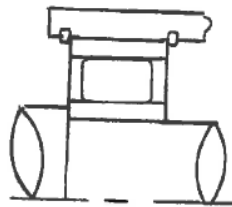
**Eccentric Sleeve  
For Belt Tightening**

Figure 12

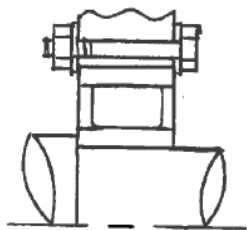
Bearing Retention



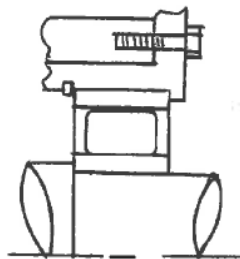
Roller Bearing mounting using retaining ring and housing flange to secure outer ring.



Roller bearing mounting using dual retaining rings to secure bearing outer ring.



Through bolt and washers used to retain bearing outer ring.



Bearing cartridge mounting allows room to remove gear.

## Bearing Life

One of the first tasks in specifying a bearing for an application is to calculate the operating life given the load and speed. Generally, rolling contact bearings fail from metal fatigue in the form of a spall (pit) usually occurring on the highly stressed inner ring. It is caused by loading and unloading the inner ring as it rotates in and out of the bearing load zone producing metal fatigue. One equation for the life of a rolling bearing is as follows:

$$L_{10} = 3000(C/P)^{10/3}(500/S)$$

- **L<sub>10</sub>** is the bearing life in B10 hours. B10 hours is the amount of time that 90% of the bearings are expected to achieve in their lifetime under a specified load and speed without failure.
- **C** is the capacity of the bearing and is found in industry catalogs. It is the number of pounds that the bearing can support for 3,000 hours of operation at 500 rpm.
- **P** is the equivalent radial load in pounds which takes into account both radial and thrust loads imposed by the application and is also found in industry catalogs.
- **S** is the bearing speed in revolutions per minute (rpm).

Should the bearing operate under a number of different loads and speeds, the following equation is used:

$$L_{10} = 1 / [(t_1/L_1) + (t_2/L_2) + (t_3/L_3) + \text{etc}]$$

**L<sub>10</sub>** is the bearing **B<sub>10</sub>** life in hours. **t** is the percent of time spend at each different life (**L**) level. The following table gives bearing life should the application require something other than **B10** life:

% Survival	B Life	% B10 Life
99	B1	21
98	B2	33
95	B5	62
90	B10	100
50	B50	400
40	B60	500

## Bearing Size

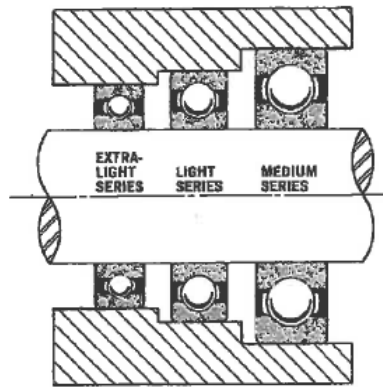
Most bearings fall into three different series or categories based on their cross-sectional area with the larger sizes able to support heavier loads. The series are extra-light, light, and medium. (See Figures 13 and 14.) Sizes that are readily available range from an extra-light bearing with a 10 mm bore, 26 mm OD, and 8 mm width to a medium series bearing with a 110 mm bore, 240 mm OD, and 50 mm width. Bearings are normally manufactured to metric dimensions although inch sizes are also available.

Ball bearing mounting surface dimensions fall under an industry wide standard so that the product from the various manufacturers can be used interchangeably. It is standard practice to have the bearing rotating ring be a press fit on its mounting member and the non-rotating ring be a loose fit on its mounting member. The following table is an example of the rotating inner ring fit and the stationary outer ring fit for a commonly used light series 40 mm bore ball bearing for the five industry-wide Annular Bearing Engineers Committee (ABEC) standard fit classifications:

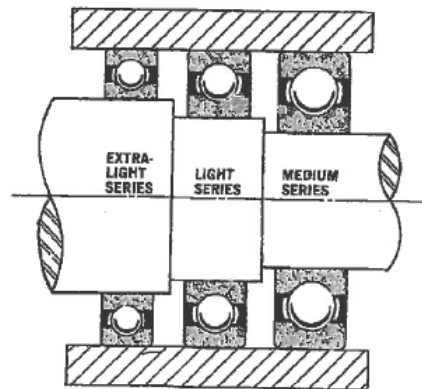
<b>ABEC Number</b>	<b>Rotating Inner Ring</b>	<b>Stationary Outer Ring</b>
1	.0009T-.0001L	.0001T-.0010L
3	.0006T-.0001L	.0001T-.0008L
5	.0004T-.0001L	.0000-.0006L
7	.0003T-.0001L	.0000-.0004L
9	.0001T-.0001L	.0000-.0003L

It can be seen from the tables that as the ABEC number increases, the tolerances get tighter and the precision gets greater resulting in closer control of the fit of the rings on their mounting surfaces. ABEC 1 is the standard grade of ball bearing precision and is generally adequate for most ball bearing applications. ABEC 3 and 5 grades are specified where narrower tolerances are required to give desired refinements in mounting and running characteristics. ABEC 7 and 9 are available for applications where extreme accuracy and true running are necessary. These super precision grades are used in aircraft, machine tool, and fine instrument service.

**Figure 13**  
**Bearing Sizes**



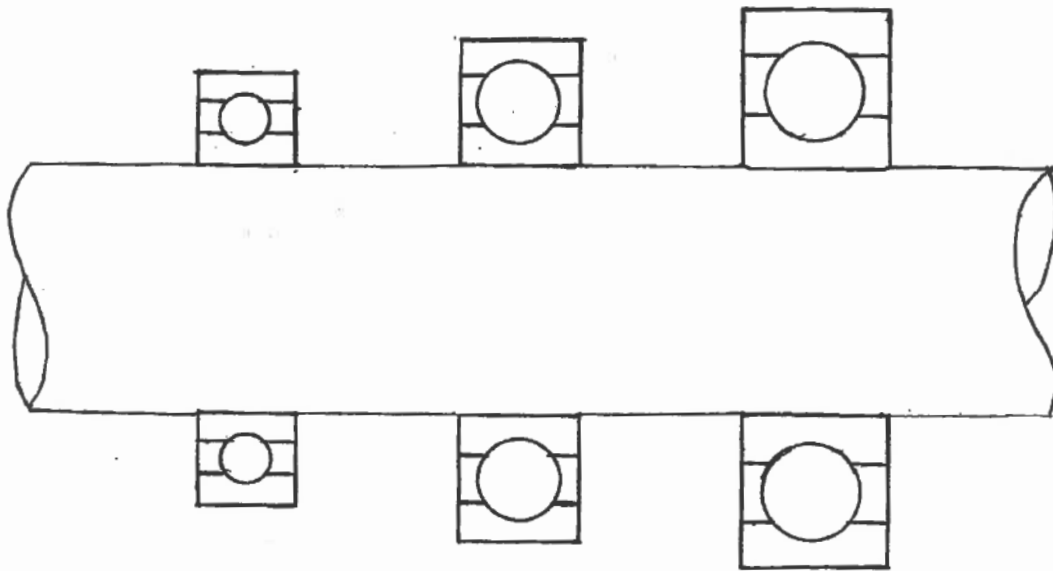
Relative Proportions of Bearings  
With Same Inside Diameter



Relative Proportions of Bearings  
With Same Outside Diameter



**Figure 14**  
**Bearing Sizes**



<u>Extra Light Series</u>	<u>Light Series</u>	<u>Medium Series</u>
Bore 35 mm	Bore 35 mm	Bore 35 mm
OD 62 mm	OD 72 mm	OD 80 mm
Width 14 mm	Width 17 mm	Width 21 mm
Balls 11-5/16 in	Balls 9-15/32 in	Balls 8-9/16 in
Capacity 950 lb	Capacity 1900 lb	Capacity 2400 lb

## Internal Clearance

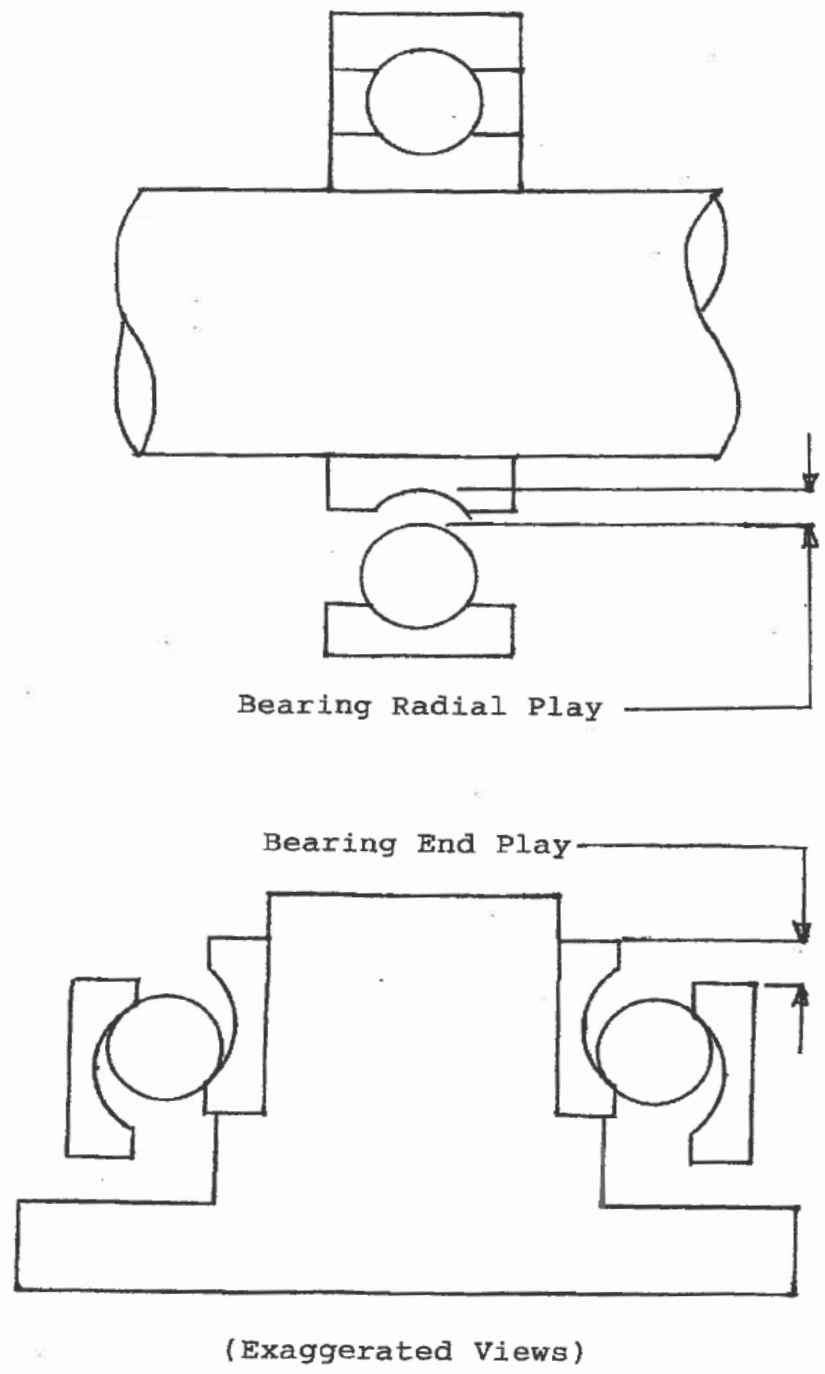
All non-separable bearings are normally built with a slight looseness called internal clearance. If measured in the radial direction it is called *radial play* and if measured in the axial direction it is called *end play*. (See Figure 15.) Radial play is equal to the outer ring pathway diameter minus the inner ring pathway diameter minus twice the rolling element diameter. This is accomplished in production by gaging the inner and outer ring pathway diameters and selecting a class of rolling elements with a diameter that results in the specified radial play. The purpose of radial play is as follows:

- Radial play allows the inner ring to misalign slightly with the outer ring without preloading the bearing thus accommodating shaft and housing manufacturing tolerances and shaft deflection under load.
- It permits interference fits of inner rings on shafts and outer rings in housings. Interference fits on shafts and in housings cause pathways to expand when press fitting inner rings, and pathways to contract when press fitting outer rings. The amount of expansion or contraction of pathways is approximately 80% of the press fit.
- It allows unequal thermal expansion of the shaft and housing. Shafts normally run hotter than housings which will expand the inner ring more than the outer ring. This results in producing unwanted preload in the bearing if it had no internal clearance.

The average free radial play for a light series 40 mm bore radial ball bearing is .0005 inches. The ABEC 1 average press fit for the same bearing rotating inner ring is .0004 inches.  $80\% \text{ of } .0004 = .0003$ . Then,  $.0005 - .0003 = .0002$  inches which is the average running radial play for the subject bearing with a rotating inner ring. The average free radial play for the same size cylindrical roller bearing is .0013 inches. This is higher than radial ball bearings because of higher roller bearing stress when preloaded or misaligned.

Standard radial play satisfies the requirements of most applications. For unusual applications special radial play may be required. Lower than standard radial play (.0002 inches average) may be required for ball bearings operating at low to moderate speeds where accurate radial and axial location is critical. Higher than standard radial play (.0014 inches average) is specified for high speed and high thrust loads; however, no load acceleration can cause ball skidding with higher than standard radial play.

Figure 15  
Internal Clearance



## Preloading

It is important to design machines so that the products they manufacture are made as accurately as possible. One way to do this is to ensure that the shafts and spindles (short shafts) in these machines to which the manufacturing tools are attached to are rigidly supported and run true. The graph at the top of Figure 16 has a load vs. deflection plot for a typical angular contact ball bearing. It can be seen that the slope is the greatest at the beginning of the curve and lessens as the curve progresses to the right. If something could be done to make the bearings run higher on the curve, the spindles that the bearings support would be more rigidly supported and run truer. The process that is used is called “preloading”.

Figure 17 has a sketch of a spindle supported by two angular contact ball bearings. The inner rings of the bearings are clamped tight against the shaft shoulder. Each outer ring is mounted on its own sleeve. Torquing the nut N puts an axial load on the right (back) bearing through sleeve B. This load is then transferred through the clamped inner rings to the front (left) bearing putting the shaft in tension and preloading the two bearings.

Assume that nut M is torqued so that a preload of 3,000 lb tension is put on the bearings and shaft and then a work force of 2,500 lb is applied to the right on the front (left) bearing end of the shaft. This additional force increases the load on the front bearing while decreasing the preload (tension) on the shaft and decreasing the load on the rear bearing. The front bearing is now supporting less than the preload and the additional work load ( $3,000+2,500=5,500$  lb) and the rear bearing is supporting less than the 3,000 lb preload. Both bearings are now operating above the steepest part of the curve and are giving the shaft greater support and accuracy.

The two additional plots on Figure 16 can now be used to determine the load and deflection of each of the two angular contact ball bearings. The middle plot shows that the part of the curve from 0 to 3,000 lb is rotated up. The load of 3,000 lb was chosen because it is the initial preload that was put on both bearings. This section of the plot was rotated up because this is the path taken when preload is being relieved. The lower chart plot shows this part of the curve moved to the right to 5,500 lb which is the momentary load on the front bearing. Moving up the transplanted curve from 5,500 lb to the original curve shows that the final load on the front bearing is 4,500 lb.

Applying the distance R to the 3,000 lb line of the original curve shows that the rear bearing final load is 2,000 lb. Without preload, the 2,500 lb work load would have produced a shaft deflection of .0030 inch, but with preload, shaft deflection is reduced to .0010 inch which is a big improvement when the machine spindle is used to grind precision parts such as ball bearing inner and outer rings.

With the preload set at 3,000 lb, it can be seen on the graph that each bearing deflects .0035 inch. In order to reduce the preload down to zero, the spindle would have to be deflected twice that amount or .0070 inch. The force required to eliminate the preload can be seen on the graph to be 10,000 lb or 3.33 times the amount of the preload itself.

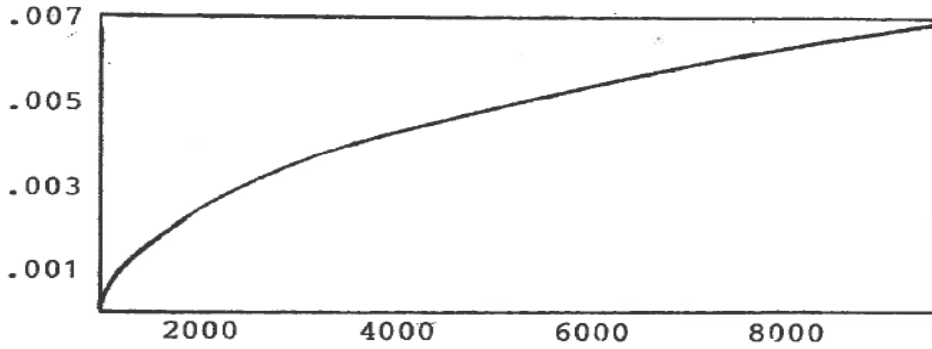
A double row ball bearing can be manufactured preloaded. The lowest graph on Figure 17 compares the load vs. deflection of a double row ball bearing to a similar sized non-preloaded single row ball bearing. It can be seen how much more axial stiffness the preloaded double row bearing has compared to the non-preloaded single row bearing. The double row bearing preload is relieved at 5,000 lb and, after that, the two plots are parallel.

Shaft and Housing Accuracy: If the accuracy of the shaft and housing is not to specification, the performance of the bearings will be affected. Shaft and housings must be strong and rigid and their shoulders square to adequately support and align bearings. For optimum performance and to ensure and maintain specified press fits, the surface finish of shaft and housing mounting surfaces should be as good as bearing mounting finishes. When two or more bearings are mounted in one single piece housing, the housing should be thru-bored for optimum alignment between opposing bearings. When two-piece housings are used, great care should be taken to properly align the bearing bores for optimum performance.

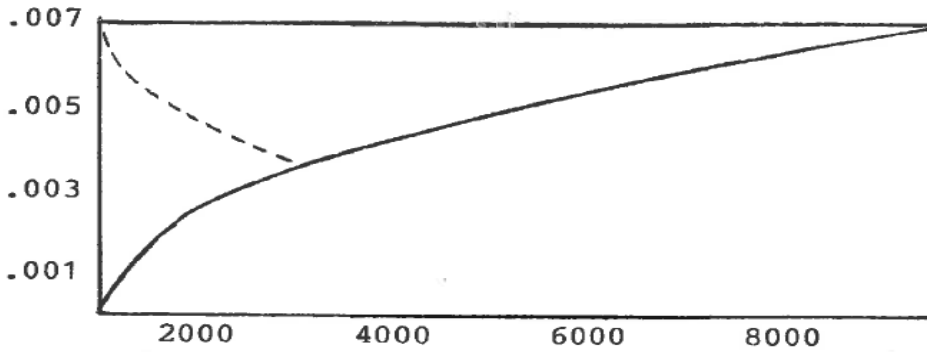
Figure 16

Bearing Preloading

Deflection in inches vs axial load in pounds



Typical Load vs Deflection Curve



0 to 3000# Part of Curve Rotated Upward

Rotated Part of Curve Moved to 5500#

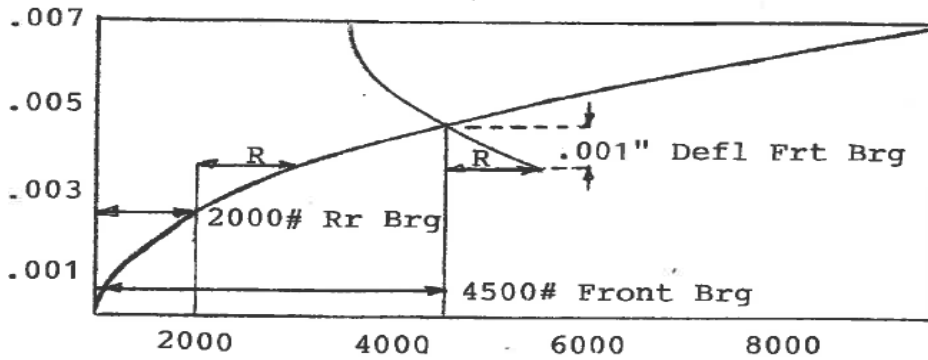
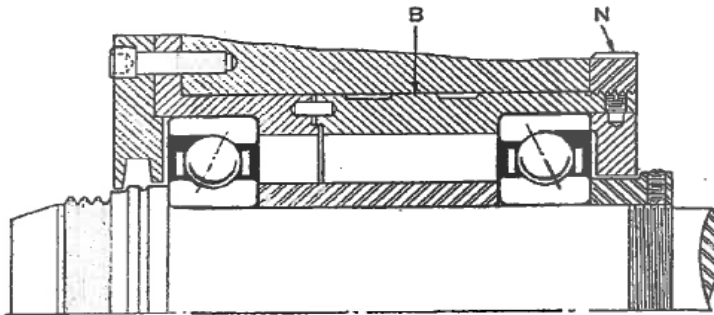
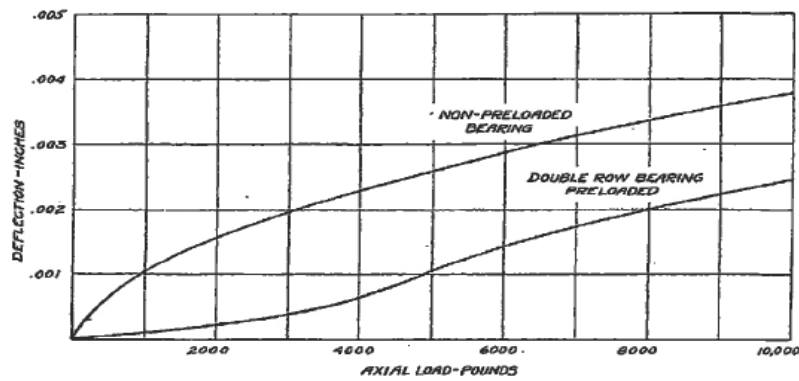


Figure 17  
Bearing Preloading



Preloaded Angular Contact Bearings



Non-Preloaded vs Preloaded  
Double Row Bearing

## **Cylindrical Roller Bearing Configurations**

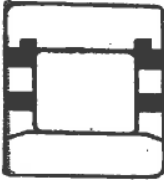
Cylindrical roller bearings have an advantage in that they can be manufactured in a variety of different configurations making them ideally suited for a number of different applications:

- The configuration at the top of Figure 18 is a two-part bearing with a separable inner ring. It is the lowest priced of all the configurations. The rings are centerless ground for excellent concentricity and wall thickness. The rollers are retained radially by a stamped steel separator and axially by split retaining rings that are fitted in outer ring grooves. The separable inner ring allows shaft axial movement due to accumulated manufacturing tolerances and differential thermal expansion of the shaft relative to the housing. The inner ring of this configuration can be omitted and the rollers run directly on hardened and ground shafts enabling the shafts to be made larger and stronger.
- The second configuration on Figure 18 has a variation of the above design having two ribs on the inner ring making it a non-separable bearing for ease of shipping, handling, and assembly. It should be noted that retaining rings are not designed to support the full thrust load that inner and outer ring ribs are designed to do.
- The third sketch on Figure 18 has a configuration that incorporates a rib on opposite sides of the inner and outer rings which allows the bearing to support one-direction thrust loads.
- The fourth sketch on Figure 18 depicts a bearing with an inner ring side plate and a u-shaped outer ring that allows the bearing to support two-direction thrust loads. The side plate can also be incorporated with the outer ring and a u-shaped inner ring to support two-direction thrust loads. This configuration has a separator consisting of formed bars and side rings riveted together for higher speed and quieter operation.
- The fifth sketch has a bearing with a cylindrical outer ring and a u-shaped inner ring. The outer ring can be eliminated and the rollers run in the housing bore. This configuration also has a high speed separator.
- The sixth sketch has a version with no separator and a full set of rollers for maximum capacity but with some reduction in limiting speed.



Figure 18

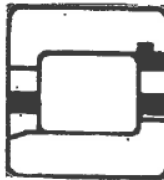
Cylindrical Roller Bearing  
Design Configurations



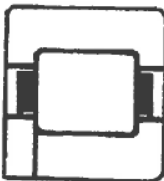
Low cost two-part bearing. Inner ring can be removed and bearing run directly on shaft.



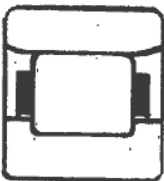
Non-separable bearing design for ease of shipping, handling, and assembly.



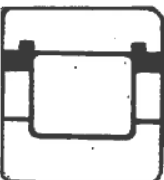
Ribs on opposite sides of bearing allow for supporting one-directional thrust.



Inner ring plate allows two-direction thrust. Has formed bar and side ring high speed separator.



Outer ring can be removed and bearing run directly in housing. Has high speed separator.



No separator allows full complement of rollers and maximum load capacity. Speed limited.

## **Bearing Material and Manufacture**

**Ball Bearings:** The specification for ball bearing material is very demanding. In normal service the steel must withstand 300,000 psi compressive stresses and, in extreme service, compressive stresses of 500,000 psi.

The standard grade steel for ball bearings is high carbon, high chromium, vacuumed degassed AIS/SAE 52100. The high carbon content of 1% makes the steel responsive to heat treatment resulting in very high strength and hardness. The high chromium content of 1.35% further increases response to heat treatment and adds depth of hardness penetration. Vacuum degassing removes impurities making the steel extra clean for extremely critical applications. Consumable electrode vacuum melted steel is available for an even higher degree of cleanliness and uniformity.

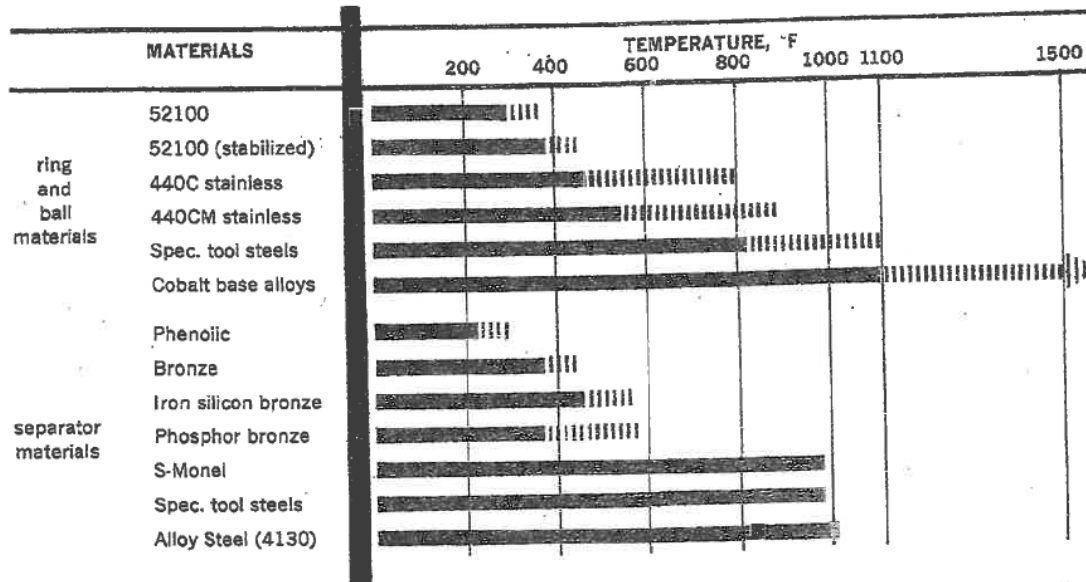
Rings and balls are heat treated throughout to the RC60 hardness level for optimum toughness and strength at operating temperatures up to 300°F. For operating temperatures over 300°F, the steel softens and loses dimensional stability. A special stabilization heat treat procedure is available for continuous operation at temperatures up to 400°F. Stabilization tempers the steel at a temperature above what is encountered in service resulting in a slight decrease in hardness from the RC60 level.

Stainless steel is used for rings and balls for corrosion resistance and high temperature operation up to 550°F. For even higher temperatures up to 1,100°F, special tool steels and cobalt alloys are used.

Separator steel for most bearings is low carbon steel. Most angular contact bearings operating at high speed use a non-metallic separator material. Non-metallic combines low friction, light weight, and strength at temperatures up to 275°F. With higher temperatures and speeds, iron silicon bronze and phosphor bronze provide low friction and a high strength-to-weight ratio. For temperatures up to 1,000°F, S-Monel, special tool steel, and alloy steel are available. Figure 19 gives temperature limitations of the various bearing and separator materials.

The Conrad method of ball bearing assembly procedure, as explained previously, is shown on Figure 4.

Figure 19  
Ball Bearing Material



Ball Bearing Ring, Ball, and Separator  
Material Temperature Limitation

Roller Bearings: One of the best materials used in the manufacture of roller bearings is ASI/SAE 8620. It contains .20% carbon, .80% manganese, .55% nickel, .50% chromium, and .20% molybdenum. Carbon, as mentioned, gives steel good strength and responsiveness to heat treatment. Manganese serves as a deoxidant and also adds strength and responsiveness to heat treatment. Nickel gives good impact resistance at low temperatures. Chromium increases response to heat treatment and depth of hardness penetration. Molybdenum increases the depth of hardness penetration, increases toughness, and helps to resist softening at high temperatures.

Heat treating roller bearings involve a case-hardening operation as opposed to the thru-hardening treatment used on ball bearings. Case-hardening is accomplished in a furnace where the steel is raised to a high temperature in the presence of a carbon-rich gaseous atmosphere. Carbon is absorbed into the outer layers of steel which are then hardened. The inner core remains at a lower hardness level. The hard outer layers give roller bearings good load carrying capabilities while the softer inner core provides good impact load resistance.

Inner and outer rings are processed as follows:

- The rings are machined from sized steel tubing.
- They are case-hardened in heat-treat furnaces.
- Every surface is fine ground to exacting tolerances.

Rollers are processed as follows:

- They are cold-headed from drawn bar.
- They are case-hardened in heat treat furnaces.
- They are hard ground to a fine finish.

Bearings are assembled as follows:

- The roller assembly is installed into the IR or OR.
- The opposite ring is installed.
- On one-part bearings, a retaining ring is installed.
- In two-part bearings, the bearing is a separable unit.

## Bearing Lubrication

Highly refined mineral oils are among the best lubricants for rolling bearings. Synthetics have been developed that are good but some do not form EHD (*elastohydrodynamic*) films as well as mineral oils. EHD refers to what happens to the oil between the rolling element and pathway when the bearing is rotating. Research has shown that a film of oil builds up and, under some circumstances, becomes thick enough to completely separate the rolling elements from the pathways. Thicker films result in longer than what the life equation predicts while films that are too thin result in excessive metal-to-metal contact and shorter lives than what the equation predicts.

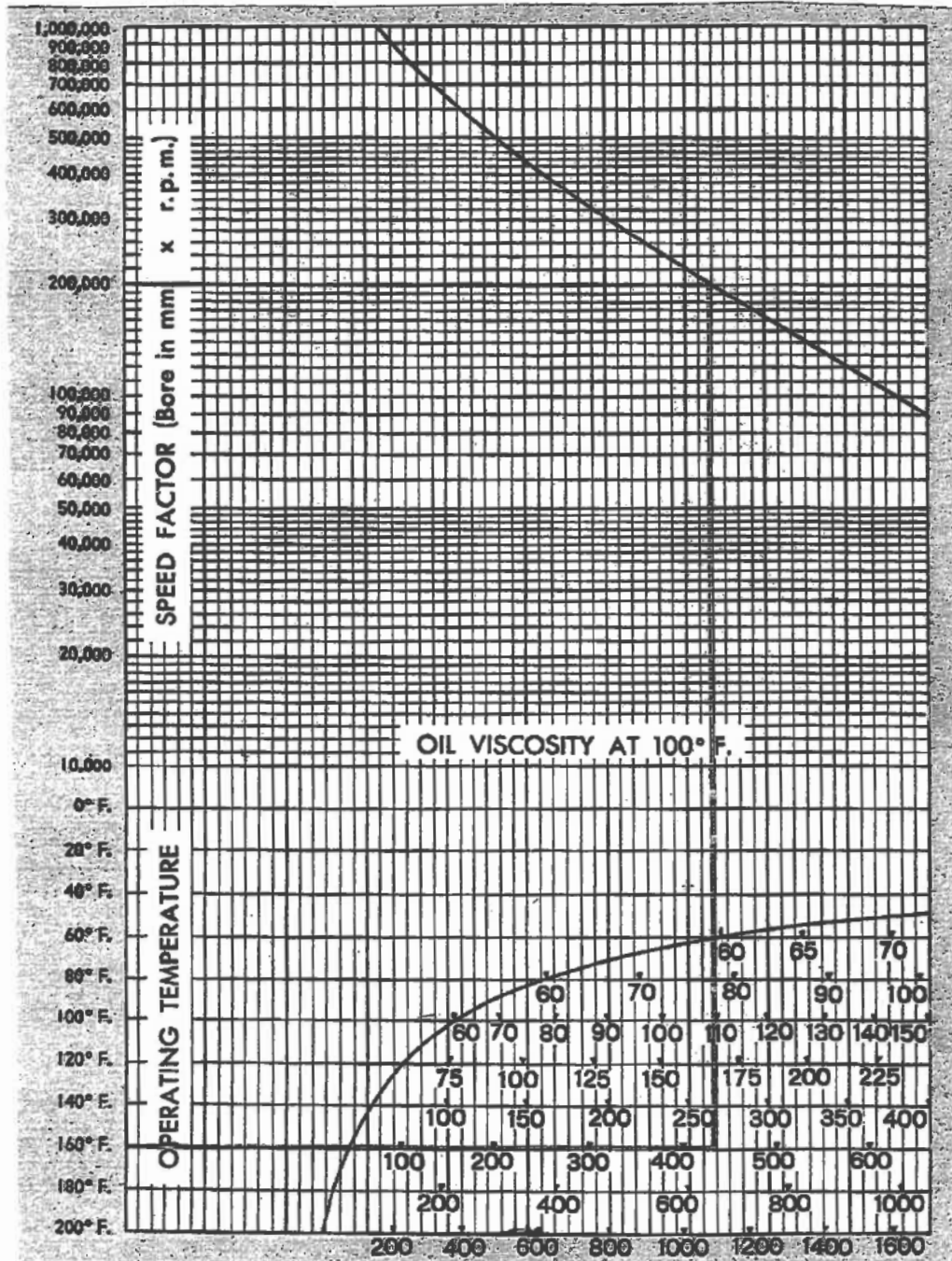
Commonly used means for delivering oil to bearings include jet, bath, mist, and wick feed. The best overall system is oil jet combined with a recirculating system. This method directs a pressurized stream of oil into the bearing load zone. The oil is then collected in a sump where it is filtered, cooled, and returned. This system is good for a variety of loads and speeds. The oil bath system is commonly used in gear boxes. The housing is filled with oil until it just touches the lowest rotating component distributing the oil throughout the gearbox internals. Mist systems use pressurized air to atomize oil. The mixture is then sprayed onto the bearing where it lubricates and cools. Air-oil mist systems are used primarily for high speed applications. Wick systems use an absorbent material to store oil and slowly deliver it to a bearing in a controlled manner. Wick systems are used in electric motors. A simple method of lubricating bearings is by using grease. A carefully measured quantity of grease is evenly distributed throughout the bearing where it is contained by seals or shields. This system can run for the life of the bearing. Grease consistency is important. Greases that are too soft will cause excessive churning losses in a bearing while greases that are too hard will not lubricate properly. The following is a list of important greases:

- Mineral oil greases for general purpose operation from  $-30^{\circ}$  to  $+300^{\circ}\text{F}$
- Ester based greases for operation from  $-100^{\circ}$  to  $+350^{\circ}\text{F}$
- Silicone based greases for operation from  $-100^{\circ}$  to  $+350^{\circ}\text{F}$  but lack good load carrying ability

Figure 20 has a chart to determine oil viscosity: 1) Multiply bearing bore in millimeters by rpm; 2) Draw a line to the upper right reference line and down to the operating temperature; 3) Read the recommended oil viscosity at  $100^{\circ}\text{F}$ .

Figure 20

Bearing Lubrication



## **Bearing Closures**

Bearing closures are sealing devices that are installed on one or both sides of a ball bearing to contain grease lubricant, to protect against dirt or foreign object entry, or to control the flow of lubricant into the bearing when exposed to an oil sump. Grease and double sealed bearings can offer maintenance free operation for the life of a ball bearing.

Atop Figure 21 is a sketch of a single rubber lip seal installed on a standard width ball bearing. This seal has rubber molded around a flat steel ring insert which imparts rigidity and strength to the construction and helps to control lip pressure which is needed to accommodate relative movement of the bearing rings. The seal is snapped into a groove in the outer ring where the rubber provides a leak proof joint. A standard design synthetic rubber seal has an operating temperature range of  $-65^{\circ}\text{F}$  to  $+225^{\circ}\text{F}$ . There are other elastomeric materials available for higher temperature operation. The limiting speed of operation is 2,000 rpm for a large 70 mm bore ball bearing to 13,000 rpm for a small 10 mm bore bearing.

The ability to design and assemble sealing elements on both sides of a standard width ball bearing without going outside the bearing envelope, and to grease lubricate the bearing for a lifetime of operation offers a distinct advantage to the designer in packaging mechanical devices over having to provide alternative means of lubrication for the bearing, or having to provide extra space to accommodate an extra wide sealed bearing.

Another version of the single lip seal is shown as the second sketch on Figure 21. It consists of a steel shield on the outside with a rubber lip seal molded on the lower inside. The metal is positioned on the outside to protect the bearing internals from hard foreign object entry. The metal is crimped into a groove in the outer ring and becomes a permanent part of the bearing. The operating temperature range and limiting speed of operation are the same as the standard snap-in seal.

The third sketch on Figure 21 is of a triple lip seal with the outer steel shield protection as discussed above. The seal is called “land riding” because the three lips ride on the inner ring outer diameter rather than on a notch as do the previous two lip seals. Besides having three lips for triple sealing, grease can be packed between the lips to further impede contaminant and moisture entry and to lubricate the lips. This concept is the ultimate in lip seal design for heavy duty applications. The drag of the three lips causes an increase in the torque level of the bearing; consequently, speeds are limited to 30 rpm for large size bearings described above and 2,500 rpm for the small bearing. It is commonly used in farm machinery, construction equipment and automotive engine water pump bearings.

The fourth sketch on Figure 21 is a felt seal. It is held between two steel pieces that are crimped into a notch in the outer ring. Felt seals are good for lubricant retention and light particle entrance and their low friction allows for higher speeds of operation than all other seal designs. The limiting speed is 3,000 rpm for the larger size bearing and 19,000 for the small bearing. Limiting temperature is 275°F which is the charring temperature of the felt element.

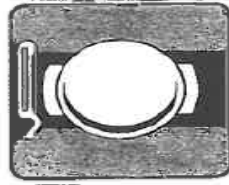
The bottom closure on Figure 21 is a one piece, all metal design called a shield. It is crimped permanently into a groove in the outer ring. It does not contact the inner ring so it does not limit bearing speed. It is used to contain grease or control the amount of oil ingested into the bearing when exposed to an oil sump. Excessive oil in a bearing can cause high running torque and subsequent failure.

Rolling contact bearings can and do operate with grease lubrication but are seldom used in a sealed bearing package.



Figure 21

Ball Bearings Closures



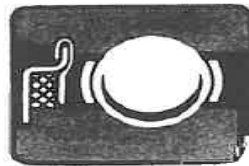
Standard Rubber Lip Seal



Lip Seal With Outer Guard



Triple Lip Seal With Guard



Felt Seal



Double Shields

## **Bearing Application**

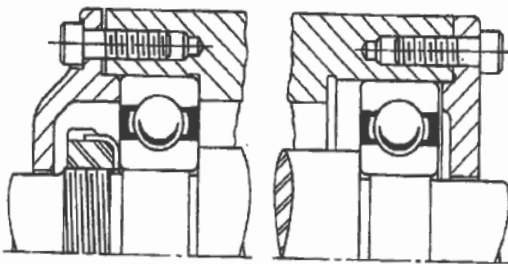
**Radial Ball Bearings:** The application of ball bearings involves more than load and speed calculations. Of equal importance is how bearings are to be mounted and retained in order to minimize machining and aid assembly. Fixing one bearing on a shaft and then freeing the opposite bearing is a common practice to accommodate machining tolerances and thermal differential expansion between the shaft and housing. The sketch at the top of Figure 22 illustrates how the bearing on one end of a shaft is clamped tight and the other is allowed to move axially in the housing. The second sketch reveals how both bearings can be made to float if shaft end play is not critical. The third sketch shows how loading grooves put in bearing rings enabling the assembly of extra balls can be used to support heavy radial loads when high thrust loads are present.

The top sketch of Figure 23 has a flexible shaft handpiece supported by two radial ball bearings. The flexible shaft connects on the right and the appropriate tool attaches on the left. The assembly must be small enough to conveniently fit inside a clasped hand. Radial ball bearings are well suited for this application where moderate thrust loads are resisted by a single bearing. The larger bearing on the right is axially clamped on the shaft and in the housing to support the two-direction thrust loading. The long, tightly clamped sleeve helps to stiffen the shaft. The smaller bearing on the left is free to float to accommodate manufacturing tolerances and differential thermal expansion between the shaft and housing.

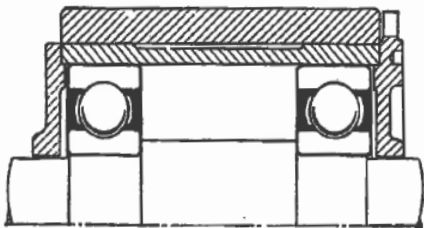
The sketch at the bottom is of the flexible shaft multi-speed drive. The flexible shaft attaches at the upper left with the pulley tensioning device at the top and the drive motor and pulley at the bottom. The drive motor bearings have seals on the exposed end to contain grease lubrication. Both bearings are mounted to float in the housing as shaft end play is not critical. The upper multi-groove pulley is supported with a larger radial ball bearing on the right, which supports moderate bi-directional thrust axial loading and incorporates a seal on the exposed end to contain the lubricant. The left hand bearing is free to float.

Figure 22

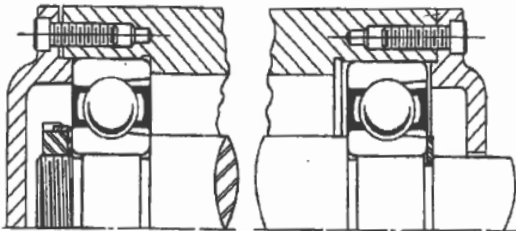
Ball Bearing Application



The bearing on the left is clamped to the housing and the shaft. The bearing on the right is free to accommodate shaft thermal expansion and tolerance build-up.



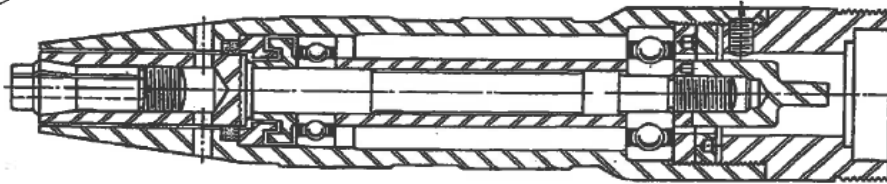
Both bearings can be made to float in the housing if shaft end play is not critical.



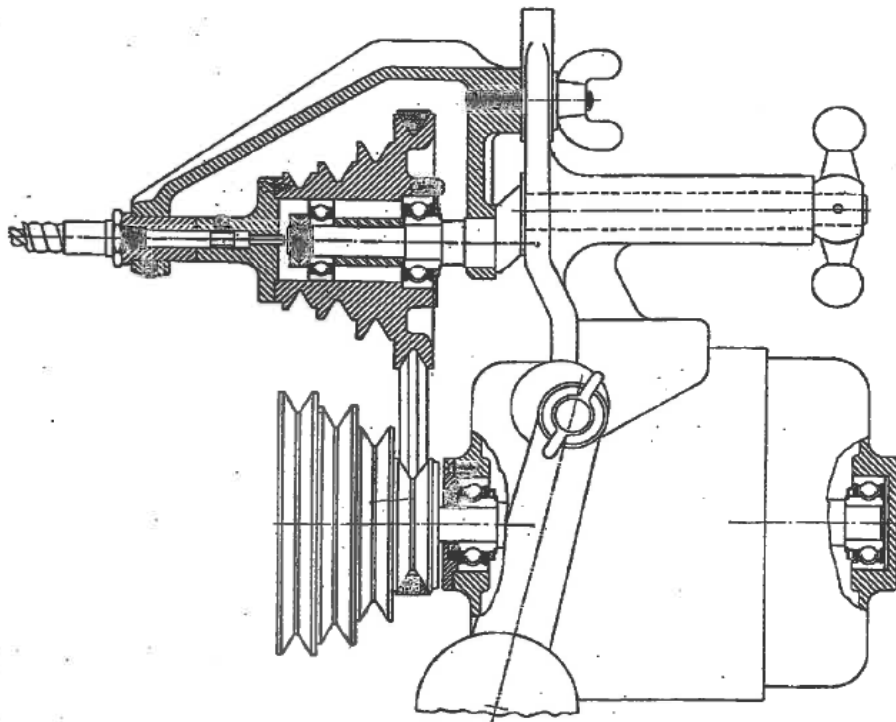
When thrust loads are low, loading groove bearings can be used to take heavy radial loads.

**Figure 23**

**Ball Bearing Application**



**Flexible Shaft Handpiece**



**Flexible Shaft Drive Unit**

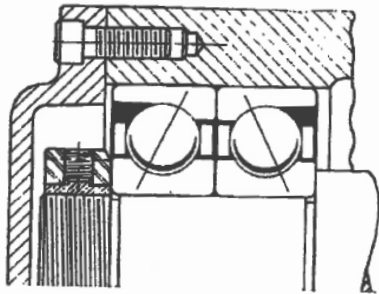
Angular Contact Ball Bearings: The top sketch of Figure 24 has two angular contact ball bearings mounted back-to-back with inner rings clamped and outer rings free to float that can be used to resist high moment loads. The second sketch shows how two angular contact ball bearings mounted face-to-face with both inner and outer rings clamped can be used to accommodate high shaft misalignment. The third sketch on Figure 24 illustrates how two angular contact ball bearings mounted in tandem can be used to support high one-direction thrust loads.

The two precision bench lathe spindles shown on Figure 25 employ a light series radial ball bearing on the left side and two extra light series angular contact ball bearings on the right side. This is done so that the housing can be thru-bored for better bearing and shaft alignment. All three bearing inner rings on both spindles are clamped tight. The two angular contact bearings on the right are back-to-back mounted and are precision off-set ground so that clamping the inner rings results in the correct preload. The back-to-back mounting adds rigidity to the shaft for better alignment under load. The clamped flange on the right bearing pair outer ring fixes the two bearings while the extreme left hand bearing is free to float to accommodate manufacturing tolerances and differential thermal expansion.

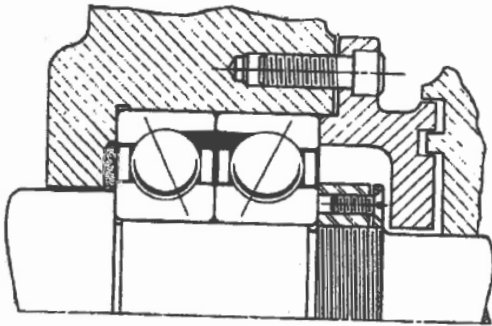
The boring machine spindle at the top of Figure 26 is supported by a single radial ball bearing on the right and two angular contact ball bearings on the left. The two angular contact ball bearings are fixed while the single row radial ball bearing is free to float axially to accommodate the above mentioned length changes. The two angular contact ball bearings have the ring faces precision ground so that when the inner rings are clamped tightly together the prescribed internal preload is automatically established. The two angular contact bearings are mounted back-to-back (DB) to provide the maximum amount of resistance to shaft bending caused by the nearby gear. The sketch at the bottom of Figure 26 has a massive gear cutting spindle supported by two angular contact bearings mounted face-to-face (DF) at the left and two spaced apart angular contact bearings at the right. The right hand bearings are mounted with the contact angles internally divergent to provide the smaller diameter section of the shaft with added rigidity

Figure 24

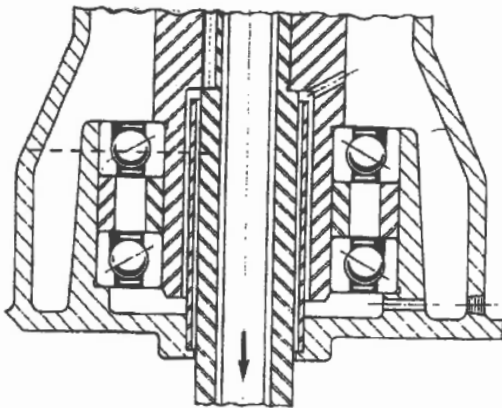
Ball Bearing Application



Maximum resistance to high moment loading is obtained by using two angular contact ball bearings mounted back-to-back.



Compliance to high shaft misalignment is accommodated by using two angular contact ball bearings mounted face-to-face.



Support of high one-direction thrust loading is accomplished by using two angular contact ball bearings mounted in tandem. The thrust is downward on the shaft.

Figure 25

Ball Bearing Application

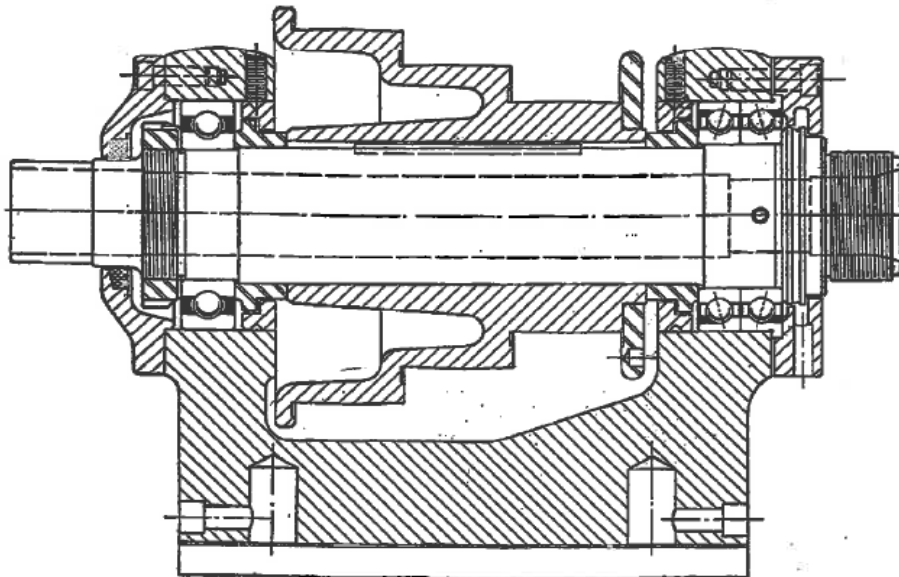
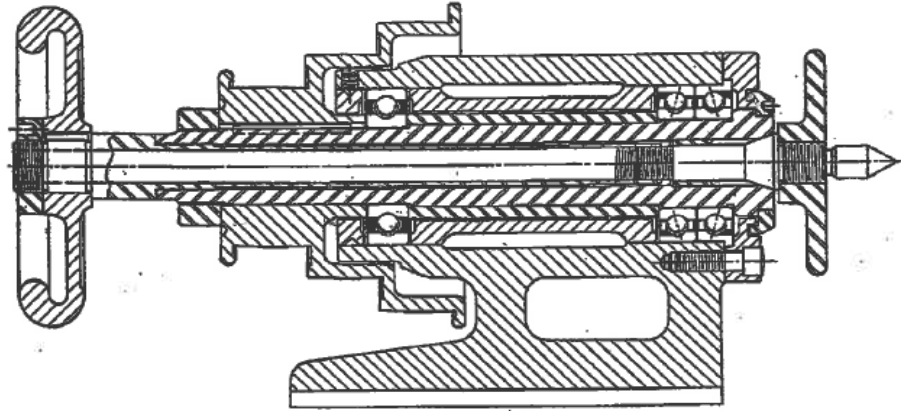
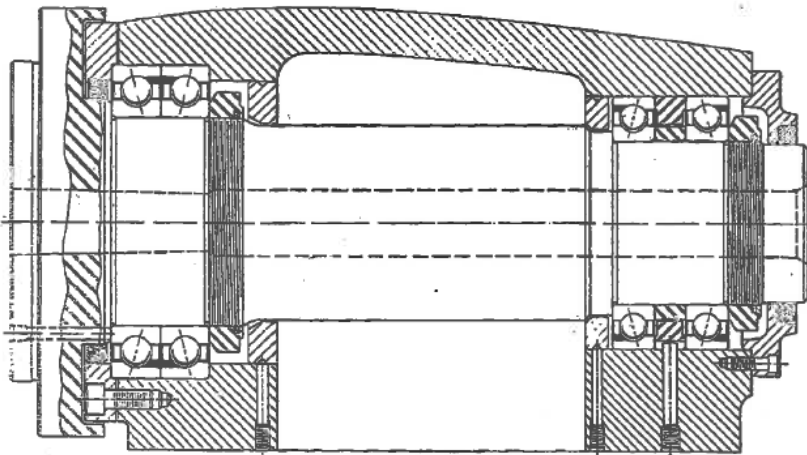
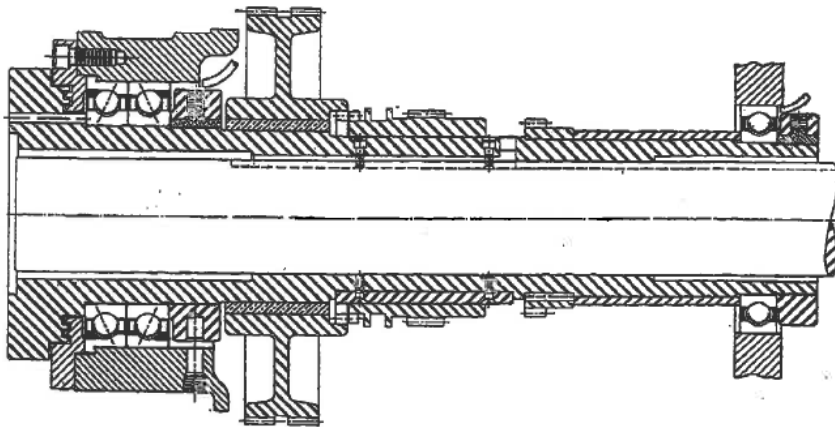


Figure 26  
Ball Bearing Application





Double Row Ball Bearings: Another form of a ball bearing not previously mentioned is a double row bearing. The advantage of using double row ball bearings is that they fit in a narrower space than two side-by-side single row ball bearings that have the same inside and outside diameters.

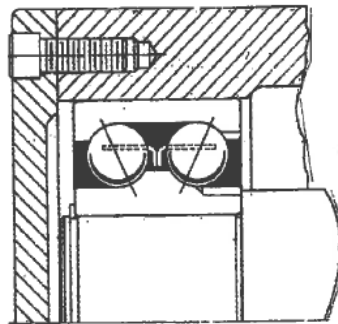
The top sketch of Figure 27 has a double row ball bearing with internally converging contact angle lines. This design can support heavy radial loads and is compliant to shaft misalignment. The lower sketch on Figure 27 has a double row ball bearing mounted with internally diverging contact angle lines supporting a gear. The advantage of this configuration is that it can be used in a single bearing mounting and support heavy radial and overturning moment loading.

The upper sketch on Figure 28 illustrates a double row ball bearing retained with a snap ring. This eliminates the need for a flange on the housing and allows thru-boring for better bearing and gear alignment. The lower sketch on Figure 28 has a double row ball bearing also with internally diverging contact angle lines. The bearing is clamped tight on both the inner and outer rings and is able to support heavy reversing thrust loads.

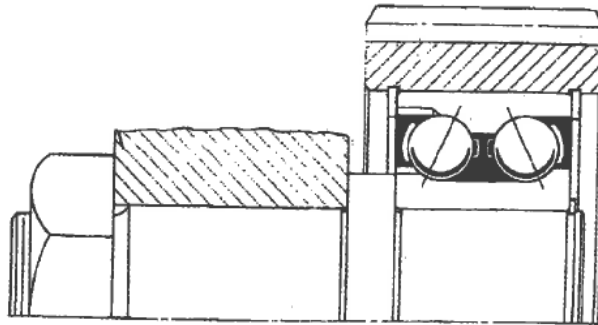
The sketch on Figure 29 is of a speed change mechanism. Both shafts are supported by a double row bearing on one end and a radial ball bearing on the other. (The third set of bearings support gears.) The DB mounted double row ball bearings mounted close to the gears gives shafts needed stiffness for proper gear teeth alignment. Notice that snap rings are used to mount the double row bearings on the left; thereby, eliminating the need for housing shoulders and again allowing for thru-boring the housing for good bearing and gear alignment. A double row ball bearing is used to give rigid support to the smaller gear at the top. The larger gear at the bottom is supported by two wide-mounted single row radial ball bearings.

Figure 27

Ball Bearing Application



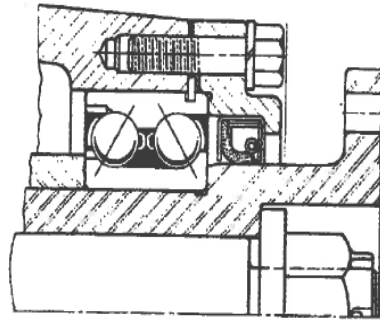
Double row ball bearings with contact angles internally convergent can take misalignment and heavy radial loads.



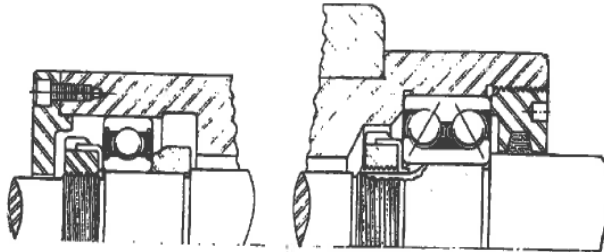
Double row ball bearings with contact angles internally divergent can take heavy overturning moment loading.

Figure 28

Ball Bearing Application



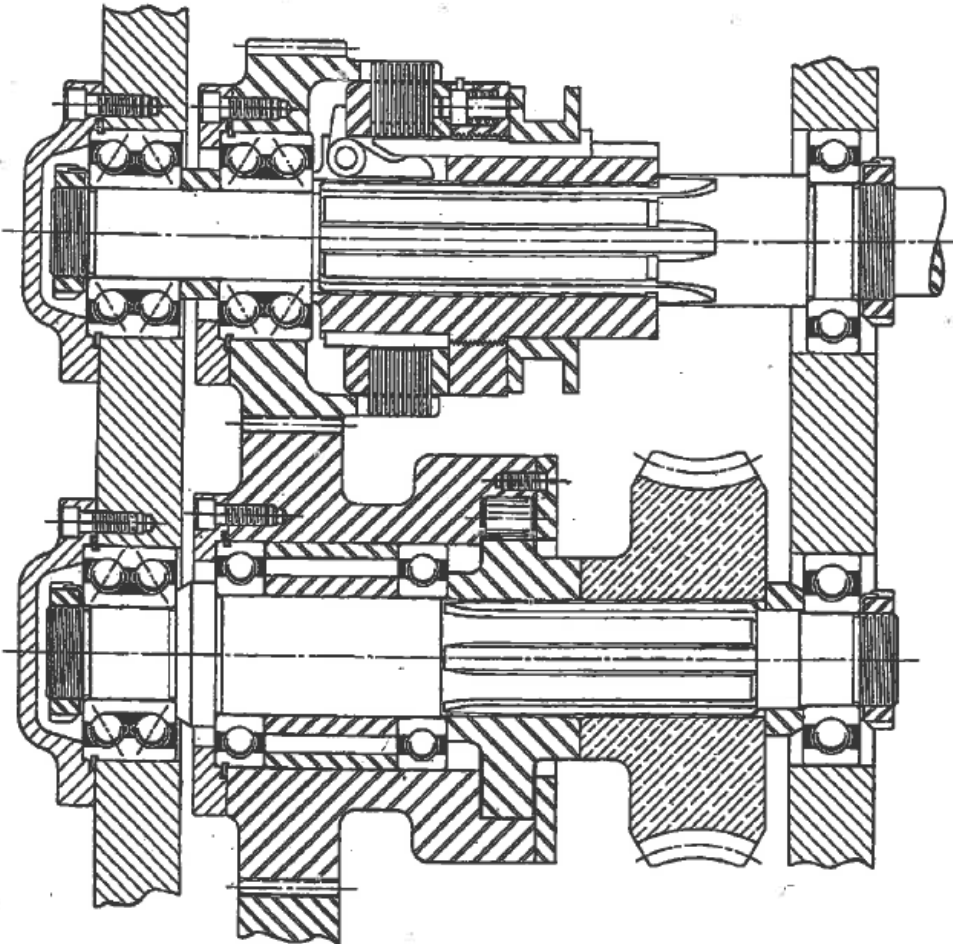
The housing can be thru-bored when a snap ring is used on the bearing outer ring.



A double row ball bearing is used when reversing thrust loads are present in an application.

Figure 29

Ball Bearing Application



Cylindrical Roller Bearings: Cylindrical roller bearings are the bearings of choice in applications where spur gears are used. Spur gears exert high radial loads and little or no thrust loads which is exactly what cylindrical roller bearings are designed to support. Figure 30 contains a sketch of a spur gear application where two cylindrical roller bearings are used to support the gear. The bearings have u-shaped inner rings and opposed single-ribbed outer rings to provide axial support for the gear. There is clearance between the right hand bearing outer ring face and the bearing cap for shaft expansion due to machining tolerances and differential thermal expansion.

Figure 31 has an application where the outer ring of the cylindrical roller bearing has been omitted and the rollers allowed to run on the gear inside diameter. The bearing cost has been reduced; the gear rim has been strengthened; and assembly has been facilitated.

Figure 32 has an installation where the cylindrical roller bearing without an inner ring has rollers that run directly on the shaft. The bearing cost has been reduced; the shaft diameter is increased and made stronger; and assembly has been made easier.

The sketch at the top of Figure 33 has a double row cylindrical roller bearing supporting a gear and running directly on the shaft. The installation at the bottom features two cylindrical roller bearings supporting a shaft with the left bearing fixed and the right bearing free to float.

The top of Figure 34 has a cylindrical roller bearing which supports radial load from the gear and allows easy removal of the worm. The double row ball bearing on the right supports both radial and thrust loads. The bottom of Figure 34 has cylindrical roller bearings with u-shaped outer rings and single ribbed inner rings to support a spur gearset.

Figure 30  
Cylindrical Roller Bearing  
Application

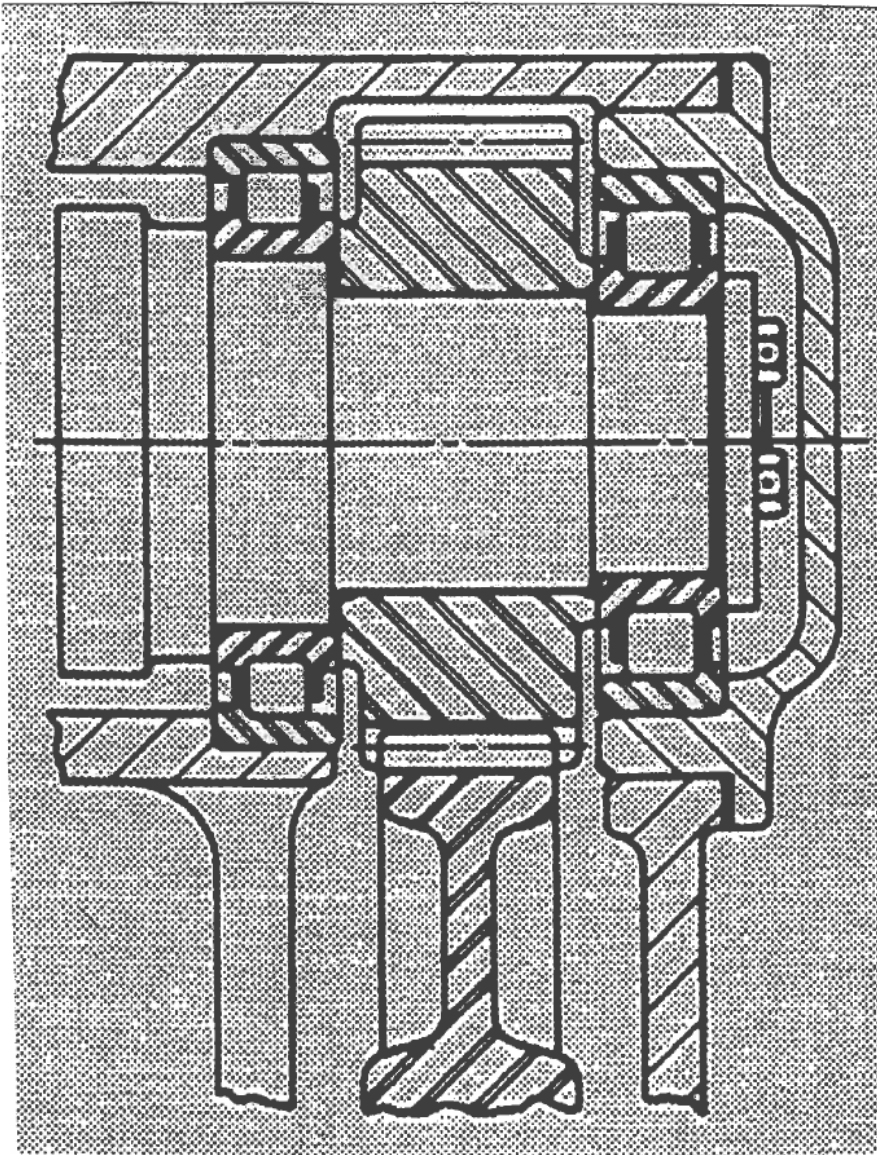


Figure 31  
Cylindrical Roller Bearing  
Application

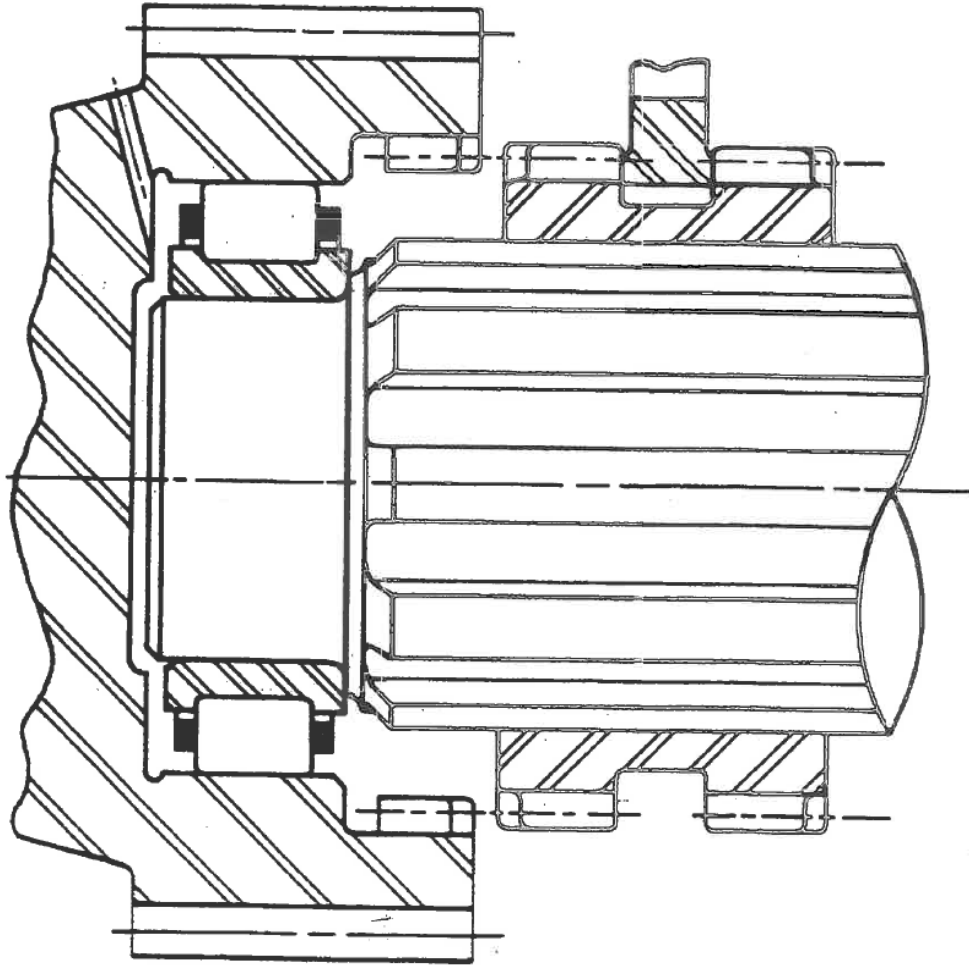




Figure 32  
Cylindrical Roller Bearing  
Application

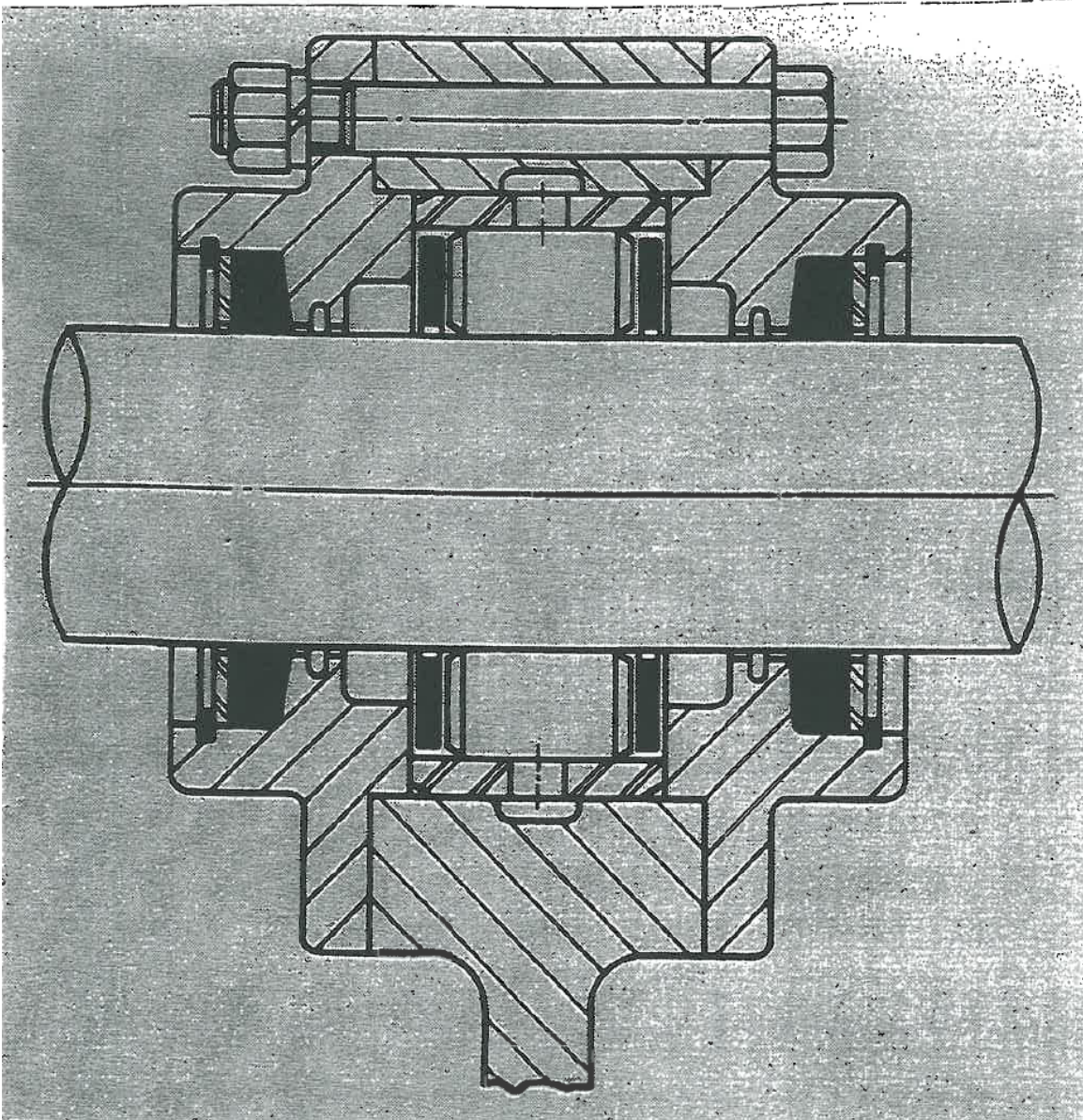
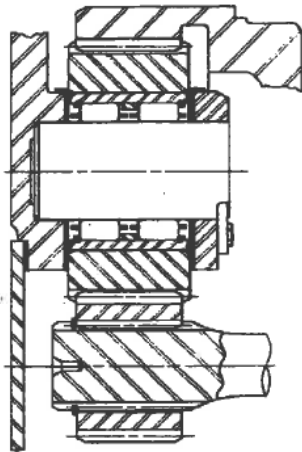




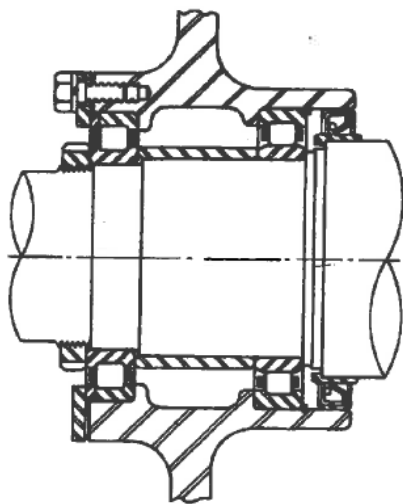
Figure 33

Cylindrical Roller Bearing

Application



Double row roller bearing runs directly on the shaft saving cost, weight, and space.

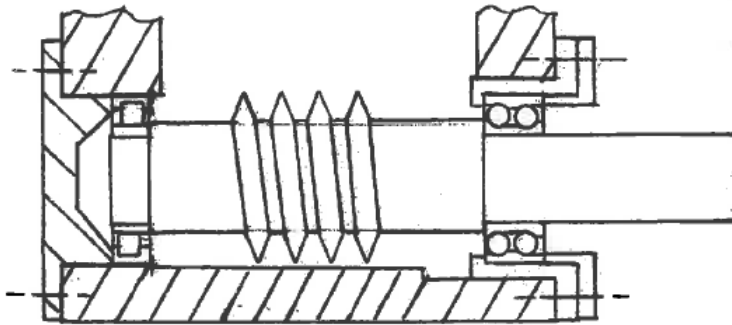


The roller bearing on the left locates the gear while the one on the right allows for shaft thermal expansion and tolerance build-up.

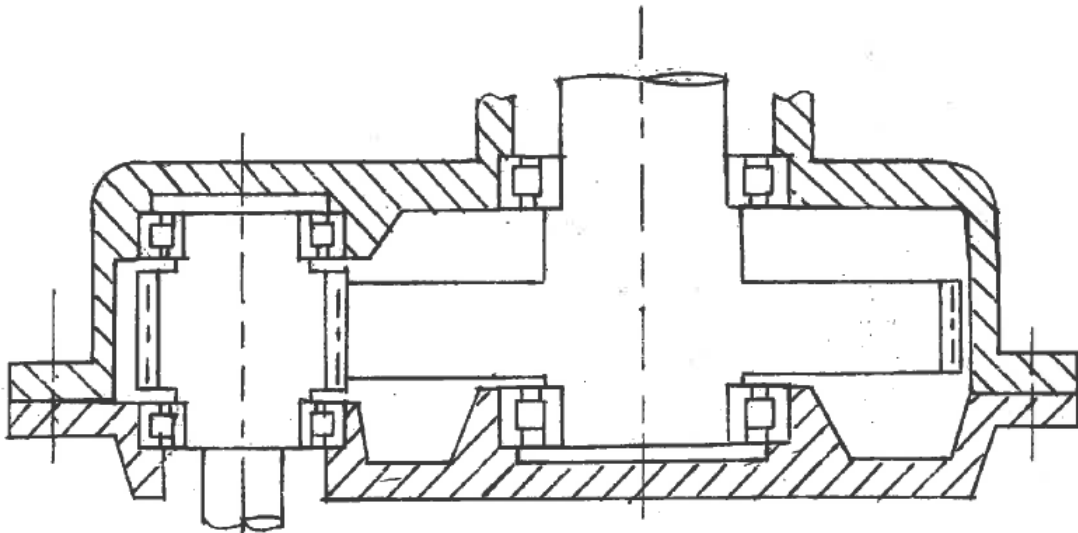
**Figure 34**

**Cylindrical Roller Bearing**

**Application**



Roller bearing left of worm gear takes radial loading and allows easy removal of worm gear. Double row ball bearing on right locates shaft and supports thrust loads.



Roller bearing on each end of each shaft of gearbox absorb heavy radial loads from spur gears and allow easy assembly and disassembly of gearbox.

Tapered Roller Bearings: Tapered roller bearings are used extensively in automotive design, where their ability to support both high radial and thrust loads makes them the choice for a number of important applications. Figure 35 has a drawing of the center section of an automotive drive axle. The input is on the right and the two output shafts that drive the two wheels are on the left. The input spiral bevel gear pinion is supported by two tapered roller bearings mounted in a stiff back-to-back pattern. They are nut adjusted with a slight preload. The mating spiral bevel gear is supported by two tapered roller bearings mounted face-to-face in a compliant pattern. They are shim adjusted with a slight preload. The two differential bevel gears in the center are supported by sleeve bearings.

Another high volume use of tapered roller bearings is shown on Figure 36. It illustrates how two tapered roller bearings are used to support non-drive wheels of an automotive vehicle. The bearings are assembled, grease lubricated, and retained by a locknut that is used to set bearing end play to a precise amount. The end cap is installed making the assembly self contained and lubricated for life.

Figure 37 shows how two close coupled and tapered roller bearings are used to support the front drive wheels of an automotive vehicle. The pair is used with carefully measured and selected spacers which set end play at the bearing manufacturing plant rather than the automotive assembly plant. They are then grease lubricated, packaged, and shipped as a match set to the automotive assembly plant.

Figure 35

Tapered Roller Bearing Application

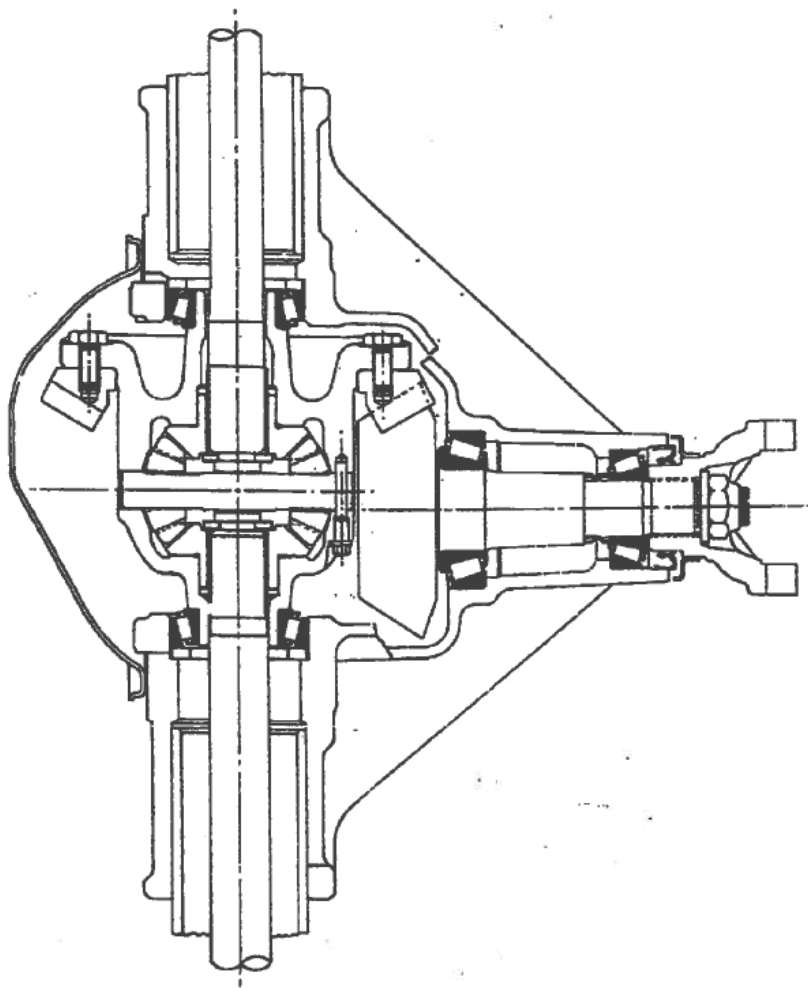


Figure 36

Tapered Roller Bearing Application

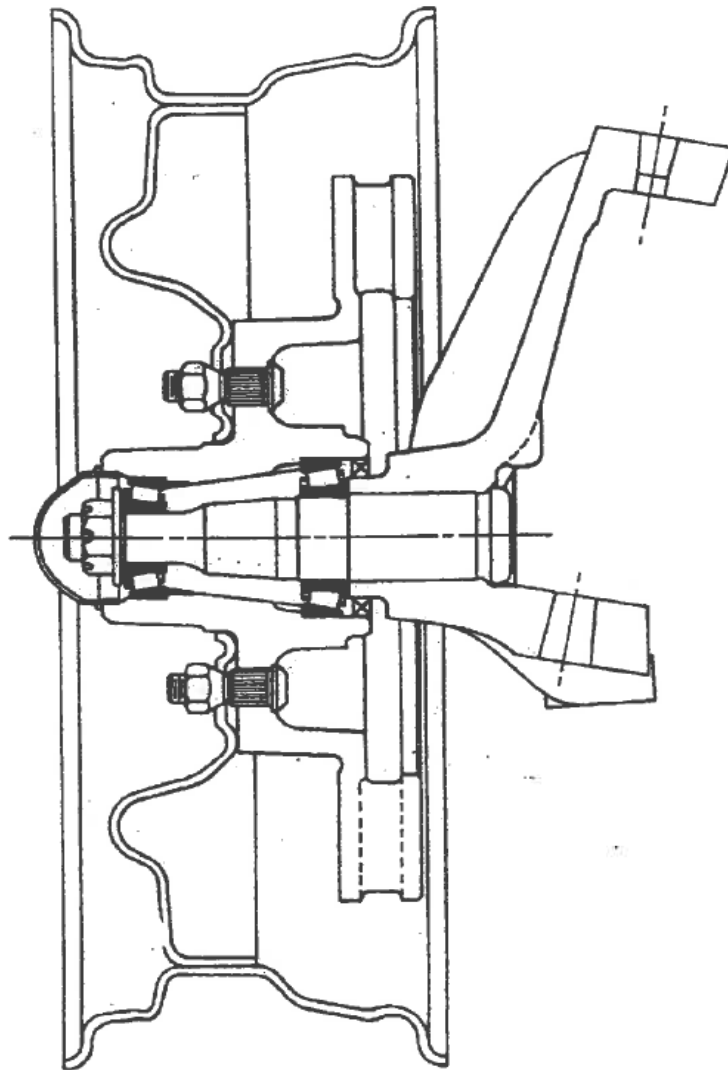
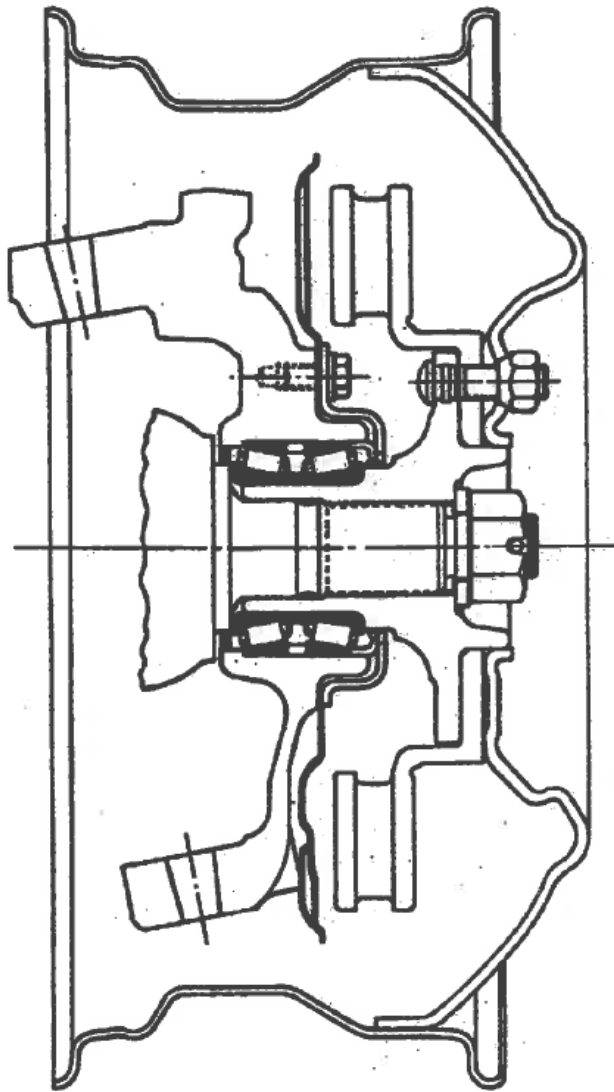


Figure 37

Tapered Roller Bearing Application



## **Summary**

This course teaches some of the aspects of understanding and applying the several different kinds of rolling contact bearings. It starts out with the basics such as types and characteristics of ball and roller bearings; it continues with their mounting, material, lubrication and life calculation; and it ends with examples of the application of ball and roller bearings in mechanical equipment with expert analysis.