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DESIGN FACTORS WHEN USING SMALL BEARINGS

Part 2: Mounting and Fitting

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Miniature bearings are generally used in applications where rotational performance (i.e. predictable low torque, runout, stiffness, etc.) is the primary design goal, rather than load/lifetime issues. A previous paper has discussed how the internal geometry of the bearing itself influences the rotational performance of a bearing assembly. This paper addresses the importance of proper handling and assembly methods in the application of miniature bearings.

Radial Play and Interference Fits

The cross-section of the inner and outer races of miniature bearings (sometimes called the turning rings) can be very thin. For bearings of 1/4-inch OD or smaller, the thickness of the race under the ball groove can be less than 0.008 inches. This means that even though the bearing material may be relatively hard steel (Rc 60+), the races are extremely fragile and can be significantly damaged or distorted by the slightest force during the mounting and assembly process.

For such thin section bearings it is also extremely important to note that up to 80% of the interference with mating components will translate into loss of radial play. Since a standard miniature bearing has a radial play between 0.0002 and 0.0004 inches, this means that total interference of 0.0003” can be expected to close up some bearings to the point that they will no longer rotate.

In general, radial play values should be reduced by an amount proportional to the interference with the mating part:

$$\Delta_{rf} = \Delta_r - f_p \cdot I$$

Where: Δ_{rf} = final radial play after pressing bearing
Δ_r = initial bearing radial play
f_p = interference factor
I = interference between bearing and mating part

The interference factor fp is dependent on the thickness of the bearing race and the material and geometry of the mating part. It is suggested that the following empirically determined values are used:

Values for Interference Factor f_p

BEARING RING THICKNESS*	MATING MATERIAL		
	STEEL	BRASS/ALUMINUM	PLASTIC (filled)
<0.015	0.8	0.6	0.3
0.015 - 0.030	0.7	0.4	0.2
>0.030	0.6	0.2	0

Bearing ring thickness is calculated as follows:

Inner ring thickness = $(l_i - d)/2$
Outer ring thickness = $(D - l_o)/2$

Where: d = bearing bore
D = bearing OD
l_i = inner race land diameter (open bearing)
l_o = outer race land diameter (open bearing).

Note that open bearing land diameter values are always used, even if the bearing used has shields or seals.

The above f_p values are intended as a guideline only. If the mating part itself has a thin section, then the above factor will be reduced slightly. The important point is that the interference can significantly reduce radial play and must be accounted for in a design to arrive at the final desired radial play. For this reason it is recommended that a higher radial play bearing (e.g. 0.0005 to 0.0008 inch) be used where an interference fit is needed.

Tolerance of Mating Components

If an interference fit is desired, then the dimensions of these parts must be carefully controlled and the tolerances of the bearing bore and OD must be factored into a calculation of the maximum and minimum interference.

The following table shows recommended shaft and housing sizes and tolerances for different applications. It is assumed that bearings used are ABEC 5 tolerance (+0 to -0.0002 inch) for bore and OD. If a different grade of bearing is used, this will affect the recommended dimensions of the mating part.

Table of Recommended Fits

ROTATING RING			INNER RING	OUTER RING
APPLICATION	DESIRED FIT TYPE	DESIRED FIT (inches)	USE SHAFT DIAMETER	USE HOUSING DIAMETER
Preloaded assemblies (see pages 31 & 36)	Bonding (no adhesive grooves.)	.0004L to .0008L	d - .0006 d - .0008	D + .0004 D + .0006
Low speed, or spring preload.	Loose	.0001L to .0005L	d - .0003 d - .0005	D + .0001 D + .0003
Medium speed	Transition	.0002L to .0002T	d - .0000 d - .0002	D - .0000 D - .0002
High speed	Light press*	.0000 to .0004T	d + .0002 d - .0000	D - .0002 D - .0004
High speed, high load	Tight press*	.0002T to .0006T	d + .0002 d + .0004	D - .0004 D - .0006

STATIONARY RING			INNER RING	OUTER RING
Most applications (see pages 31 & 36)	Line - line to loose	.0000 to .0004L	d - .0002 d - .0004	D - .0000 D + .0002

L = Loose fit   T = Tight fit   d = Bearing bore from table   D = Bearing O.D. from table

Important notes for press fit bearings:

1. *The interference factor fp (above) will affect final radial play. This must always be taken into account in designing a press fit bearing to a specific radial play range.*
2. *Allow for relative thermal expansion in calculating final radial play (see table next page).*
3. *MC5 radial play bearing (0.0005 to 0.0008 in.) recommended for tight press fit.*
4. *Tight press NOT recommended for bearings with ring thickness < 0.030 in.*

Thermal Expansion

When bearing subassemblies are used at high temperatures, the differential expansion of the bearings and mating parts must be considered in addition to normal interference effects. It can be seen from the table below that many commonly used materials have higher coefficients of thermal expansion than bearing steel. Particular care must be given to designs where an aluminum shaft is pressed onto a thin section bearing.

Thermal Expansion Coefficients

Bearing Materials → (DR/ES1 stainless, 400 series stainless, 52100 chrome steel)

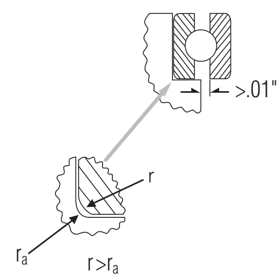
MATERIAL	LINEAR EXPANSION COEFFICIENT	
	ppm/°C	ppm/°F
DR/ES1 stainless	10	6
400 series stainless	10	6
52100 chrome steel	12	7
300 series stainless	16	9
Aluminum	23	13
Brass	19	11
Bronze	18	10
Copper	16	9
Invar	1	0.6
Iron	12	7
Lead	29	16
Nickel	13	7
Magnesium	8	4
Titanium	9	5
ABS	72	40
ABS (glass reinforced)	31	17
Delrin/Acetal	85	48
Epoxy	54	30
Epoxy (glass reinforced)	36	20
Nylon	81	45
Nylon (glass reinforced)	23	13
Polycarbonate	65	36
Polycarbonate (glass reinforced)	22	12

Shoulder Design

When a bearing is located against a shoulder in a mating part, care must be taken that the rim of the shoulder clears the opposing ring. This is achieved when the diameter of the shoulder has clearance over the opposing race land diameter.

Maximum shaft shoulder diameter = Outer ring land diameter – Clearance*
Minimum housing diameter = Inner ring land diameter + Clearance*
**Clearance should be > 0.010 inch (0.25 mm) to allow for normal tolerances.*

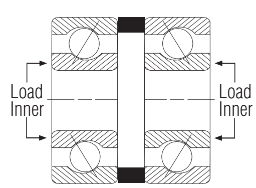
The corner radius of the shoulder (r_a) should be less than the fillet radius (r) of the mating bearing to allow the bearing to fully seat against the shoulder.



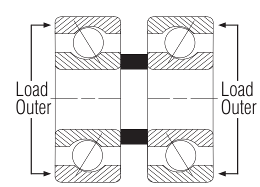
Bearing land diameters and the maximum shoulder corner fillet radii for bearings are given in bearing specifications in most bearing catalogs.

Preload Assembly Methods

Preload is the force applied between the races of a pair of bearings to remove the axial play and to further compress the bearings to provide both axial and radial stiffness. It is an important design parameter, affecting rotational performance and lifetime of a bearing assembly. After preload, the resulting ball contact angle α must be considered (see Part I – Bearing Geometry).

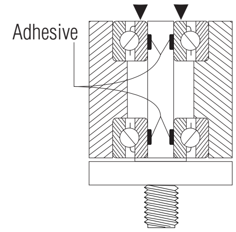


Standard preload - Inner rings pressed together (maximum stiffness)

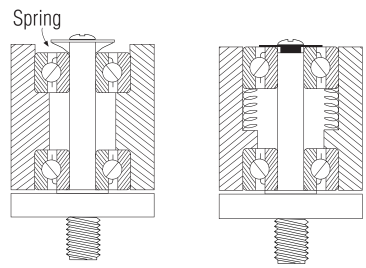


Outer rings pressed together (less stiffness)

The are 3 methods typically used to achieve preload in a bearing pair.

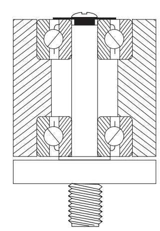


1. Deadweight: A fixed weight is set against the bearing ring while adhesive cures to retain the bearings. This system is used in many applications, and gives well-controlled torque values as well as maximum stiffness. Disadvantages are cure time and special handling of adhesive in mass-production. Care must be taken to allow for relative thermal expansion effects if different materials are used in mating parts.



2. Spring: Spring is used to press inner rings together or outer races apart. This system is easy to assemble, but has minimal stiffness since the spring can move after assembly so that the stiffness of the final assembly is controlled by the spring rate rather than the raceway-ball elasticity. Thermal effects from relative expansions of mating parts are minimized. Spring preload is often used in high speed applications.

Note: For Belleville or wavy-washer springs the tolerance stack up of mating parts can give a variation in spring compression that is a large percentage of the maximum allowable compression of the spring. This means that the preload can vary greatly unless a spring with a low spring rate is used (can be difficult to find).



3. Solid clamping: Component parts are machined to precise dimensions to remove axial play when the races are clamped together. In theory, is easy to assembly has few components and good stiffness. However, due to the natural range of the bearing axial play, it is difficult to achieve in practice. Unless components and bearings are matched to a very high precision the resulting assembly may be damaged through raceway brinelling or may not have adequate preload.

Note: precision matched bearing pairs are available as Duplex Pair Bearings, but these are significantly more expensive than standard bearings).

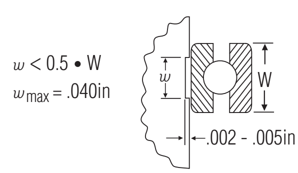
Adhesive Practices

As discussed, bearings are often bonded in place with adhesive. This method also allows bearing pairs to be preloaded with a weight to remove axial play while the adhesive is curing. With proper design and handling, a bearing assembly using adhesive bonds can be extremely strong. This section deals with some of the issues involved in adhesive bonding.

Adhesive types: Most adhesives used for metal-to-metal bonding are of the anaerobic type. These adhesives require the absence of oxygen before curing can start. At least one mating surface must be porous to oxygen in order to allow absorption of oxygen from the bond. This type of adhesive can have shear strength in the order of 2-5,000 pounds per square inch, resulting in push-out forces of hundreds of pounds, even for a small assembly.

There are many types of suitable anaerobic adhesives available from several manufacturers. The specific adhesive used will depend on the materials to be bonded and the application itself. Information on specific adhesives is available from its manufacturer.

Adhesive grooves: For maximum strength, there must be a gap between mating components of 0.002 to 0.005 inches. In order to reduce overall runout, it is usual to design an adhesive groove in the mating surfaces that gives sufficient clearance for bond strength and also provides a trap for excess adhesive. The other areas of the mating surfaces should be kept at a minimum clearance to improve runout characteristics.



Applying adhesive: The following lists good manufacturing practices for using adhesive to bond small bearings.

- Clean mating surfaces - surfaces must be cleaned and free from grease or oils. Since bearings will have been lubricated, it is particularly important to clean the outer surfaces of the races. In some cases, bearings are available pre-cleaned by the manufacturer.

- Use primer if necessary - anaerobic adhesives require at least one mating surface to have some porosity to oxygen. If coated or anodized materials are used, then a suitable primer will be necessary. The use of a primer may also improve bond strength when dissimilar materials are used in bearings and mating components. See adhesive manufacturers specifications on primer use.

- Control the amount of adhesive applied - if possible, use an electronic dispenser that delivers an accurately controlled amount of adhesive. This amount should be set to minimize excess adhesive outside the adhesive groove(s). Distribute the adhesive evenly around the circumference of the part.

- Set-up time - a bonded assembly needs to be left undisturbed for enough time that the adhesive sets up sufficiently to retain the components in place. This period is specified by the adhesive manufacturer and is different from the time to achieve full cure.

- Remove excess adhesive - anaerobic adhesive sets in the absence of air. Any excess adhesive left on the outside of the mating surfaces will not set properly and represents a hazard to the bearing as it may migrate into the raceways, causing damage. All visible excess adhesive should be wiped off after the part has set-up. Alternatively, an ultraviolet curing adhesive can be used, where exposure to a strong UV source after set-up will cure any remaining adhesive.

Bearing Handling

Miniature and instrument-sized ball bearings are high precision machine parts with tolerances and raceway finishes that are measured in millionths of an inch. At the same time, their small size and often thin sections makes them vulnerable to excessive handling forces. High quality bearings cannot be expected to fulfill their performance potential if they are mistreated or contaminated and most small bearing failures can be traced to the user's poor handling techniques. Common sense in handling a precision part goes a long way towards avoiding such problems, and the user should consider the following as good manufacturing practices.

Avoid contamination: Bearings are supplied in packages that are usually sealed after final inspection in class 100 clean room conditions. Even sub-micron contaminants can have a serious adverse affect on torque, noise, bearing life, etc.

Contamination is avoided by installing bearings in a clean environment. While a clean room or laminar flow workbench is recommended, these are not essential for normal applications as long as basic precautions are used.

- Never handle bearings with bare hands. Use talc-free finger cots or surgical gloves. This is also important to avoid corrosion of 52100 chrome steel bearings.
- Work areas and benches should be cleaned daily to avoid dust build up.
- Keep bearings in original packaging until used. Never leave bearings exposed to the environment.
- Work tools must be kept clean and burr-free
- It is preferable that assembly workers wear clean external clothing (caps, smocks, shoe-covers) that meets clean-room specifications. No make-up or cosmetic powder.
- Mating components should be cleaned prior to use. Be careful in the choice of cleaning materials as regular cotton swabs and cleaning cloths may add contamination from lint. Use specific lint-free clean room products.

Avoid excessive force: The most common cause of small bearing failure is excessive force applied during assembly, which usually results in noise, higher torque, raceway damage, etc. Excessive forces during assembly of small bearings are usually generated by poor handling techniques or incorrect/uncontrolled interference due to poor design or tolerance stack up.

- NEVER press fit a bearing to a mating component by applying force across the bearing raceways through the balls. This will always result in brinelling damage to the bearing. Press the inner ring for shaft press fit or the outer ring for housing press fit.

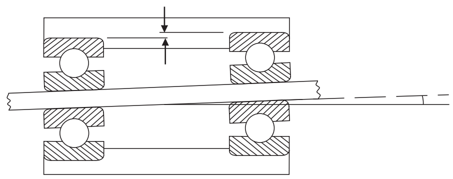
- Calculate the effect of worst-case tolerances on interference fits. Allow for thermal expansion and material type in calculating the maximum loss of radial play. Use a bearing with suitable radial play range. Loss of radial play will change the mechanical characteristics of the bearing (contact angle, torque, resonant frequency), and can ultimately cause bearing failure.

- Follow all guidelines for mounting practices. Make sure that fixtures are aligned.

- Bearings are susceptible to shock or impact loads, especially when the axial play has been removed through preload. Dropping a pre-loaded assembly, or even placing it on a hard surface, can cause brinelling. It is recommended that assembly work surfaces are covered with a layer of shock-absorbing material.

Avoid moisture and high humidity: Bearings are susceptible to corrosion and should be kept in a dry environment. The lubricant in a bearing will provide some measure of corrosion resistance to the internal raceways, but the acid from skin can corrode the outer surfaces. 52100 chrome steel bearings will quickly corrode if the lubricant is cleaned out, so bearings made from this material should never be used dry.

Bearings must be aligned in an assembly: Misalignment during assembly is a common cause of bearing noise, increased torque, and general poor performance. The free angle of misalignment that a small bearing can tolerate is typically less than 1°.



Bearing Misalignment

- Locating shoulders on mating components must be parallel to bearing raceway faces.

- Shaft and housings must be concentric. This is particularly true when more than 2 bearings share a common component.

This is the second article in a series of four on design factors when using small bearings.