2.0 SINTERED-METAL BEARINGS

2.1 General Properties

Sintered-metal self-lubricating bearings are based on powder-metallurgy technology. They are economical, suitable for high production rates and can be manufactured to precision tolerances.

General properties of porous-metal bearing materials have been described in *Machine Design* magazine (Vol. 54, #14, June 17, 1982, pp. 131-132), with whose permission the following material is reprinted:

Sintered-metal self-lubricating bearings are widely used in home appliances, small motors, machine tools, aircraft and automotive accessories, business machines, instruments and farm and construction equipment.

Most porous-metal bearings consist of either bronze or iron which has interconnecting pores. These voids take up to 10% to 35% of the total volume. In operation, lubricating oil is stored in these voids and feeds through the interconnected pores to the bearing surface. Any oil which is forced from the loaded zone of the bearing is reabsorbed by capillary action. Since these bearings can operate for long periods of time without additional supply of lubricant, they can be used in inaccessible or inconvenient places where relubrication would be difficult.

Many variations are possible to meet specific requirements. From 1% to 3.5% graphite is frequently added to enhance self-lubricating properties. High porosity with a maximum amount of lubricating oil is used for high-speed light-load applications, such as fractional-horsepower motor bearings. A low-oil-content low-porosity material with a high graphite content is more satisfactory for oscillating and reciprocating motions where it is hard to build up an oil film.

Powder producers can control powder characteristics such as purity, hydrogen loss, particle size and distribution, and particle shape. Each of these properties in some way affects performance. In the bronze system, for example, shrinkage increases as particle size of tin or copper powder in the mix decreases. Graphite additions result in growth but always lower the strength of the bearings. Lubricants used in the mix have only a slight influence on dimensional change, but a more pronounced effect on the apparent density and flow rate.

After sintering, the bearing must be sized to the specific dimensions. Sizing reduces interconnected porosity and produces greater strength, lower ductility and a smooth finish.

Bronze: The most common porous bearing material. It contains 90% copper and 10% tin. These bearings are wear-resistant, ductile, conformable, and corrosion-resistant. Their lubricity, embeddability and low cost give them a wide range of applications from home appliances to farm machinery.

Leaded Bronzes: Have a 20% reduction of the tin content of the usual 90-10 bronze and 4% reduction in copper. Lead content is 14% to 16% of total composition and results in a lower coefficient of friction and good resistance to galling in case the lubricant supply is interrupted. These alloys also have higher conformability than the 90-10 bronzes.

Copper-Iron: The inclusion of iron in the composition boosts compressive strength although the speed limit drops accordingly. These materials are useful in applications involving shock and heavy loads, and should be used with hardened shafts.

Hardenable Copper-Iron: The addition of 1.5% free carbon to copper-iron materials allows them to be heat-treated to a particle hardness of Rockwell C65. They provide high impact resistance and should be used with hardened and ground shafts.

Iron: Combine low cost with good bearing qualities, widely used in automotive applications, toys, farm equipment, and machine tools. Powdered-iron is frequently blended with up to 10% copper for improved strength. These materials have a relatively low limiting value of PV (on the V side), but have high oil-volume capacity because of the high porosity. They have good resistance to wear, but should be used with hardened and ground steel shafts.

Leaded Iron: Provide improved speed capability, but are still low-cost bearing materials.

Aluminum: In some applications they provide cooler operation, greater tolerance for misalignment, lower weight and longer oil life than porous bronze or iron. The limiting PV value is 50000, the same as for porous bronze and porous iron.

2.2 Sizing Sintered Bearings

The load-carrying capacity of porous-metal bearings can be measured by a friction/wear criterion, which is a measure of the heat generated by the bearing. It is called the PV factor. The PV factor, as its name implies, is the product of the bearing load, P, expressed in pounds per square inch of projected bearing area, and the surface velocity of the shaft expressed in feet per minute.

If d = inside bearing diameter (in)
l = length of bearing (in)
F = bearing load (lbs)
and N = shaft speed (rpm), then:

$$P = \frac{F}{l d} \quad \text{(lbs/in}^2\text{)} \tag{14}$$

$$V = \frac{\pi d N}{12} \quad \text{(ft/min)} \tag{15}$$

and hence,

$$PV = \left(\frac{F}{l\,d}\right)\left(\frac{\pi d N}{12}\right) = \frac{\pi F N}{12\,l} = \frac{0.262\ FN}{l} \tag{16}$$

Most engineering data relating to the PV factor lists an upper limit to the factor; i.e., a value which should not be exceeded for satisfactory bearing operation. The working value of the PV factor, however, is often less than this upper limit, such as in the case where the sliding velocity is not sufficiently high to maintain an adequate lubricating film. In addition, the PV limit is affected by the static load-carrying capacity of the material, which should not be exceeded. The latter is a function of environmental factors, bearing clearances, geometry and the nature of the load (continuous, intermittent or shock loading). Detailed information on these considerations is usually furnished by the metal manufacturer. General guidelines are summarized in **Table 2-1**.

2.3 Clearances

As in all bearings, satisfactory operation of porous-metal bearings require suitable clearances between shaft and housing. While guidelines depend on the materials used and the nature of the application, a representative chart showing recommended bearing clearances for porous-bronze and porous-iron bearings is given in **Figure 2-1**.

We carry a full line of both thick and thin wall bushings. Please consult the tables in this section of the handbook for information on recommended shaft size and bore diameter to be used with various bushing sizes.

Table 2-1 General Guidelines for the PV Factor in Porous-Metal Bearings

Limiting conditions for operation of porous bearings can be expressed as a PV factor. Since P = load, psi; V = surface velocity, fpm; the PV value gives an index of frictional heat generated on a unit area of the bearing surface. A maximum value of 50000 is common for porous bearings. For long-time running with no additional lubrication, 20000 should be a limit in selecting loads for various speeds. For thrust bearings, a maximum PV of 10000 should be used.

Provision to replenish the oil supply is desirable when the PV factor approaches the maximum under continuous operation for extended periods of time, or for high temperatures. For such cases, oil can be applied to the OD or ends of the bearing. From there it is drawn, by capillary action, into the bearing and metered to the shaft. A reservoir of grease next to the bearing also can be helpful.

Material	PV	Static P (psi)	Dynamic P (psi)	V (fpm)
Bronze	50000	8000	2000	1200
Lead-Bronze	60000	3500	800	1500
Copper-Iron	35000	20000	4000	225
Hardenable Copper-Iron	75000	50000	8000	35
Iron	30000	10000	3000	400
Bronze-Iron	35000	10500	2500	800
Lead-Iron	50000	4000	1000	800
Aluminum	50000	4000	2000	1200

Under certain conditions these recommended values can be exceeded but with a sacrifice in service life.

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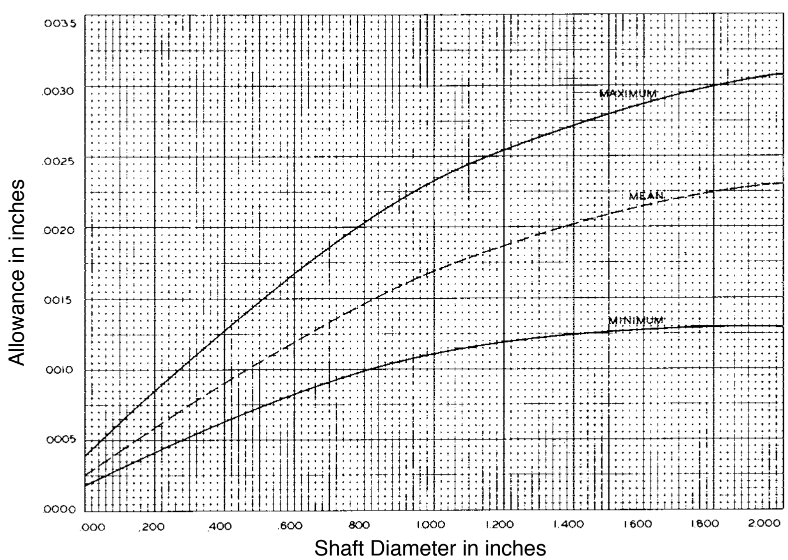


The upper curve (maximum) and all allowances above the mean are suggested for iron-based bearings only. The chart is representative of average conditions, and each application needs to be evaluated individually.

Fig. 2-1 Recommended Bearing Clearances*

*Reprinted with the permission of Keystone Carbon Company, St. Mary's, PA, from Keystone Porous-Bronze and Porous-Iron Bearings, **Fig. B-34**, p. 9.

SINTERED BEARINGS INSTALLATION DATA

Table 2-2 Thin Wall Bearings

Nominal Hole Size		Hole to Accommodate Bearing		Bearing Outside Diameter		Interference	
Fractional	Decimal	Min.	Max.	Min.	Max.	Min.	Max.
3/16	.1875	.1875	.1885	.1895	.1905	.0010	.0030
1/4	.2500	.2500	.2510	.2520	.2530		
5/16	.3125	.3125	.3135	.3145	.3155		
3/8	.3750	.3750	.3760	.3770	.3780		
7/16	.4375	.4375	.4385	.4395	.4405		
1/2	.5000	.5000	.5010	.5020	.5030		
9/16	.5625	.5625	.5635	.5645	.5655		
5/8	.6250	.6250	.6260	.6270	.6280		
11/16	.6875	.6875	.6685	.6890	.6905		
3/4	.7500	.7500	.7510	.7525	.7535	.0015	.0035
13/16	.8125	.8125	.8135	.8150	.8160		
7/8	.8750	.8750	.8760	.8775	.8785		

Nominal Hole Size		Bearing Hole Size After Close - In		Shaft Size		Clearance	
Fractional	Decimal	Min.	Max.	Min.	Max.	Min.	Max.
1/8	.1250	.1250	.1260	.1235	.1245	.0005	.0025
3/16	.1875	.1875	.1885	.1860	.1870		
1/4	.2500	.2500	.2510	.2485	.2495		
5/16	.3125	.3125	.3135	.3105	.3115	.0010	.0030
3/8	.3750	.3750	.3760	.3730	.3740		
7/16	.4375	.4375	.4385	.4355	.4365		
1/2	.5000	.5000	.5010	.4980	.4990		
9/16	.5625	.5625	.5635	.5605	.5615		
5/8	.6250	.6250	.6260	.6230	.6240		

Table 2-3 Thick Wall Bearings

Nominal Hole Size		Hole to Accommodate Bearing		Bearing Outside Diameter		Interference	
Fractional	Decimal	Min.	Max.	Min.	Max.	Min.	Max.
1/4	.2500	.249	.250	.251	.252	.001	.003
5/16	.3125	.311	.312	.313	.314		
3/8	.3750	.374	.375	.376	.377		

Nominal Hole Size		Bearing Hole Size After Close - In		Shaft Size		Clearance	
Fractional	Decimal	Min.	Max.	Min.	Max.	Min.	Max.
1/8	.1250	.1245	.1255	.1230	.1240	.0005	.0025
3/16	.1375	.1875	.1885	.1860	.1870		
1/4	.2500	.2500	.2510	.2485	.2495		

2.4 Press Fits

A press fit is used when available space and torque to be transmitted is limited. Tolerances of mating parts have to be closely controlled to assure a minimum and avoid all excessive interference.

Formulas for press fit are:

$$p = \frac{eE}{2d}\left[1 - \left(\frac{d}{D}\right)^2\right] \text{ and } T = \frac{p}{2}\, pmd^2L,$$

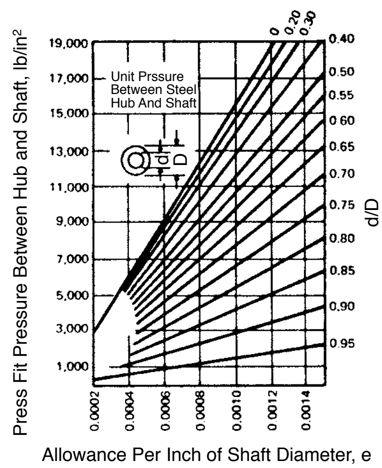
from here $$T = 0.785mdLeE\left[1 - \left(\frac{d}{D}\right)^2\right] \quad \text{(lb in)} \qquad (17)$$

$$S = \frac{2P}{1 - \left(\frac{d}{D}\right)^2} \text{ or } S = \frac{eE}{d} \qquad (18)$$

where:

- p = unit pressure on the interfering surfaces (lb/in^2)
- e = amount of interference (in)
- E = modulus of elasticity (psi)
- d = shaft diameter (in)
- m = coefficient of friction (assume 0.1-0.2)
- L = length of interference surfaces (in)
- S = combined stress resulting from circumferential tension and radial compression (psi)
- T = slip torque (to be divided by safety factor of 2) (lb in)

Graph gives value of p for different d/D ratios and different values of e.



By permission, *Product Engineering*, May 1960

Table 2-4

Running Clearance

Proper running clearance for bearings depends, to a great extent, on the particular item. Only minimum recommended clearances for oil-impregnated bearings used with ground steel shafting are listed.

Running Clearance

Shaft Size in.	Clearance, min. in.	
	Bronze Base	Iron Base
Up to 0.760	0.0005	0.001
0.761 to 1.510	0.001	0.0015
1.511 to 2.510	0.0015	0.002
Over 2.510	0.002	0.0025

Press Fits

Plain cylindrical journal bearings are commonly installed by press fitting the bearing into a housing with an insertion arbor. For housings rigid enough to withstand the press fit without appreciable distortion and for bearings with thickness approximately one-eighth of the bearing outside diameter, the press fits shown are recommended.

Recommended Press Fits

Outside Dia. in.	Press Fit, in.	
	Minimum	Maximum
Up to 0.760	0.001	0.003
0.761 to 1.510	0.0015	0.004
1.511 to 2.510	0.002	0.005
2.511 to 3.010	0.002	0.006
Over 3.010	0.002	0.007

Oil-impregnated sintered bearings are manufactured under strictly controlled conditions, and are subjected to in-process inspection. They are tested for radial crushing strength of magnitude:

$$P = \frac{K\,L\,T^2}{D - T} \quad \text{(lbs)}$$

where:

D = O.D. of bearing (in)
T = wall thickness of bearing (in)
L = bearing length (in)
K = strength constant = 22500

Should additional shaft to bearing clearance be required, a ball burnishing operation should be used for the following reasons:

a) to maintain concentricity
b) to maintain surface finish of I.D.
c) to reduce contamination of surface

The required size of the bearing can be determined from equations:

1) $P = \frac{W}{L\,d}$ (lbs/in^2) (load on projected bearing areas not to exceed 1000 psi)

2) $V = \frac{d\,\pi\,N}{12}$ (ft/min) (surface speed at bearing I.D. not to exceed 1000 ft/min)

3) $PV = \frac{W\,N\,\pi}{12L}$ (PV factor – not to exceed 50000)

where:

W = bearing load (lbs)
L = bearing length (in)
N = shaft speed (rpm)
d = bearing I.D. (in)

Above values are reasonable for the following conditions: continuous rotation, oil impregnation without additional lubrication.

2.5 Standardization

American Society for Testing of Materials (ASTM, 100 Ban-Harbor Drive, W. Conchohocken, PA 19428, Tel. 610-832-9500) publishes detailed specifications dealing with Sintered Bronze Bearings. It is designated as B438-83 (published in 1983). The most significant data pertaining to products listed in this catalog can be summarized as follows:

Table 2-5 Material Composition

Material	%
Copper	87.5 – 90.5
Iron	1.0 Max.
Lead	(a)
Carbon (Graphite Max.)	1.75 Max.
Tin	9.5 – 10.5
Zinc	——
Acid Insolubles	——
Total Other Elements	0.5

(a) included in other elements

Table 2-6 Physical & Mechanical Properties

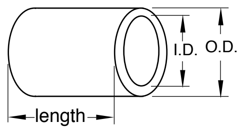
Characteristic	Value
Density (g/cm^3)	6.4 – 6.8
Porosity (% by volume)	19 min.
"K" Strength Constant	26500
Tensile Strength (psi)	14000
Elongation (% per in)	1
Yield Strength in Compression (psi)	11000

Table 2-7 Miscellaneous Designations

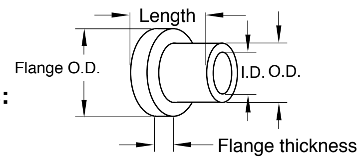
Organization	Designation
ASTM	B-438-83 Grade 1, Type 2
Military	MIL-B-5687D Type 1,Grade 1
MPIF Standard 35	CT-1000-K26
SAE	
New	841
Old	Type 1 Class A
AMS	4805

Table 2-8 Tolerances of Plain and Flanged Bearings

Plain Bearings:



Flanged Bearings:



	Over (in)	Up to & Including	Tolerance
Inside & Outside Diameters (in)	— 1/2 1 1-1/2 2-1/2 3-1/2	1/2 1 1-1/2 2-1/2 3-1/2 4-1/2	+.000 – .001 +.000 – .001 +.000 – .001 +.000 – .0015 +.000 – .002 +.000 – .0025
Length (in)	— 1-1/2 3	1-1/2 3 4-1/2	± .005 ± .0075 ± .010
Flange Diameter, Based on Flange OD	— 1-1/4 2-1/2 4	1-1/4 2-1/2 4 4-1/2	± .005 ± .010 ± .015 ± .025
Flange Thickness, Based on Flange OD	— 1-1/4	1-1/4 2-1/2	± .0025 ± .005
Flange Fillets, Radii, Based on Body OD	— 1 2 2-1/2	1 2 2-1/2 4	1/32 ± .010 3/64 ± .010 1/16 ± .010 3/32 ± 1/64
Concentricity, ID with Respect to OD (Maximum Total Dial Indicator Reading) Based on ID	— 1 1-1/2 3	1 1-1/2 3 4-1/2	.003 .003 .004 .005

2.6 Conclusion

Sintered bearings are used widely in instruments and general machinery, in which their self-lubricating characteristics and load-carrying ability is very desirable. When properly designed, they can be both economical and highly functional.

Their manufacturing method consists of briquetting the metal powder mixtures to the proper density. Subsequently, they are sintered for different duration subject to the temperatures. Sintered bearings are then sized to obtain the required dimensional characteristics. This is followed by inspection and impregnation with a lubricating oil.

3.0 PLASTIC AND NONMETALLIC BEARINGS

3.1 General Characteristics

Among the significant characteristics of plastic bearings, the following are noteworthy:

- Self-lubricating
- Low wear rates
- Relatively high performance rating (PV) among sleeve bearing materials
- Bearing O.D.'s compatible with standard sintered bronze sizes for upgrading existing equipment
- Kinetic and static coefficient of friction virtually the same under heavy loads
- Extremely low coefficient of friction, as shown in **Figure 3-1**
- Lightweight
- Ability to conform under load
- Resistance to chemicals

The design characteristics of plastic and nonmetallic bearings bear both similarities and differences relative to those of porous-metal bearings. This will now be described in greater detail.

3.2 Properties of Plastic and Nonmetallic Bearing Materials

Plastics (such as acetal, nylon, PTFE), carbon graphite and other nonmetallic materials have been increasingly used as self-lubricating bearings. Their composition has been refined over many years so as to obtain favorable bearing characteristics. These include low friction, corrosion resistance, ability to conform under load (plastic bearings), ability to function over wide temperature ranges and substantial load-carrying capability. Although temperature ranges, dimensional stability and load limitations of plastic bearings are in general less than for metallic bearings, plastic bearings are remarkably versatile and economical.

A summary of characteristics of representative plastic and nonmetallic materials has been given by *Machine Design* magazine (Vol. 54, #14, June 17, 1982, p. 132) with whose permission the following material is reprinted.

Phenolics: Composite materials consisting of cotton fabric, asbestos, or other fillers bonded with phenolic resin. The good compatibility of the phenolics makes them easily lubricated by various fluids.

They have replaced wood bearings and metals in such applications as propeller and rubber-shaft bearings in ships, and electrical switch-gear, rolling-mill and water-turbine bearings. In small instruments and clock motors, laminated phenolics serve as structural members as well as a bearing material. They have excellent strength and shock resistance, coupled with resistance to water, acid, and alkali solutions.