Principles and Use of Ball and Roller Bearings

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Robert P. Tata, P.E.

CED engineering.com
PDH FOR THE PROFESSIONAL

Continuing Education and Development, Inc.
22 Stonewall Court
Woodcliff Lake, NJ 07677

P: (877) 322-5800
info@cedengineering.com

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Robert P. Tata
Robertptata@aol.com

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Ball Bearings

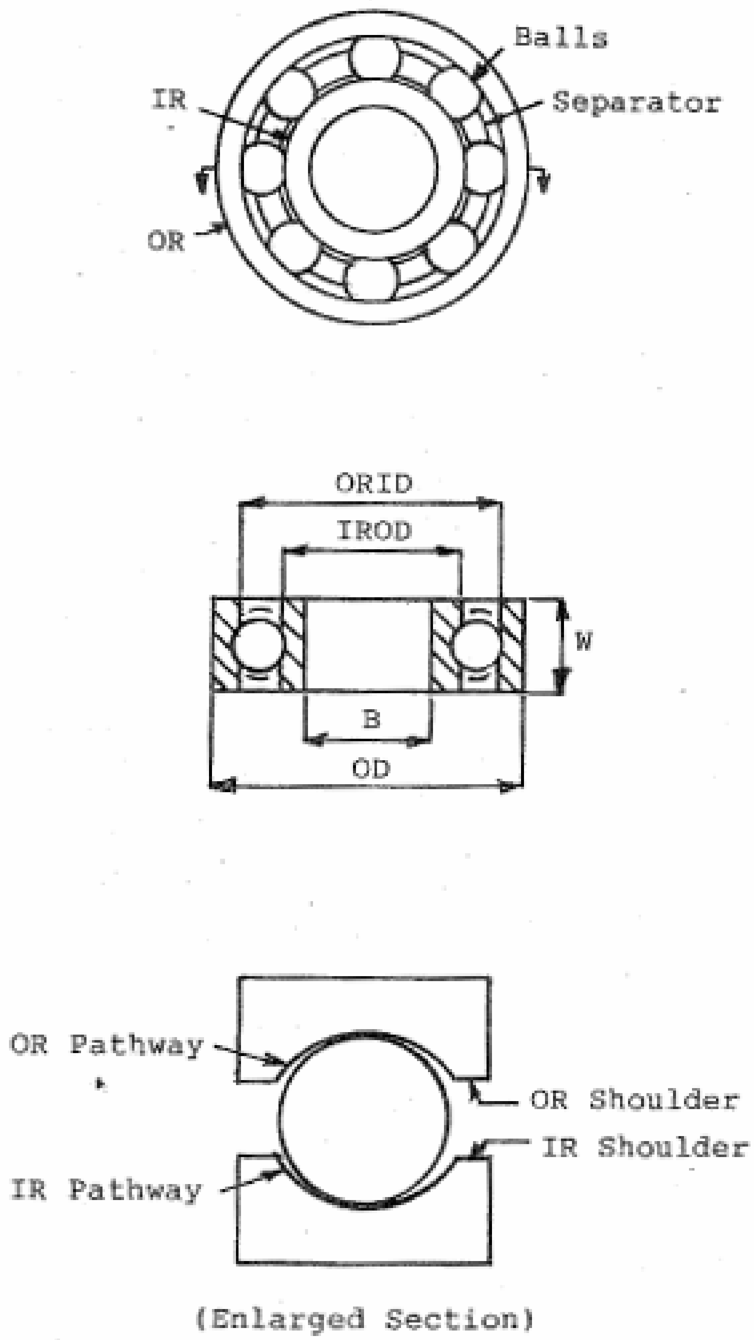
Purpose: Ball Bearings are used primarily to support rotating shafts in mechanical equipment. They can be found in the smallest electric motors to the largest pieces of industrial equipment. They are of simple design and can be precision manufactured in mass production quantities. They can support heavy loads over a wide speed range and do it virtually friction free. They come in many different sizes and shapes, are relatively inexpensive, and require little or no maintenance. They have predictable design lives and operating characteristics and are truly a valuable asset to the rotating equipment industry.

Description: A ball bearing consists of an inner ring (IR), an outer ring (OR), a complement of balls, and a separator. See Figure 1. The outer diameter of the inner ring (IROD) and the inner diameter of the outer ring (ORID) have a groove in which the balls roll. The groove is commonly called the pathway. The raised surface on each side of the pathway is called the shoulder. The balls are held equally spaced around the annulus of the bearing by the separator. The basic dimensions of the bearing are the bore (B), outside diameter (OD), and the width (W). The radius of curvature of the pathway must be closely controlled in relation to the ball diameter in order for the bearing to operate satisfactorily. If the radius of curvature is too close to the ball diameter, the bearing will operate with a high amount of friction. If the radius of curvature is too large in relation to the ball diameter, the bearing will operate under a high stress level. Both conditions will contribute to premature bearing failure. The radius of curvature of the inner ring and outer rings is normally held to 52 - 53% of ball diameter. See Figure 1.

Theory of Operation: In most applications, there are two ball bearings supporting a rotating shaft. The inner ring is a press fit on the shaft while the outer ring is a close push fit into the housing. The shaft and inner ring rotate together while the outer ring remains stationary or undergoes slight rotational creep in the housing. The separator and ball complement rotate around at about half the speed of the inner ring. The balls rotate around their own axis about twice the speed of the inner ring. Loads, or forces, are imposed on the bearings by the equipment that is driving or being driven by the shaft. The loads can be separated into a radial component that acts 90 degrees to the shaft and a thrust component that acts along the centerline of the shaft. Normally the radial component is reacted by just a few balls in the bearing while the thrust component is supported by all the balls in the bearing.

Figure 1

Ball Bearing Terminology



Assume that the radial load is acting in the downward direction. The balls at the top of the bearing are under little or no load. As they rotate to the bottom of the bearing, they are compressed between the rings. As they rotate back to the top, the compressed metal expands back to its original state. This constant compression and expansion of metal after many revolutions of the bearing leads to fatigue failure. The failure usually occurs as a small pit or spall in the inner ring. The bearing then begins to make noise and is replaced. Figure 2 shows how to calculate individual ball loads in a bearing.

<u>Manufacture:</u> Ball bearings are manufactured to a very high precision level in high volume quantities. In some cases, lines are completely automated starting from the raw material phase to the finished product. Great care has to be taken to keep all parts clean and free of rust. The material used is a high carbon, high chromium alloy steel that is freer of voids and impurities than standard grades. High carbon content makes it heat treatable to high hardiness levels throughout the part. High chromium levels impart high temperature strength.

Inner and outer rings are processed as follows:

a) They are machined from special sized steel tubing.
b) They are thru-hardened in heat treat furnaces.
c) Every surface is fine ground to exacting tolerances.
d) Pathways are honed to even finer surface finishes.

Balls are processed as follows:

a) They are cold headed to a spherical shape from drawn bar.
b) They are soft ground.
c) They are thru-hardened in heat treat furnaces.
d) They are hard ground.
e) They are lapped to a mirror-like finish.

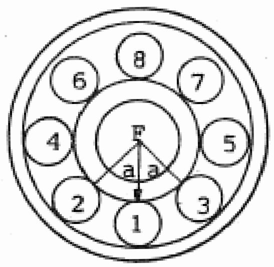
Assembly is accomplished as follows:

a) The inner ring is placed off-center inside the outer ring.
b) The balls are put inside the crescent shaped space.
c) The inner ring is centered and the balls are evenly spaced.
d) The separator is installed. See Figure 3.

<u>Types:</u> Heretofore the type of ball bearing discussed has been the single row radial. Radial bearings are used to support loads that are predominantly radial or perpendicular to the bearing axis of rotation. Another type of radial bearing is the maximum capacity bearing. It has a loading groove cut across one shoulder of each ring allowing more balls to be assembled into the bearing.

Figure 2

Ball Bearing Theory



Exaggerated view showing effect of
radial load on ball force distribution.

1) With radial load acting down on inner ring,

2) Ball number 1 is the heaviest loaded,

3) Balls 2 and 3 are the next heaviest loaded,

4) Balls 6, 7, and 8 have no load.

Radial load = $F_1(1+2\cos^{5/2}a+2\cos^{5/2}2a+\text{etc})$.

Using above formula with radial load = 100 lb,

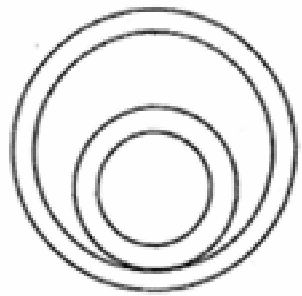
Force on ball number 1 = 54 lb,

Force on ball numbers 2 and 3 = 23 lb each.

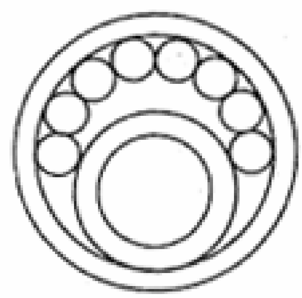
[All above forces in vertical (down) direction.]

Figure 3

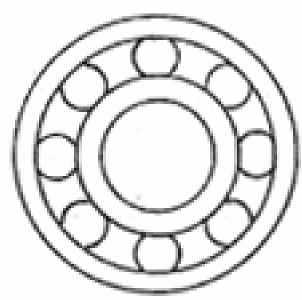
Conrad Assembly



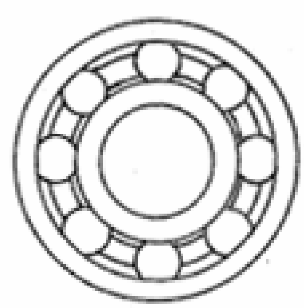
The IR is placed off-center inside the OR.



The balls are placed in the open space.



The IR is centered and the balls spaced.



The separator is installed.

Bearing capacities can be increased approximately 10% to 35% with the maximum capacity design. Because the loading grooves cut into the ball pathway shoulders, thrust capacity is limited. Moderate thrust loads can be taken if accompanied by substantial radial loading. See Figure 4.

Single row radial ball bearings can be furnished with shields, seals, and snap rings. Shields and seals are closures which are used to retain lubricant and prevent contaminant entry. A shield is a thin metal disc that is crimped into a groove in the outer ring ID. It can cover either one or both open ends of a bearing. It rides close to but does not contact a groove in the inner ring OD. Shields can also be used to control the flow of lubricant supplied to the bearing from an adjacent housing.

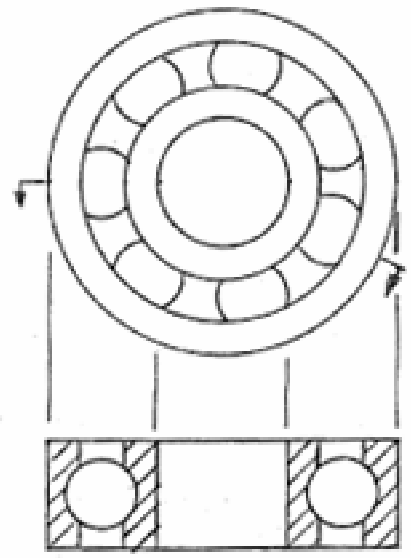
Seals are constructed of a thin layer of rubber covering a thin metal stiffening disc. They snap into the outer ring groove and have a rubber lip that firmly contacts the inner ring notch. The lip is intricately designed to seal in lubricants and seal out contaminants. Some seals have two or three lips for even greater protection to the bearing. Bearings can be furnished, greased and double sealed and can run maintenance free for their entire design lives. Snap rings are used for retention of bearings in housings. See Figure 5.

Another type of a single row ball bearing is the angular contact bearing. An angular contact bearing is not a radial bearing; instead, it has a contact line that is at an angle to that of a radial bearing. The contact angle can be from 15 to 35 degrees. One whole shoulder of the outer ring is removed allowing a full complement of balls to be assembled into the bearing. The contact line is directed away from the side of the outer ring that has the shoulder removed. Angular contact bearings can support higher thrust loads than other types of single row bearings. In pairs with back-to-back mounting, they provide good axial rigidity. In pairs with face-to-face mounting, they can accommodate high misalignment. Tandem mounting provides even better thrust capability than a single bearing. See Figure 6.

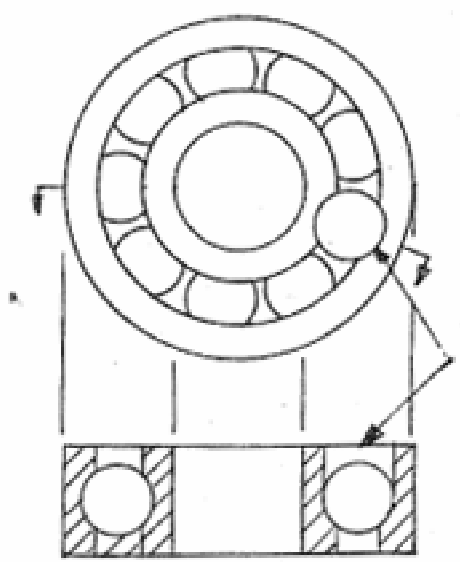
Double row ball bearings have extra wide inner and outer rings containing two separate side-by-side ball rows. They operate like two adjacent angular contact ball bearings but in a narrower space. They can withstand a combination of high radial and thrust loads. They can be furnished with the contact angles internally divergent or internally convergent. Internally divergent designs provide resistance to shaft bending while internally convergent designs are used where shaft misalignment is expected. See Figure 7.

<u>Figure 4</u>

<u>Ball Bearing Types</u>



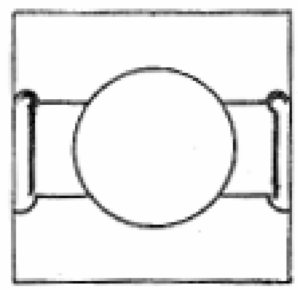
Radial Ball Bearing
7-13/32 in Balls
Capacity = 1200 lb



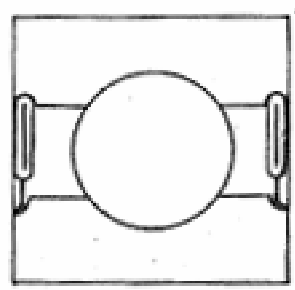
Maximum Capacity Version
of Above Bearing
9-13/32 in Balls
Capacity = 1440 lb

Figure 5

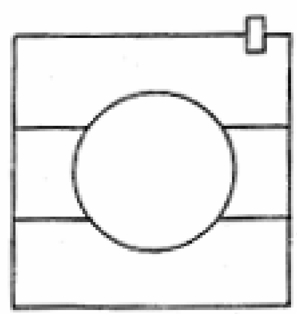
Ball Bearing Attachments



Ball Bearing
With
Non-Contacting Shields



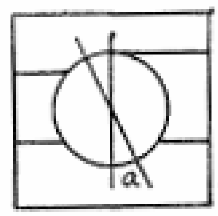
Ball Bearing
With
Contacting Seals



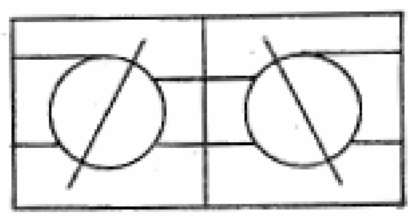
Ball Bearing
With
Snap Ring

Figure 6

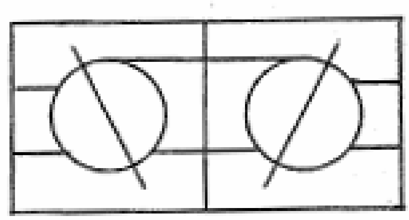
Ball Bearing Types



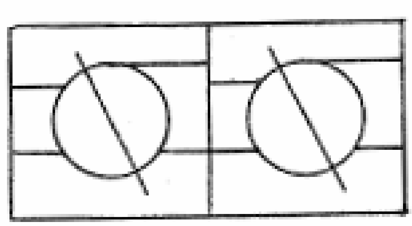
Angular Contact (a)
Ball Bearing



Back-to-Back
Mounting



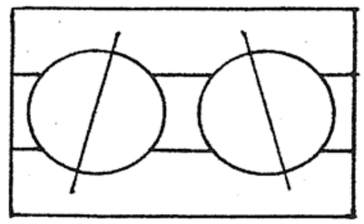
Face-to-Face
Mounting



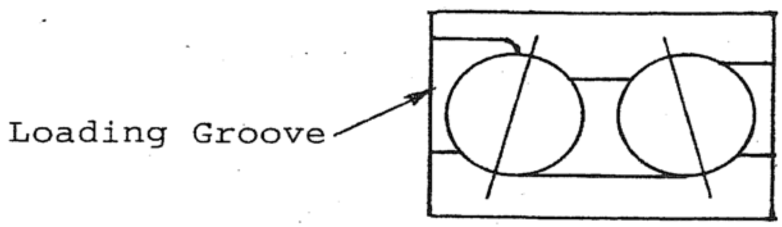
Tandem
Mounting

Figure 7

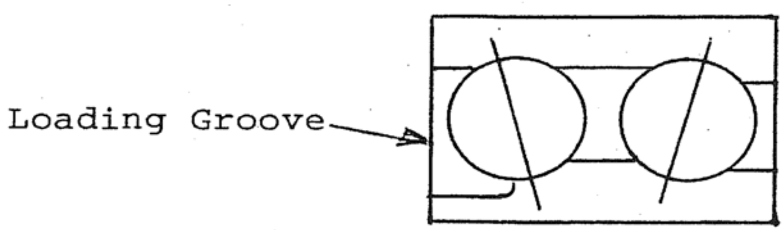
Ball Bearing Types



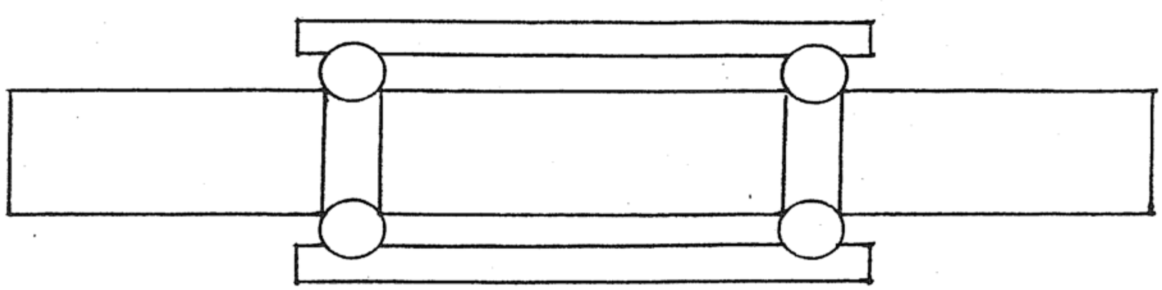
Double Row
Internally Divergent



Internally Divergent
Larger Sizes



Double Row
Internally Convergent



Integral Shaft
Double Row Ball Bearing

Most bearings come in three different series: extra light, light, and medium. The lighter series provide design compactness while the heavier series provide good load carrying capability. See Figure 8. All the series come in metric as well as inch (British System) sizes. See Figure 9.

Selection: Bearings are selected by the hours of life required under the conditions imposed by the application. The formula below is one used to calculate the bearing life. Bearing life is expressed in B10 hours which are the hours that 90% of all bearings are expected to meet. The remaining 10% may not meet the calculated value.

$$\text{Life}=3000\text{x}(\text{C}/(\text{RxF}))^{\text{E}}\text{x}(500/\text{S})$$

C is the capacity of the bearing in pounds and is found in bearing catalogs. R is the radial load in pounds. F is a factor that is used if a thrust load is present and is also found in catalogs. E is the exponent 10/3 or 3.333. S is the speed in rpm. The following is a sample problem:

A shaft supported by two identical single row radial ball bearings has a gear at the center, driving a tool at one end at 2000 rpm. One bearing supports a 100# radial load while the other supports a 100# radial load and a 100# thrust load. The capacity of each bearing is 570#. The calculated life of each bearing using the above formula is as follows:

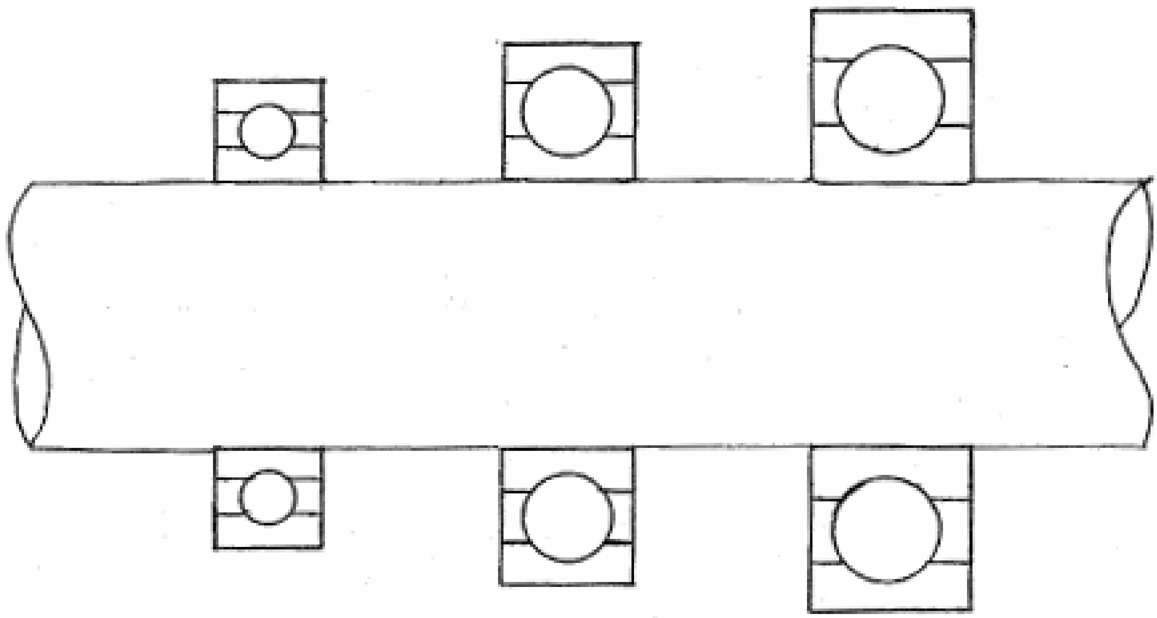
$$\text{L}=3000(570/(100\text{x}1.00))^{3.333}\text{x}(500/2000)=246{,}674\text{ B10 hr (R=100\#, T=000\#)}$$
$$\text{L}=3000(570/(100\text{x}1.72))^{3.333}\text{x}(500/2000)=\ 40{,}533\text{ B10 hr (R=100\#, T=100\#)}$$

The B10 life of the first bearing is very high. A smaller bearing could be used; however, it is common to use the same bearing at each end of a shaft for reasons of standardization and also to simplify shaft and housing design and manufacture. The B10 life of the second bearing represents 4.6 years of continuous operation.

Suppose the machine tool in the previous example experienced severe vibration and corrective action had to be taken. One approach in solving the problem is to preload the bearings. Preloading is accomplished by applying a thrust load to one bearing and having it reacted by the other on the same shaft. This has the effect of stiffening the bearings and making the shaft less prone to vibration. Assume that, after preloading, the thrust increases from 0# to 100# on the first bearing and from 100# to 200# on the second. The radial load remains the same.

Figure 8

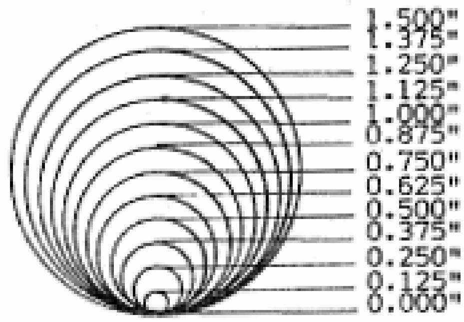
Ball Bearing Series



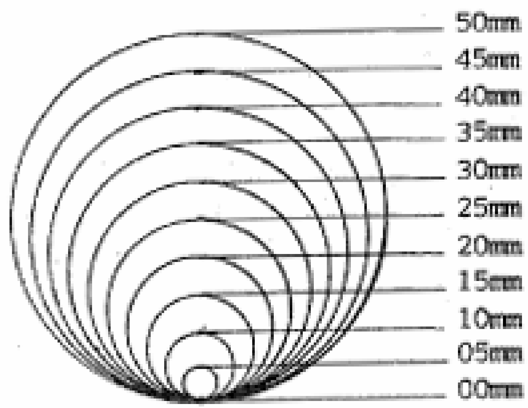
Extra Light Series	Light Series	Medium Series
Bore 35 mm	Bore 35 mm	Bore 35 mm
OD 62 mm	OD 72 mm	OD 80 mm
Width 14 mm	Width 17 mm	Width 21 mm
Balls 11-5/16 in	Balls 9-15/32 in	Balls 8-9/16 in
Capacity 950 lb	Capacity 1900 lb	Capacity 2400 lb

Figure 9

Ball Bearing Bore Sizes



Relative Bore Sizes
Inch Series
Full Scale



Relative Bore Sizes
Metric Series
Full Scale

Using the existing radial bearings, the new calculated lives are as follows:

$$L=3000(570/(100x1.72))^{3.333}x(500/2000)=40,534 \text{ B10 hr } (R=100\#, T=100\#)$$
$$L=3000(570/(100x2.84))^{3.333}x(500/2000)= 7,631 \text{ B10 hr } (R=100\#, T=200\#)$$

It can be seen that the lives of the bearings have decreased significantly from the 246,670 and 40,533 numbers obtained before preloading. Now, let us repeat the above calculations using angular contact bearings with the same basic dimensions:

$$L=3000(475/(100x1.03))^{3.333}x(500/2000)=121,816 \text{ B10 hr } (R=100\#, T=100\#)$$
$$L=3000(475/(100x1.69))^{3.333}x(500/2000)= 23,420 \text{ B10 hr } (R=100\#, T=200\#)$$

The use of angular contact ball bearings, as seen from the above calculations, has increased predicted life by more than threefold. This exercise has shown how angular contact ball bearings can improve design life when higher thrust loads are present.

Another possible solution to the tool vibration would be to use the original radial bearing in the first position and replace the radial bearing in the second position with a double row ball bearing. The double row ball bearing would be the same size as the original bearing except that it would be 45% wider. The additional width could easily be accommodated by a minor rework to the shaft and housing. The double ball bearing would be internally divergent which would add rigidity to the shaft and prevent tool vibration. It would also eliminate the need for preloading the two bearings as was investigated in the previous analysis. The life of the bearing in position 1 would remain at a very high level. The life of the double row ball bearing in position 2 would be as follows:

$$L=3000(800/(100x2.08))^{3.333}x(500/2000)=66,558 \text{ B10 hr } (R=100\#, T=100\#)$$

The life of the double row ball bearing in position 2 is a 64% increase over the original radial ball bearing. In summary, the double row ball bearing, because of its inherent design, stiffened the shaft to prevent machine tool vibration and increased the life of the bearing in position 2. The design no longer needs special devices to preload the two bearings which can be a bigger task than fitting in a slightly wider bearing in the position.

Specialty Ball Bearings: Integral shaft ball bearings as previously seen in Figure 7 are an excellent design tool used in everything from lawn mowers to washing machines. Inner pathways are ground directly on a hardened steel shaft permitting use of a larger shaft for increased strength and rigidity. The two ball rows are spread apart providing increased stability and resistance to moment loading. A variety of different seals can be used at each end to exclude contaminants and contain a large amount of lubricant that is placed between the spread-apart ball rows. The shaft extensions can be furnished to various configurations for mounting a wide variety of mechanical components. See Figure 10.

Millions of integral shaft ball bearings are being used as fan and waterpump bearings on automobile engines. The water impeller is press fit on the back shaft extension and the engine cooling fan and waterpump drive pulley are pressed onto the front extension. Because of the very stringent demands on the bearing for this application, state of the art seals and lubricant are being used. Figure 11 shows a traditional integral shaft bearing in an automobile engine waterpump and a more recent design utilizing a close coupled bearing with a stepped shaft.

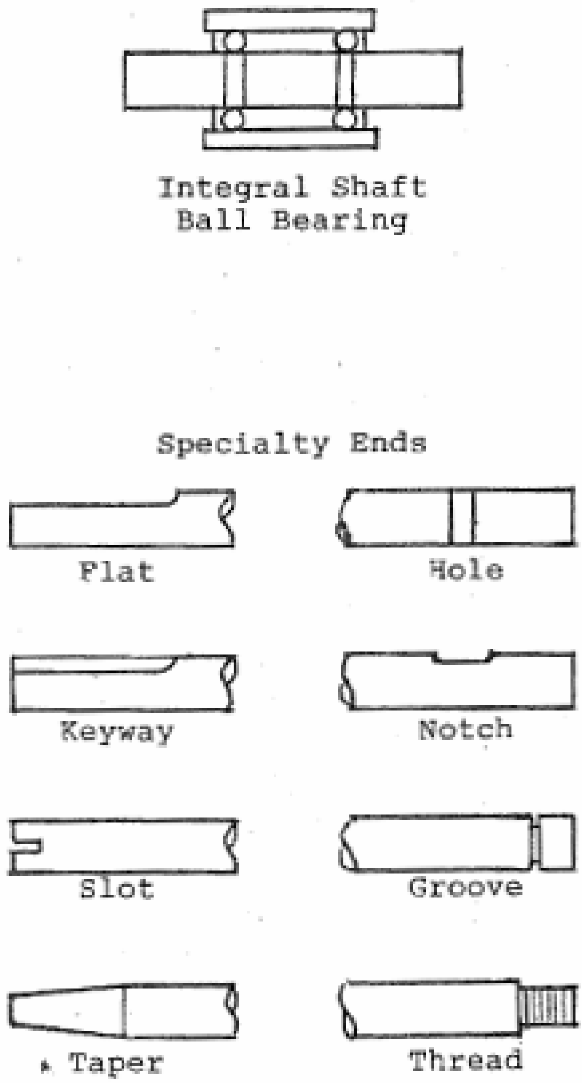
Two-piece inner ring bearings combine the advantages of the maximum capacity and angular contact types. Because of the removable split inner ring, a maximum capacity ball complement can be used enabling the bearing to withstand high thrust loads from either direction. Special inner ring grinding can tighten the internal clearance of the bearing making it a more rigid support for reducing shaft bending. See Figure 12.

Cam follower bearings have thick outer rings to provide for the strength and shock resistance required for an application where the outer rings are not supported by a housing. They are sealed, Conrad type bearings with spherical OD's for minimizing the effects of misalignment. They have bores dimensioned to receive standard machine bolts. See Figure 13.

Adapter bearings have extended inner rings with eccentric locking collars for easy mounting on standard commercial grade size shafts. The collar is rotated and locked in place with a set screw for permanent bearing mounting.

Figure 10

Specialty Ball Bearings

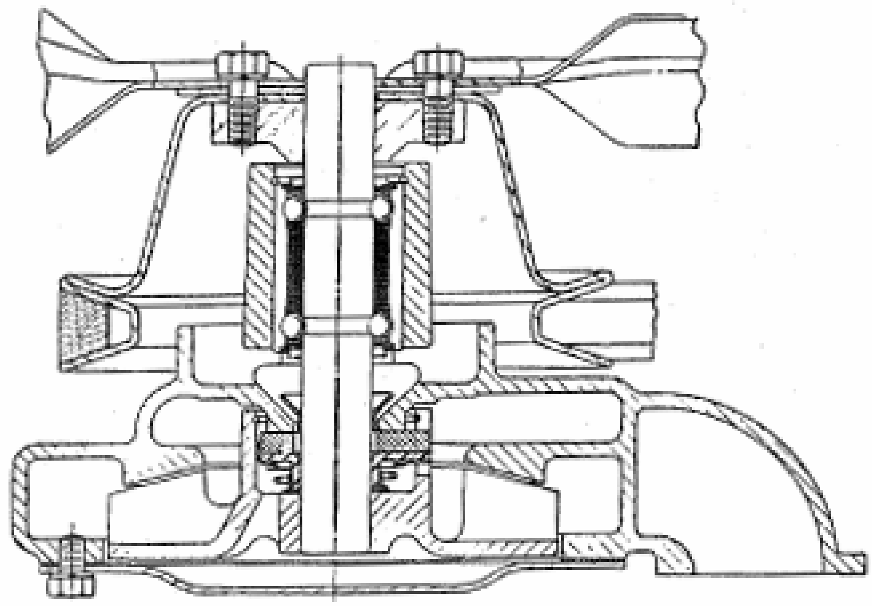


Applications

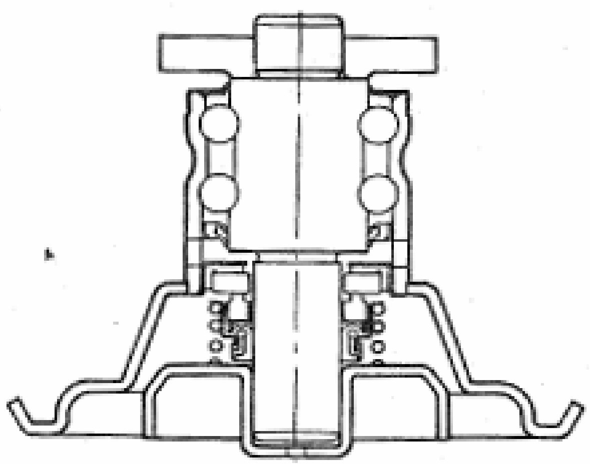
Bench Grinders
Centrifugal Pumps
Fan & Waterpumps
Fans & Blowers
Lawn Tractors
Polishing Heads
Table Saws
Washing Machines
Wheel Mounts

Figure 11

Specialty Ball Bearings



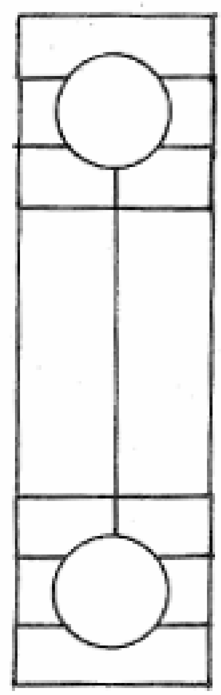
Traditional Automobile Waterpump
With Integral Shaft Ball Bearing



Later Version Waterpump
With Stepped Shaft Bearing

Figure 12

Specialty Ball Bearings



Split Inner Ring Ball Bearing

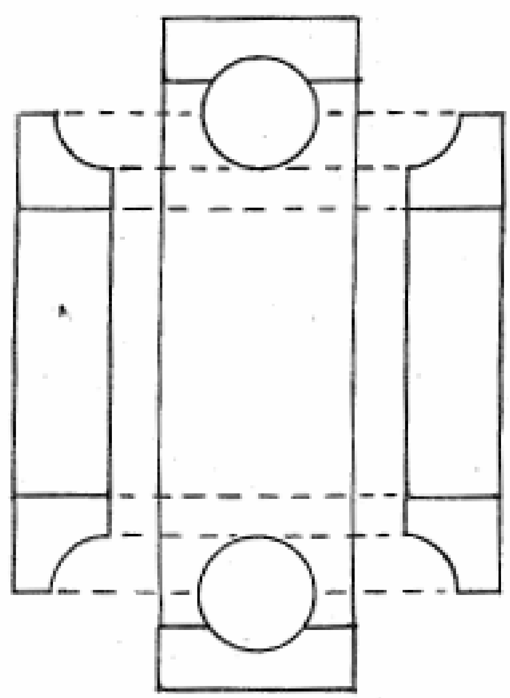
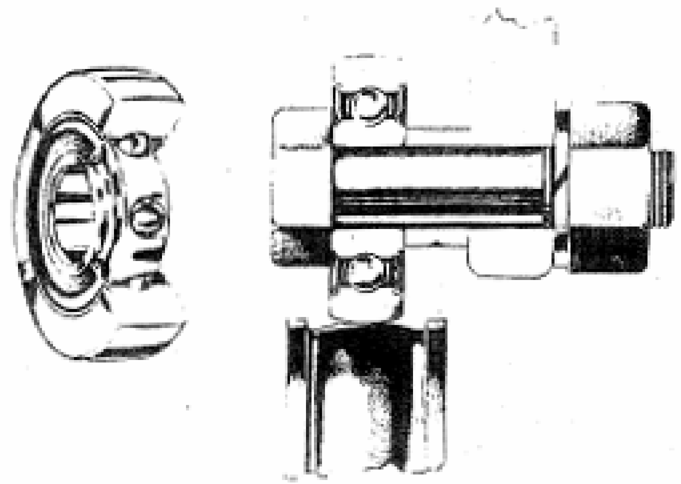
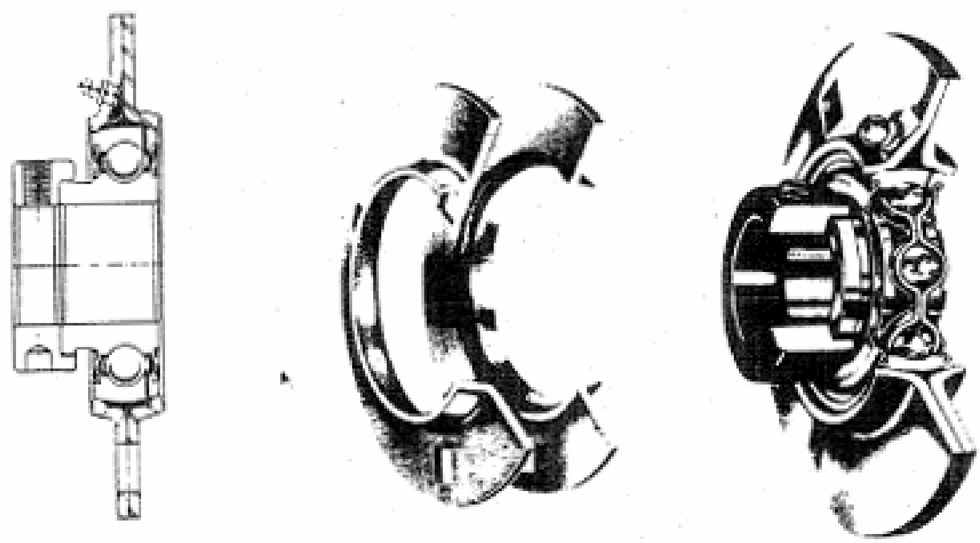


Figure 13

Specialty Ball Bearings



Cam Follower Bearing



Adapter Bearing With Flange

They are designed for installations where loads and speeds are moderate and concentricity requirements are not too critical. The bearings are lubed and sealed for life and have spherical outer rings for misalignment compensation. Two-piece flange mounting units are available which clamp onto the outer ring. See Figure 13.

Disc harrow agriculture bearings are sealed, Conrad type bearings with extra wide inner rings. They have bores which fit standard machine bolts for economical mounting. There are a number of special seals and shields available for extreme duty use. See Figure 14.

Hay rake tine bearings are standard Conrad type bearings with inch dimension bores to fit standard machine bolts for easy mounting to agricultural equipment. Special mounting studs can be shipped with the bearings. Heavy duty seals are available. See Figure 14.

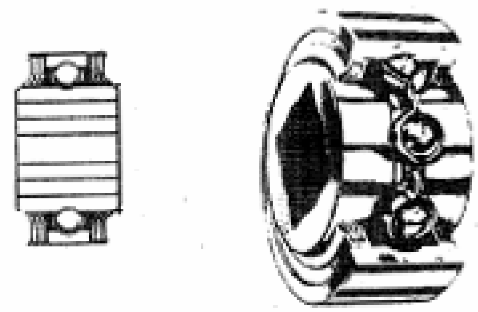
Conveyor bearings have heavy duty seals because of the contaminated conditions inside idler rolls where they are used. The bearings are lubed for life to avoid costly maintenance procedures. The bore fits standard round or hex shafts. The bearings can be supplied with special stub shafts with crowned teeth that can fit the hex bore of the bearing to compensate for misalignment. See Figure 14.

A very high volume specialty ball bearing product now being used in the automotive industry is the integral wheel bearing unit. It is comprised of two rows of balls riding directly on pathways on the spindle and in the hub. The units are assembled, grease lubricated, sealed, and tested on automatic equipment. It fits the modular assembly concept well because it comes as a sealed-for-life package that bolts directly to the vehicle and the wheels bolt directly to it. There is a design made for both drive and non-drive wheels. They are used extensively on front drive automobiles. See Figure 15.

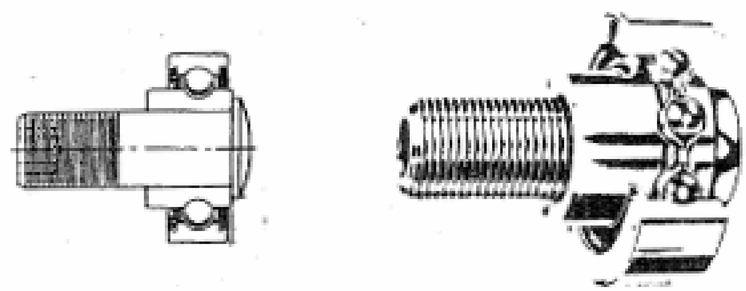
<u>Internal Clearance</u>: Internal clearance is the looseness that radial ball bearings are built to in order to operate satisfactorily. One measure of internal clearance is a term called radial play. Radial play is defined as the total travel of one ring with respect to the other in the radial direction. Another measure of internal clearance is called end play. End play is defined as the total travel of one ring with respect to the other in the axial direction. Radial play for radial ball bearings ranges from .0001" - .0005" for a small bearing to .0008" - .0024" for a large bearing.

Figure 14

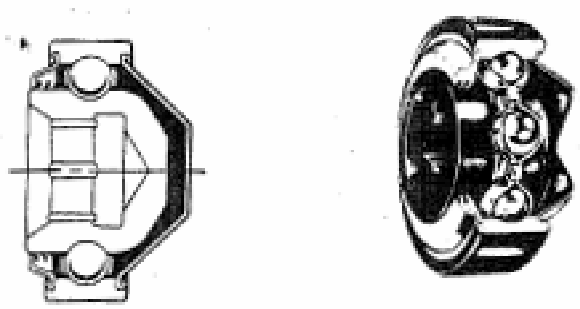
Specialty Ball Bearings



Disc Harrow Bearing



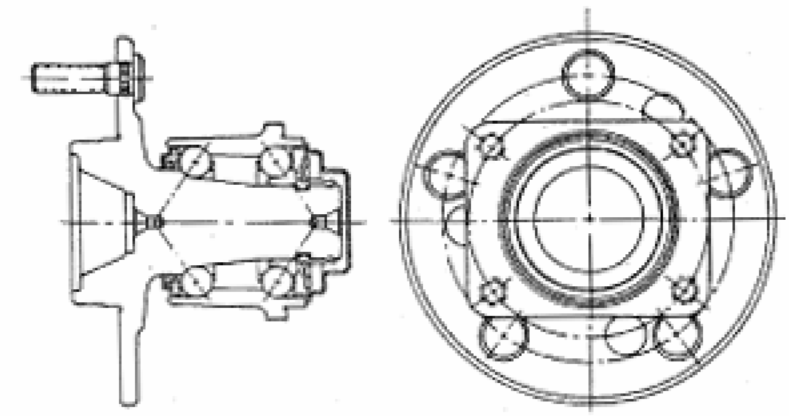
Hay Rake Tine Bar Bearing



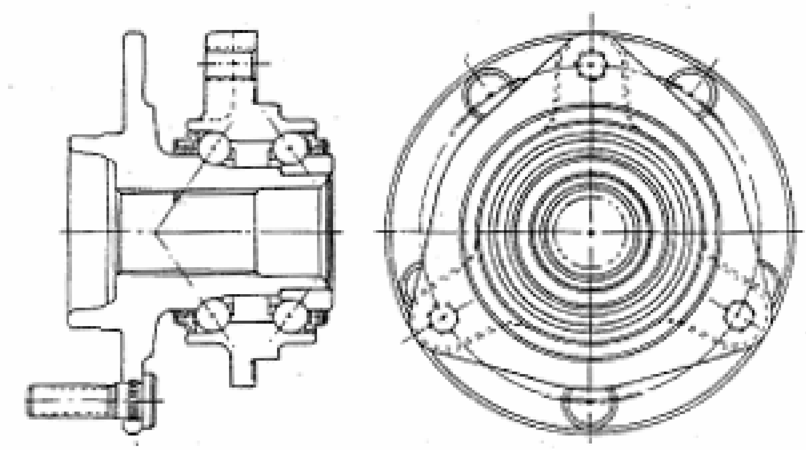
Conveyor Bearing

Figure 15

Specialty Ball Bearings



Integral Non-Drive Wheel Bearing



Integral Drive Wheel Bearing

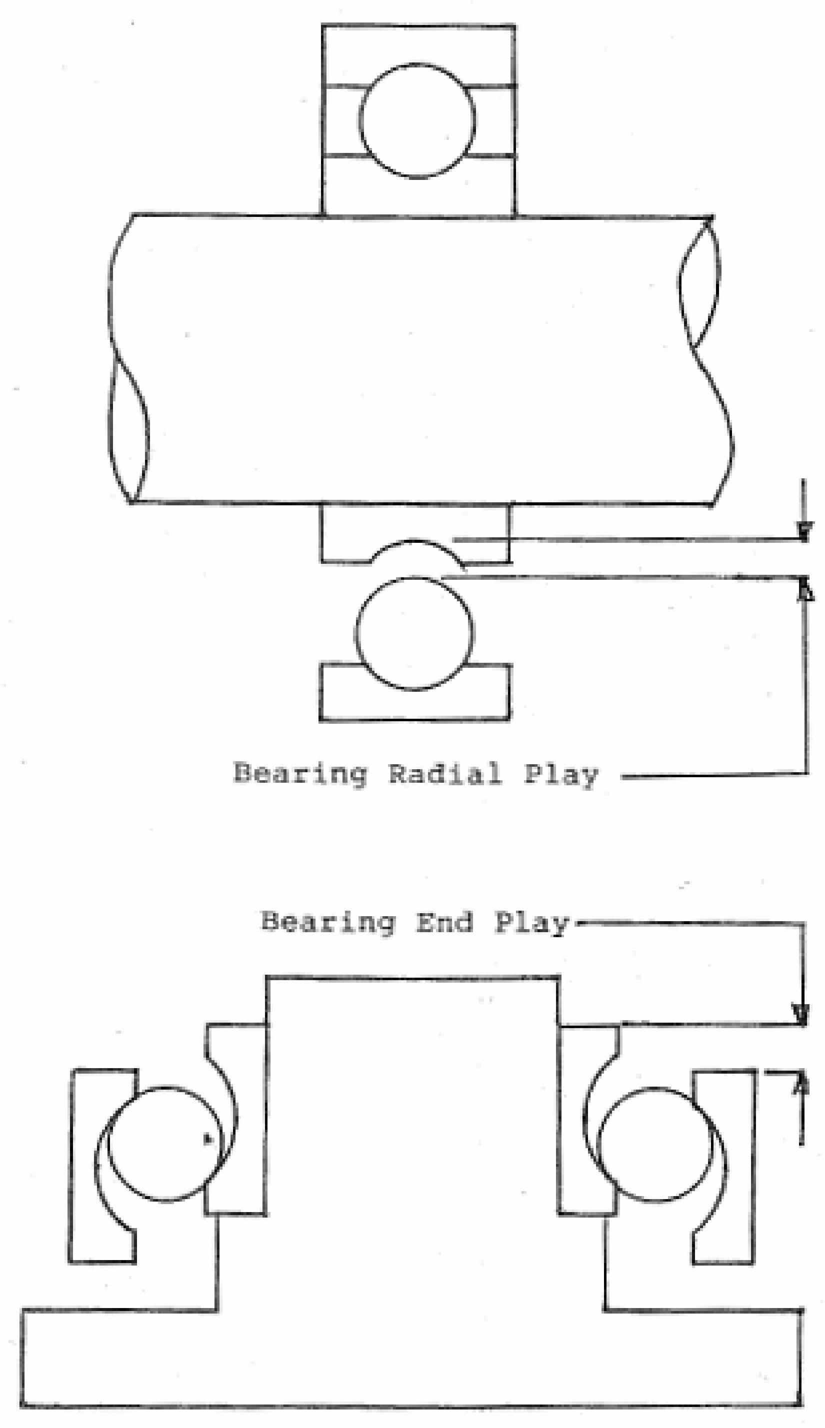
Corresponding end plays are .0020" - .0040" for the small bearing and .0145" - .0220" for a large bearing. Approximately 80% of the radial play of a bearing is lost when either the inner ring or the outer ring is press fitted onto its mounting surface. Sometimes bearings have to be built to special radial plays to compensate for non-standard press fits, non-ferrous shaft or housing materials, non-standard shaft or housing wall thicknesses, or unusual operating conditions or temperatures. See Figure 16.

Shaft and Housing Fits: Under normal load and service conditions, the rotating ring has an interference fit with its mating member and the non-rotating ring has a close push fit with its mating member. This arrangement prevents the rotating ring from spinning on its seat while the non-rotating ring is allowed to move relative to its seat. Allowing one ring to move on its seat prevents unwanted thrust loads from building up due to differential thermal expansion between the shaft and the housing. Also, installation of bearings is greatly facilitated when one of its rings is a push fit. Changes to standard fitting practices are made under the following conditions: unusual loading, abnormal operation temperatures, non-ferrous materials, and non-standard shaft and housing wall thicknesses. Normal shaft press fits range from .0005" tight to .0001" loose for a small bearing to .0017" tight to .0002" loose for a large bearing. Normal housing loose fits range from .0001" tight to .0008" loose for a small bearing to .0003" tight to .0027" loose for a large bearing.

Lubrication: High grade mineral oils are the best lubricants for ball bearings. 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 at the bearing load zone. The oil is then drained back to a sump where it is filtered, cooled, and returned. This system is good for a wide variety of loads and speeds. The oil bath method is commonly used in gear boxes. The housing is filled with oil until it just touches the lowest rotating component. The oil is then splashed throughout the gearbox. Mist systems use pressurized air to atomize oil. The mixture is then sprayed on 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. This system is used in electric motors. The simplest method of lubricating bearings is by using grease. A carefully measured amount of grease is evenly distributed throughout the bearing where it is contained by seals or shields. This configuration can run for the life of the bearing.

Figure 16

Bearing Internal Clearance



(Exaggerated Views)

Following is a list of greases:

1) Mineral oil greases are used for general purpose operation at a temperature range of -30 degrees to +300 degrees F.
2) Diester oil greases are designed for low temperature operation down to -65 degrees F.
3) Ester based greases are products that operate over a range of -100 degrees to +350 degrees F.
4) Silicone oil greases have operating temperature ranges of -100 degrees to +450 degrees F, but lack good load carrying capability.
5) Flourosilicone oil greases have all the desirable characteristics of silicone oil greases plus good load carrying capability.
6) Perfluorinated oil greases are non-flammable, have good load carrying capacity and can operate at temperatures up to +550 degrees F.

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 above greases can be obtained at various consistencies. Figure 17 is a plot of recommended oil viscosity vs. operating temperature for a 30 mm bore bearing running at 2000 rpm. It can be seen from the graph that very high viscosity oils are needed by bearings that run at high temperatures.

Application: The application of ball bearings to machine design involves more than load and speed calculations. It also involves how the bearing is to be mounted and how to prevent unwanted thrust loads from differential thermal expansion between the shaft and the housing. Figures 18, 19, 20, 21, and 22 contain drawings and explanations of the functions of ball bearings in machine parts.

Figure 17

Bearing Lubrication

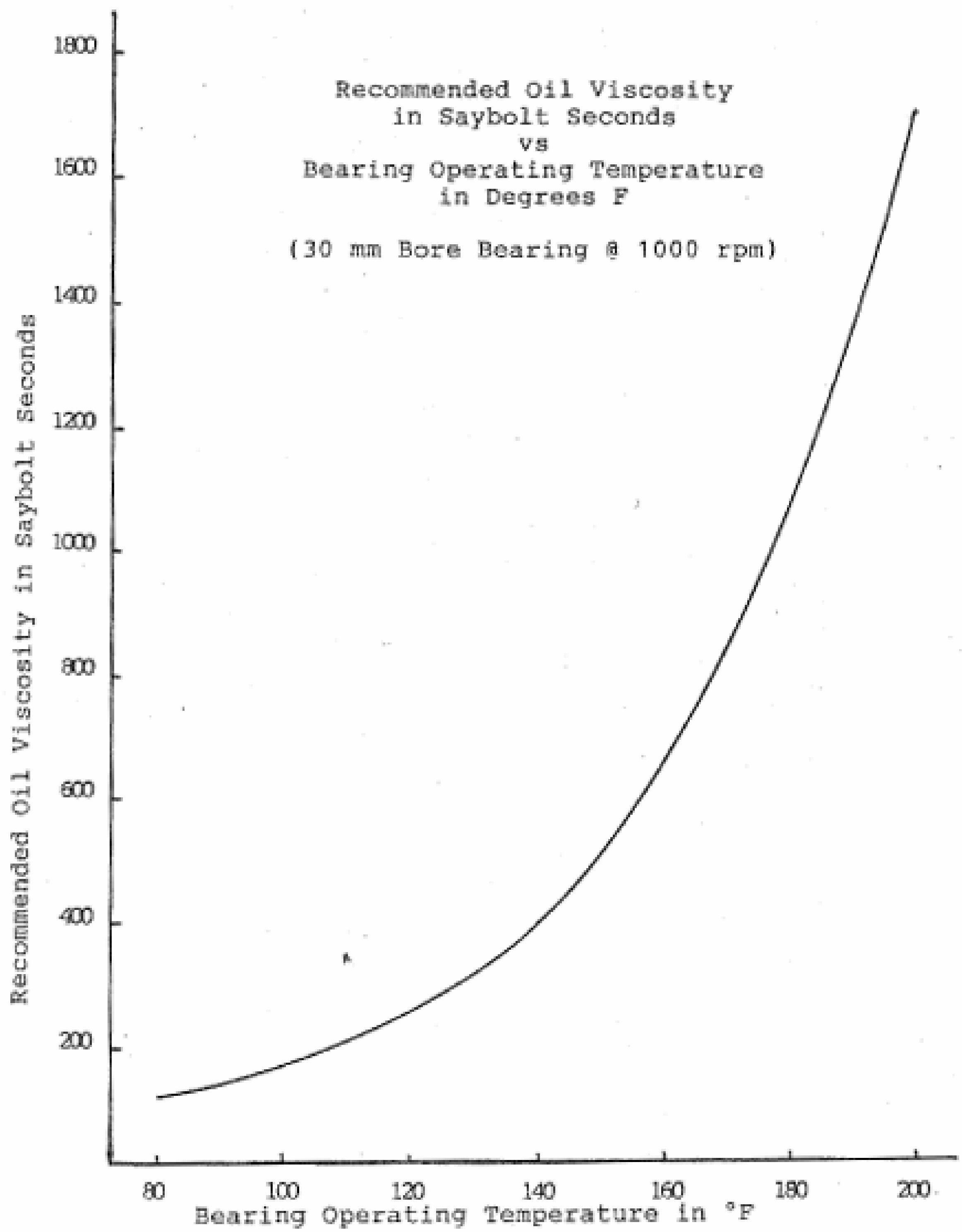
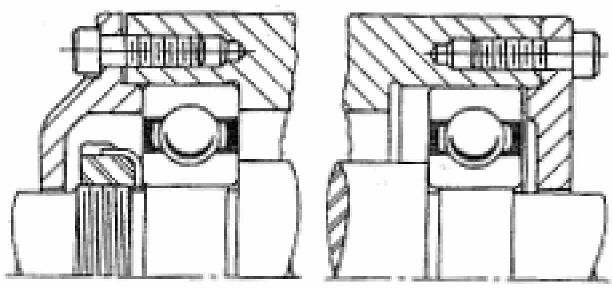
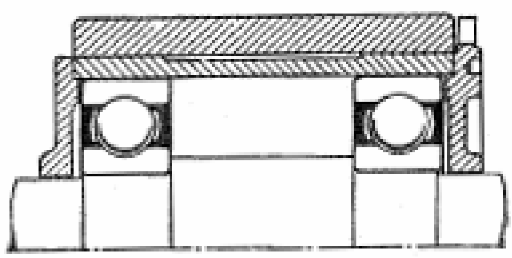


Figure 18

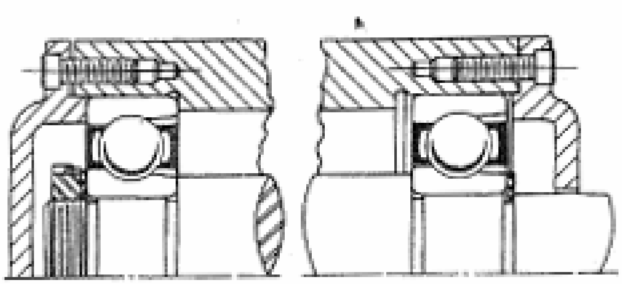
Radial Ball Bearing Application



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



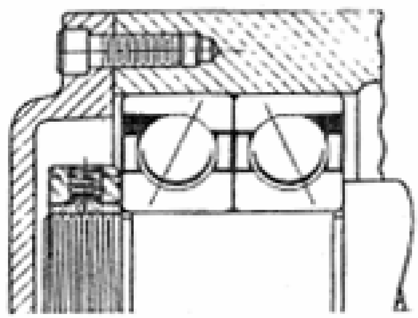
Both bearings can be made to float in the housing if shaft end play is not critical.



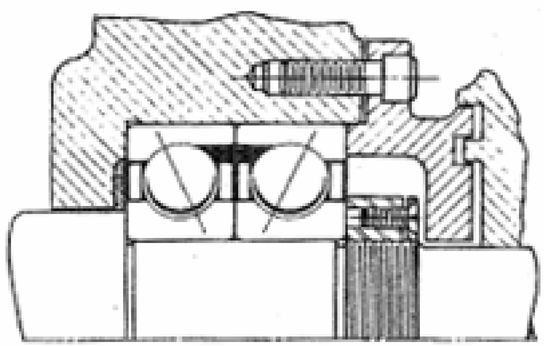
When thrust loads are low, loading groove bearings can be used to take heavy radial loads.

Figure 19

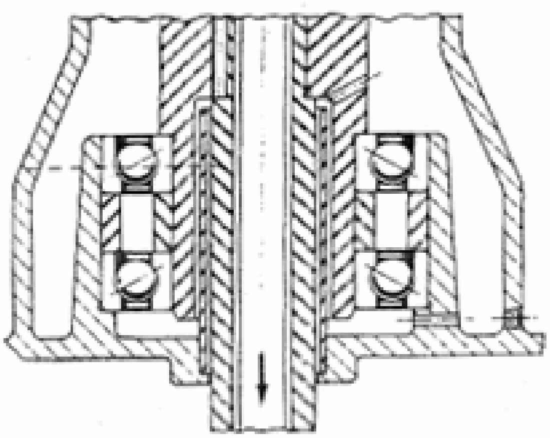
Angular Ball Bearing Application



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



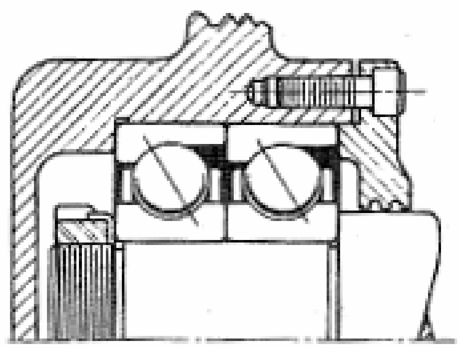
Compliance to high shaft misalignment is accomodated by using two angular contact ball bearings mounted face-to-face.



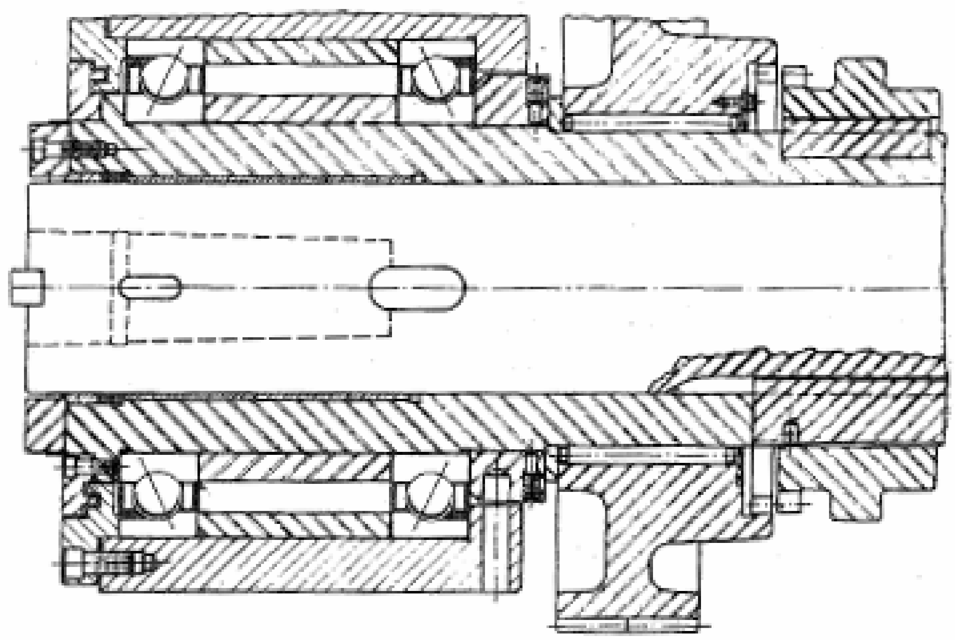
Support of high one-direction thrust loading is accomplished by using two angular contact ball bearings mounted in tandem. The thrust is downward on the shaft.

Figure 20

Angular Contact Ball Bearing Application



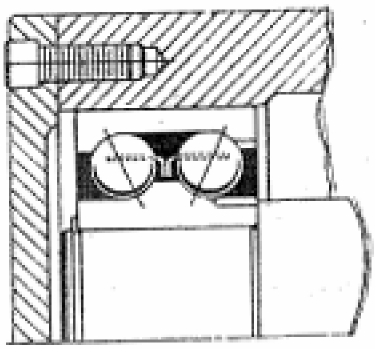
Very high one-direction thrust loads can be taken by tandem mounted angular contact ball bearings mounted face-to-back.



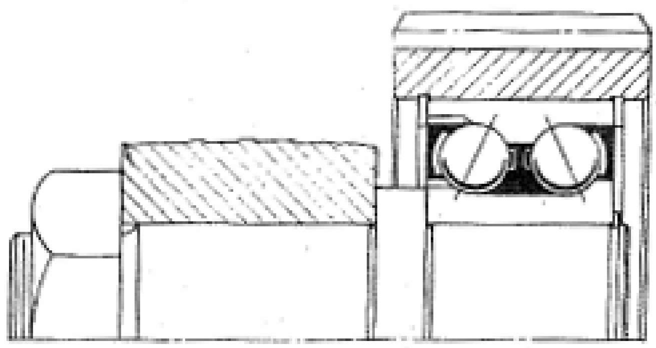
Angular contact ball bearings mounted apart and separated by spacer rings can take even more moment loading than back-to-back mounting.

<u>Figure 21</u>

<u>Double Row Ball Bearing Application</u>



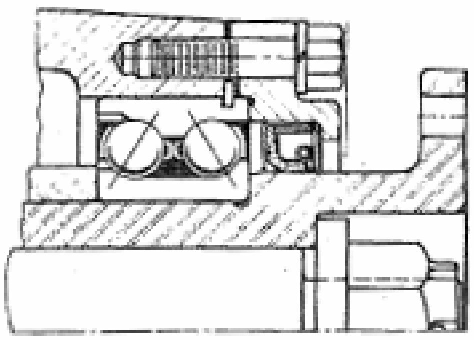
Double row ball bearings with contact angles internally convergent can take misalignment and heavy radial loads.



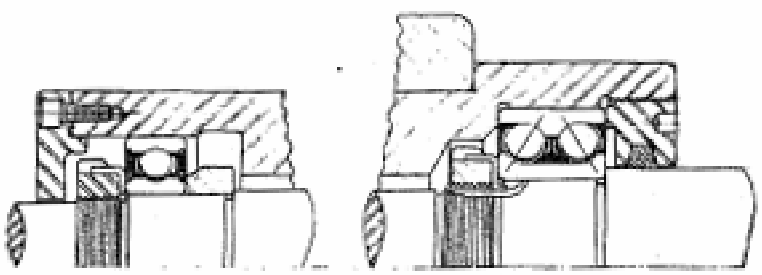
Double row ball bearings with contact angles internally divergent can take heavy overturning moment loading.

<u>Figure 22</u>

<u>Double Row Ball Bearing Application</u>



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.

Roller Bearings

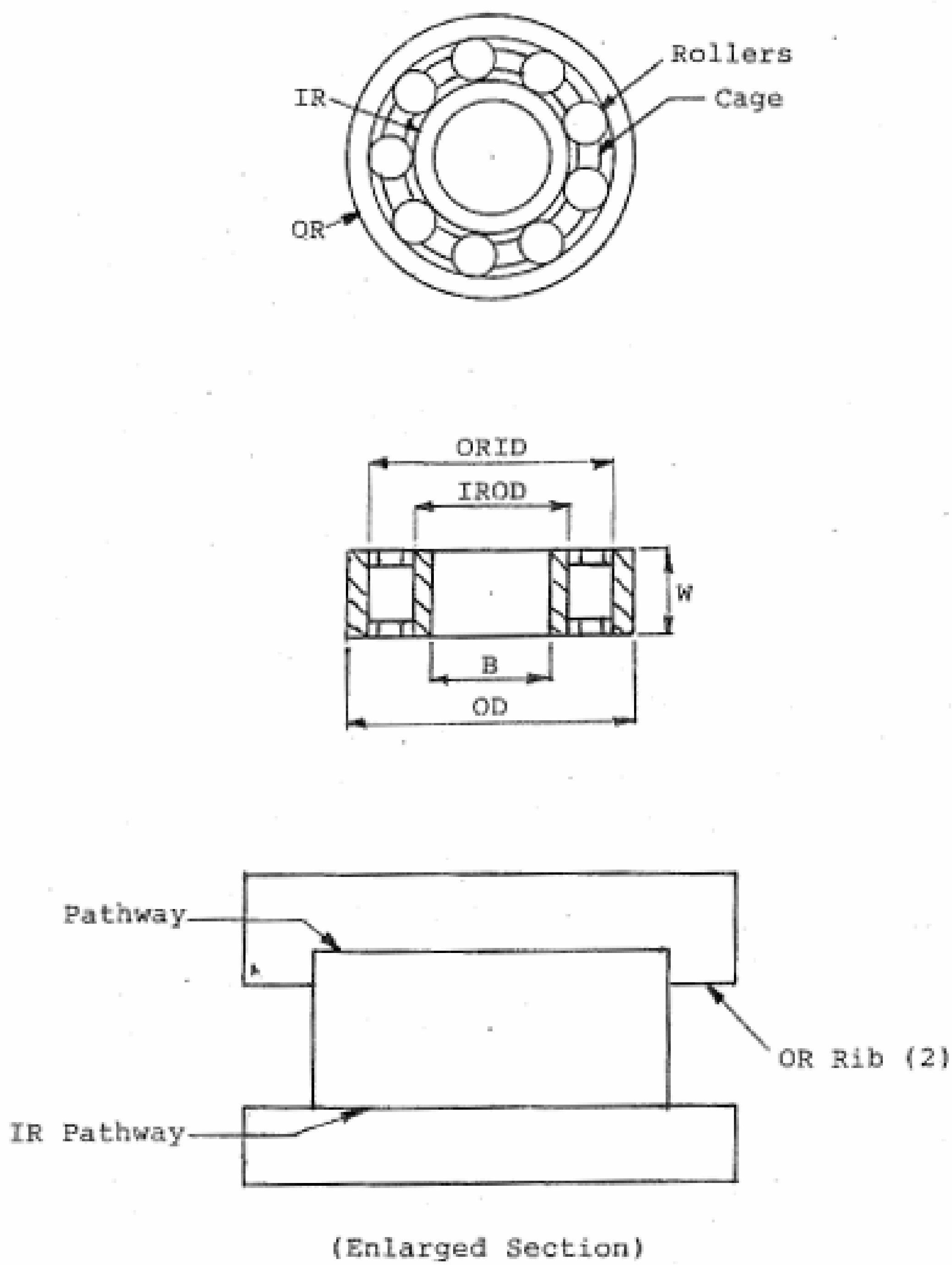
Purpose: Roller bearings, like ball bearings, are used primarily to support rotating shafts found in many pieces of mechanical equipment used today. Roller bearings are classified as anti-friction bearings like ball bearings. It is to a designer's advantage to put a roller bearing at one end of a shaft and a ball bearing at the other end. Roller bearings are a simple, rugged design tool that can be precision manufactured in mass production quantities. They can support heavier radial loads then ball bearings but are limited in thrust capacity to 20% of the radial load. They come in many different sizes and configurations, are relatively inexpensive, and require little or no maintenance. They have predictable design lives and operating characteristics and, like ball bearings, are a valuable asset to the rotating equipment industry today.

Description: A roller bearing consists of an inner ring (IR), an outer ring (OR), a complement of rollers, and a cage. The outer diameter of the inner ring and the inner diameter of the outer ring are surfaces that the rollers ride on. They are called the pathways. Pathways sometimes have shoulders or ribs on either side which give the rollers axial support. The rollers are held equally spaced around the annulus of the bearing by the cage. The basic dimensions of the bearing are the bore (B), outside diameter (OD), and the width (W). See Figure 23.

Theory of Operation: In most applications, there are either one or two roller bearings supporting a rotating shaft. The inner rings are a press fit on the shaft while the outer rings may or may not be a press fit. Unlike balls riding in a groove in ball bearings, rollers ride on a flat surface and are free to move axially on the pathway. The ability of rollers to move axially on pathways eliminates unwanted thrust from occurring due to differential thermal expansion between shafts and housings. For this reason, roller bearings do not have to have outer rings mounted loose in housings as do ball bearings. Roller bearings can support heavier loads than ball bearings of the same size because of having line contact between the rollers and rings as opposed to point contact for ball bearings. Line contact has more area supporting the load and thus less stress than ball bearing point contact. This feature also makes roller bearings a stiffer support to a shaft which may or may not be an advantage.

Figure 23

Roller Bearing Terminology



Roller bearings support predominantly radial loads while thrust loads are limited to 20% of radial load. Ribs on ring pathways are used for roller end contact when the thrust load is present. Roller bearings fail in fatigue similar to ball bearings with the inner ring pathway most likely to spall out.

Manufacture: Roller bearings, like ball bearings, are manufactured to a very high precision level in high volume quantities. A low-carbon, chrome-moly steel is used by some manufacturers. Chromium and molybdenum improve high temperature properties. Heat treating roller bearings involves a case-hardening operation as opposed to the thru-hardening treatment given to 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 by the outer layers of steel which are then hardened. The inner layers remain at a lower hardness level. The hard outer layers give roller bearings good load carrying capability while the softer inner core provides good shock or impact load resistance.

Inner and outer rings are processed as follows:

a) The rings are machined from special sized steel tubing.
b) They are put in heat treat furnaces and case-hardened.
c) Every surface is fine ground to exacting tolerances.

Rollers are processed as follows:

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

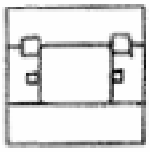
Assembly of the bearing is accomplished as follows:

a) The rollers and cage are assembled to either the IR or OR.
b) The opposite ring is pressed into place.
c) On one-part bearings, a retaining ring is installed.
d) On two-part bearings, the bearing is a separable unit.

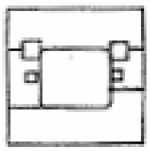
Configurations: Roller bearings come in many different sizes and shapes offering designers great flexibility. Most have the exact same envelope dimensions as ball bearings but with greater radial load carrying capacity. Bearings without outer rings can be run directly on housings saving design cost and weight. Others without inner rings can be run directly on shafts which then can be made bigger and stronger. Cages can be omitted and extra rollers added making bearing capacities even higher than standard designs. Roller bearings prove to be a very valuable tool when high radial loads and low thrust loads are present. See Figures 24 and 25 for sketches and descriptions of some of the more common configurations.

Figure 24

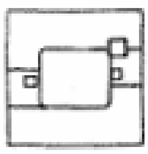
Roller Bearing Configuration



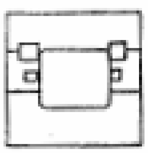
Two part bearing with two outer ring retaining rings. Separable inner ring simplifies assembly. Inner ring fits other bearings. Low cost design.



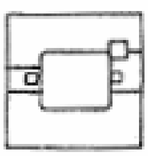
Two part bearing with one outer ring retaining rings. Separable inner ring simplifies assembly. IR rib locates outer ring in one direction.



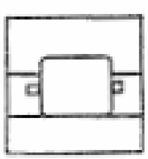
Two part bearing with one outer ring retaining ring. Separable inner ring simplifies assembly. Inner and outer ring ribs allow one way thrust.



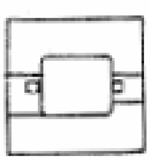
Non-separable bearing assembly. Used where complete bearing assembly needed. Outer ring doesn't need to be axially retained.



Non-separable bearing assembly. Used where complete bearing assembly needed. Ribs allow thrust in one direction.



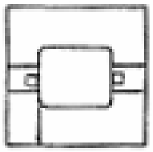
Two part bearing with cylindrical inner ring. Separable inner ring simplifies assembly. Has special high speed design separator.



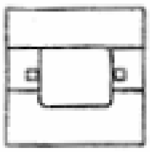
Two part bearing with separable inner ring. Ribs allow thrust in one direction. Has special high speed design separator.

Figure 25

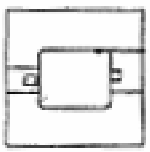
Roller Bearing Configuration



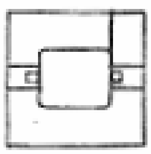
Three part bearing with separable IR & side plate.
Inner ring locates shaft and allows one-way thrust.
Has special high speed separator.



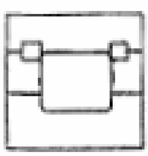
Two part bearing with separable outer ring.
Used where rollers need to be with inner ring.
Has special high speed separator.



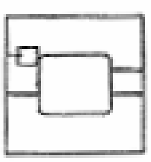
Two part bearing with separable outer ring.
Used where rollers need to be with the inner ring.
Ribs allow one-direction thrust.



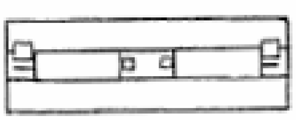
Three part bearing with separable OR & side plate.
Inner ring locates shaft and allows one-way thrust.
Has special high speed separator.



Non-separable bearing assembly.
No separator allows more rollers and capacity.
Lower speed design.



Non-separable bearing assembly.
No separator allows more rollers and capacity.
Lower speed design.



Two part assembly with two roller rows.
Takes more load than single row.
Extra width limits shaft deflection.

<u>Selection:</u> Roller bearing life for a device is calculated using the same formula as is used for ball bearings. There is no factor for thrust load in the formula because thrust load is reacted by the roller ends and this condition does not add stress to the roller pathway load zone. Roller bearing thrust capacity is limited to just 20% of the radial load on the bearing. The roller bearing life formula is as follows:

$$\text{Life}=3000\text{x}(C/R)^{E}\text{x}(500/S)$$

C is the capacity of the bearing in pounds. R is the radial load in pounds. E is the exponent 10/3 or 3.333. S is the speed in rpm.

Let's increase the radial load from 100# to 500# on each bearing in the previous sample problem where radial ball bearings were used. The thrust will remain at 100# which is exactly 20% of the radial load. The lives of the original ball bearings at the new loads are as follows:

$$L=3000(570/(500\text{x}1.00))^{3.333}\text{x}(500/2000)=1160\text{ B10 hr (R=500\#, T=000\#)}$$
$$L=3000(570/(500\text{x}1.00))^{3.333}\text{x}(500/2000)=1160\text{ B10 hr (R=500\#, T=100\#)}$$

It can be seen that the life of the ball bearing in position 1 had decreased from 246,674 to 1160 B10 hr and the life of the ball bearing in position 2 has decreased from 40,533 to 1160 hr. The lower thrust to the radial load factor in position 2 has made the thrust load insignificant and the life the same as position 1. Let's substitute the same size roller bearings for both positions and recalculate life:

$$L=3000(1060/500)^{3.333}\text{x}(500/2000)=9157\text{ B10 hr (R=500\#, T=000\#)}$$
$$L=3000(1060/500)^{3.333}\text{x}(500/2000)=9157\text{ B10 hr (R=500\#, T=100\#)}$$

Both calculations end up being the same and the roller bearing has increased the life at each position by almost 8 times.

In all the previous sample problems, the bearing size was known and the equation was used to calculate bearing life. Sometimes the reverse is true where the desired life is known and the size of the bearing has to be determined. As a sample problem, an application for a roller bearing has a desired life of 5000 B10 hr. The speed is 1000 rpm and the load is 1000# radial. What size bearing is needed? The original equation is transposed to the following to solve the problem:

$$C=(R\text{x}LF)/SF$$

C is the capacity of the bearing needed to fulfill the requirements of the application. R is the radial load in pounds. LF is the life factor which is based on the 5000 B10 hr required and is found in a catalog. SF is the speed factor which is based on the 1000 rpm given and is also found in a catalog. Solving the problem using the above equation follows:

$$C=(1000 \times 1.166)/.812=1436 \text{ lbs}$$

A roller bearing with a capacity of at least 1436# is needed for the application. Searching through the roller bearing catalog reveals that a 30 mm bore medium series bearing has a capacity of 1600# and will therefore fulfill the requirements of the application. Generally, there are bearings in other series that will also have the desired capacity but their use will depend on space requirements of the application.

Internal Clearance: Internal clearance for roller bearings is the same as for ball bearings. The proper internal clearance for roller bearings is needed for roller bearings to operate satisfactorily. Radial play is a measure of internal clearance and is the total travel of one ring with respect to the other in the radial direction. End play is not used for roller bearings. Radial play is higher for roller bearings than ball bearings. Radial play for a small roller bearing is .0004" to .0016" and for a large roller bearing, .0024" to .0049". These numbers are over three times larger than the numbers for small ball bearing and over two times larger than the numbers for large ball bearings. Like ball bearings, roller bearing internal clearance is designed to accommodate the press fit of one ring. Special internal clearances are needed to accommodate press fitting two rings, non-ferrous shaft or housing materials, non-standard shaft or housing wall thicknesses, or unusual operating or temperature conditions. Figure 16 shows ball bearing radial play.

Shafts and Housing Fits: Roller bearing shaft and housing fits are similar to ball bearing shaft and housing fits. Under normal load and service conditions, the rotating ring should have an interference fit with its mating member. The non-rotating ring should have a close push fit with its mating member.

This arrangement prevents the rotating ring from spinning on its seat. Also, installation of a non-separable roller bearing is greatly facilitated when one ring is a push fit. Changes to standard fit practices for roller bearings are made for the same reasons as for ball bearings mentioned earlier. Normal shaft press fits range from .0003" tight to .0009" tight for a small bearing to .0012" tight to .0032" tight for a large bearing. Normal housing push fits range from .0000" line to line to .0012" loose for a small bearing to .0000" line to line to .0030" loose for a large bearing. The shaft press fits are, on the average, about 2 to 3 times greater than for ball bearings because of the tendency for roller bearing rings to turn on their seats more so than ball bearings. The outer ring push fits are nearly the same for roller bearings as they are for ball bearings.

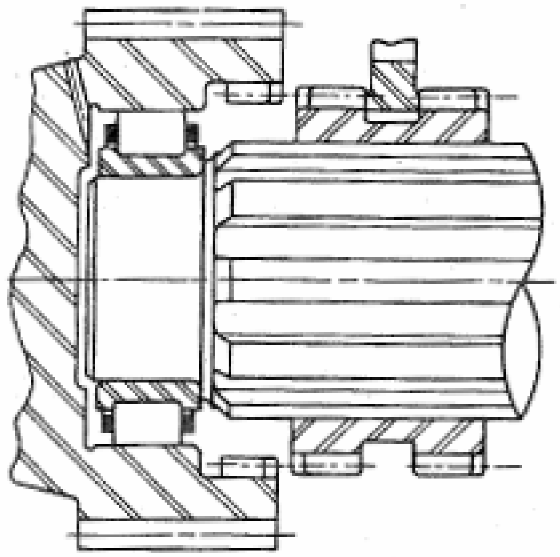
Lubrication: Lubrication for roller bearings is much like what it is for ball bearings. The best lubricant is mineral oil with a light additive package. The additives reduce oxidation, improve lubricity, and prevent breakdown under extreme pressure. Excessive additives are not recommended for bearings as they may actually impair performance. Oil viscosity is just as important for roller bearings as it is for ball bearings. The graph on Figure 17 also applies to roller bearings. The graph illustrates the importance of selecting the correct oil viscosity for the actual bearing operating temperature.

Grease can be used as a lubricant for roller bearings, although it is not as commonly used in a double sealed package as it is for ball bearings. The same grease mentioned earlier for ball bearings applies equally well to roller bearings. Bearings should always be relubricated with the same grease as originally used. If a grease change is to be made, the bearing should be thoroughly cleaned free of the original grease. Some greases, when mixed together, are not compatible and could impair bearing performance.

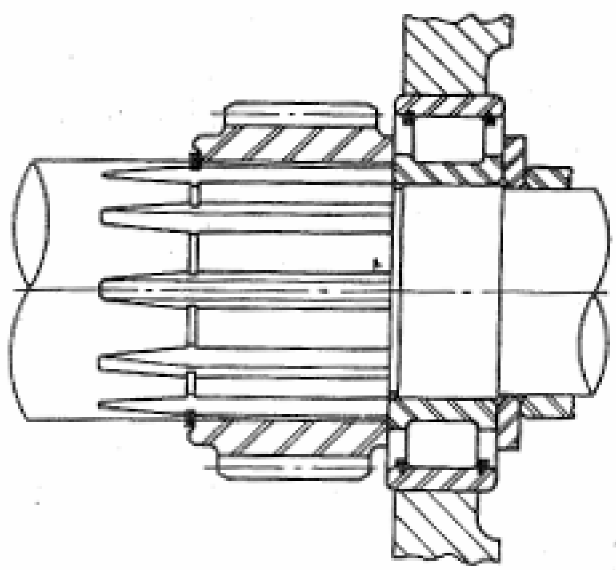
Application: Roller bearings are valuable design tools in applications where spur gears are used. Spur gears exert high radial loads and little or no thrust loads which is well suited to roller bearings. Roller bearings running with straight cylindrical rings or running direct on shafts or housings are good accommodators of differential thermal expansion. In some designs, where helical or worm gears are used, it is sometimes beneficial to use a roller bearing at one end of a shaft and a ball bearing at the other. Figures 26, 27, 28 and 29 show examples of roller bearing usage and retention methods. Figures 30, 31, 32, 33 and 34 pose questions at the bottom pertaining to the sketches on top.

Figure 26

Roller Bearing Application



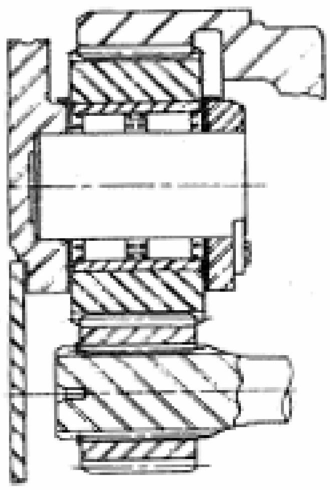
Roller bearing without an outer ring runs on inside of the gear saving cost, weight, and space.



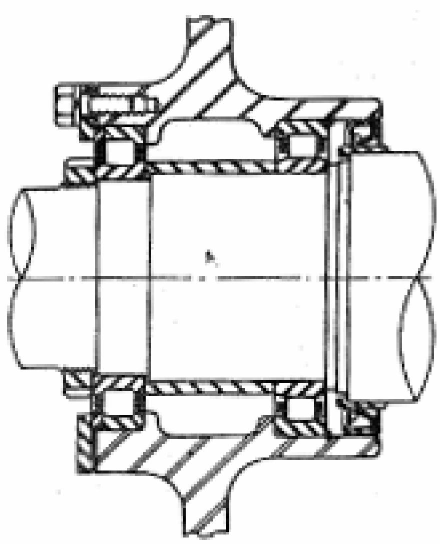
Roller bearing with U-type inner ring. Retaining rings in the outer ring guide the rolling elements.

Figure 27

Roller Bearing Application



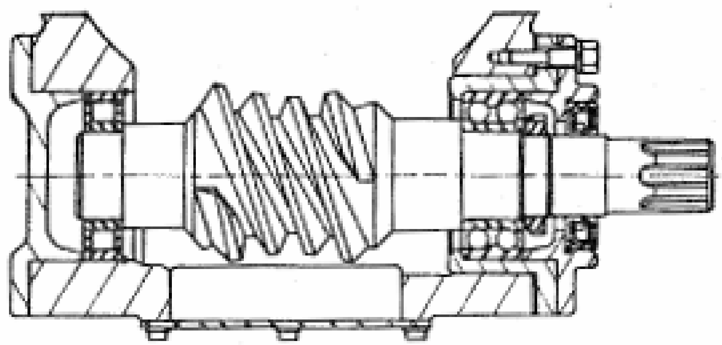
Double row roller bearing runs directly on the shaft saving cost, weight, and space.



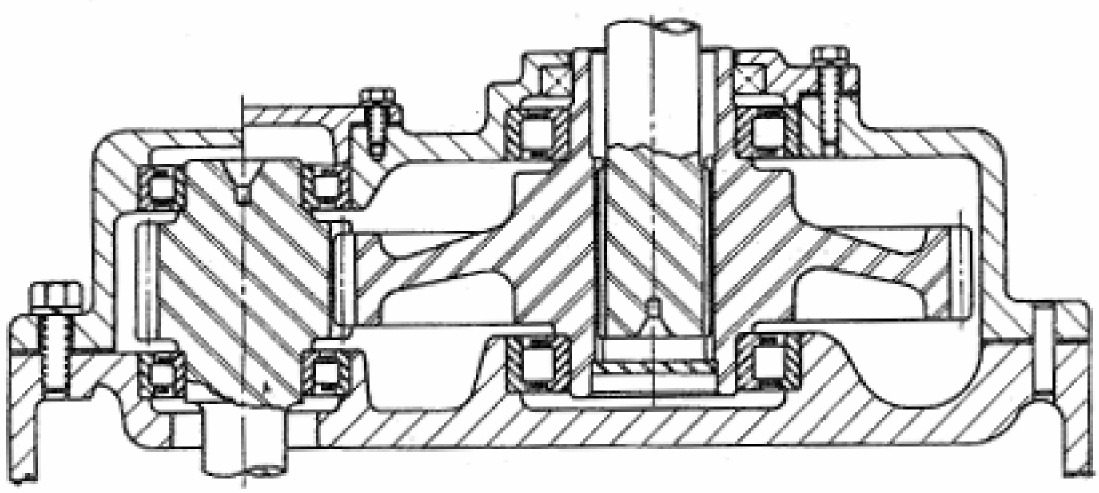
The roller bearing on the left locates the gear while the one on the right allows for shaft thermal expansion and tolerance build-up.

Figure 28

Roller Bearing Application



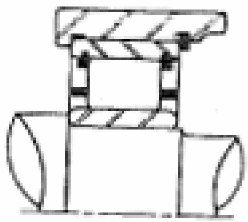
Roller bearing left of worm gear takes radial loading and allows easy removal of worm shaft. Double row ball bearing on right locates shaft and supports thrust loads.



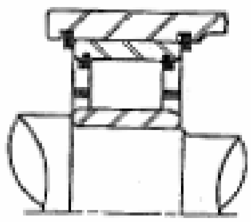
Roller bearings on each end of each shaft of gearbox absorb heavy radial loads from spur gears and allow easy assembly and disassembly of gearbox.

Figure 29

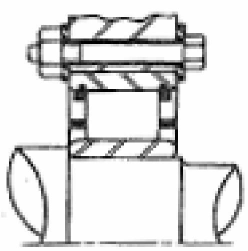
Roller Bearing Application



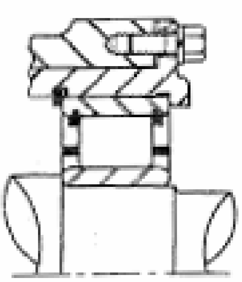
Roller bearing mounting using retaining ring and housing flange to secure outer ring.



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



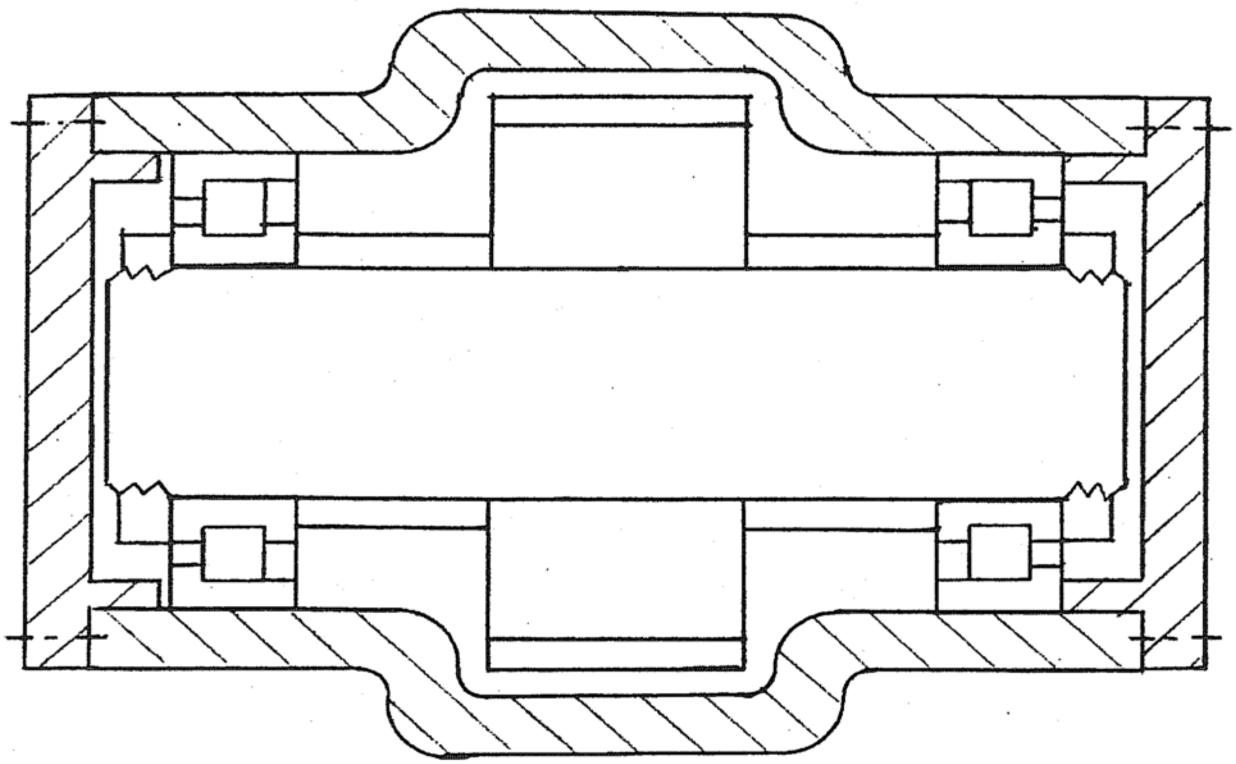
Through bolt and washers used to retain bearing outer ring.



Bearing cartridge mounting allows room to remove gear.

Figure 30

Roller Bearing Application



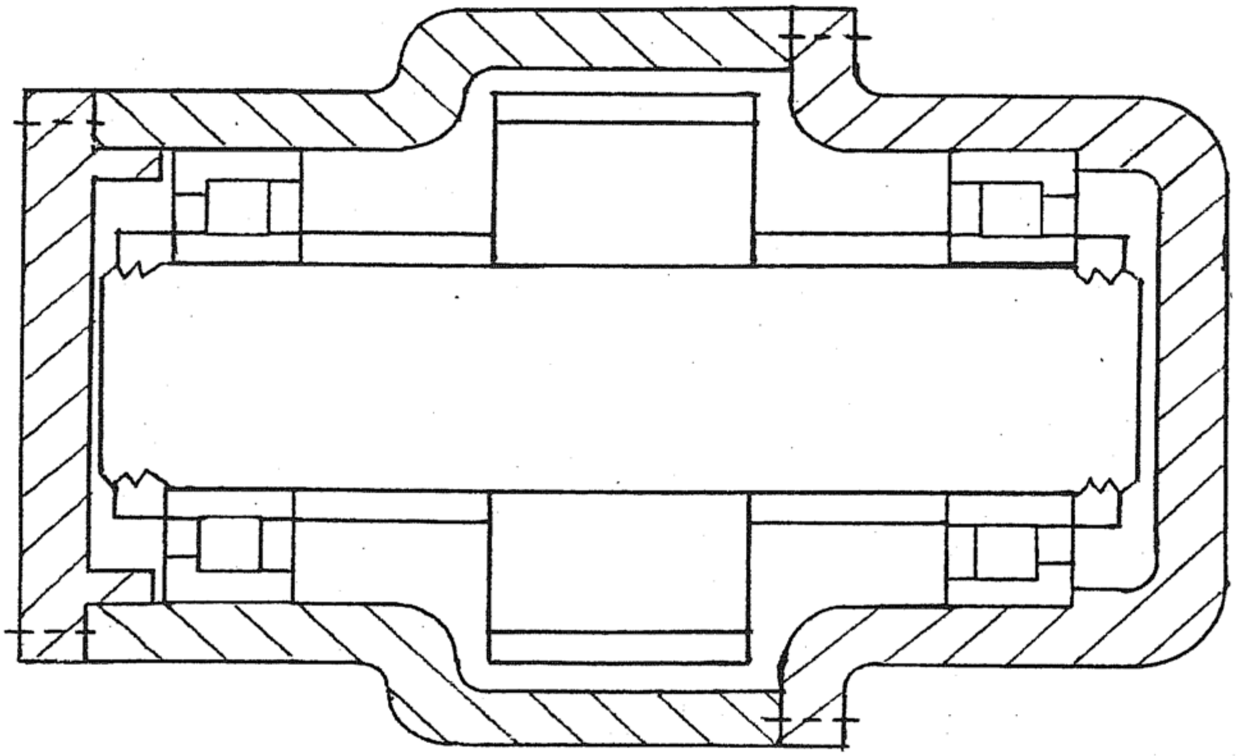
What's wrong with this assembly?

(Turn page for answer at bottom.)

The gear is bigger than the housing and
therefore cannot be assembled into the housing.

Figure 31

Roller Bearing Application



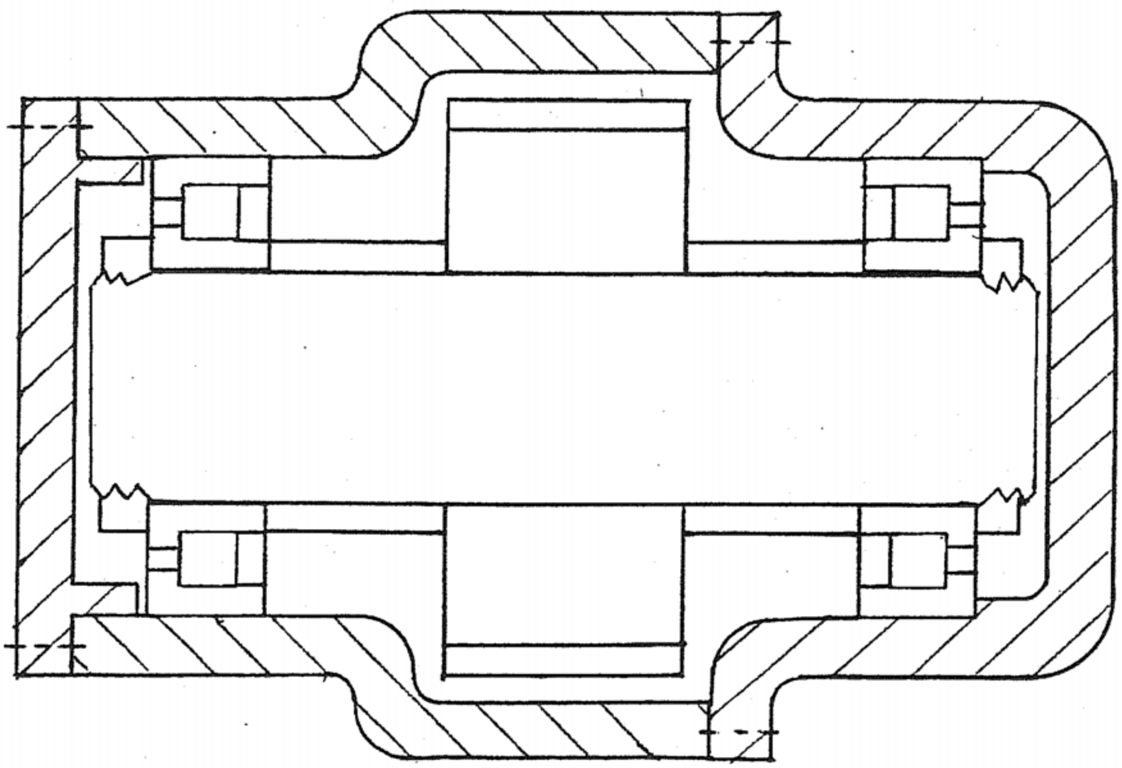
What's wrong with this assembly?

(Turn page for answer at bottom.)

The shaft is not fixed axially.

Figure 32

Roller Bearing Application



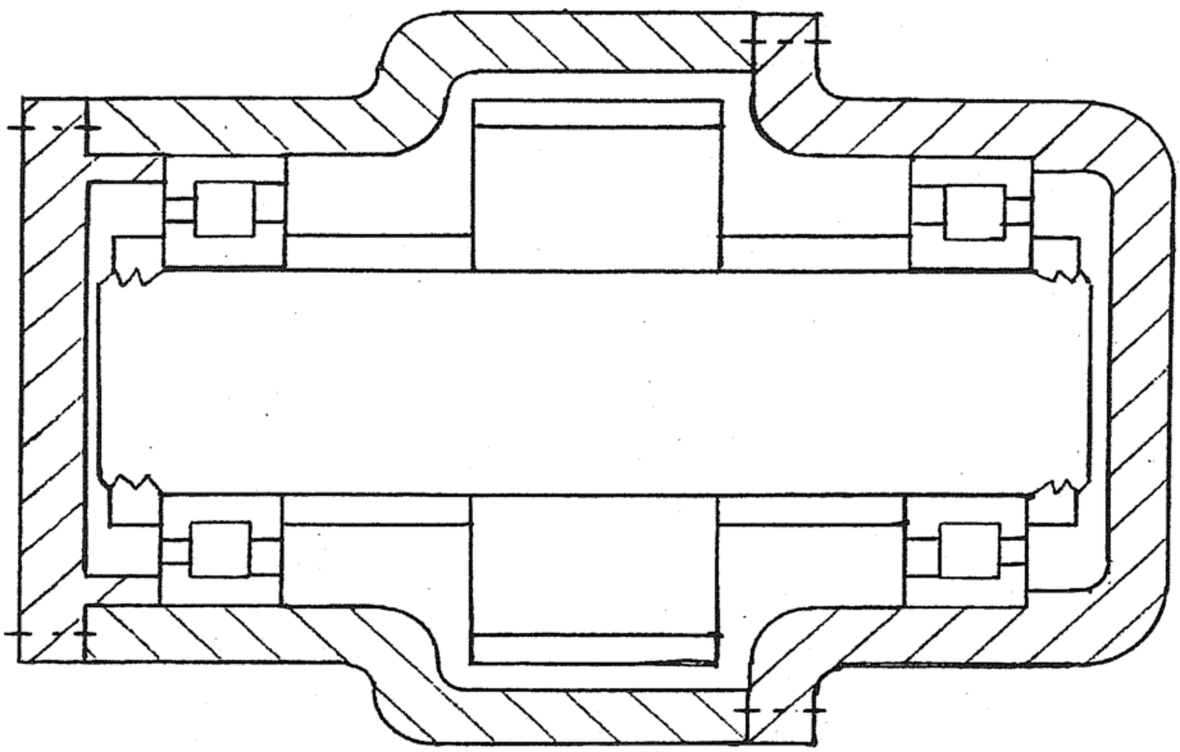
What's wrong with this assembly?

(Turn page for answer at bottom.)

The shaft is not fixed axially.

<u>Figure 33</u>

<u>Roller Bearing Application</u>



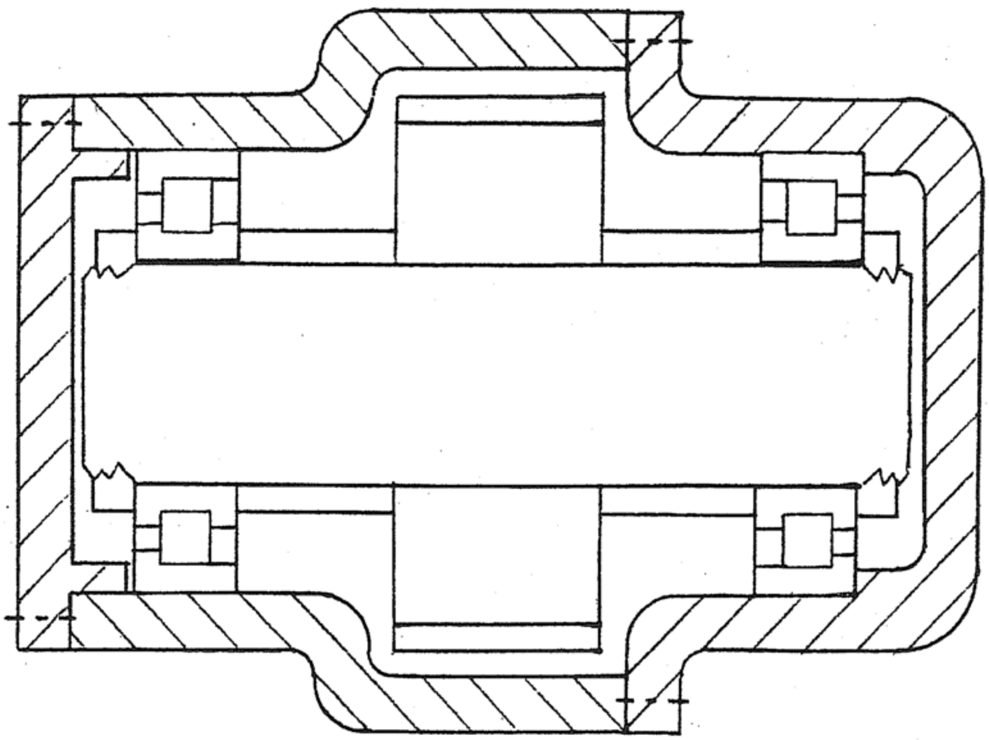
What's wrong with this assembly?

(Turn page for answer at bottom.)

There is no clearance for expansion of the shaft.

Figure 34

Roller Bearing Application



Below are random steps needed to assemble the above unit. Put letters in order on lines below. Do LH shaft items before RH.

Y ___ ___ ___ ___ ___ ___ G ___ ___ ___ ___ ___ B

A) Install RH shaft nut.	J) Install LH brg outer ring.
B) Bolt on RH end cover.	O) Install LH sleeve on shaft.
D) Install LH shaft nut.	O) Lay RH cover open side up.
D) Press RH brg onto shaft.	O) Put shaft assy in RH cover.
D) Fit housing on shaft assy.	O) Bolt LH end cap in place.
G) Install RH brg outer ring.	U) Press LH bearing on shaft.
I) Slide RH sleeve on shaft.	Y) Press gear to shaft center.

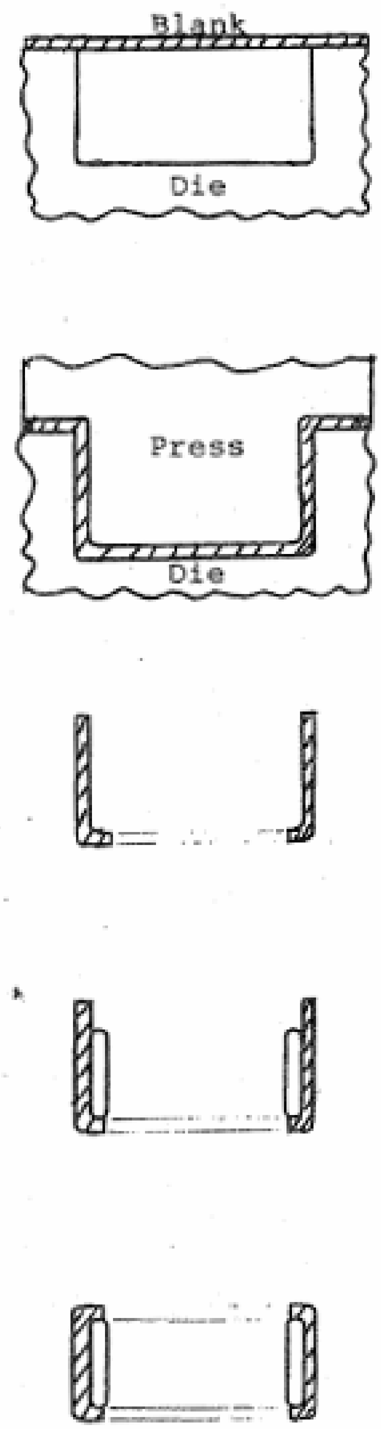
(Turn page for answer at bottom.)

Y O U D I D A G O O D J O B

Drawn Cup Roller Bearings: Drawn cup roller bearing outer rings are formed in a press from a flat piece of sheet steel. The blank is drawn into a die where it takes a cup-like shape. The top of the cup is trimmed square and the bottom is punched out. The part is then given a surface heat treatment. Rollers are inserted and the top is folded down forming a complete bearing assembly. This method uses less material and is faster than conventional methods for making outer rings. See Figure 35. When the outer ring is removed from the die, it springs out of shape slightly; however, it regains its true form when it is pressed into a housing. Drawn cup bearings are high volume products used in automotive rear axle tubes and alternators.

Figure 35

Drawn Cup Roller Bearings



Sheet metal blank
on top of die.

Cup drawn into
die with press.

Top trimmed.
Hole put in bottom.

Rollers inserted.

Top folded down.

TAPERED ROLLER BEARINGS

Purpose: Tapered roller bearings are anti-friction bearings that combine the thrust load carrying capability of ball bearings with the radial load carrying capability of roller bearings. Tapered roller bearings are widely used in a variety of equipment where high combined thrust and radial loads are experienced. Tapered roller bearings are somewhat more complicated in design than ball and roller bearings. Great care must be taken in their manufacture to maintain the critical dimensional control that is needed to ensure good bearing performance. Despite the complexity, tapered roller bearings are precision manufactured in high volume quantities competitively with other types.

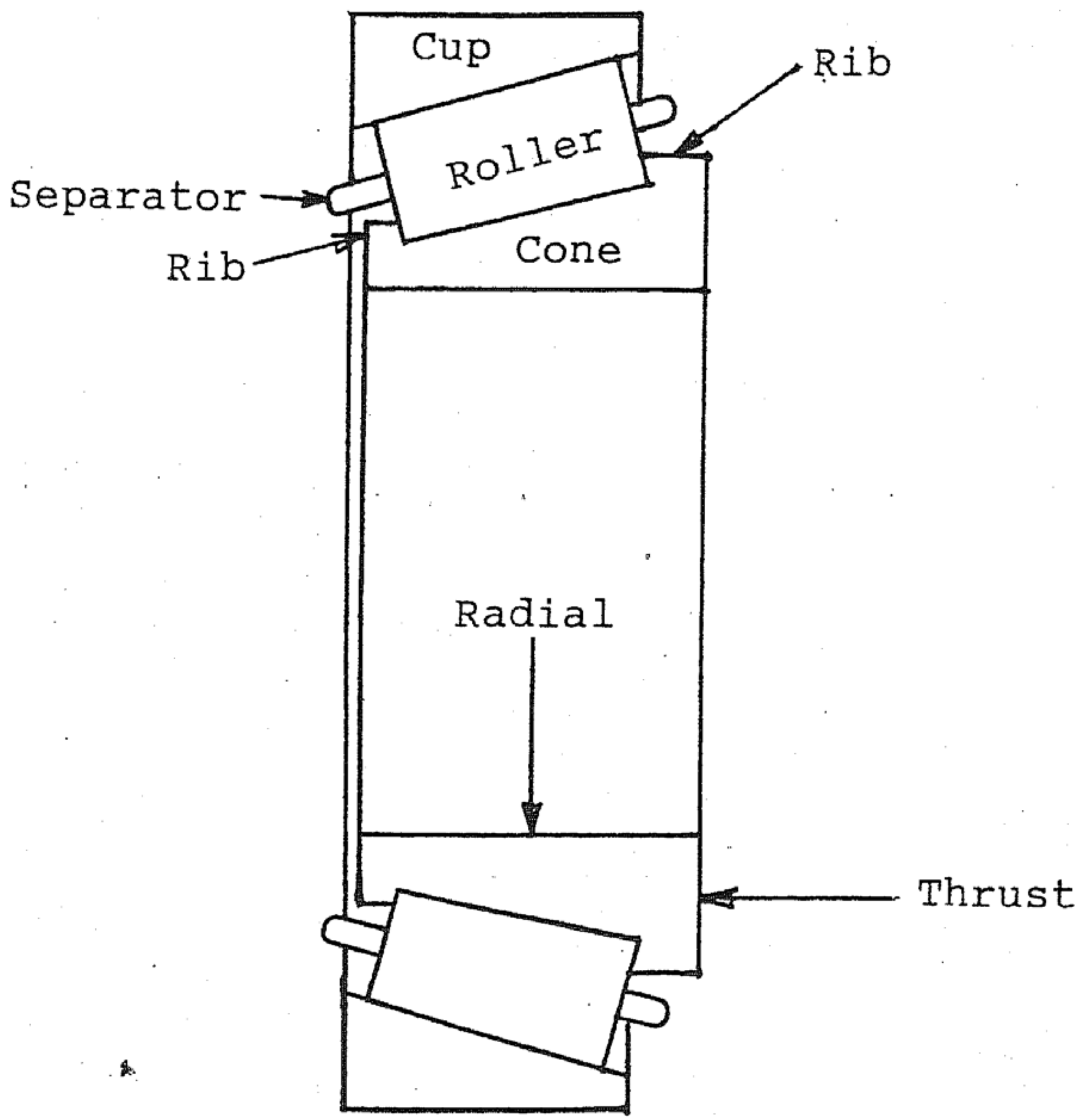
Description: Tapered roller bearings, as the name suggests, are roller bearings with rollers that are tapered instead of cylinder shaped. Since the rollers are tapered, the inner ring (cone) pathway and the outer ring (cup) pathway are also tapered. It is the unique angular construction of the tapered roller bearing that makes it inherently able to support both thrust and radial loads. The cone, as the name suggests, is cone shaped and the cup is cup shaped. It helps to distinguish between the two by remembering the phrase, "The cone goes in the cup". The cone has a rib on each side of the pathway to contain the roller complement and separator. The cup is separable. See Figure 36.

Theory of Operation: It is essential that the tapered roller bearings be designed so that straight lines extending from the cup pathway and the cone pathway meet the centerline of the bearing at the same point. This common point of intersection is called the apex. It is this design feature that enables tapered roller bearings elements to undergo pure rolling when the bearing is rotated. Deviation from this condition will lead to edge loading, roller skewing, and premature failure. The ratio of thrust to radial load that a bearing can take is determined by the cup angle. Larger cup angles enable bearings to support a higher proportion of thrust loads while smaller cup angles are used to support a higher proportion of radial loads. Cup angles range from 20 degrees to 55 degrees. See Figure 37.

An important aspect of tapered roller bearings is the contact between the large roller end and the cone rib face. During bearing operation, the roller is "squirted" or forced against the rib face where a type of sliding motion occurs. To prevent excessive heat generation and galling, the roller end is fine ground to a spherical radius and the rib face is ground to a precise angle with the cone pathway.

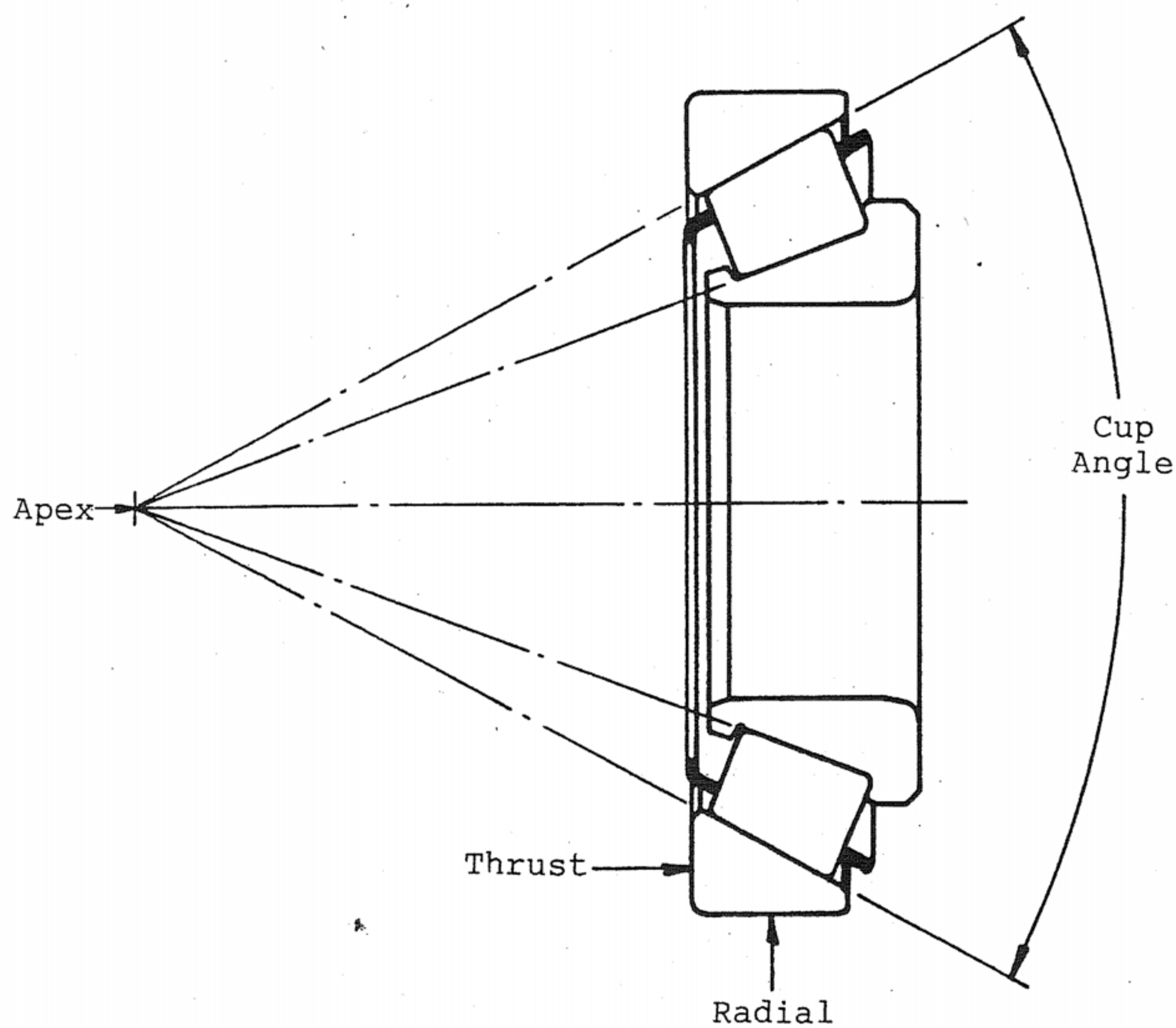
Figure 36

Tapered Roller Bearing Terminology



<u>Figure 37</u>

<u>Tapered Roller Bearing Design</u>



These two dimensions are carefully calculated to put the contact point approximately halfway up the rib face. Contact at the edges can produce premature bearing failure. See Figure 38.

Another feature that tapered roller bearings have is crowning. Crowning refers to grinding the cup, cone, and roller pathways so that they have a slight rise in the center. Without crowning, the roller edges tend to "dig into" the cup and cone pathways producing edge loading and high end stress characterized by a "dog bone" stress pattern. Carefully calculated crowning reduces the effects of edge loading and produces a more uniform stress pattern across the pathways. Crowning also allows tapered roller bearings to accommodate a higher degree of misalignment than they could with flat ground pathways. See Figures 39 and 40.

Tapered roller bearings have chamfered separator bars where they contact the rollers. This feature allows more conformance of the roller to the separator reducing friction and allowing the bearing to operate more efficiently. This feature is also used to control separator "shake" or movement in the bearing. See Figure 41.

<u>Manufacture:</u> Tapered roller bearings are manufactured similar to cylindrical roller manufacture. Essentially, all components are machined, (headed in case of rollers), hardened and ground. The material used is a low carbon, nickel-chrome-moly alloy steel. Nickel imparts shock resistance while chromium and molybdenum improve high temperature properties. Tapered bearing rings and rollers are case-hardened similar to cylindrical roller bearings. The hard outer case offers good load carrying capacity while the soft inner core provides good impact load resistance.

The assembly of tapered roller bearings is accomplished by using a press and closing die. The separator, which as formed has the individual pocket bars bowed out, is placed in the closing die. The rollers are loaded and the cone placed inside. The press is brought to bear on the face of the cone forcing the roller-cone assembly deeper into the tapered pocket in the die. This action forces the separator bars inward to a straightened position holding the rollers against the cone creating a non-separable assembly. See Figure 42.

The roller-cone assembly can be "bumped" or disassembled using the separable cup from the same bearing. The cone assembly is placed on a flat surface with the protruding (small diameter) end of the separator contacting the table.

Figure 38

Tapered Roller Bearing Design

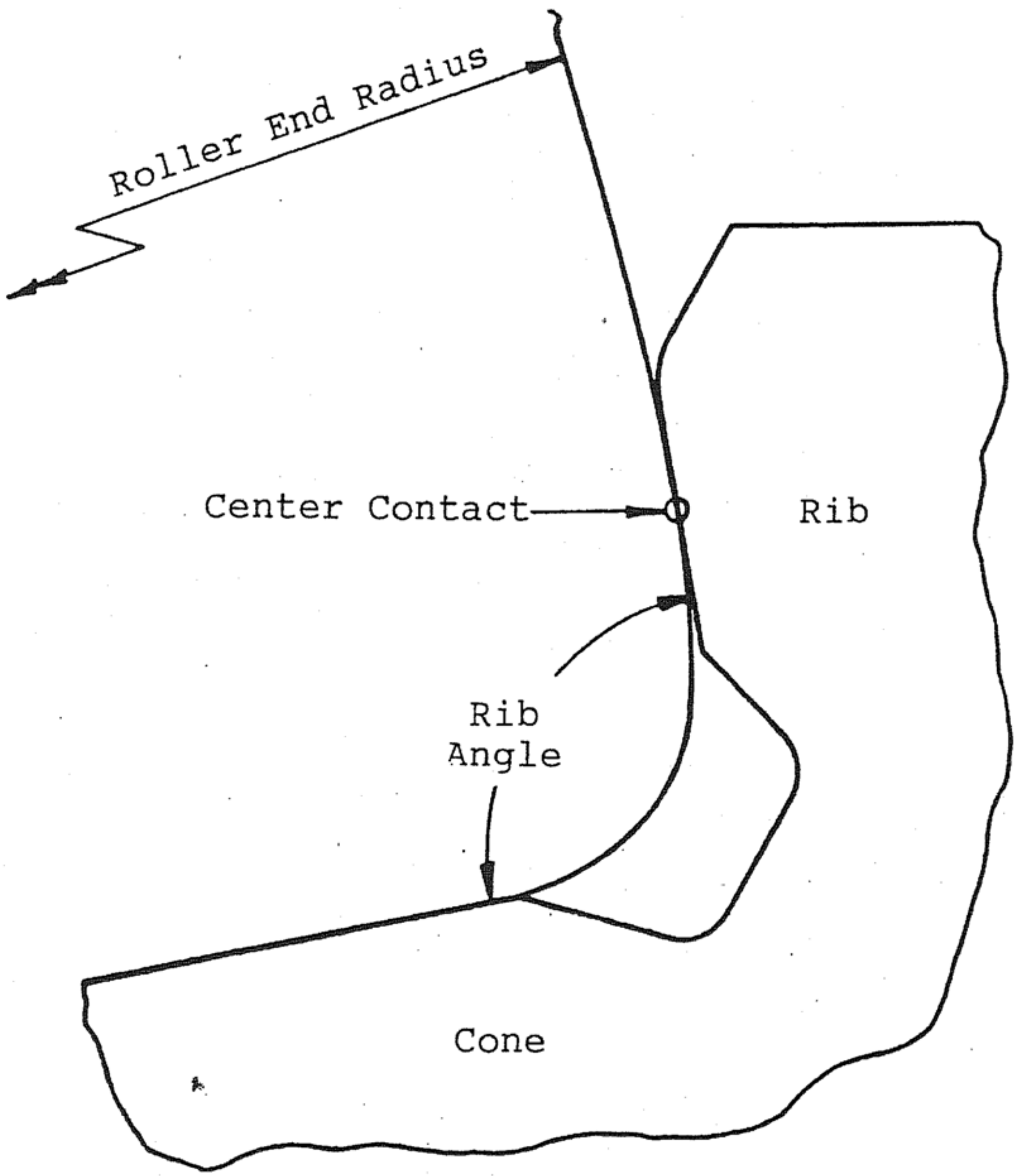


Figure 39

Tapered Roller Bearing Design

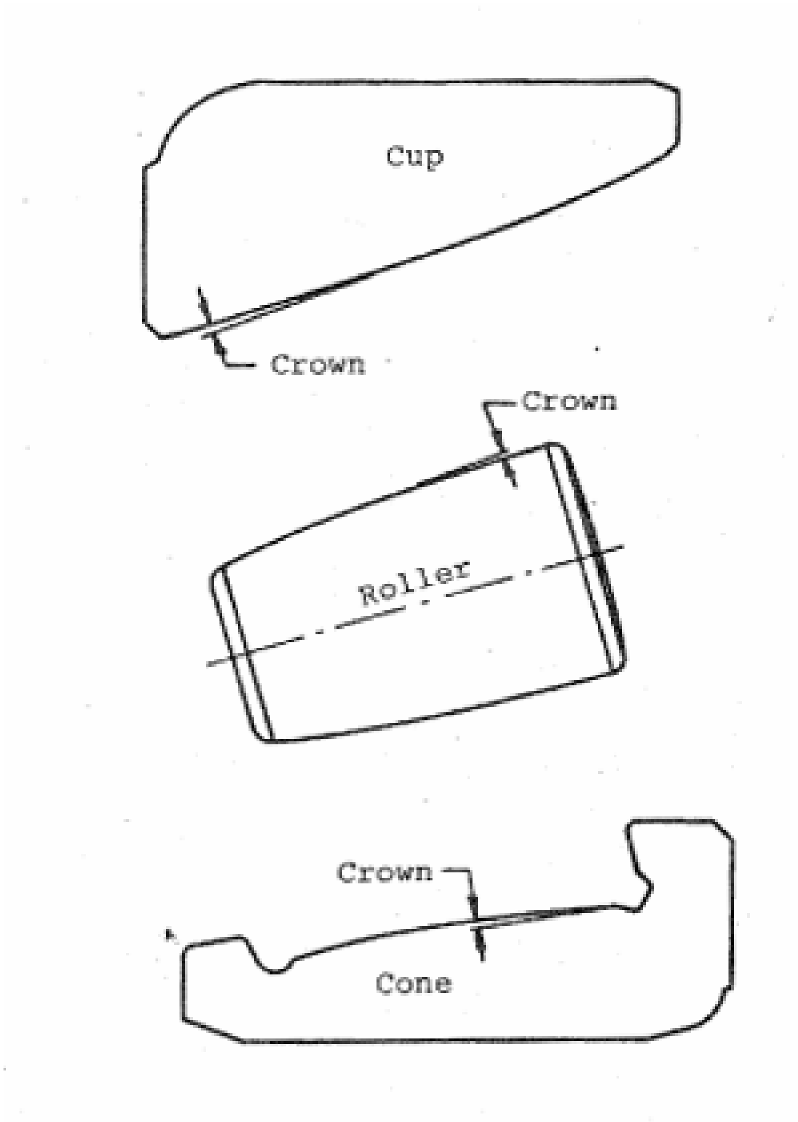
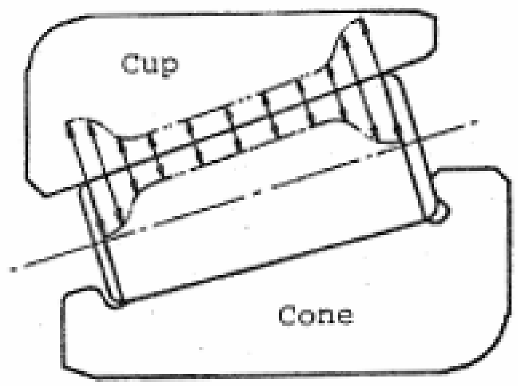
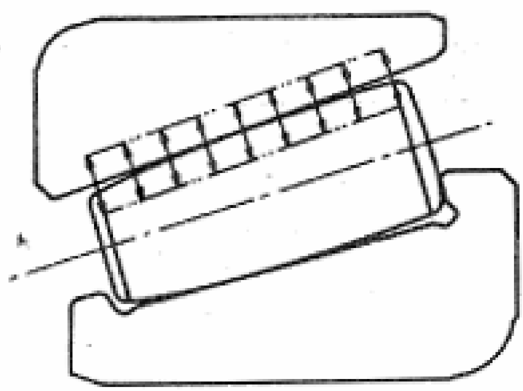


Figure 40

Tapered Roller Bearing Design



Stress Distribution With
Non-Crowned components.



Ideal Stress Distribution
With Crowned Components.

Figure 41

Tapered Roller Bearing Design

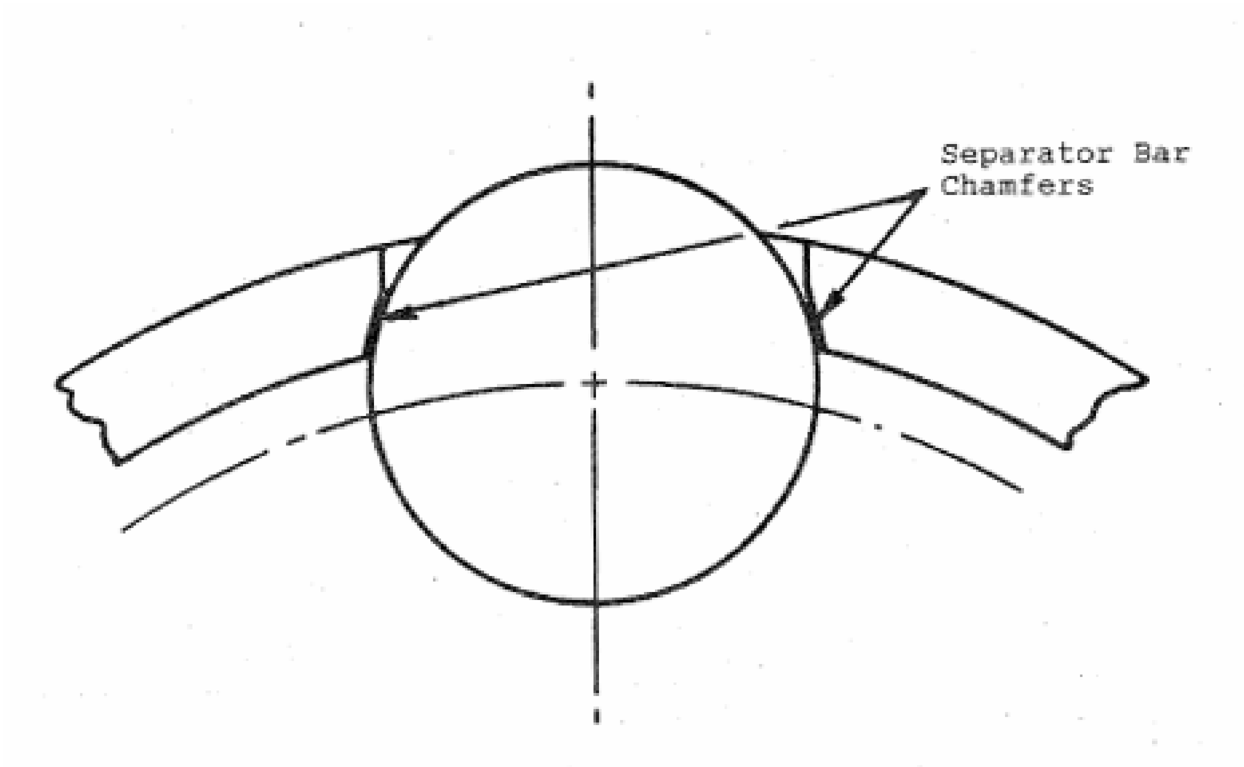
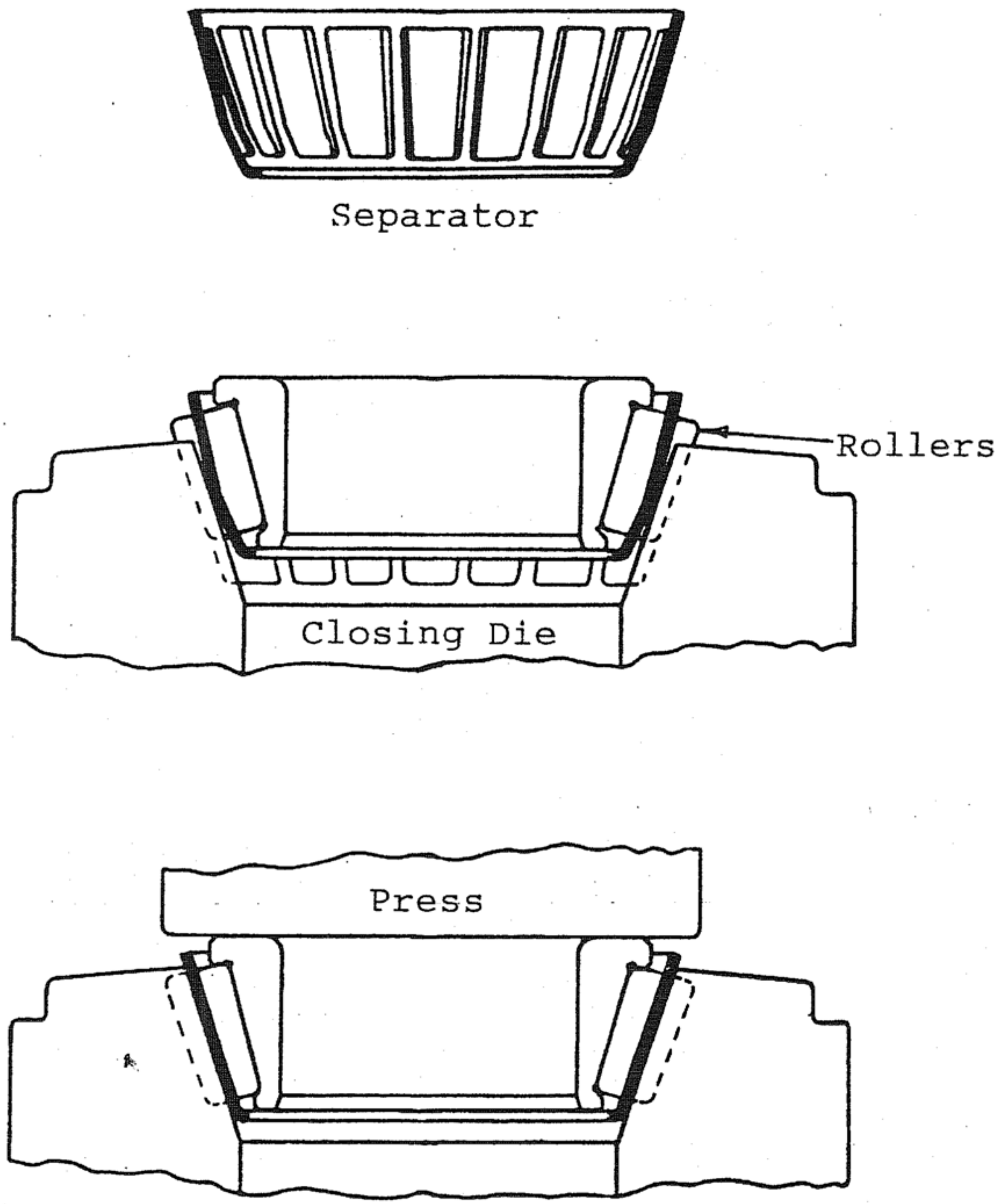


Figure 42

Tapered Roller Bearing Assembly



The large end of the cup is placed on top of the separator. Pressure is brought to bear on the top of the cup putting force on both ends of the separator. This action bows out the separator bars to their originally manufactured shape. Now, when the roller-cone assembly is hand spun, it falls free of the cone's small end disassembling the bearing. See Figure 43.

Unlike other anti-friction bearings, tapered roller bearing pathway diameter controls bearing assembly width. A method of gaging called "standout gaging" has been developed to control tapered bearing assembly width. A gage plug is inserted into the cup and the small gap between the end of the plug and the large end of the cup is defined as the "cup standout". For cone assemblies, a gage cup is placed over the cone assembly. The distance from the back of the cup to the large end of the cone is defined as the "cone assembly standout". Putting the necessary tolerances on cup and cone assembly standout controls the overall bearing assembly width. See Figure 44.

<u>Configurations:</u> Tapered roller bearings, like cylindrical roller bearings, have various configurations rather than the many types and specialty products that ball bearings have. Tapered roller bearing single row configurations include the common high volume design with the pressed metal separator, the maximum capacity design with the pin type separator, the flanged cup type, the single sealed design, and the thrust bearing. Double row configurations include the back-to-back mounting with two spacers, the face-to-face mounting with cup spacer, and the back-to-back mounting with cone spacer. See Figure 45.

<u>Selection:</u> The selection of tapered roller bearings for an application is based on the same equation that is used for ball and cylindrical roller bearings. It is as follows:

$$\text{Life}=3000(C/R)^{E}x(500/S)$$

C is the Bearing capacity in pounds and is found in bearing catalogs. R is the radial load in pounds. If a thrust load is also present, an equivalent radial load must be calculated taking into account the thrust load. E is the exponent 10/3 or 3.333. S is the speed in rpm.

A comparison can be made to ball bearings by repeating the original sample problem using similar size tapered bearings. Tapered bearings under radial load exert or induce a thrust load of their own.

Figure 43

Tapered Roller Bearing Disassembly

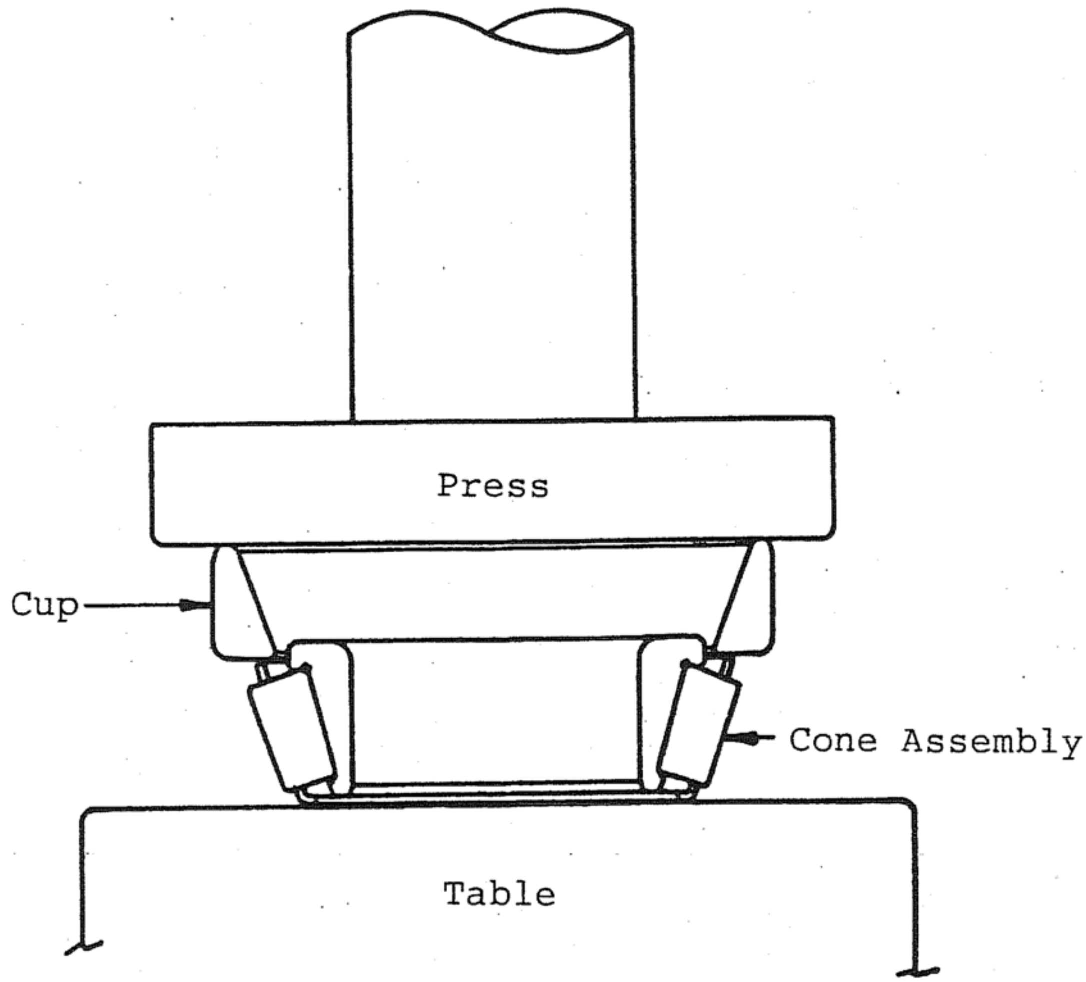


Figure 44

Tapered Roller Bearing Gaging

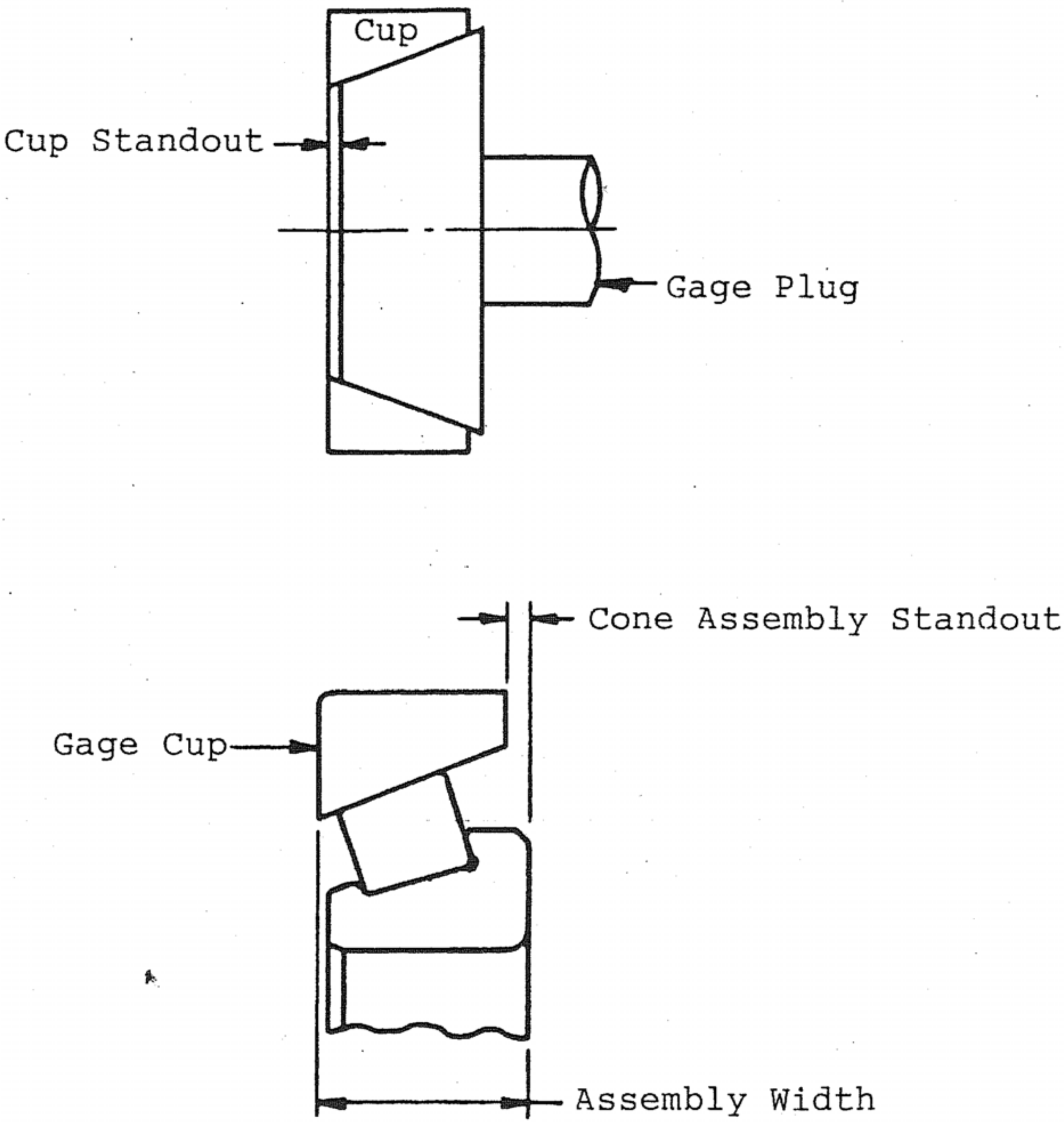
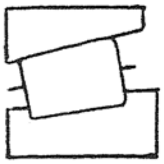
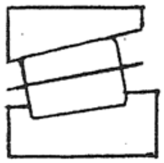


Figure 45

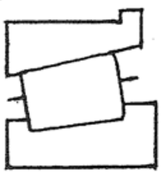
Tapered Roller Bearing Configuration



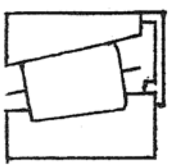
Single row with pressed metal separator.
Most common type. Made with various cup angles.
Can support a variety of radial and thrust loads.



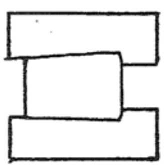
Single row with pin type separator.
Pins go thru roller centers allowing more rollers.
Maximum capacity design.



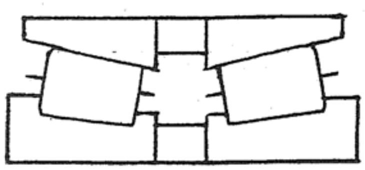
Single row with flanged cup.
Flange mounts against housing face.
Allows through boring of housing.



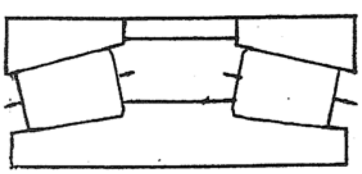
Single row with seal.
Seal fits over cone. Rubs against cup face & housing.
For grease lubrication applications.



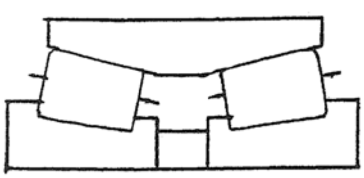
Single row thrust bearing.
Roll. center at 0 deg. May or may not have separator.
Shipped with retainer to hold together.



Double row with cup and cone spacers.
Back to back mounting for internal divergence.
Can have seal at one or both ends.



Double row with common cone and sep. cups.
Face to face for internal convergence.
Not practical to seal.



Double row with common cup and sep. cones.
Back to back mounting for internal divergence.
Can have seal at one or both ends.

The thrust load is the result of the radial load "squirting" or forcing the tapered roller against the cone rib face. The load on the bearing in position 1 remains at 100# radial. Since there is a 100# radial load and a 100# thrust load on the bearing in position 2, the following equation (Timken Products Catalog, The Timken Company, Canton, Ohio, 2006, Page A31) is used to calculate the equivalent radial load:

$$R=(0.4xR_2)+(KT)$$

R is the equivalent radial load that is to be used in the life equation. R_2 is the 100# radial load in position 2. K is the radial to the thrust capacity factor for the tapered bearing which is found in a bearing catalog, and for this bearing is 1.69. T is a position 1 thrust factor plus an applied load thrust factor. The equivalent radial load for position 2 is as follows:

$$R=(0.4x100)+(0.47x100)+(1.69x100)=256\#$$

The calculated lives for tapered bearings replacing the radial ball bearings in the original sample problem are as follows:

$L=3000(1170/100)^{3.333}x(500/2000)=2,724,738$ B10 hr (R=100#, T=000#)
$L=3000(117/256)^{3.333}x(500/2000)=\quad 118,757$ B10 hr (R=100#, T=100#)

The lives for the radial ball bearings under the same service conditions were 246,674 and 40,533 B10 hrs respectively. The tapered roller bearing lives are from 2.9 to 11 times higher than the ball bearing in the same application.

Application: One of the largest users of tapered roller bearings is the automotive industry. Tapered bearings are used in cars, trucks, farm and construction equipment, mining machines, and even in railroad cars. One of the most common applications is to support non-drive wheels in automobiles. The cups are press fit into the rotating hubs and the cones are slip fit onto the stationary spindles. The bearing endplay is adjusted to several thousandths of an inch with the use of an adjusting nut on the end of the spindle. The nut is locked in place with a cotter pin. The bearings are lubricated with the best water resistant and temperature resistant grease on the market. There is a rubber lip seal on the inboard side of the bearing package and a dust cap on the outboard side to contain the lubricant and prevent contaminant entry. See Figure 46.

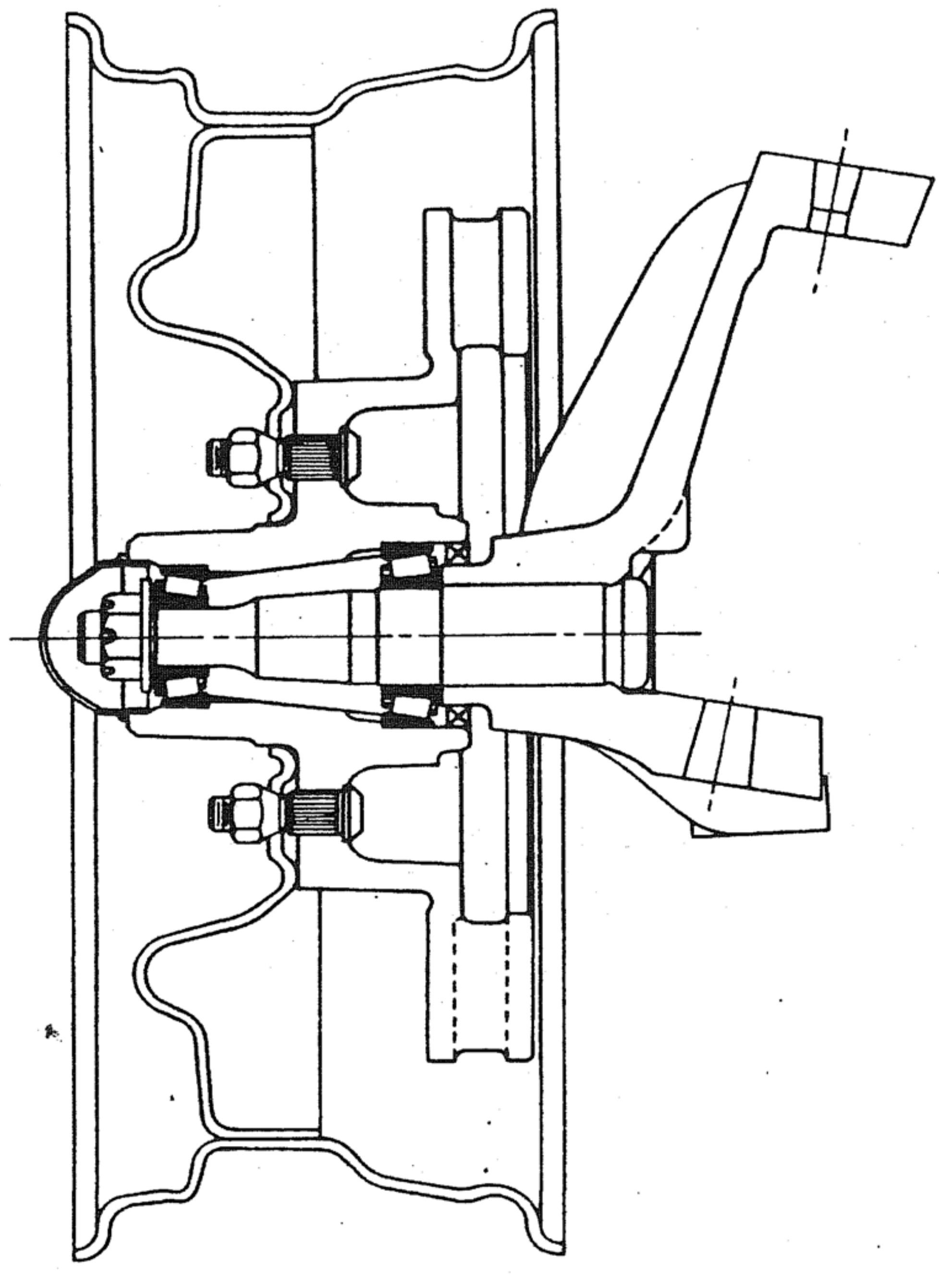
In some early front drive passenger cars, two identical tapered roller bearings were used to support the front drive wheels. The cones are press fit onto the rotating spindles and the cups are slip fit into the stationary knuckle. The bearings are lubricated and the end play set at the manufacturing plant. The endplay is set to several thousandths of an inch by means of a spacer between the cups. The entire package is sealed with two rubber lip seals and held in place by the drive shaft unit. See Figure 47.

Four tapered bearings are used in conventional drive axle assemblies. Two are used to support the pinion gear and two are used to support the ring gear. One pinion shaft bearing is shimmed to locate the pinion gear while the other is nut adjusted to preload the two bearings. One ring gear bearing is shimmed to locate the ring gear while a force fit between the two housing mounts preloads the two ring gear bearings. Bearing preloading minimizes gear deflection under higher loading conditions. See Figure 48.

Figure 49 shows three different gearbox arrangements with the pros and cons of each. Figure 50 shows the upper half of seven different bearing arrangements with the advantages and disadvantages of each.

Figure 46

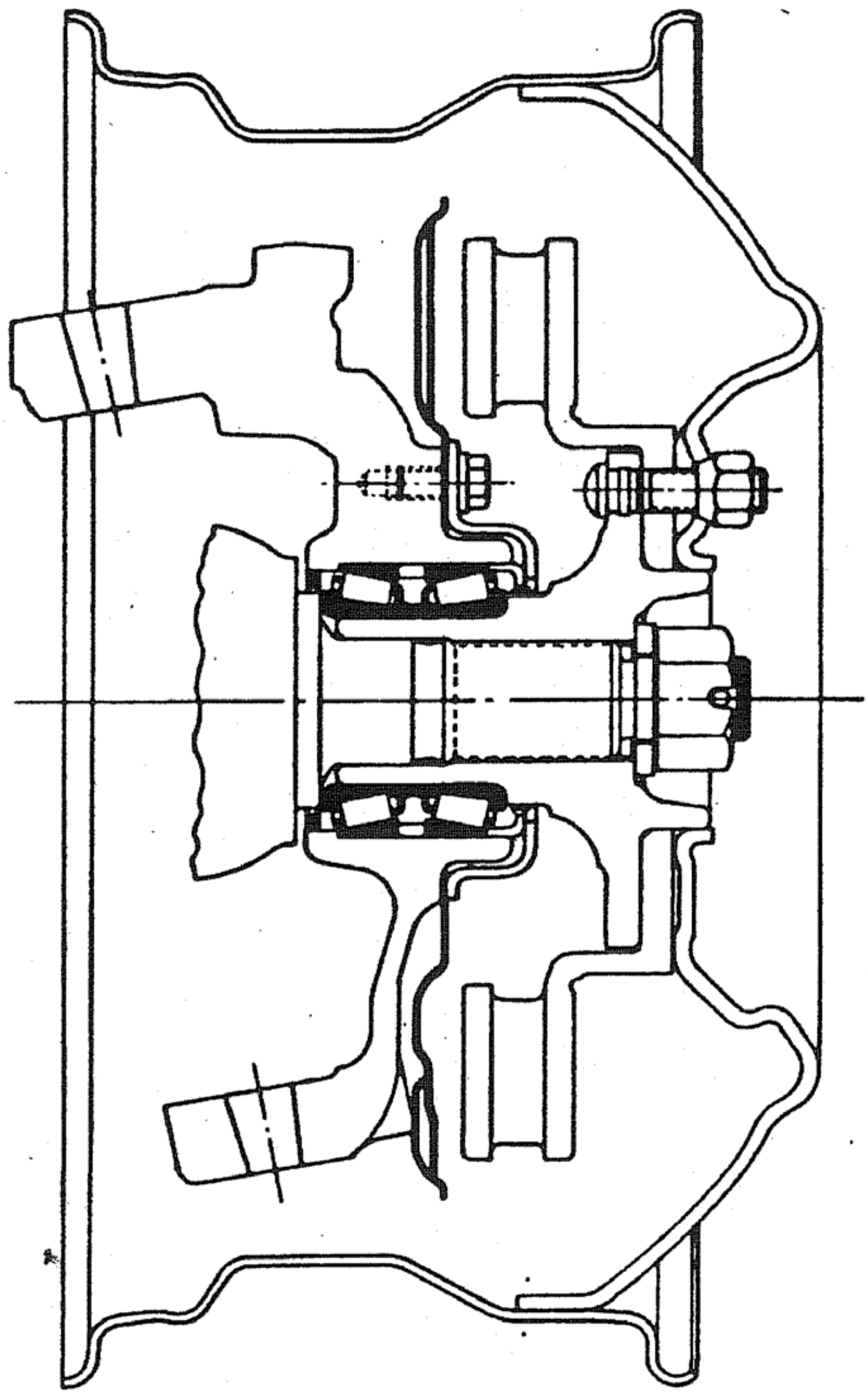
Tapered Roller Bearing Application



Non-Drive Wheel
Tapered Bearing Arrangement

Figure 47

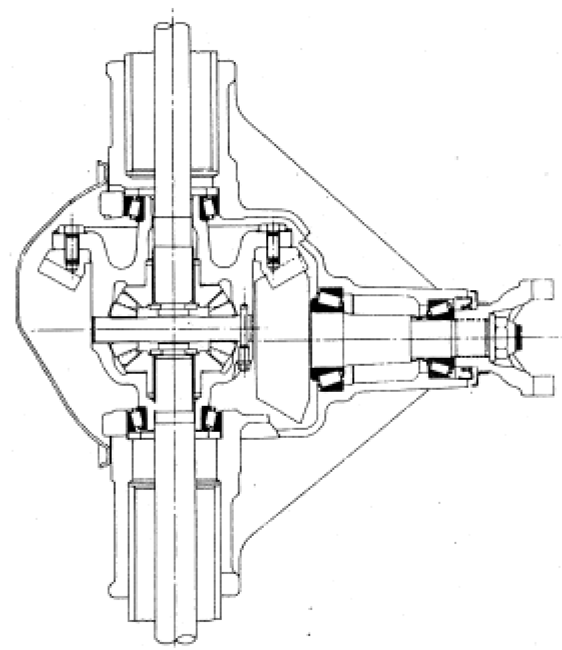
Tapered Roller Bearing Application



Drive Wheel Tapered Bearing Arrangement

Figure 48

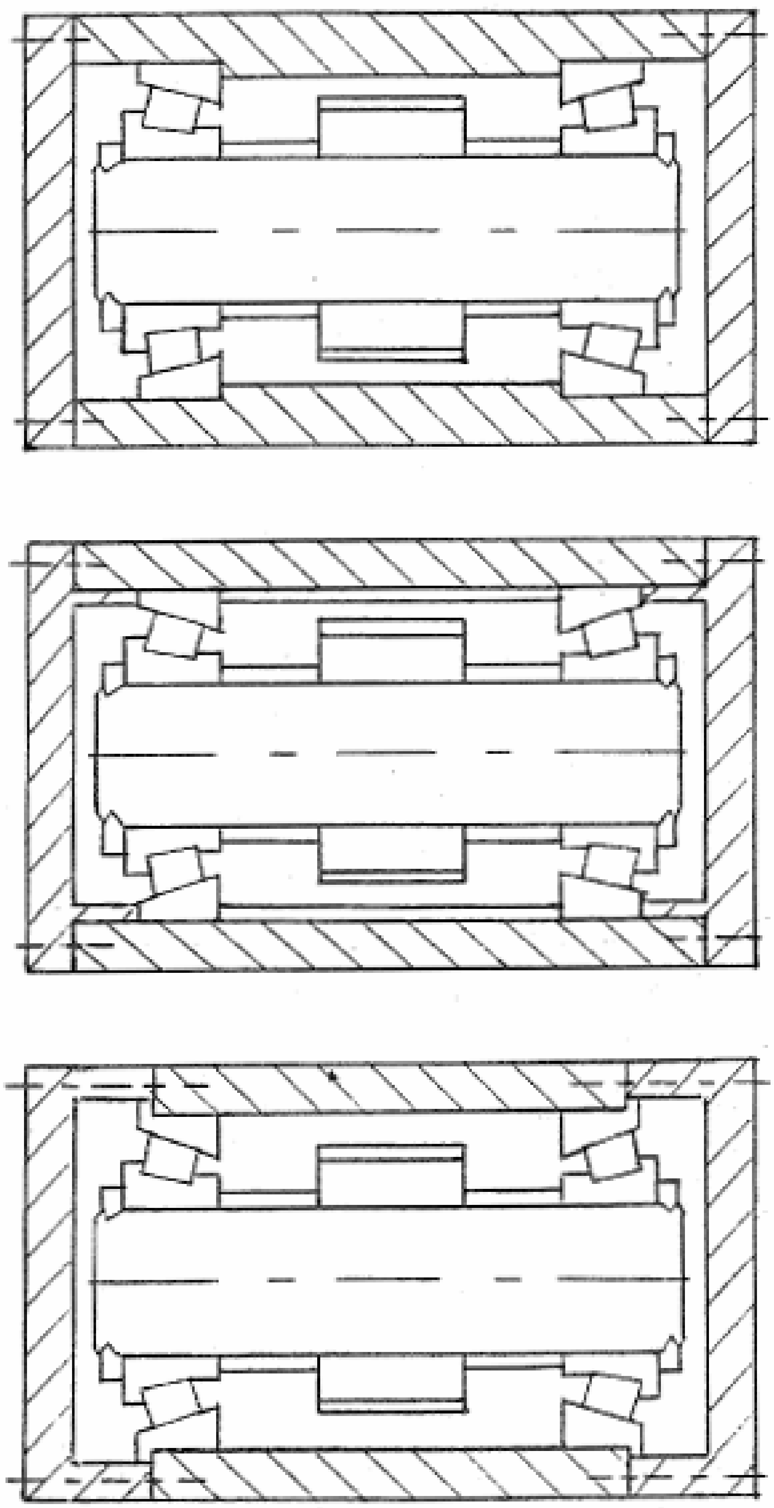
Tapered Roller Bearing Application



Drive Axle Bearing and Gear Arrangement

Figure 49

Tapered Roller Bearing Application



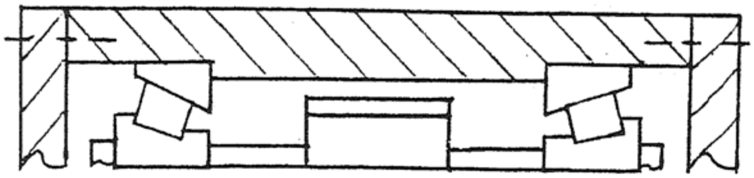
Standard bearing type.
Non thru-bored housing.
No cup spacer.
Plain end caps.

Standard bearing type.
Through-bored housing.
Cup spacer.
Extended end caps.

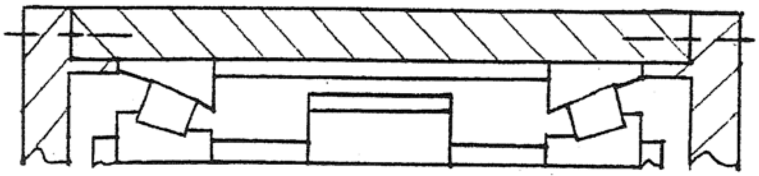
Flanged cup bearing.
Through-bored housing.
No cup spacer.
Extended end caps.

<u>Figure 50</u>

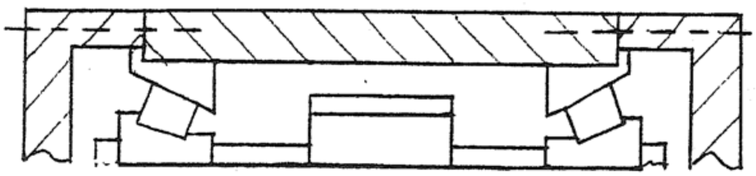
<u>Tapered Roller Bearing Application</u>



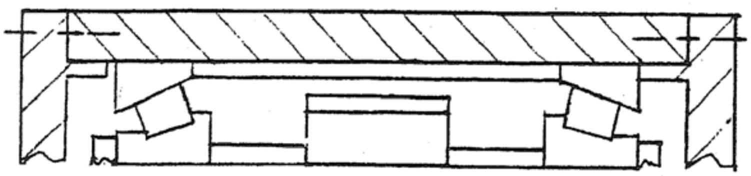
Good design for moment loading. Harder to assy.



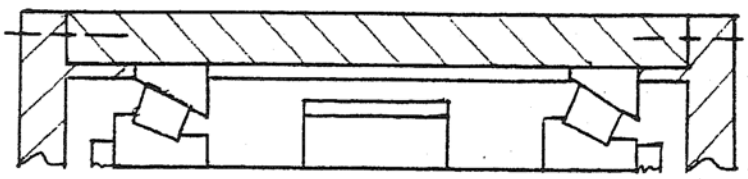
Good design for moment loading. Easier to assy.



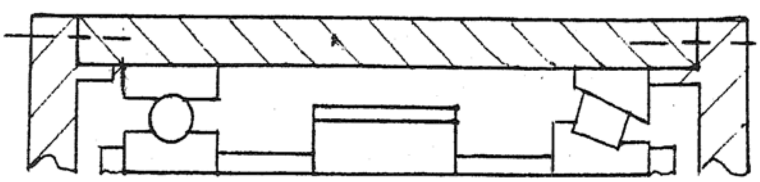
Good design for moment loading. Easier to assy.



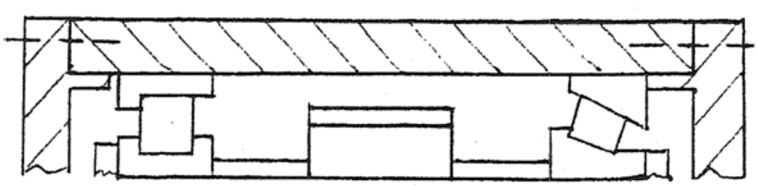
Good design for misalignment. Easier to assemble.



Good design for one direction thrust load.



No distinct advantage. Seldom used.



No distinct advantage. Not commonly used.

ELASTOHYDRODYNAMIC LUBRICATION

Elastohydrodynamic (EHD) lubrication refers to what happens to the oil between the ball or roller and the pathway of the bearing ring when the bearing is rotating. Research has shown that a film of oil builds up and can actually separate the ball or roller from the ring pathway. Thick films can result in longer bearing lives than what the previous formulas predict while thinner films result in metal-to-metal contact and shorter lives than what the formulas predict. Various factors affect the thickness of the oil film that is produced. Equations have been developed that calculate oil film thickness, which can be used to assist in the prediction of bearing performance. One equation used is as follows:

$$T=B(OS)^{0.7}xL^{-.09}$$

T is a measure of the oil film thickness. B is a bearing factor which takes into account the physical properties of bearings that influence oil film thickness. B is largely dependent on bearing size with larger diameter bearings developing thicker oil films. The kind of bearing used plays a more minor role with standard design ball and roller bearings falling into the middle of the category. O is an oil factor which is influenced primarily by oil viscosity at bearing operating temperature. The type of oil used plays a more minor role with napthenic being the best, paraffinic being in the middle, and synthetic being the worst. S is a speed factor which shows that higher speeds produce thicker oil films because of the wedging effect of oil into the contact zone. L is a load factor showing that higher loads result in thinner oil films. Graphs of all of the above factors have been developed which make it easy to calculate oil film thickness and its affect on bearing life. Use of the graphs simplifies the equation to the following:

$$T=BxOxSxL$$

The above equation can be used to predict the effect of the oil film on the life of the ball bearing in the original sample problem. B is the bearing factor and can be found on a graph. The ball bearing in the sample problem is a radial ball bearing and its bore is 17 mm, which are used to find the bearing factor. The speed factor is found based on the 2000 rpm of the bearing in the sample problem. The load factor is found based on the 172# effective load of the position 2 bearing in the sample problem. Substituting the numbers found on the graphs into the above formula results in the following:

$$T=44,000x(1/.0000001)x200x0.63=0.8$$

The graph shown on Figure 51, known as the "waterfall curve", can now be used to see that a T value of 0.8 puts the bearing in the region of "marginal lubrication". The equation will now be rearranged to find out what oil viscosity will result in a T factor of 2 which will put the bearing well up the waterfall curve. The new equation is as follows:

$$O=T/(BxSxL)$$

Inserting the values of the parameters results in the following:

$$O=2/(44,000x200x.63)=4x10^{-7}$$

From a graph, it can be found that in order to obtain an oil factor (O) of $4x10^{-7}$, the oil viscosity must be 290 SSU at operating temperature.

Figure 51

Elastohydrodynamic
Lubrication