Manufacturing of Ball Bearing

Course Project | ME 338: Manufacturing Processes II
Department of Mechanical Engineering, IIT Bombay

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Description:

A ball bearing is a rolling-element bearing that uses balls to maintain the separation between the bearing rings (races). It serves three primary functions while facilitating motion: it carries radial and axial loads, reduces rotational friction and positions moving machine parts. The main principle of ball-bearing is that the rotation of the balls causes a reduced coefficient of friction compared with flat surfaces rubbing against each other.

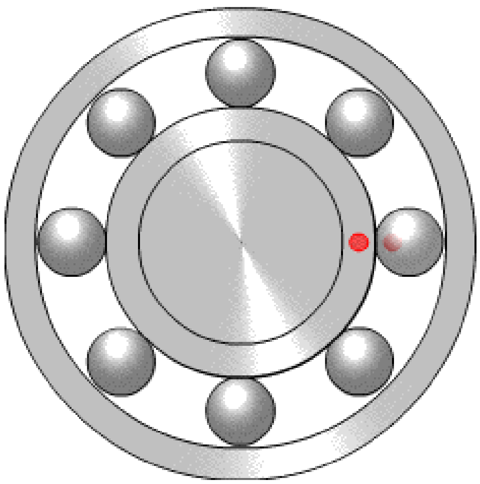


Figure 1: Typical Ball-Bearing
Source: [Ball-bearing]

A ball bearing consists of an inner ring (IR), an outer ring (OR), a complement of balls, and a separator to contain the balls. (See Figure 2.) The outer diameter of the inner ring (IROD) and the inner diameter of the outer ring (ORID) have a groove on which the balls roll on. This groove is commonly called the pathway. The raised surfaces on each side of the pathway are called the shoulders. 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 width (W).

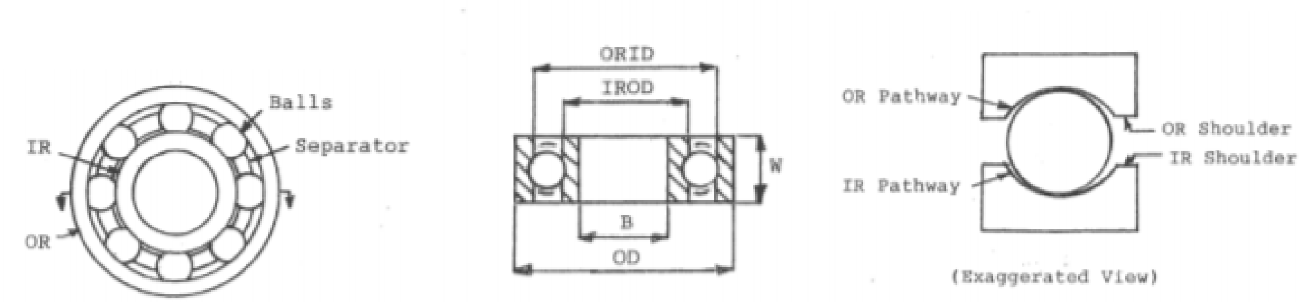


Figure 2: Design of Ball-Bearing
Source: Ball-Bearing: Design and Applications

In most applications, one bearing ring is stationary and the other is attached to the rotating assembly (e.g., a hub or shaft). As one of the bearing races rotates, it causes the balls to rotate as well. Ball bearings have lower load capacity for their size than other rolling-element bearings due to the smaller contact area between the balls and rings (races). However, they can tolerate some misalignment of the inner and outer bearing rings.

Applications:

Primarily the ball bearings are used to support the rotating shafts in mechanical instruments. However, it also serves to reduce the friction and thus the wear and tear caused by it. Modified and modern bearings are also able to support a significant amount of load. They do not bring any hindrance to the mobility and speed of the machine. Instead, bearings can be designed to enhance the operating speed of mechanical machines.

We can observe its presence:-

- In the household items: Bicycles, Sewing Machines, Washing Machines
- At the office: Xerox machines, Fax Machines, Fans
- In the Industries: Elevators, Dental Equipment, Wind Turbines, Pumps and Compressor
- In the automobile: Engines, steering, Transmission

Figure 3. Bearings in cycle wheel
Source: Link

Figure 4. Bearings in Transmission
Source: Link

Since it has a large area of applicability, it comes with engineering modification in its design. Based on specific applications, some standard designs enhance their particular application by a significant amount. For example:-

- Angular Contact Bearings: designed to work under combined radial and axial loads.
- Axial Bearings(thrust ball bearings): designed to work under the force applied parallel to the bearing's axis or thrust loads.
- Deep-Groove Bearings: designed to carry both radial and light axial loads.
- Linear Bearings: designed to allow movement in one direction along a linear axis.
- Self-aligning Ball Bearings: bearings with two sets of self-aligning balls and carry both radial and light axial loads.
- High-Speed Angular Contact Bearings: designed to handle high RPMs with precision and accuracy.

For analysis purposes, we shall consider Deep-Groove Ball Bearings as our product.

Approximate cost:

Product Considered: Radial Ball Bearing, Open, 20 mm Bore Dia., 42 mm Outside Dia. | Item # 35HZ52 | Mfr. Model # 6004/C3 | UNSPSC # 31171504

Pricing: **$7.14** / each (**₹530.51** / each)

Technical Specs

Item	Radial Ball Bearing	ABEC Tolerance	1
Unmounted Bearing Item	Radial Ball Bearing	Dynamic Load Capacity	2,110 lb
Single Row/Double Row	Single Row	Static Load Capacity	1,140 lb
Seal/Shield Type	Open	Max. RPM	18,000 RPM
Bore Dia.	20 mm	Temp. Range	-40 Degrees to 350 Degrees F
Bore Tolerance	+0/-0.01mm	Bearing Material	Steel
Outside Dia.	42 mm	Cage Material	Pressed Steel
Outside Dia. Tolerance	+0/-0.01mm	Industry Number	6004/C3
Width	12 mm		

Table 1. Technical Specs

Competition Product: Timken 6204 Deep Groove Ball Bearings (Bore Dia 20 mm, Outside Dia 47 mm, Width Dia 14 mm) | Item Code 100417194

Pricing: **₹170** / each

Components:

A typical rolling bearing consists of the following components:

- an inner ring
- an outer ring
- balls, as rolling elements
- a cage (and rivets to hold the cage)

Bearings can be equipped with seals and shields to protect the ball and cage from dust and water. However, they do not drastically affect the efficiency of the bearing.

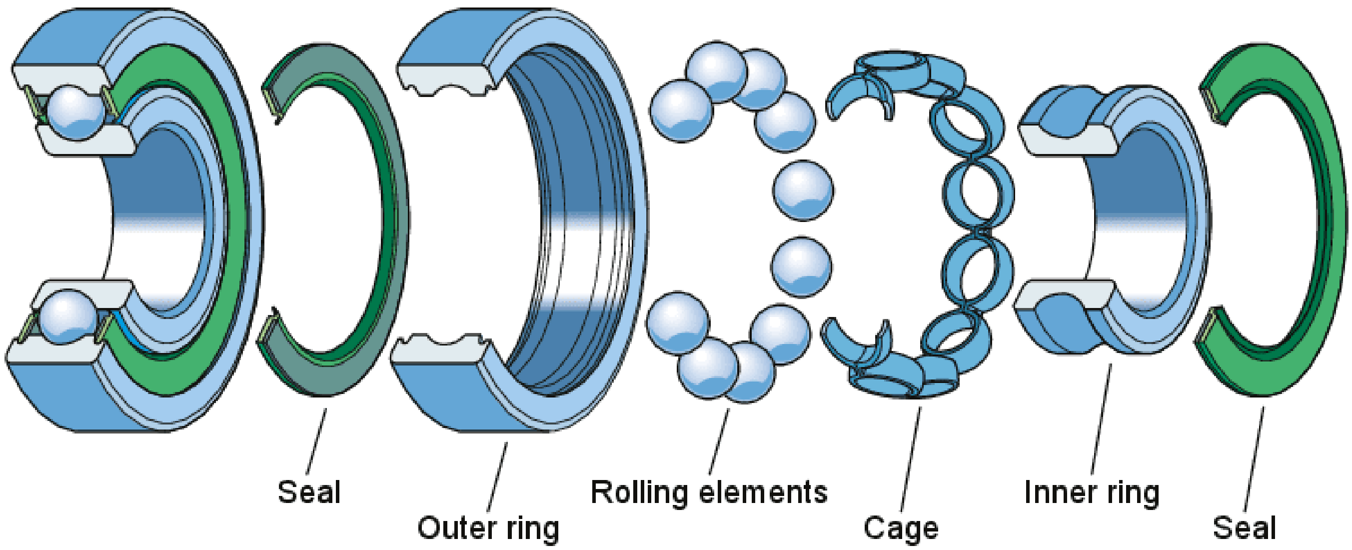


Figure 5. Ball-Bearing Components
Source: [Components and materials | SKF | SKF]

Inner Ring / Outer Ring:
The bearing ring on the inside, into which the shaft is inserted, is called the inner ring. It has a groove on its outer diameter to form a raceway for the balls. The surface of the outside diameter path is finished to extremely tight tolerances and is honed to be a very smooth surface. The one on the outside is called the outer ring and is inserted into the housing. There is a groove on its inside diameter on the outer ring to form a pathway for the balls. It also has the same high precision finish as the inner ring.
The inner and outer rings support a force applied perpendicularly to the shaft and are typically made from high-purity, chrome alloy steel. This material has the necessary hardness and purity, essential factors for high load ratings and long service life. The pressure at the rolling contact area and the cyclic over rolling creates fatigue in the bearing rings when the bearing is in operation. To cope with such fatigue, rings that are made of steel must be hardened.
The standard steel for bearing rings and rolling elements are AISI 52100, steel containing approximately 1% carbon and 1.5% chromium.

Unique materials such as ceramic and plastics are also used for production. Although plastics cannot withstand extremely high temperatures, they are considerably lighter than steel, making them invaluable in the automotive industry, where every ounce matters.

Rolling Elements:

Rolling elements can be balls, rollers, cones, spheres or needles. They transfer the load between inner and outer rings. They roll on the raceways of the rings, are separated and guided by the cage and permit the bearing to rotate with minimal friction. The dimension of the rolling elements is made slightly smaller than the track on the inner and outer rings. Rolling element dimensions are controlled to very high accuracy. Surface finish and size variations are important attributes. These attributes are controlled to a micro inch level. They are usually made from a special high-purity, chrome alloy steel. Special materials such as ceramic and plastics can also be produced. Bearings containing ceramic rolling elements are considered hybrid bearings and are becoming more and more common.

Cage:

The cage is responsible for keeping the rolling elements separated while guiding them in motion. The materials used include steel, brass and plastic. Solid metal cages can be produced using machining techniques, while pressed cages are made from sheet metal. Similarly, plastic cages can be machined from solid plastic or injection molded.
The primary purposes of the cage in bearings are to separate the rolling elements for reduced friction, maintaining a constant spacing between the inner and outer rings for optimized load distribution, accurately guide the rolling elements in the path during rotation and prevent the rolling elements from falling out when a bearing ring is removed during mounting or dismounting.
Cages centred on the rolling elements permit the lubricant to enter the bearing quickly. Ring centred cages, which provide more precise guidance, are typically used when bearings must accommodate high speeds, high vibration levels or inertia forces stemming from movements of the whole bearing.
The main cage types are:

- Stamped metal cages:

These are made of sheet steel or sometimes sheet brass. They are lightweight and withstand high temperatures.

- Machined metal cages:

These are made of brass or sometimes steel or light alloy. They permit high speeds, temperatures, accelerations and vibrations.

- Polymer cages:

These are made of polyamide 66 (PA66), polyamide 46 (PA46) or sometimes polyetheretherketone (PEEK) or other polymer materials. The good sliding properties of polymer cages produce little friction and, therefore, permit high speeds. Under poor lubrication conditions, these cages reduce the risk of seizure and secondary damage because they can operate for some time with limited lubrication.

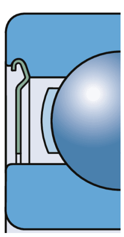
- Pin-type cages:

Steel pin-type cages need pierced rollers and are only used together with large-sized roller bearings. These cages have relatively low weight and enable a large number of rollers to be incorporated.

Figure 6. Different Cages
Source: [Components and materials | SKF | SKF]

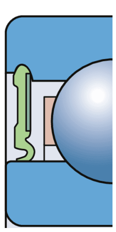
Integral Sealing:
Integral sealing can significantly prolong bearing service life because it keeps lubricant and contaminants out of it.

- Shields



Bearings fitted with shields are used where relatively clean operating conditions or low friction are essential because of speed or operating temperature considerations. This results in a bearing that has very low torque.

- Seals



Bearings with seals are preferred for arrangements where contamination is moderate. Where the presence of water or moisture cannot be ruled out, contact seals are typically used. These seals make positive contact with the sliding surface on one of the bearing rings.

Figure 7. Shield and Seal
Source: [Components and materials | SKF | SKF]

Design:

There are some types of ball bearings :

1. Radial ball bearings
    a. Deep groove
    b. Angular contact
2. Thrust ball bearings

We are majorly focusing on the Deep groove type of Radial ball bearings as our desired product. Radial, or deep groove bearings, can take radial and axial loads to vary degrees but are used when the primary load is radial. They consist of an inner ring, an outer ring, balls and sometimes a cage to contain and separate the balls.

Deep Groove Ball bearings:

The term ball bearing includes the roller bearing, the type of ball bearing most frequently used in terms of quantity. The technically correct term is a deep groove ball bearing. Deep grooves guide the balls in the inner and outer race with a narrow bevelling plane. The small contact areas between the balls and the raceway (point contact) make the rolling resistance very small. A cage keeps the balls apart and prevents them from touching. This leads to relatively low-friction loads being transmitted between parts of a machine that move with one another. The load transmission takes place between the ball and the inner or outer race. Modern ball bearings are assembled according to the Conrad method.

To reduce rolling friction, deep groove ball bearings are usually lubricated by oil or grease. A lubricating film is formed during the rotational movement between the ball and the raceway, preventing direct rolling contact (dry running). The lubricant has a significant influence on the reliability of a bearing. For this reason, modern roller bearings are filled with suitable roller bearing grease in the factory. Cover or sealing plates that are fitted additionally to the narrow ends ensure enough lubricant in the bearing and prevent soiling outside. This makes deep groove ball bearings maintenance-free for many applications.

In a deep-groove radial bearing, the race dimensions are close to the dimensions of the balls that run in it. Deep groove bearings support higher loads than a shallower groove. Like angular contact bearings, deep-groove bearings support both radial and axial loads but without a choice of contact angle to allow a choice of the relative proportion of these load capacities. The outstanding characteristics of ball bearings result from technically demanding quality characteristics that achieve maximum performance limits. Design is mainly oriented towards designing the bearings to support Axial, Radial and Moment loads while having low friction. Various measures in design can be taken in order to achieve the goals.

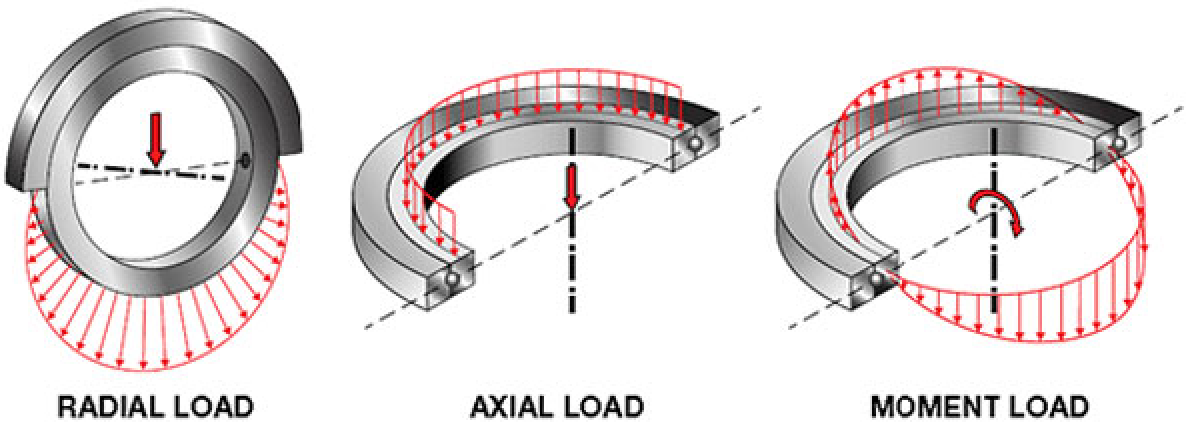


Figure 8. Load on Ball Bearings Source: Link

In the bearings, there are various dimensional bounds associated with each of the components of the bearing. Just to mention; ball diameter (Db), pitch diameter, number of balls(Z) etc. These correlated dimensional parameters affect the design of the bearings. The following discussion can illustrate this:

With increasing RPM (from about n · Dm = 1.5 . 106 mm / min.), the progressively increasing centrifugal force can cause a widening of the internal ring radially (d) and lead to functional impacts. For example:

- Slipping of the inner ring at the contact with the shaft and at the contact surfaces
- Frictional corrosion (due to increase in normal force)
- Vibrations

In order to counteract the lifting of the inner ring, a stronger fit is recommended.

Design Parameters:

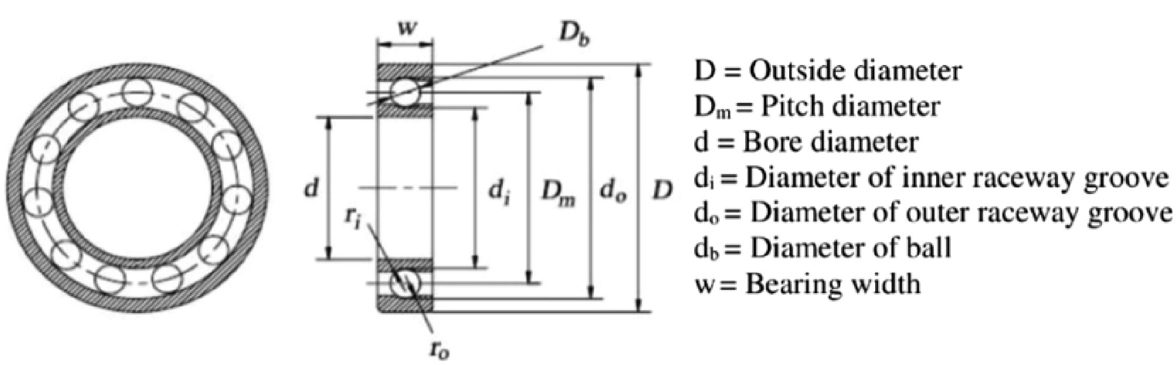


Figure 9. Ball Bearing Parameters Source: Link

D = **1.6535 in (42 mm)**	D_m = **1.22 in (31 mm)**
d = **0.7874 in (20 mm)**	D_b = **0.24 in (6.1 mm)**
w = **0.4724 in (12 mm)**	d_i = **0.49 in (12.45 mm)**
Z = **9**	d_o = **0.74 in (18.8 mm)**

The design parameters are internal structural dimensions of a ball bearing, as shown in Fig9. The five design parameters of ball bearing are the diameter of ball (Db), the number of balls (Z), pitch diameter (Dm) and curvature coefficient of the outer raceway groove (fo = ro/Db) and inner raceway groove (fi = ri/Db). ro and ri are the curvature radius of the outer and the inner raceway groove, respectively.
Table 2 shows the design parameters and their ranges. (Our ball bearing parameters fall in given ranges)

Design parameters	**Ranges**
Diameter of the ball (Db)	0.15(D−d) to 0.45(D−d)
Pitch diameter (Dm)	0.5(D+d) to 0.6(D+d)
Number of balls (Z)	4 to 50
Curvature coefficient of the inner raceway groove (fi)	0.515 to 0.52
Curvature coefficient of the outer raceway groove (fo)	0.515 to 0.53

Table 2: Allowable ranges of Design Parameters

Operating Specifications:

Necessary operating specifications to consider when searching for bearings include rated speed, dynamic axial or thrust load, and dynamic radial load.

- The rated speed for a bearing running with grease lubrication is lower than a bearing with oil lubrication.
- The dynamic axial or thrust load is the calculated constant axial load. A group of identical bearings with stationary outer rings can theoretically endure a rating life of 1 million revolutions of the inner ring.
- The dynamic radial load is the calculated constant radial load. A group of identical bearings with stationary outer rings can theoretically endure a rating life of 1 million revolutions of the inner ring.

Bearing Speed:

Bearing speed limitations are almost impossible to conclude from application to application. Several design factors directly correlate to speed capabilities, however:

- Size: Higher speeds can be obtained by more miniature bearings. These bearings have experienced less torque and have better precision. Miniature bearings usually have a thin, weak retainer and may be less capable.
- Ring rotation: A smaller inner ring can rotate 33% faster than its larger, outer ring counterpart.
- Retainer/cage material: In order of speed capabilities, phenolic and other nonmetallic materials (very high speed), hardened steel (high speed), entire race (moderate speed), loose-crimp ribbon (low speed), and PTFE spacers (low speed).

Calculating Basic Load Rating:

$$C = f_c(i\ cos\alpha)^{0.7} Z^{\frac{2}{3}} D^{1.8}$$

Where C = basic load rating (lbs)

i = number of rows of balls in the bearing (1 in our case)

α= nominal contact angle, degrees (0 degrees in our case)

Z = number of balls in a single row = 9

D = ball diameter (in) = 0.24

f_c= geometry factor of bearing = 4550 in

For f_c, we have to calculate $Dcos\alpha/d_m$, where d_m is the mean diameter of the inner and outer ring

$Dcos\alpha/d_m$ = 0.24/1.22047 = 0.19665

According to table 2 of this, f_c= 4550 in

Putting values to get C = 1508.6 Lbf

This is an average of dynamic load capacity and static load capacity.

For our product:

Dynamic load capacity: 2,110 lb

Static load capacity: 1,140 lb

Max. RPM: 18,000 RPM

The fatigue life of a bearing (in millions of revolutions) that is subjected to applied dynamic equivalent radial load F is given as:

$$L_{10} = (\frac{C}{F})^a \text{ and } L_{10h} = \frac{10^6}{60n} L_{10}$$

Where

L10 is rated bearing life (in millions of revolutions),

C is dynamic load capacity (N),

F is applied dynamic equivalent radial load (N),

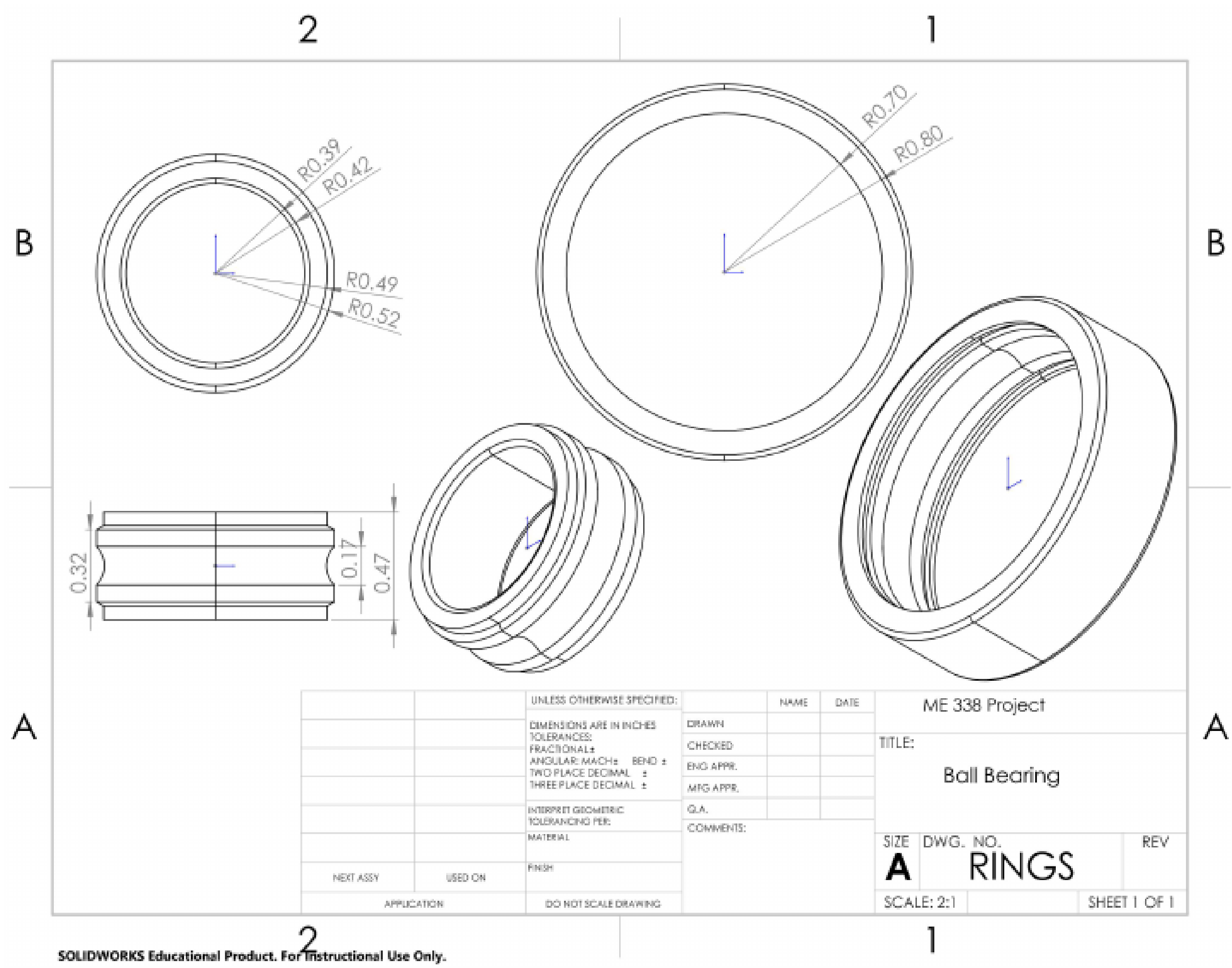
a is 3 for ball bearings,

L10h is rated bearing life (in operating hours) and n is rotational speed in rpm.

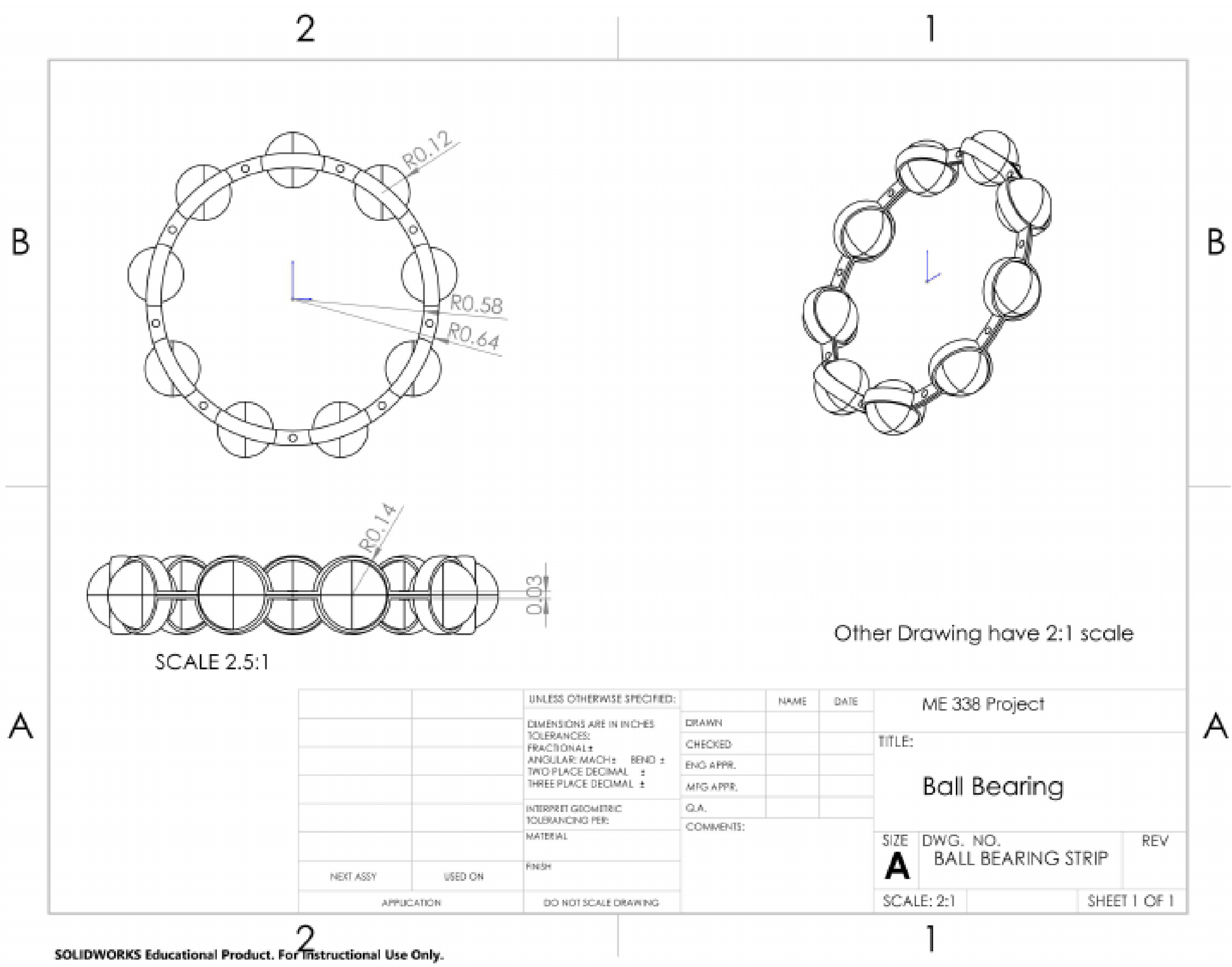
Note: Here, the values of F and n are dependent on the application of ball bearing. We can use this formula to determine the Fatigue life of ball bearing for given F and n.

Engineering Drawings:

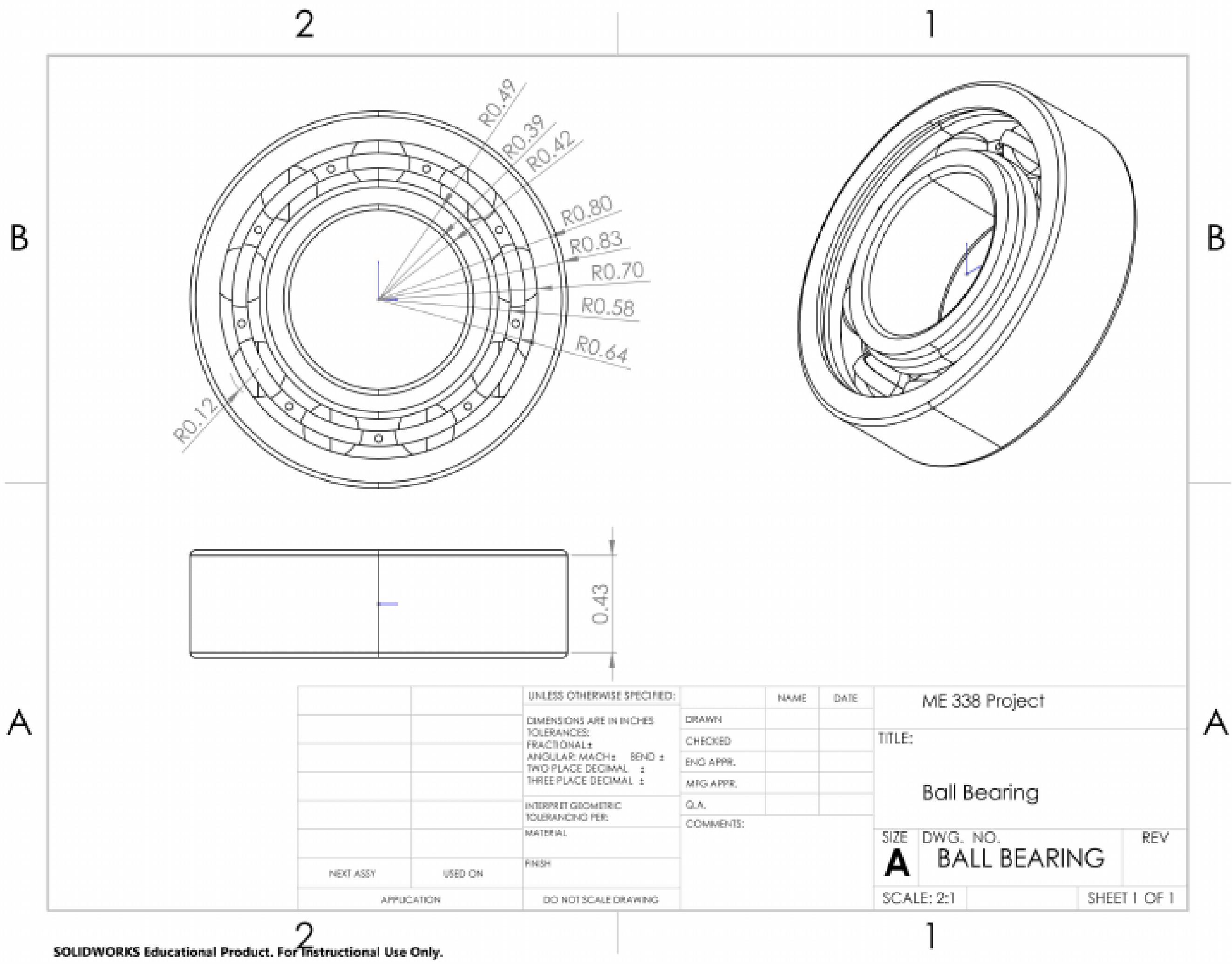
Inner and Outer Ring - Engineering Drawings



Retainer and Balls - Engineering Drawings



Ball Bearing - Engineering Drawings



Materials and (corresponding) Process Selection:

Reference Video: [Bearings Manufacturing Process By Kasuma Auto Engg. Pvt. Ltd. - YouTube]

Inner and Outer Ring:

The bearing rings are subjected to repetitive high pressure with a small amount of sliding. Therefore, the materials used for rings require the following characteristics:

- High strength against rolling contact fatigue due to large repetitive contact load
- High hardness
- High wear resistance
- High dimensional stability
- High mechanical strength

Other necessary characteristics, such as easy production, shock and heat resistance, and corrosion resistance, are required depending on individual applications.

Comparison of standard solutions

Classification of material and heat treatment according to performance capability under various requirements.

Material solution, heat treatment	Resistance to						Price[1]
	Fatigue	Thermal influences	Sliding (slippage) load	Mechanical shock[2]	Particle overrolling	Corrosion[3]	
100Cr6, martensite SN (reference 1)	≡	–	≡	≡	≡	≡	≡
100Cr6, martensite S0 (reference 2)	≡	≡	≡	≡	≡	≡	≡
100Cr6, martensite S1	≡	+	+	–	– –	–	≡
100Cr6, bainite S1	+	+	+	+	+	–	≡
St4, case hardened	–	–	≡	≡	≡	≡	≡
100CrMnSi6-4, modified martensite	+	≡	≡	≡	+	≡	ˆ
100CrMnSi6-4, carbonitrided	++	–	+	≡	++	–	ˆ
Case hardening steel, case hardened	+	≡	+	+	++	–	ˆ
Case hardening steel, carbonitrided	++	≡	+	+	++	–	ˆ
Cronidur 30	+++	≡ … ++[4]	++	≡	++	++	ˆˆ
Cronitect	+	≡	+	≡	≡	++	ˆ

In technical comparison with reference:
+++ Excellent
++ Significantly better
+ Better
≡ Identical
– Worse
– – Significantly worse

In price comparison with reference:
ˆ Slightly more expensive
ˆˆ More expensive

1) The cost-effectiveness only provides an initial qualitative indication, while the costs and prices are essentially dependent on the product and quantity.
2) Stress peaks in the region of the static load carrying capacity.
3) The classification can differ depending on the medium and the temperature.
4) ≡ With standard heat treatment (W230),
++ With heat treatment for dimensional stabilisation (W230S, secondary hardening).

Table 3. Comparison of Standard Solutions Source: [Link]

Various materials with different compositions of elements are used in the manufacturing of the rings. Selection heavily depends on the application of the bearings. Some commonly used materials along with their properties are given as follows:

Comparison of special solutions

Classification of material and heat treatment according to performance capability under various requirements.

Material solution, heat treatment	Resistance to						Price[1]
	Fatigue	Thermal influences	Sliding (slippage) load	Mechanical shock[2]	Particle overrolling	Corrosion[3]	
100Cr6, martensite SN (reference 1)	≡	–	≡	≡	≡	≡	≡
100Cr6, martensite S0 (reference 2)	≡	≡	≡	≡	≡	≡	≡
M50, martensite	≡	++	≡	≡	–	–	^^
M50NiL, case hardened	++	++	++	++	+	–	^^
Austenite, carburised	–	+	≡	≡	–	+	^^
M50NiL, duplex hardened	++	++	++	++	++	–	^^^
32CrMoV13, nitrided	++	++	++	+	++	≡	^^
Vacrodur	+++[4]	+++	++	++	+++	≡	^^
Cermadur	++	+++	+++	≡	+++	+++	^^^
Si_3N_4 (rolling elements)	+	+++	++	≡	≡	++	^^^
ZrO_2 (rolling elements)	–	+++	≡	–	–	+++	^^

In technical comparison with reference:
+++ Excellent
++ Significantly better
+ Better
≡ Identical
– Worse

In price comparison with reference:
^ Slightly more expensive
^^ More expensive
^^^ Significantly more expensive

1) The cost-effectiveness only provides an initial qualitative indication, while the costs and prices are essentially dependent on the product and quantity.
2) Stress peaks in the region of the static load carrying capacity.
3) The classification can differ depending on the medium and the temperature.
4) Higher performance capability compared with Cronidur 30.

Table 4. Comparison of Special Solutions   Source: Link

1. Heat-treated high carbon chromium bearing steel (HCC Steel) is the most common material used for rings and balls.
    - Due to its low chromium content, it exhibits poor corrosion resistance.
    - The material does exhibit good mechanical properties up to 250℉ continuously. Above 250℉ bearing life is reduced as well as load capacity.
    - Dimensional changes occur that require compensation in the overall bearing design and bearing fits.
    - (AISI) 52100 is magnetic.

Standard	Code	Chemical composition (%)						
		C	Si	Mn	P	S	Cr	Mo
JIS G 4805	SUJ 2	0.95 - 1.10	0.15 - 0.35	Not more than 0.50	Not more than 0.025	Not more than 0.025	1.30 - 1.60	Not more than 0.08
	SUJ 3	0.95 - 1.10	0.40 - 0.70	0.90 - 1.15	Not more than 0.025	Not more than 0.025	0.90 - 1.20	Not more than 0.08
	SUJ 5	0.95 - 1.10	0.40 - 0.70	0.90 - 1.15	Not more than 0.025	Not more than 0.025	0.90 - 1.20	0.10 - 0.25
SAE J 404	52100	0.98 - 1.10	0.15 - 0.35	0.25 - 0.45	Not more than 0.025	Not more than 0.025	1.30 - 1.60	Not more than 0.06

Table 5. Variety of HCC Steel with various compositions   Source: Link

2. Stainless steel materials are also used because they are more resistant to surface corrosion due to the higher content of chromium (~18%) with the addition of nickel. The chromium reacts with oxygen to form a layer of chromium oxide on the surface, creating a passive film.
    - Heat-treated 440C Stainless Steel offers fair to good corrosion resistance. It is the most common stainless steel used for rings and balls. The load capacity of 440C is about 20% less than that of 52100. With design considerations, this material can handle service temperature up to 350℉ with adequate load capacity. Beyond 350℉, capacity and life are reduced.
    - 300 series stainless steel can be chosen for improved corrosion resistance over 440C. These materials are not heat-treated, so load capacity is significantly less than AISI 52100 & 440C.
3. Hybrid and full ceramic bearings are made using Silicon Nitride (Si_3N_4) or Zirconium Oxide (ZrO_2) material.
    - The density of ceramic is 40% that of steel. The resulting weight reduction reduces centrifugal forces imparted on the rings, reducing skidding, allowing up to 30% higher running speeds with less lubrication.
    - Ceramic has a lower coefficient of friction and is nearly twice as hard as bearing steel resulting in minor wear with less lubrication. Bearing life can be increased.
4. Numerous types of plastics can be used to produce semi-precision bearings.
    - Environment compatibility determines the variety. Acetal (Delrin) is the most common for the rings with either acetal or stainless steel balls.
    - Other materials such as PEEK, PPS, Vespel, Nylon and many others can be used for the rings.
    - Lightly loaded low RPM applications requiring corrosion resistance, non-magnetic/non-metallic and lightweight bearings may benefit from a plastic ball bearing.

AISI (or SAE) 52100 - Chrome Steel:
For our analysis purposes, we shall use AISI 52100, a high carbon, chromium containing low alloy steel, as the material of the inner and outer ring of the bearing. Some of its characteristics are as follows:
- High wear resistance
- High rolling fatigue strength
- Higher hardness → longer life ratings
- Cost-effectiveness
- Good for temperatures of 120°C constants; up to 150°C intermittent
- Poor corrosion resistance

This is the standard steel for most ball bearings. It is harder than stainless steel, thus having more excellent life ratings. It also has superior low noise qualities to standard 440-grade stainless steel. Chrome steel has a low chromium content and is therefore not corrosion resistant. Chrome steel can tolerate continuous temperatures of up to 120°C. Above this temperature, it undergoes greater

dimensional change and the hardness is affected, reducing load capacity. It can withstand up to 150°C intermittently but above this temperature, bearing life is significantly reduced.
The chemical composition of AISI 52100 alloy steel is as follows:

Element	Content (%)
Iron, Fe	96.5 - 97.32
Chromium, Cr	1.30 - 1.60
Carbon, C	0.980 - 1.10
Manganese, Mn	0.250 - 0.450
Silicon, Si	0.150 - 0.300
Sulfur, S	≤ 0.0250
Phosphorous, P	≤ 0.0250

Physical properties of AISI 52100 alloy steel are as follows:

Properties	Metric	Imperial
Density	7.81 g/cm^3	0.282 lb/in^3
Melting point	1424°C	2595°F

Mechanical properties of AISI 52100 alloy steel are as follows:

Properties	Metric	Imperial
Bulk modulus (typical for steel)	140 GPa	20300 ksi
Shear modulus (typical for steel)	80 GPa	11600 ksi
Elastic modulus	190-210 GPa	27557-30458 ksi
Poisson's ratio	0.27-0.30	0.27-0.30
Hardness, Brinell	-	-
Hardness, Knoop (converted from Rockwell C hardness)	875	875
Hardness, Rockwell C (quenched in oil from 150°C tempered)	62	62
Hardness, Rockwell C (quenched in water from 150°C tempered)	64	64
Hardness, Rockwell C (quenched in oil)	64	64
Hardness, Rockwell C (quenched in water)	66	66
Hardness, Vickers (converted from Rockwell C hardness)	848	848
Machinability (spheroidized annealed and cold drawn. Based on 100 machinability for AISI 1212 steel)	40	40

Thermal properties of AISI 52100 alloy steel are as follows:

Properties	Metric	Imperial
Thermal expansion co-efficient (@ 23-280°C/73.4- 36°F, annealed)	11.9 µm/m°C	6.61 µin/in°F
Thermal conductivity (typical steel)	46.6 W/mK	323 BTU in/hr.ft². °F

It can be hardened by cold and hot working processes, responds to annealing and tempering, and can be strengthened using the heat treatment process. It is readily forged and formed, as well as machined, from its annealed condition. It is beneficial in bearings, mill rolls, and vehicle parts due to its combination of strength, hardness, and workability. The most common form of 52100 stock is bar stock, but it can also be found in tube, wire, flat-rolled, and forging stocks.

Manufacturing Process: (of bearing rings - inner and outer)
Material: heat-treated AISI 52100 steel in the form of bars

1. Forging:
    - The material bar is first heated then cut. It is then pressed by machine and molded into inner and outer ring shapes. The designated shapes are formed by hot forging.
    - Forging is used to obtain the semi-finished ring similar to the bearing, to enhance the efficiency of metal material and reduce the mechanical machining work, thus saving the cost of production.
    - Hot forging, wherein metal piece is heated to above the crystallization temperature, is widely used.
2. Turning:
    - Rough turning removes the oxide skin of parts and reserves a margin according to the size of the finished product.
    - The turning of the inner ring:
        - First, the surface on one side is cut, then the other. After that, the bore is cut. Then, it is chamfered. Finally, the raceway is cut, and the turning of the inner ring is completed.
    - The turning of the outer ring:
        - Similar to that of the inner ring.
        - The marks are stamped on the side surfaces of the ring, indicating information such as the brand and part number. Nowadays, more manufacturers are using laser marking machines for stamping purposes.
    - Turning is used to make the bearing ring and roller be the same shape as the finished products.
    - Automatic machines similar to lathes use cutting tools to cut the basic shape of the race, leaving all of the dimensions slightly too large. The reason for leaving them too large is

that the races must be heat treated before being finished, and the steel usually warps during this process. They can be machined (by grinding process) back to their finished size after heat treating.

3. Heat Treatment:
    - Because the inner and outer rings work under tremendous pressure and repeatedly go through rolling motions, they must be highly rigid and wear-resistant.
    - So, they have to go through quenching, where they are heated between 800℃ and 860℃, then instantly cooled by dipping into an oil bath.
    - They are held at 1450℃ to 2000℃ for an extended period to boost wear resistance, then cooled slowly. This process is called tempering. Tempering must be done soon after quenching to reduce the risk of cracking.
    - This whole heat treatment process improves the inner quality of rings, thus making them both hard and tough.
    - After this test, a hardness test is performed to ensure that the process has been according to the standards.
4. Grinding:
    - After the heat treatment process, the rings are ready for finishing. However, the rings are now too hard to cut with cutting tools, so the rest of the work must be done with grinding wheels.
    - For the grinding of the outer ring, the side surface of the ring is first ground. Then the outer surface is ground so that it is precisely perpendicular to the side surface. Then using the outer surface as a reference, the raceway groove is honed. The exact process applies to the inner ring.
    - It is the final processing of the bearing ring. Hence it is also called finished product processing.
    - The ring produced must be finely ground, and the ovality, flatness, and wall thickness of the bearing ring can be effectively controlled to ensure the accuracy of finished bearings.
    - Almost every place on the race is finished by grinding, which leaves a very smooth, accurate surface. A very fine abrasive slurry is used to polish the races for several hours to get almost a mirror finish.
    - Grinding makes the bearing ring be in accordance with the design requirements in size and shape precision, thus qualifying it for the assembly stage.

Cage :

Cages greatly influence the performance and reliability of rolling bearings. Material for cage manufacturing is chosen in accordance with:

- geometry of bearing
- ease of lubrication
- Strength
- abrasion resistance.

There are some metallic and nonmetallic options for material selection to manufacture the cage.

Among non-metallic materials, phenolic resin machined cages and other synthetic resin molded cages are often used. Materials typically used for molded cages are polyacetal, polyamide (Nylon 6.6, Nylon 4.6), and fluorine polymer, strengthened with glass and carbon fibres. Standard plastic corrosion-resistant bearings have nylon (**PA66**) cages. They will, however, corrode in the presence of certain chemicals and PA66 cages will absorb water after long exposure causing loss of tensile strength. Several alternative materials for cages are available such as polypropylene, **PTFE**, **PEEK**, or **PVDF**.

Phenolic Resin - Retainers are manufactured from linen and or paper-based phenolic materials because of their ability to absorb oil lubricants. During bearing operation, the lubricants are wicked or forced out of the retainers due to G-forces, which provide extra lubricant to the rolling and sliding elements. The phenolic materials are manufactured from linen or paper sheets coated with a phenyl formaldehyde resin which are rolled into tubes under high heat, tension, and pressure. Phenolic tubes for ball bearing retainers should be formed with less tension and pressure than the tubes manufactured for structural end-use. This ensures that the paper and linen fibers are not filled with the resin, leaving virgin paper or linen available to absorb and act as a reservoir for oil lubricants. The retainers are then machined from the tubes.

PEEK and **Vespel** are generally considered vacuum compatible. **PPS** offers the most significant chemical resistance and along with **PEEK,** is FDA and USDA compliant. **PEEK** and **PPS** offer the highest speed capability as a retainer material. Material compatibility in critical and or sensitive environments such as vacuum applications is subject to your bench testing and datasheet evaluation. Since application environments vary greatly, the following chart is simply a guideline.

Material	Max Temp	Speed (dN)*%	Outgassing	Particle Generation	Cost
PEEK	480 F	650,000	Excellent	Excellent	Moderate
PPS	425 F	650,000	Good	Excellent	Moderate
VESPEL	500 F	600,000	Excellent	Excellent	High
TORLON	500 F	600,000	Excellent	Excellent	Moderate
TEFLON	550 F	30,000	Good	Good	Low
NYLON	250 F	250,000	Poor	Good	Low
PHENOLIC	300 F	600,000	Poor	Poor	Low

Table 6. Properties of Different materials Source: Link

Upon analyzing various materials, we have concluded that using metallic material is suitable for our case. Since the rings and balls are themselves made up of metals, which inclines us to choose metallic material to reduce abrasion and other limitations in the application.

SPCC steel is a commercial quality cold-rolled steel. SPCC is a material grade and designation defined in JIS G 3141 standard. As a basic Carbon Steel, it can be enumerated in dead mild steel. JIS G 3141 is a Japanese material standard for cold-rolled steel.

SPHC steel is a commercial quality hot rolled steel. SPHC is a material grade and designation defined in JIS G 3131 standard. JIS G 3131 is a Japanese material standard for hot-rolled steel. The commercial quality hot rolled steel is a type of steel that can be used commercially for forming purposes that can also include the shearing of a metallic sheet. SM570 Steel is also hot roll steel but it is used explicitly for welded structures because of its high material strength.

Typical materials used for metallic cages are shown in the following table
(A) Chemical compositions of pressed cage steel sheet
(B) Chemical compositions of machined cage carbon steel

	Standard	Code	Chemical composition(%)						
			C	Si	Mn	P	S	Ni	Cr
(A)	JIS G 3141	SPCC	Not more than 0.12	-	Not more than 0.50	Not more than 0.040	Not more than 0.045	-	-
	JIS G 3131	SPHC	Not more than 0.15	-	Not more than 0.60	Not more than 0.050	Not more than 0.050	-	-
	BAS 361	SPB 2	0.13 - 0.20	Not more than 0.04	0.25 - 0.60	Not more than 0.030	Not more than 0.030	-	-
	JIS G 4305	SUS 304	Not more than 0.08	Not more than 1.00	Not more than 2.00	Not more than 0.045	Not more than 0.030	8.00 - 10.50	18.00 - 20.00
(B)	JIS G 4051	S 25 C	0.22 - 0.28	0.15 - 0.35	0.30 - 0.60	Not more than 0.030	Not more than 0.035	-	-

Table 7. Chemical Composition of Different materials Source: Link

SPHC is the input material to make SPCC. Even though SPCC has some advantages over SPHC, it is not a great choice economically. SPHC being cheaper than SPCC it is easily manufactured and thus easily available. For our analysis, we are using SPHC of the JIS G 3131 standard.

- The tensile strength of the SPHC Steels is expressed in Newton per millimeter and must be at least 270 N/mm2 (MPa).
- Bending, shaping, lancing, piercing, etc. all are common operations that can be done on these steels.
- Density being 7.8 - 7.9 g/cm^3 at 23 degree centigrade
- Elastic Modulus 200-215 GPa at 23 degrees centigrade
- Poisson's ratio 0.29
- Shear Modulus 82GPa at 23 degrees centigrade
- Tensile Strength 270MPa at 23 degrees centigrade
- Coefficient of thermal expansion 1.32E-5 - 1.38E-5 1/K
- Melting Point 1480 - 1526 degree centigrade
- Specific heat capacity 456 J/(kg)(K)
- Thermal Conductivity 25 - 93 W/(m)(K)

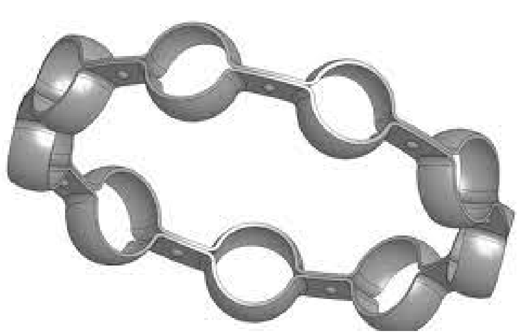
Manufacturing of the cage:

1. **Steel sheet punching**

Firstly, a circular disk is punched out from the desirably thick steel sheet leaving holes in it. Then again, the sheet is punched around the previously punched holes. This gives us a circular ring which we have to process further.

Figure 10: Punched ring Source: Link

2. **Forging**



Then these rings are placed into the die. These die bend the ring so that it creates a semi-circular room where balls can be placed. Also, these die to make holes for the rivets. Once this is done, we have half part of the steel cage. Once a pair is ready for such parts, then it can be sent to be assembled in the ball bearings as a cage.

Figure 11. Assembled two half rings Source: Link

Ball:

Material:

Bearing balls are also most commonly manufactured from AISI 52100 steel. Other bearing ball materials include AISI 440C stainless and other stainless materials, ceramic, glass, and even plastic.

The AISI 52100 is a high-carbon chromium alloy steel explicitly developed for the use of ball bearings. Its high resistance to wear and plastic deformation, without fracture, are what make this steel a high-quality choice for ball bearing applications

Ball Manufacturing:

Bearing balls are manufactured using a multi-step process:

1. Balls start as a wire or rod slug containing the proper amount of material required in the finished ball
2. The slugs then undergo a cold heading process to form a nearness spherical shape
3. The balls are then filed or tumbled to remove flash and burrs
4. Soft grinding is employed to produce balls of uniform size
5. Balls are hardened using a process similar to the one used for bearing rings
6. The hardened balls undergo a finish grinding process to achieve finished size and roundness specifications
7. Finally, the balls undergo a lapping process to achieve final tolerances and surface finish requirements

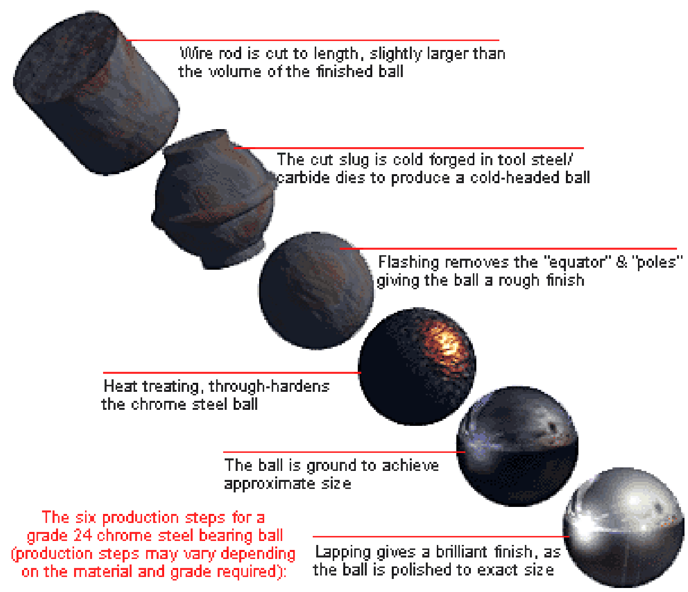


Figure 12. Bearing ball manufacturing process
Source: [Link]

Slug forming

Metal bearing balls are manufactured from steel wire or rods. During the first step in the process, the wire or rod is cut into small slugs pieces. The volume of material for the slug is slightly larger than that of the finished ball. The excess material is removed in subsequent machining steps. At this stage, the material has not been hardened and is somewhat malleable. This is important so that the slug can be formed into a spherical shape in the next manufacturing step.

Heading

The slug is then fed to a header machine, where the balls are put through a cold-forming process called heading. In cold heading, the slug is placed between two semi-spherically shaped dies and shaped under pressures between 10 and 20 tons. It is a high-speed process and can be very loud, especially for large-diameter balls, requiring ear protection for machine operators. Heading forms the slug into a spherical shape called a raw ball. There is a bit of excess material that still needs removal.

Flashing

The excess material, called flash or burrs, needs to be filed away. This is done in the flashing process, also referred to as filing. This removes the flash, but they are not yet perfectly round and the metal is still soft. Manufacturers use two different machining variations, but both involve rolling the balls between metal plates.

1. Flash is removed by rolling them between heavy cast-iron plates that rotate in opposite directions.
2. Flash is removed by passing the balls between grooves in two metal plates, one rotating and one stationary.

Figure 13. A cold-headed ball with flash present Source: [Link]

Soft grinding

Some manufacturers will then put the balls through a soft grinding process. It is referred to as soft because the material is not yet hardened. This operation is similar to the flashing process but an abrasive grinding stone is used instead of one of the metal plates.

Heat treating

Now that the balls have had the excess material removed and are relatively round, they are put through a heat-treating process to harden and strengthen. The balls are heated to approximately 1,500° F and then quenched in an oil bath. They are heated again to a much lower temperature—approximately 325° F, resulting in a through-hardened ball.

Descaling

After heat treating, the balls are discoloured and covered with oxide deposits. To remove these deposits, the balls are put through a process called descaling. Descaling involves using a chemical agent, usually an acidic compound, to remove the build-up on the balls.

Grinding

Now that the balls are hardened and relatively round, they are nearing the end of the manufacturing process. The next step is to grind the balls to size them and improve roundness geometry. The process is similar to the soft grinding process used earlier — the balls are rolled between a steel plate and a fine-grit grinding wheel.

Lapping

The last step in the process is to lap the balls. Lapping is a superfinishing process that improves the surface finish or geometry and removes tiny amounts of material so that the balls attain the tight, required tolerances.

The balls are rolled between two hardened steel plates, one fixed and one rotating at a low speed. The balls are now perfectly round and have a mirror-like finish.

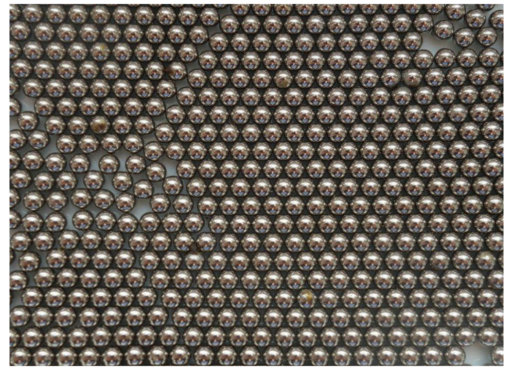


Figure 14. Finished steel balls Source: [Link]

Washing and sizing

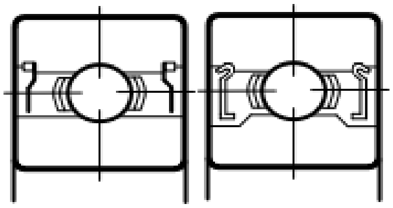
Now that the manufacturing process is complete, they are washed to remove any leftover residue. Lastly, the clean balls are inspected for scratches and sizes. Even though the balls all have the same nominal outside diameter, small variances still occur. The ball grade defines the geometric tolerances of the bearing. The lower the grade number, the tighter the tolerances. The number of the grade is related to the sphericity and diameter variation of the balls. The tolerances are incredibly tight and the variation between balls is relatively small. The following table defines this relationship.

Grade	Unit	Sphericity	Lot diameter variation	Nominal ball diameter tolerance	Maximum surface roughness (Ra)
3	in	0.000003	0.000003	±0.00003	0.5 µin
	mm	0.00008	0.00008	±0.0008	0.012 µm
5	in	0.000005	0.000005	±0.00005	0.8 µin
	mm	0.00013	0.00013	±0.0013	0.02 µm
10	in	0.00001	0.00001	±0.0001	1.0 µin
	mm	0.00025	0.00025	±0.0013	0.025 µm
25	in	0.000025	0.000025	±0.0001	2.0 µin
	mm	0.0006	0.0006	±0.0025	0.051 µm
50	in	0.00005	0.00005	±0.0003	3.0 µin
	mm	0.0012	0.0012	±0.0051	0.076 µm
100	in	0.0001	0.0001	±0.0005	5.0 µin
	mm	0.0025	0.0025	±0.0127	0.127 µm
200	in	0.0002	0.0002	±0.001	8.0 µin
	mm	0.005	0.005	±0.025	0.203 µm
1000	in	0.001	0.001	±0.005	
	mm	0.025	0.025	±0.127	

Table 8. Grade tolerances for inch and metric sizes Source: [Link]

Shields:

Shields on stainless steel bearings are generally made from AISI 304 stainless steel.



- Prevent contamination by larger particles
- Reduce lubricant leakage
- Do not increase torque
- Wide temperature range, especially stainless steel

Figure 15. Shields Source: Link

Seal:

Contact Seals (2RS)

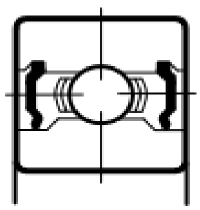
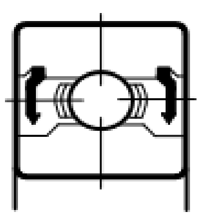


Figure 16. Contact Seals Source: Link

The standard bearing seal consists of nitrile/BUNA-N rubber bonded to a metal washer. The washer is SPCC cold-rolled steel for chrome steel bearings or 304 stainless steel for stainless steel bearings. High-temperature PTFE seals (up to 250°C) or Viton seals (up to 230°C) are available in some sizes. The inner lip of the seal rubs against the bearing inner ring to provide an effective seal against smaller particles such as dust and moisture while preventing lubricant leakage. Contact seals produce much higher frictional torque levels than shields and reduce the maximum speed of a bearing. Below -40°C, nitrile rubber and Viton will stiffen and provide a less effective seal, so PTFE seals or metal shields should be considered for very low temperatures.

- Good protection against contamination
- Greatly reduce lubricant leakage
- Reduce maximum speed by approx. 40%
- Greatly increase bearing torque

Non-Contact Seals (2RU)



These seals are also made of nitrile rubber bonded to a metal washer but do not rub against the bearing inner ring and therefore do not have the same effect on bearing torque and maximum speed as contact seals to be used for low torque, high-speed applications. They offer superior protection over metal shields but do not provide as effective a seal as the contact type.

Figure 17. Non-Contact Seals Source: Link

- Good protection against contamination
- Reduced lubricant leakage
- No torque increase
- Do not affect the maximum speed

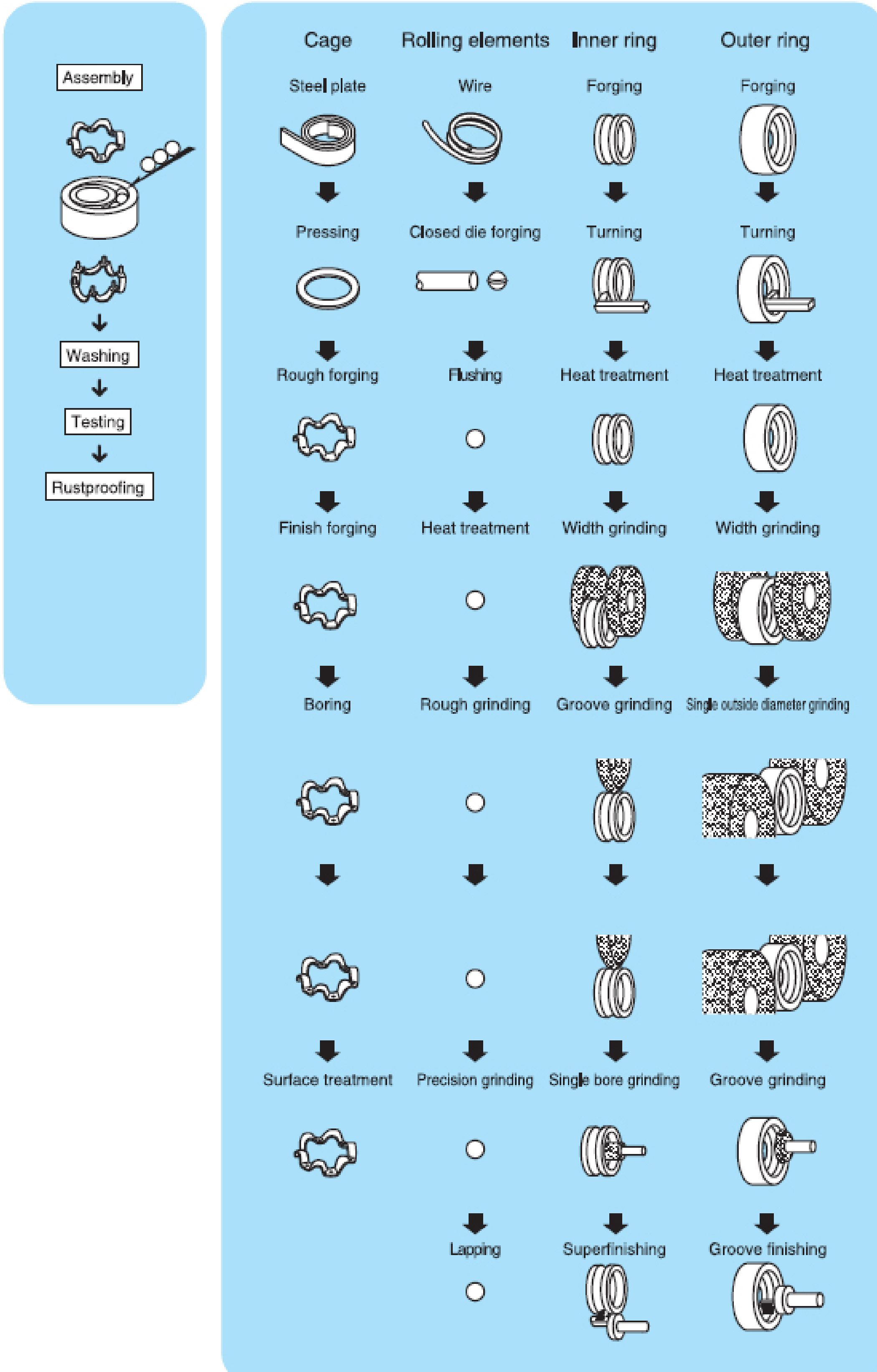


Figure 18. Manufacturing of Ball Bearing Components [for representative purposes] Source: Link

Manufacturing:

Inner & Outer Ring:

As explained before, the manufacturing of rings for the bearing is a simple 4-step process involving the following processes:

I. Forging: The steel bar is first heated then cut. It is then pressed by machine and molded into inner and outer ring shapes. (See manufacturing machine Fig 22)
II. Turning: Automatic machines similar to lathes use cutting tools to cut the basic shape of the race, leaving all of the dimensions slightly too large. (See machine Fig 23)
III. Heat Treatment: Involves Quenching (to 800-860℃), Cooling and Tempering (1450-2000℃) to improve the hardness and wear resistance of the rings. (See machine for process Fig 24)
IV. Grinding: This makes the bearing ring be following the design requirements in quality, dimension, size and shape precision, thus qualifying it for the assembly stage. The rings are fully smoothened in this stage and cut to specific dimensions. (See machine for process Fig 25)

Cage:

Steel sheet punching: Firstly, a circular disk is punched out from the desirably thick steel sheet, leaving holes. Then again, the sheet is punched around the previously punched holes. This gives us a circular ring which we have to process further. See Fig 21 for the machine used in the Punching process

Forging: Then, these rings are placed into the die. These dies bend the ring so that it creates a semi-circular room where balls can be placed. Also, these die to make holes for the rivets. Once this is done, we have half part of the steel cage. Once a pair is ready for such parts, then it can be sent to be assembled in the ball bearings as a cage.

Final dimensions of cage: Inner radius, Rin = 0.58 inches
Outer radius, Rout = 0.68 inches
Thickness, t = 0.015 inches
Space for balls, Z = 9

To met this dimensions after forging we have to punch ring of following dimensions:
Inner radius, Rin = 1.81 inches
Outer radius, Rout = 1.844 inches
Thickness, t = 0.015 inches

This punching operation will be performed in two steps. One punching the inner disc out. And another punching out the ring for forging which already has a pre-punched disc out from it. And thus the force required for both passes are 3.87 Ton and 3.93 Ton respectively. These values are calculated using the following formula:

$$\textbf{Punching Force } (kN) = \textbf{Perimeter } (mm) * \textbf{ Plate thickness}(mm) * \textbf{ shear strength } (kN/mm^2)$$

Balls:

- The balls start out as thick wire. This wire is fed from a roll into a machine (See Fig 28) that cuts off a short piece, and then smashes both ends in toward the middle. This process is called cold heading. The ring around the balls in the middle is called "flash." (See Fig19A)
- The first machining process removes this flash. The ball bearings are put between the faces of two cast-iron disks, where they ride in grooves. The inside of the grooves is rough, which tears the flash off of the balls. One wheel rotates, while the other one stays still. The stationary wheel has holes through it so that the balls can be fed into and taken out of the grooves. A special conveyor feeds balls into one hole, the balls rattle around the groove, and then come out of the other hole. They are then fed back into the conveyor for many trips through the wheel grooves, until they have been cut down to being fairly round, almost to the proper size, and the flash is completely gone. Once again, the balls are left oversize so that they can be ground to their finished size after heat treatment. The amount of steel left is only about 8/1000 of an inch. (Used machine for this stage, see Fig 29)
- Since the balls have the same steel as rings, the heat treatment process (To be done in Rotary Furnace, see Fig 32) for the balls is similar to make the balls hard and tough. After heat treatment, the balls are put back into a machine (See Fig 30) that works the same way as the flash remover, except that the wheels are grinding wheels instead of cutting wheels. These wheels grind the balls down so that they are round and within a few ten-thousandths of an inch of their finished size. (See Fig 19E)
- After this, the balls are moved to a lapping machine (See Fig 31), which has cast iron wheels and uses the same abrasive lapping compound as is used on the races. Here, they will be lapped for 8-10 hours, depending on how precise a bearing they are being made for. Once again, the result is steel that is extremely smooth.

Figure 19. Resulting Balls after Different Processes
Source: [Link]

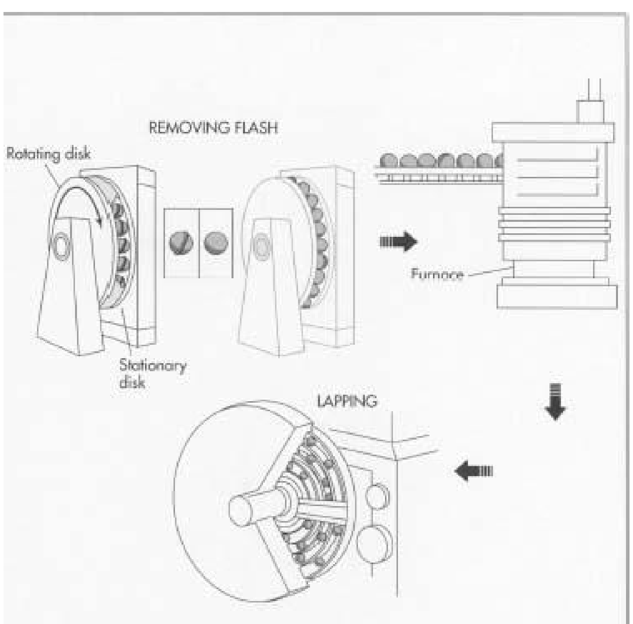


Figure 20. Grinding, Heating and Lapping Process
Source: [Link]

Finishing & Coatings:

Before finishing and then lubrication and coating, there is a need to clean the whole bearing, including all its components.

Cleaning:

The components are cleaned in multiple process steps before coating:

- Ultrasonic cleaning
- Degreasing
- Vacuum drying
- Plasma cleaning

Coating Materials:

Various high-purity materials are used as adhesive or functional layers depending upon the area of application:

- Silver (Ag)
- Lead (Pb)
- Gold (Au)
- Molybdenum disulfide (MoS_2)

Applying specific coatings such as silver plating, DLC and anodising, to protect metallic cages made from steel, aluminium or titanium to rolling elements and raceways can also reduce wear and friction.
Performance Benefits:

- Both bare surfaces and coated surfaces can help to raise race performance
- The patented process generates super-finished surfaces with shallow roughness values
- Isotropic surfaces improve friction and wear resistance in marginal lubrication conditions
- DLC-like coatings reduce wear and friction on rolling elements and raceways
- Other coatings such as silver plating, DLC and anodising protect metallic cages

Lubrication:

To reduce rolling friction, deep groove ball bearings are usually lubricated by oil or grease. A lubricating film is formed during the rotational movement between the ball and the raceway, preventing direct rolling contact (dry running). The lubricant has a significant influence on the reliability of a bearing. For this reason, modern roller bearings are filled with suitable roller bearing grease in the factory. Cover or sealing plates that are fitted additionally to the narrow ends ensure enough lubricant in the bearing and prevent soiling from the outside. This makes deep groove ball bearings maintenance-free for many applications.

Effective lubrication for radial ball bearings includes oil, grease, and dry films.

Synthetic oils are most common for quality bearings.

- Mineral oils are appropriate for high-speed use.
- Synthetic oils are good for moderate to high speeds.
- Petroleum exhibits good lubrication under heavy-load/high-speed conditions.
- Silicone oils offer good heat resistance and do not corrode rubber but are more appropriate for low speeds.

Oils can be dropped, centrifuged, or impregnated into bearings.

Greases are best for moderate to high rotation speeds. Typically, the high-speed torque of a greased bearing is lower than an oiled bearing, but the opposite is true at lower speeds. These are usually applied via grease pack, but grease plating is also available. Silicone greases offer good heat resistance and do not corrode rubber but are best for low to moderate speed applications.

Dry films should only be used where 'wet' lubricants will prove unsuitable or accumulate large dirt. Dry films are difficult to apply and produce wear flakes as the bearing rotates, possibly obstructing bearing operation.

Grease life in shielded/sealed ball bearing:
Grease life can be estimated by the following equation when a single-row deep groove ball bearing is filled with grease and sealed with shields or seals.

$$logL = 6.10 - 4.40 \times 10^{-6} d_m n - 3.125(\frac{P_r}{C_r} - 0.04) - (0.021 - 1.80 \times 10^{-8} d_m n)T$$

L: grease life (hr)

d_m: $\frac{D+d}{2} = \frac{42 + 20}{2} = 31$ mm where, D: outside diameter; d: bore diameter (mm)

n: rotational speed (min^{-1}) (max speed = 18000 RPM)

P_r: dynamic equivalent radial load (N)

C_r: basic dynamic radial load rating (N) = 9385.7 N

T: operating temperature of bearing (℃)

Now depending on the application of ball bearing, we can know the values of P_r, n and T. So we can find the value of L.

Required oil supply in forced oil circulation: (oil jet lubrication methods)

$$G = \frac{1.88 \times 10^{-4} \mu \cdot d \cdot n \cdot P}{60\ c \cdot r \cdot \Delta r}$$

G: required oil supply (L/min)

μ: friction coefficient (0.0010-0.0015, for deep groove ball bearing)

d: nominal bore diameter (mm)

P: the dynamic equivalent load of bearing (N)

c: specific heat of oil (1.88-2.09 $kJ/kg \cdot K$)

r: density of oil (g/cm^3)

Δr: temperature rise of oil (K)

Main roles of lubricants:

- Decrease friction and wear – direct metal-to-metal contact between bearing rings, rolling elements, and cages is prevented by the use of lubricating film that decreases friction and wears in the contact areas.
- Extended fatigue life-bearing fatigue life depends, in particular, on the viscosity and film thickness of the lubricant between contact surfaces.
- Heat dissipation – oil circulation can dissipate excess frictional heat or heat from the external environment from the bearing, thereby protecting the bearing against overheating and the oil against degradation.
- Protection of bearing surface against corrosion
- Preventing the entry of foreign particles (contaminants) into the bearing, removal of foreign particles from the bearing oil circulation.

Machines/Equipment:

Machine required for making Cage and Rings:

Punching Machine:
It is used in making thin rings used in cages.

Machine for punching sheet metal:
Requirements:- 3.7-3.9 tons of force is needed
Max sheet thickness 0.015 inches

Price: Rs 95,000

Figure 21. Punching Machine Source: Link

Forging and Rolling process:

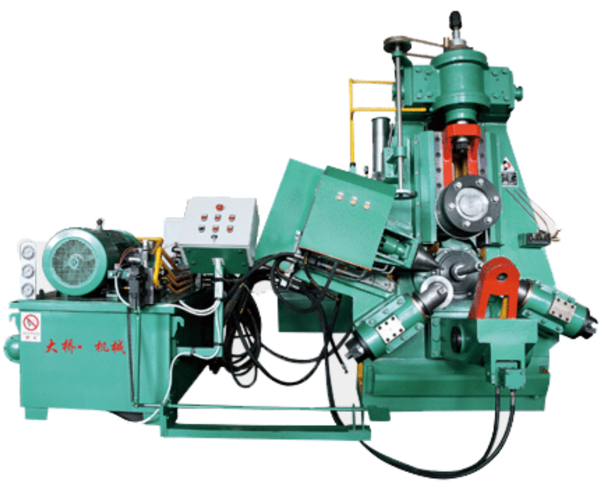


Figure 22. Hot ring rolling machine Source: Link

A CNC ring rolling machine is used in forging and rolling of inner and outer rings of the ball bearing. Also used in forging of cage rings for cage manufacturing.

CNC machine:
CNC machine required for the turning process in the manufacturing of Rings. Price: ₹10 Lakh

Quenching and Tempering equipment:

This equipment is used for the Rings in the Quenching and Tempering process

Figure 24. Quenching and Tempering Equipment Source: Link

Figure 23. CNC machine Source: Link

Grinding and Finishing processes:

For the grinding process of rings following machines are used:

1) CNC Internal Grinder for Ball Bearing Ring (Fig 25A)
2) CNC Raceway Grinder for Ball Bearing Inner Ring (Fig 25B)
3) Raceway Grinder for Ball Bearing Outer Ring (Fig 25C)

Figure 25. Grinding Machines for Rings Source: [Link]

For the finishing process of rings, a Superfinishing Machine is used.

Figure 26. Super Finishing Machine Source: [Link]

Assembly Machine:

This is the product of the company CIXI HOTO (CIXI HOTO is a Chinese manufacturer). The complete work is illustrated in the video featured on this website: [Made In China Superior Quality Automatic Intelligence Ball Bearing Assembly Making Machine - Buy Ball Bearing Making Machine, Assembly Machine, Bearing Assembly Machine Product on Alibaba.com]

Price: $10,000.00 - $35,000.00

Figure 27. Assembly Machine Source: [Link]

Ball Making Machines:

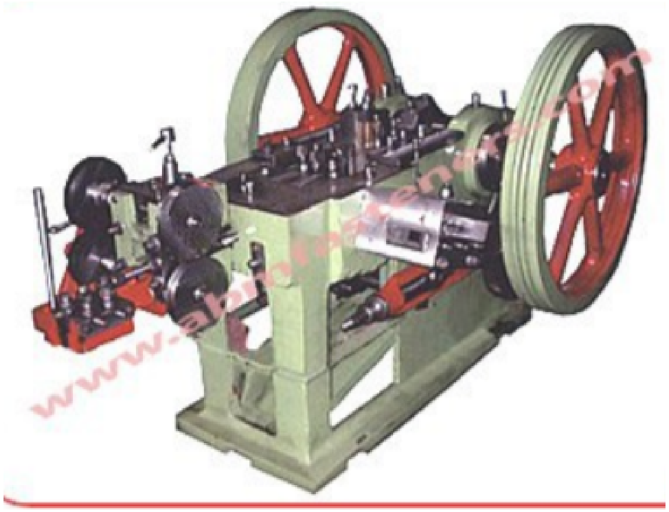


Figure 28. Single Stroke Cold Heading Machine

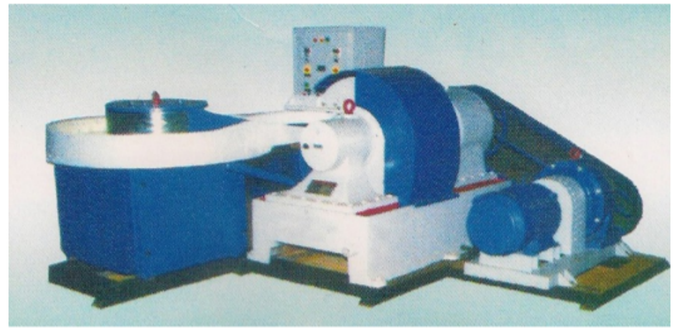


Figure 29. Ball Flashing Machine

Figure 31. Ball Lapping Machine

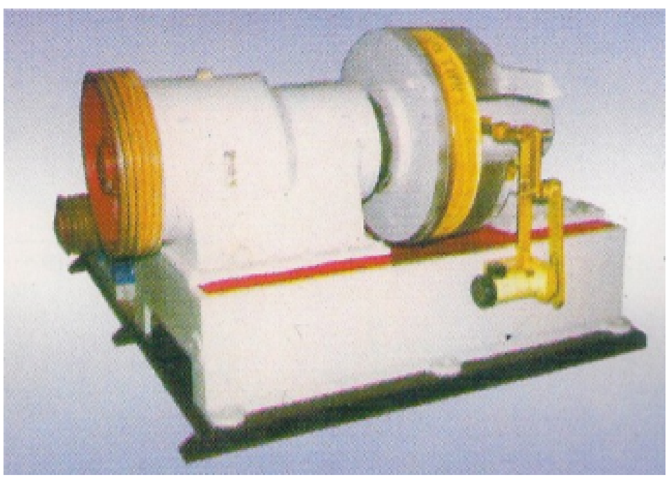


Figure 30. Ball Grinding Machine

These are all machines used in making rolling element balls at various stages. (Mentioned in manufacturing of balls) The rotary furnace is used in heating the ball.

Figure 32. Rotary Furnace

All Figure Source: Link

Assembly:

Here comes the assembly part. All the separately manufactured components should be assembled in a proper manner to get our desired final product. This should be done with close to none damages given to the components. The figure below is the schematic representation of assembling a single ball bearing.

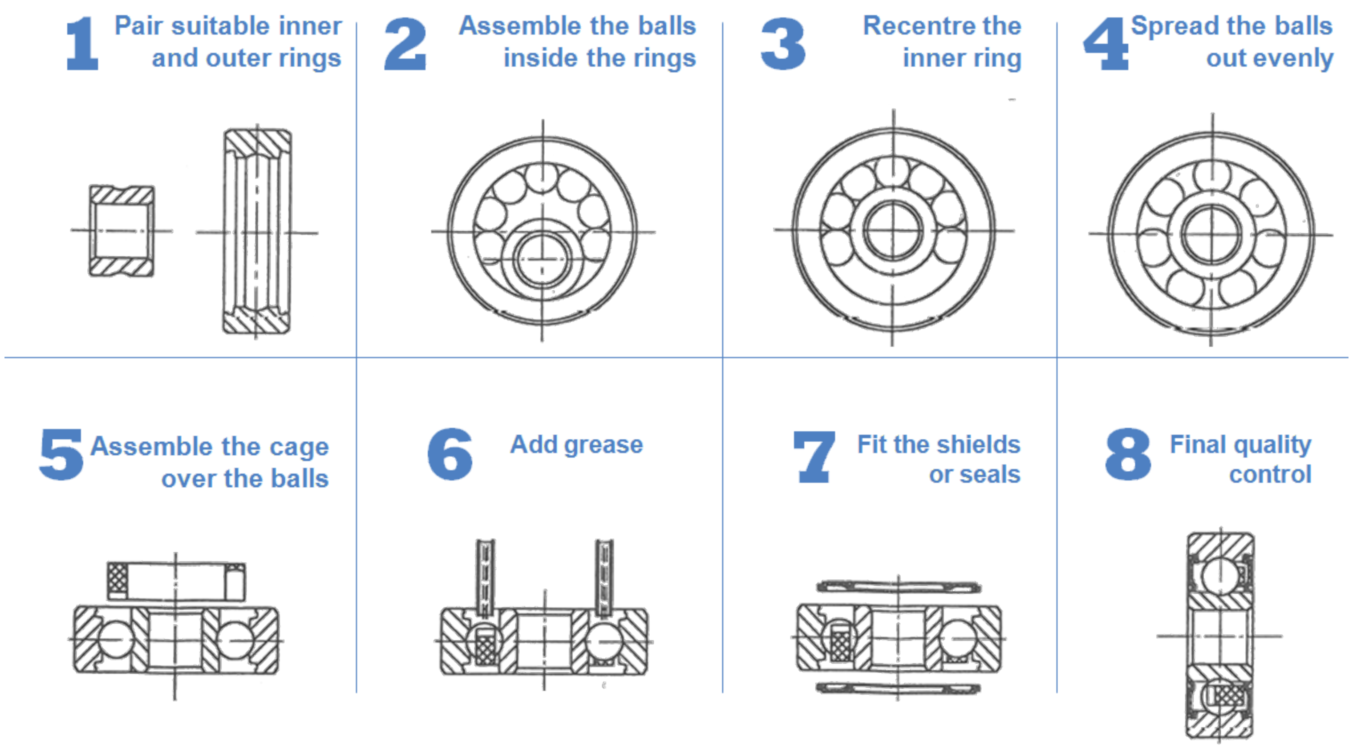


Figure 33. Assembly of Ball Bearing Source: [Link]

As shown here at process ***1*** inner and outer rings are placed con-centered. Then at process ***2***, already finished balls are placed between both the rings. This shifts the inner ring to another side. But then this inner ring is recentered with the help of external mechanical force in the process ***3***. Even after we don't have evenly spread balls. This is also done by external mechanical force which also consists of the clamping of both rings in process ***4.*** In process ***5,*** cages are assembled over the balls which will hold the balls at the desired place. Next, in process ***6***, lubricants are added which are then sealed with shields or seals. And finally, the ball bearing goes through multiple quality checks.

Processes ***1-7*** are done by a single assembly machine (See Fig 27). Details of machines are explained in the Machines/Equipment part of the report.

Inspection:

Bearing making is a very precise business. Tests are run on samples of the steel coming to the factory to make sure that it has the right amounts of alloy metals in it. Hardness and toughness tests are also done at several stages of the heat-treating process. There are also many inspections along the way to make sure that sizes and shapes are correct. The surface of the balls and where they roll on the races must be exceptionally smooth.

There are three basic types of bearing tests:

- Application Simulation: During this type of analysis, bearings are tested in either a prototype or the actual assembly where they operate.
- Computer Simulation: Accurate simulation models are employed on a computer which is made to undergo simulations in application-related software.
- Individual Bearing (tested in the lab): Laboratory testing is useful in determining the design and manufacturing capabilities. Such testing is done at both the component level (individual bearings) and in the intended application positions.

Depending upon the accuracy, time and costs involved a particular test can be performed in one of the above 3 ways.

Bearing Life Testing:
By calculating load and RPM, we can find out the hours for bearing and accordingly we can test the L10 Life of bearings. Because the life of bearing depends on the application of bearing, this test also depends on the application of bearing. Other factors can also be accounted for such as temp. of bearing, the axial and radial load applied on the bearing etc.

Basic Dynamic Load Rating:
It is one of the principal technical parameters of rolling bearings. It expresses the constant dynamic load of bearings under which their nominal life is 1 million revolutions. The values of this parameter are generally established by internationally accepted calculations expressed in the ISO 281 standard. During this test, the real service life at constant revolutions and load is checked and reversely the basic dynamic load is determined.

Surface Roughness Testing:
Surface roughness testing is done to check the surface finish of the races after honing and grinding process.

Noise Checking:
This test ensures noise and vibration level of taper, cylindrical, spherical, angular contact and deep groove ball bearings.

Roundness Testing:
It is done to check the Roundness/Eccentricity of all round parts.

Hardness Testing:
Hardness testing is mainly done to check the hardness of races and rollers, which should be within the specified standards of 58-65 HRC (Rockwell Hardness).

Profile Checking:
Inner Ring & Outer Ring Radius & Chamfer are magnified with the help of magnifying glass.
On-screen, we can compare the shadow with the master drawing profile for any complicated forms.

Crack Detection:
The Vinze Magnafield crack detector machine can be used for checking the crack in the components (Inner Ring, Outer Ring & Rollers) which is not visible by naked eyes. This is a non-destructive test machine.

Chemical Analysis of Raw Materials:
We can check chemical composition like C, Cr, Mn, S, Hardness, Decarb, Microstructure and Grain size in raw material and annealed material. We can also check the Hardness (HRC), Microstructure, Grain size & Inclusion rating of heat-treated components.

Radial Clearance:
The radial clearance is measured for each bearing before and after mounting. To measure the radial clearance, the free-hanging outer ring of the bearing is pushed (with a defined test pressure) into the upper-end position and the distance is measured.

Cost Evaluation:

> *"The standard grade steel for ball bearings is a high carbon, high chromium, vacuumed degassed **AISI/SAE 52100**. The high carbon content of l% gives the steel an excellent response to heat treatment resulting in very high strength and hardness. The high chromium content of 1.35% further increases responsiveness to heat treatment and adds depth of hardness penetration."*

Inner Ring, Outer Ring, Ball: AISI 52100
Retainer: Pressed Steel (considered to be of AISI 1200)

AISI 52100 Steel: Density: **7.81 g/cm^3** Price per kg: ₹59
Pressed Steel: (considered to be of AISI 1020) Density: **7.87 g/cm^3** Price per kg: ₹65

The volume of components of a ball bearing: (according to CAD model of product)

Outer Ring: 4318.72 mm^3
Inner Ring: 2451.23 mm^3
Balls (x9): 122.39 mm^3×9 = 1101.51 mm^3
Retainer: 123.00 mm^3

Total Mass of a bearing:

$$M = M_{outer\ ring} + M_{inner\ ring} + M_{Balls} + M_{Retainer}$$
$$= ((4318.72 + 2451.23 + 1101.51) * 7.81) + (123.00 * 7.87)) * \frac{1}{1000}\text{gm}$$
$$= (61476.1026 + 968.01) * 0.001\text{gm}$$
$$= 62.4441126\text{gm}$$

Material Cost of a bearing:

$$C_m = (M_{outer\ ring} + M_{inner\ ring} + M_{Balls}) * C_{52100} + M_{Retainer} * C_{1020}$$
$$= 61.4761026 * 59 * 0.001 + 0.96801 * 65 * 0.001$$
$$= 3.6270900534 + 0.06292065$$
$$= ₹\, 3.6900107034$$

Labors and overhead charges: 161.7 rupees
Material cost: 3.69 rupees
Technology and Machining cost: 32.2 rupees
Packaging and taxes: 50.4 rupees
Depreciation and other external services and repairs: 103.4 rupees

The total cost of ball bearing: **351.39** rupees per ball bearing

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