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Primer for Sleeve Bearing Design

by S.J. Hudak, 1995

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Preface

The information contained in this guide has been compiled and used with refinements over approximately a 50-year period during the employment of the writer with various bronze companies.

It has been applied successfully to sleeve bearing problems and designs by the writer based on personal experiences, interpretation of various engineering papers and bearing articles along with observation of tests.

Because the usage of much of this data covered a period of 50 years, it is impossible to list all the credits since they constitute much from recollection of the writer's memory. While there is no intent to circumscribe or omit credits that herald the work of others, tests and articles, this guide is intended to outline the various features of design and application still in the writer's memory that have been successfully used to solve bearing problems. It is an attempt primarily to consolidate data to permit a more direct reference and to preserve the data and assist the young bearing engineer without experience to use tried and proven data without the necessity of the individual to search out and research many of the data and information contained herein.

The writer attended Youngstown College in 1946 and began as a manufacturing engineer at Johnson Bronze Co. in New Castle, Pa. The company cast and produced all types of sleeve bearings. These included wrought sleeve bearings, bi-metal sleeve bearings, solid bronze and aluminum bearings, plastic and polymer bearings, and other bronze products.

Hudak also served as vice president of Magnolia Metal Corporation in Auburn, Nebraska; sales and product engineer for Bronze and Metal Corp. and Marion Bronze Co., both of Marion, Ohio; and sales engineer for B-Mold Co. in Mansfield, Ohio, a division of Eagle Picher. Eagle Picher later became Bunting Bearing Corp. from which the writer retired after six years.

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CHAPTER ONE
DESIGNING THE SLEEVE BEARING

The sleeve bearing designer can well appreciate the many contributing factors of load, speed, shaft material, finishes, hardnesses, clearances and lubrication, all of which influence the final design, material or alloy choice.

Each of these factors must be given full consideration to determine the importance of each to meet the greatest need of the application.

To narrow some of the more obvious factors such as speed or type of motion - whether rotating, oscillating or reciprocating - coupled with the type of load as continous, intermittent with or without shock or impact loading, generally point to the mode of lubrication that may be indicated.

That is, the Pressure Velocity factor (PV) gives a reasonable indication of the possible success based on its product.

In order to obtain the PV, it is necessary to convert the total weight (W) to be supported in pounds to the unit load (P) in pounds per square inch and the speed in revolutions per minute to the velocity (V) in feet per minute.

The following formula can be used for **rotary motion**:

Pressure (P) = Total Load (W) / Projected Bearing Bronze Area = PSI

note: P is the unit load in PSI
W is the total load in pounds
PBA is the bearing diameter times the length

Velocity (V) = π x D x N / 12 = .262 DxN = fpm
note: V is surface feet per minute
π is a constant 3.1416
D is the shaft or bearing diameter
N is the RPM

The following formula is used for **linear motion**:

Pressure (P) = Total Load (W) / Projected Bearing Bronze Area = PSI
note: P is the unit load in PSI
W is the total load in pounds
PBA is the bearing diameter times the length

Velocity (V) = feet traveled per minute (length of stroke)

The following formula is used for **oscillating motion**:

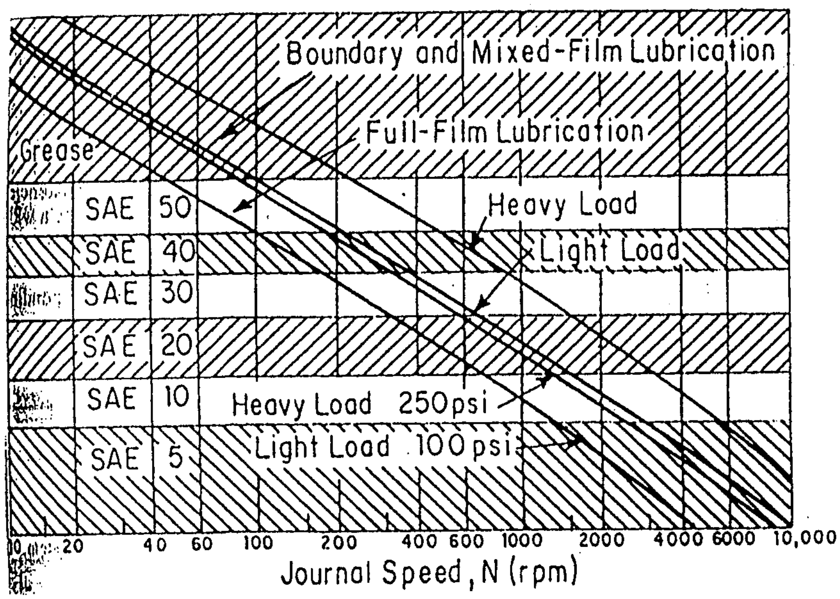
Pressure (P) = Total Load (W) / Projected Bearing Bronze Area = PSI

note: P is the unit load in PSI
W is the total load in pounds
PBA is the bearing diameter times the length

Velocity (V) = .0029 X ID X Degree in one stroke

For applications having ideal lubrication, the PV factor can range well above 150,000.
For severe service, the PV factor should be reduced to 90,000.
For extreme severe duty, the PV factor should be reduced to 60,000.

Using an arbitrary limiting bearing temperature of 250 degrees F, and using the power formula MDWN, with an assumed constant friction factor (M) of .075, a relatively straight line value can be obtained. This result should only be used as a guide because other factors and considerations may modify and affect the final decision.



The heat so generated by a load (P) in combination with a low velocity (V) will be substantially less than with a low load (P) and a high velocity (V) because velocity or speed influences the temperature more than load or pressure does.

In actual bearing service, and as a general rule, bearing temperatures should not exceed 140 degrees F to 160 degrees F or endure a rise of more than 70 degrees F. For large or heavy equipment applications, a temperature rise of 55 degrees F is acceptable.

CHAPTER TWO
LUBRICATING MODES

Sleeve bearings operate in one of four lubrication modes or a combination therein; the thick film or full hydrodynamic, the mixed film or thin film, boundary and the negligible speed mode such as in an oscillating speed which generally requires a solid film lubricant.

The thick film hydrodynamic mode gives the lowest friction and least wear with the lowest loss of power since the unit load is supported by a lubricant film and only permits contact of the mating surfaces during start up and shut down.

Although full hydrodynamic mode can be realized at substantially low surface speeds coupled with low loads, the greater frequency of obtaining this mode is above 70 fpm.

As an example, the sintered powdered metal self-lubricating bearing with 18% porosity must operate at about 70 fpm or more in order to generate sufficient frictional heat to permit the oil within its impregnated structure to seep from its pores and establish a reasonable film thickness.

When full film lubrication is achieved, the coefficient of friction value that can be obtained is in the range of .001 to .005.

The mixed film lubrication mode is the transitional point between fluid film and boundary where there is a partial separation of the mating surfaces generally occurring between 15 fpm and up to 70 fpm.

Wear in this mode depends upon the degree of surface roughness since the mixed film mode leads to intermittent metal to metal contact resulting in higher temperatures and increased coefficient of friction values in the range of .02 to .08.

Boundary lubrication mode generally occurs in surface speeds below 30 fpm and in oscillating and reciprocating motion. The coefficient of friction generally results in a range from .08 to .14 or more.

Although this mode is best served by the greases, it also is served by solid lubricants such as graphite or molybdenum disulphides in collodial form as suspensions in the greases.

Solid lubrication mode is considered when speed or velocity is negligible or where the application is to operate under abnormal temperature conditions. The solid lubricant is contained in form of plugs, filled grooves, spray coating or held in other configurations. The coefficient of friction generally runs in the range of .14 through .35.

This mode is taken up at greater length in later chapters.

CHAPTER THREE
SELECTING THE BRONZE SLEEVE BEARING ALLOY

While the bronze alloys are the most common and versatile of sleeve bearing materials, the alloy selected must contain various features as load carrying ability without deformation; low coefficient of friction; wear resistance; compatibility with shaft materials; finishes; and hardnesses. It also must have a resistance to pounding loads or impacts when encountered, corrosion resistance and other properties.

These properties are derived from the addition of various elements to the bronze alloy at casting.

Since there is no bronze alloy that possesses all of the desired properties, the alloy will always be a compromise.

Bronze is an alloy of copper and tin. Several of the following elements can be added to obtain the most important, desired effects.

Lead (Pb), even in amounts as small as 1% or less, improves the working qualities and machine-ability of the alloy.

Because lead does not alloy with bronze over 3%, it retains its characteristics and melting point. The lead separates in form of globules and are trapped in the copper-tin dendrites. These globules act as a natural lubricant because lead has a low affinity for steel, reducing the tendency to seize or weld to the shaft, even when lubrication fails.

In lead content exceeding 10%, the load-carrying ability with impacts, or pounding loads are reduced in proportion to the copper-tin ratio.

The lead content permits the alloy to operate at high surface speeds and the ability is increased with increased lead content.

Tin (Sb), in any amount, hardens copper and is a measure of the alloys ability to carry the load. As the tin content increases, its load-carrying ability increases.

Bronze alloys with less than 4% tin content are generally unsuited for bearing purposes because the alloy has a low resistance to deformation and exhibits the tendency to wear rapidly in the absence of lubrication.

Increasing the tin content to 5 to 11% improves the hardness and the tensile strength; above 11%, however, it has the effect of reducing the ductility and increasing the brittleness.

Zinc (Zn), when added to bronze in amounts of 3% or less, acts as a deoxidizer, a hardener and increases the fluidity of the metal during casting.

Zinc additions increase corrosion resistance of copper in environments such as natural gas or where sulfur attack is involved.

Above 16% zinc content, the alloy becomes subject to dezincification but with small amounts of arsenic, tin or phosphorous, this process is inhibited.

Phosphorus (P) also is used as a deoxidizer and a hardener and is preferred over zinc when the alloy is used for bearing purposes.

Nickel (Ni) increases the density and hardness by grain refinement which also helps to lower the wear rate. The addition of this element also improves the corrosion resistance of the alloy.

Manganese (Mm) also is used as a deoxidizer and strengthens the alloy by grain refinement. It is limited to aluminum bronzes and manganese bronzes.

Iron (Fe) is used as a hardener and grain refiner in copper zinc and aluminum bronze alloys.

Aluminum (Al) is used as a flux and deoxidizers in yellow brass where fluidity is essential in running thin sectioned castings. It increases the yield strength and hardness in aluminum bronzes.

Increased aluminum content reduces the elongation and ductibility of the aluminum bronzes but permits heat treatment above 10% content.

Aluminum is an undesirable element in the leaded bronze alloys as the lead content is to the aluminum bronze alloys.

CHAPTER FOUR
LOAD SPEED CATEGORIES AND USAGES

The bronze alloys are categorized by their most desireable properties they offer for specific applications.

High-lead tin bronzes: High-speed, low-loads

The lead content is above 12% and higher and are best suited to meet high surface speeds but with low loads since they are considered to be more plastic in nature, conform readily to imperfections of mated parts, do not require a hardened shaft and have the least galling tendencies.

The design working load of these alloys can be taken at 1500 PSI and can accommodate surface speeds through 1000 fpm.

The permissable static load can be taken at 6000 PSI.

The average physical properties are:
Brinell hardness 50 to 60 BHN
Coefficient of friction (dry) .15
Minimum recommended shaft hardness 165 BHN
Maximum operating temperature 450 degrees F

CDA	Tensile Strength PSI	Yield Strength PSI	Elongation %	BHN
943	21000	15000	7	42
941	25000	17000	10	53
938	25000	16000	8	53

Principal uses: Turbine bearings, compressors, pumps, rotors, seals and where loads are free from shock and impacts, where lubrication is less than ideal and speeds well over 70 fpm.

Leaded tin bronzes: Medium-load, medium-speeds.

This group of alloys contain 10% or less of tin content and are generally used for the greatest number of applications. Their chemical balance combines a good tin to copper ratio for load-carrying ability and an ample amount of free lead for anti-frictional or surface action properties. They offer good wear resistance and can be used for impact and shock loading.

The design working load can be taken as 3000 PSI and a permissible static load of 8600 PSI. The surface speeds through 500 fpm or less are possible.

The average physical properties are:
Brinell Hardness 50 to 70 BHN

Coefficient of friction (dry) .25
Minimum recommended shaft hardness 250 BHN
Maximum operating temperature 500 degrees F

CDA	Tensile Strength PSI	Yield Strength PSI	Elongation %	BHN
937	35000	20000	8	60
932	35000	20000	10	65
935	32000	16000	18	60

Principal uses: Bearings for most industrial and general machinery bearings, roll neck, mill and pulley bearings.

Tin bronzes: Low-speed, high loads.

The tin bronzes are hard bronzes that offer increased load-carrying capacities. They are capable in accepting shock and impact loads but with reduced surface speeds. They possess excellent corrosion resistance but require mating with hard shafts, good surface finishes and good lubrication since they are more prone to seizure and cold-welding than the bronzes containing lead.

The working load can be taken at 5000 PSI but with reduced speeds. Surface speeds should not exceed 250 fpm unless positive and ideal lubrication are available. The permissable static load can be takenat 10,000 PSI. These alloys require accurate alignment and hardened polished shafts.

The average physical properties are:
Brinell hardness 60 to 80 BHN
Coefficient of friction (dry) .25 to .30
Minimum recommended shaft hardness 350 BHN
Maximum operating temperature 550 degrees F

CDA	Tensile Strength PSI	Yield Strength PSI	Elongation %	BHN
905	44000	25000	10	75
907	40000	25000	10	80
927	38000	20000	8	77

Principal uses: Pump impellers, valve components, wrist-pin bushings, bridge bearings and wear plates; coal-crushing machinery, press bearings, pump and paper mill bearings; worm wheels and gears.

Aluminum bearings: High-loads, low-speed

The aluminum bronze alloys are used more frequently as bushings for their wear resistance, heavy load-carrying ability, in temperature service, since they retain their physical and mechanical strengths at higher temperatures than the other bronze alloys. They possess excellent corrosion resistance and are used extensively in marine service. Because of their short freezing or solidification range in casting, they are preferred for permanent mold castings.

The aluminum bronzes with about 8% aluminum content can be cold-worked successfully. Those with aluminum content above 8% can only be hot-worked or forged. The hot-working temperature begins at 1400 degrees F.

The aluminum bronzes with less than 10% aluminum content will not respond to heat treatment. Above 10% aluminum content, they can be heat-treated.

The aluminum bronze alloys are considered to be non-sparking and suitable for equipment handling explosives, petroleum, chemical and gas products and in mines.

The average physical properties are:
Brinell hardness 140 to 230 BHN
Coefficient of friction (dry) .30
Minimum recommended shaft hardness 400
BHN with heat-treated aluminum bronzes increased to 600 BHN
Maximum operating temperatures 750 degrees with intermittent service through 1200 degrees F.

CDA	Tensile strength PSI	Yield strength PSI	Elongation %	BHN
952	68,000	26,000	20	125
953	70,000	26,000	25	140
953HT	80,000	40,000	12	175
954	85,000	32,000	12	170
954HT	95,000	45,000	10	195
955	95,000	42,000	10	195
955HT	110,000	62,000	8	230

Principal uses: Marine equipment, pump impellers, acid-resistant pumps, valve seats, guides, worm screws, nuts, gears, mine equipment, and chemical, gas and petroleum-related machinery and equipment. Several of these aluminum bronze alloys are used extensively in permanent molded castings such as pole-line hardware and other products replacing sand-cast items.

Manganese bronzes: Extreme high-loads, low-speed.

Manganese bronzes are actually brasses since they are an alloy of primarily copper and zinc. They are the strongest and one of the more wear-resistant, non-heat-treatable alloys with high tensile strength, high yield strength, hardness and ductility similar to steel.

The manganese bronze alloys require mating with a hardened shaft, good finishes, good lubrication and larger running clearances than the other bronze alloys.

Since they also exhibit a short freezing range in solidification, they are used for permanent molded castings but not to the extent of the aluminum bronzes.

The manganese bronzes have a high-compression strength suitable for vibration and heavy rolling contact but with speeds substantially below 250 fpm.

They are corrosion resistant and can be more economical than the heat-treated aluminum bronzes.

The average physical properties are:
Brinell hardness 180 to 225 BHN
Coefficient of friction (dry) .25 to .35
Minimum shaft hardness 500 BHN
Maximum operating temperature 400 degrees F

CDA	Tensile Strength PSI	Yield Strength PSI	Elongation %	BHN
862	90000	45000	18	180
863	120000	62000	12	225

Principal uses: Movable bridge bearings and plates, pump bodies, gears, roller-gate bearings, fixed wheel gates, sheaves hoists, crane wheels and off-road construction equipment and machinery, crushing machinery, and permanent molded products as wear plates, pads, hinges, etc.

Although CDA 865 Manganese bronze is in this family of brasses, the physical and mechanical properties are somewhat less than the above two, with tensile strength of 65,000 PSI, yield strength of 45,000 PSI, elongation of 20%, and a brinell hardness of 100 BHN. It can be used for surface speeds up to 250 fpm, with loads reasonably higher than the leaded bronze and tin bronze alloys.

Since it has a short-freezing range in solidification in casting, it also can be used for permanent mold castings.

The preceding lists are intended as a working guide to the selection of various bronze alloys to meet certain speed-load categories for the greatest number of desireable properties they offer based on past usage.

Many other factors enter into the final decision and when each factor is refined, they will indicate the most promising alloy to be satisfactory for that set of conditions.

CHAPTER FIVE
BEARING OD, WALL AND LENGTH CALCULATIONS

In designing a sleeve bearing, the wall thickness must be taken into consideration to retain sufficient rigidity and strength to support the load without deformation and to offset the weakening effects of such features as grooves, holes, notches or cut-outs that may be required.

Although strength of material tests show that a thinner wall will sustain a higher compression load and have a higher fatigue resistance than a heavy wall, consideration must include the housing material for the added support and strength. The thinner wall also offers a greater economy.

The wall thickness can be calculated as a percentage of the bearing inside diameter or using the following formulae:

Light service: wall thickness = .08D + 1/32 "
Medium service: wall thickness = .08D + 1/16 "
Heavy-duty service: wall thickness = .08D + 1/8 "

For standardization purposes, the results should be taken to the nearest 1/16" dimension with the high side of the wall thickness favored when designing with the features of grooves, holds, cut-outs, notches, etc.

For flanged bearings, the flange thickness can usually be taken as the wall thickness or modification to meet the design requirements.

Length calculations: The length of the bearing should be designed to meet the type of service involved and to meet the projected bearing to maintain the unit load within acceptable limits of the alloy.

However, rather than to lengthen the bearing to meet a projected bearing area for the unit load involved, it is more desireable to increase the bearing diameter which also increases the surface speed.

For high speed bearings, it is more desireable to stay within a L/D ratio of 1/2 or less. This minimizes the frictional heat being generated and to reduce the problem of edge loading.

For general bearing service, the length of the bearing should not be less than 1 to 1 1/2 times the shaft diameter.

For slow and negligible speeds coupled with heavy loads, an L/D ratio of about 3 should be satisfactory. Beyond this ratio, misalignment and edge loading may become problems.

Permissable loading where speeds are below 30 fpm, loading can approach the yield point of the alloy when divided by a safety factor of 2.

If there is shock and impact loads, the bearing may support 25 to 50% of the permissable static or yield strength. (These are merely suggestions and are not meant to be specific values.)

CHAPTER SIX
RECOMMENDED ASSEMBLY AND RETENTION PRACTICES

There are many methods used to assemble to retain sleeve bearings in an assembly to prevent movement under rotation and load in service.

Some of these methods include bolting the bearing with a retainer, a lugged end plate, set screwing, knurled or coarse threading the sleeve OD, key retention or retained by capscrew, press fitting and shrink fitting.

Although the latter two methods are the most popular and give the most positive, efficient, economical and simplest means with little or no specialized equipment being necessary, each method will be described briefly.

FIGURE 1: BOLTED:

The sleeve bearing is slip-fitted into the housing against the shoulder in the housing bore. The bolted plate is counterbored to permit the bearing to be in contact with it; the bearing length tolerance should not be greater than .005" and ends must be parallel and square.

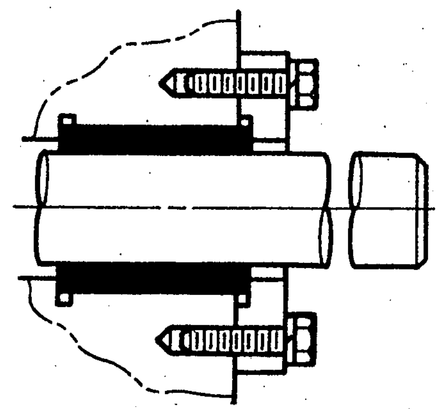


FIGURE 2:

Bearing pressed or slide fit into housing and retained by lugged end plate. Slot is milled in end of bearing to a depth of slightly below bottom surface of the lug.

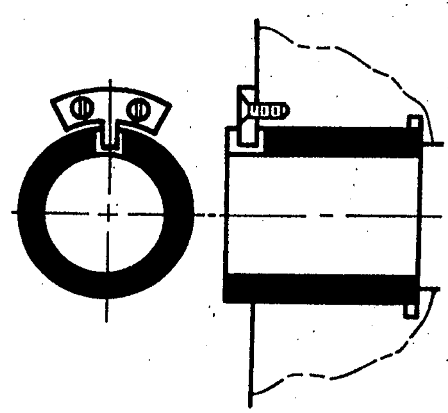


FIGURE 3:

Headless setscrew tightened against flat on bearing. Be careful not to deform bearing. The flat on the bearing is not necessary but the setscrew will form a burr on the bearing surface and make removal difficult. The setscrew may be locked in by another screw or by locking compound. Bearing can be press or slip fitted.

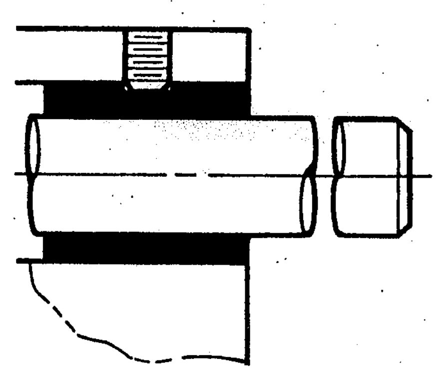


FIGURE 4:

Knurled or coarse-threaded outer surface used where a die casting is to be made around the bearing. Located one end surface of the bearing flush with surface of housing.

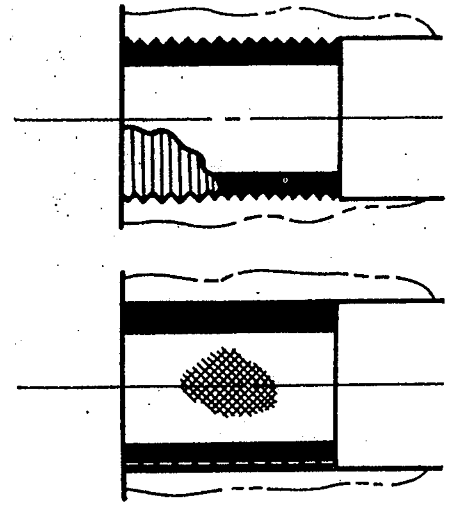


FIGURE 5:

Bearing dimensioned for key retention. Keyseat depth 1/2 wall thickness or less on small and medium bearings. Length is specified same as key length but milling-cutter overrun is shown. Finish-machine inner surface after key is in place.

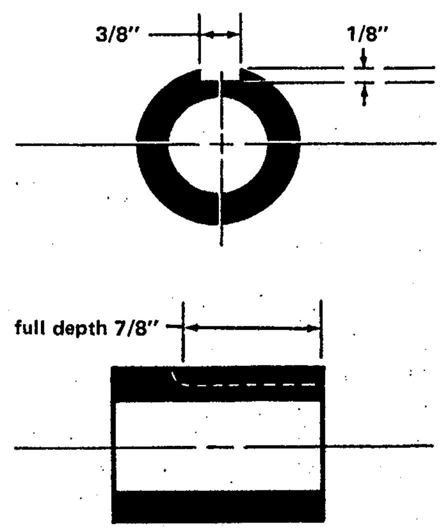
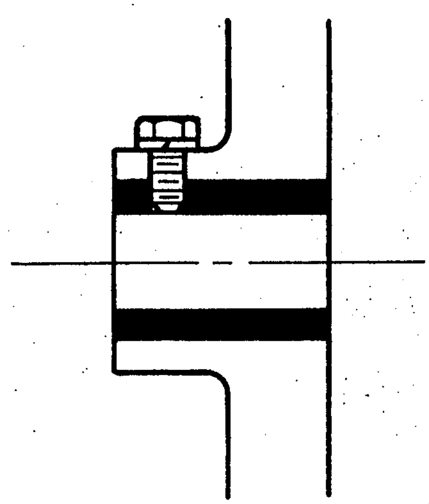


FIGURE 6:

Bearing pressed or slide fit into housing. Retained by capscrew. Hole is drilled through wall of bearing. End of capscrew is below inner surface of bearing.



Press-fit Method: The receiving hole or bore must be within certain described limits for a given method of installation or assembly.

Maximum surface contact for heat dissipation are of the utmost importance in high-speed applications, therefore a housing bore tolerance of .001" with a finish of approximately 32 RMS is recommended.

A housing bore of .002 tolerance would generally have a finish of 63 RMS and a .003 tolerance bore would indicate a 125 RMS finish. This latter tolerance bore would be suitable for slow or negligible speeds with high loads.

The receiving hole or housing bore should always have an entry chamfer to facilitate bearing alignment and entry without excess shearing. The chamfer should never be greater than 40 degrees.

For press fitting, a shouldered arbor with a piloted shaft should be used with an arbor press to prevent eschewing or tilting the sleeve bearing at press-fit operation.

Since the sleeve bearing ID will "close in" the bore after press-fit assembly, certain allowances or adjustments may be required to the sleeve-bearing bore.

If the sleeve-bearing ID is to be used as is, then the ID should be adjusted for the "close in" depending upon the interference fit. (Refer to the calculation sheet attached to this chapter.)

If the bearing is to be used in a high-temperature service, less OD interference fit should be considered since the bronze will expand at a greater rate than the steel or cast iron housing. Further the shaft expansion must be calculated and the final bearing bore size must be adjusted. (Refer to the temperature calculation sheet attached to this chapter.)

If the bearing is to be used without machining, a thin-walled bearing (1/8" wall thickness in a 2" diameter bearing) will "close in" the ID approximately 80% to 100% of the interference fit.

A heavier-walled bearing (1/4" wall thickness in a 2" diameter bearing) will "close in" the ID 60% to 80% of the interference fit. (For full particulars, refer to the calculation sheets at the end of this chapter.)

A press fit should retain a bearing rigidly in a housing within the bronze alloys elastic limit. Excessive interference fit will prevent the intended results by deforming the bearing OD and giving it a permanent set which could result in the bearing working loose in the assembly under load and speed service.

Since bronze alloys have a higher coefficient of linear thermal expansion rate, i.e. leaded bronze (10.8 X 10 -6) than a steel or cast iron housing (6.3 X 10 -6) operation from normal temperatures will require additional adjustment to the ID for these differences in expansion of mating parts. (Refer to the calculation sheet at the end of this chapter.)

In press fitting, a light coating of oil will generally prevent galling or shearing. The pressure in press fitting must be applied uniformly and in one continuous motion. Do not use any driving means such as a hammer which tends to peen the end of the bearing and distort the ID.

The press-fit stress put on a cast bronze bearing for every .001" of interference fit is approximately 12,500 PSI. Therefore, a .001" minimum press fit allowance should be minimally sufficient for bearings up to 3" OD.

For bearings above 3" OD, use .002 minimum through 6" OD.

Shrink fitting: If an arbor press is not available or its capacity is insufficient for the assembling force necessary, the bronze bearing can be assembled by the shrink-fit method.

This method requires chilling reduction of the bronze bearing or by causing a temperature increase of the housing bore by use of an induction heater. However, the plug induction heater may not be practical because of the housing bulk. In lighter housings, a plug induction heater can be used to an advantage.

The shrink-fit method is used commonly, is economical and simple. It requires the sleeve bearing to be packed in dry ice or chilling it in a commercial deep-freeze, or more desireable, by direct immersion of the bearing in liquid nitrogen.

Liquid nitrogen is particularly suitable since it is inert and free of corrosion, fire or toxic hazard. However, precautions should be taken to avoid contact with an employee's skin and it is advisable to have a ventilated space or area.

The time for chilling by immersion varies between 4 minutes for a 1" diameter bearing to contract for a .001" of interference fit to an hour for a 10" diameter bearing to contract for a .005" interference fit.

Calculation for Temperature Adjustment of Bearing ID

Maximum Operating Temperature =_______(-) 70°F = ________ΔT°F

Bushing OD & Housing Bore Expansion:

LB= 10.8 X 10 -6 (Leaded Bronze)

AB= 9.0 X 10 -6 (Aluminum Bronze)

S= 6.3 X 10 -6 (Stl. Housing & Shaft)

Maximum Bushing OD _____ X ______ ΔT°F X _________ = __________
B

Minimum Housing Bore _____ X ______ ΔT°F X_________= (-)________
S

Net ID Restriction From Press Fit & Temperature................. = ___________

Shaft Diameter Expansion:

Shaft Diameter __________ X ________ ΔT°F X _________=__________
S

Net Total Expansion Adjustments (+)..................................... __________

Running Clearance Allowance:

* .0015 per inch of diameter (graphite lube)
* .0025 per inch of diameter (or other solid lube)
* Allowance based on size and temperature

Shaft diameter at room temperature ____________ X ___________ = _______

Bushing ID adjustment for "close in" and temperature:

Shaft diameter @ room temperature = __________

Net total expansion adjustment = __________

Running clearance allowance = __________

Net bushing ID adjustment = __________ Minimum __________ Maximum

Calculations for determining bearing ID
Before press fit "close in" adjustment

Interference fit:

Bushing OD: __________ Maximum __________ Minimum

Housing Bore: __________ Minimum __________ Maximum

Interference Fit: __________ Maximum __________ Minimum

"Close in" Calculations:

Thin wall approximately 80 % to 100%
Heavy wall approximately 60% to 80%

Maximum amount of "close in" expected: _______ % X ________ = Int. Fit _______
Mininimum amount of "close in" expected: _______ % X ________ = Int. Fit _______

Running Clearance Allowance:

* .001" per inch of diameter (oil)
* .0015" per inch of diameter (grease)
* .0020" per inch of diameter (graphite)

Shaft diameter: __________ X __________ Clearance allowance = __________

Bushing ID Before Press Fit:

Shaft Diameter ________ Maximum __________ Minimum

"Close in" _________Minimum __________ Maximum

Running Clearance ________ --------- __________ ----------

Bushing ID _________ Minimum _________ Maximum

CHAPTER SEVEN
OIL HOLES AND OIL GROOVES

Oil holes and oil grooves are important features of a journal bearing to introduce and distribute the lubricant adequately to the bearing surface as needed.

Oil holes in the sleeve bearing are the simplest and most effective method in introducing the lubricant into the bearing area but must be located in the unloaded area of the bearing. The oil hole also can be located in the shaft. The oil entering through the shaft will be centrifuged into the sleeve-bearing area in the same amount or more.

Grooving is rarely necessary in short bearings with an L/D ratio of .5 or less unless high-surface speeds require a larger volume of oil to pass through to dissipate the frictional heat generated. In those cases, an annular or circular groove will enhance the results.

For bearings with an L/D ration of 1 or more, oil grooves may be necessary depending upon the speed, load and type of lubricant viscosity.

Grooves are generally required for grease lubricated bearings since grease does not have the mobility of oil nor does grease dissipate the frictional heat being generated.

Oil inlet holes should be at least as wide as the groove it is supplying. Any smaller inlet hole can be blocked with sludge or other debris and result in restricting the lubricant from entering the bearing surface and starve the application which will result in failure.

The oil inlet holes should be chamfered and have all edges rounded and broken to form unrestricted entrances for the lubricant to enter.

All grooves should be blended and rounded to reduce the effects of sharp edges that interfere and scrape the lubricant and prevent the formation of an oil film.

In high-speed bearings or pressure-lubricated bearings, a small "V" or vent groove may be added to remove entrapped air or permit dirt or other wear debris to escape and permit slight oil leakage to reduce frictional heat.

Types of Grooving

Oil hole: A single oil hole without any grooving is commonly used in short bearings with an L/D ratio of .5 or less. Oil will flow axially unaided to each side of the oil inlet hole by as much as 1/2". The oil hole should be centrally located and in the unloaded area to ensure that oil is distributed equally to both sides.

The bearing with a single oil hole can have approximately three times the load bearing capacity then a bearing with an annular or circumferential groove in the same length bearing.

Straight axial groove: is used when the bearing length exceeds an L/D ratio of 1.5 but stops short of each end by 1/8" to 1/4". The groove must be located in the unloaded area.

Circular or annular groove: is generally used when lubrication is pressure-fed or direction of load varies and a low-pressure region cannot be located. This type of groove divides the bearing into two shorter bearings which do not carry the same load as a single bearing. When an annular or circumferential groove is used, it is important that it is placed exactly along the center of the bearing. If the groove is placed off center, then half of the bearing will tend to operate with a greater eccentricity than the other.

This groove can be used in combination with a straight axial groove but the axial groove must be located in the unloaded area.

The oil flow of a bearing with a circular groove is about 2.5 times that of a bearing with an oil hole only.

Oval groove: A single- or double-oval groove connected with an oil entry hole will distribute the lubricant more positively and more copiously.

Although the groove passes angularly through the loaded area, only a small measure of load pressure will be affected. The oval groove also should run short of each end by 1/8" to 1/4" unless the lubricant is introduced from the bearing end, then that groove side should be open into the reservoir.

Figure-8 Groove: is a modification of the double-oval groove and is generally preferred in grease lubricated applications or to offer a greater exposure of graphite in graphited bearings. (For additional information on the recommendation of various groove designs, please consult the chart at the front of this guide.)

The "V-Shaped" Groove: and radiused, cross-sectioned grooves are best suited for oil lubrication since the groove edges, blended or rounded, promote the formation of the oil film.

The Rectangular, Cross-Sectioned Groove: is better suited for grease and graphite or other solid lubricants since it offers a larger surface area for the grease or graphite to adhere or offer a larger reservoir of grease.

If two bearings are used in line in an oil- or grease-lubricated mode, a central reservoir should be located between the two bearings by at least twice the wall thickness or more.

Any angular groove should be open only on the reservoir side if the lubricant is not introduced through the bearing length. Again, oil grooves or grease grooves should extend to within 1/8" to 1/4" of each bearing end when using a centrally-located inlet hole.

The groove width and depth will depend on the volume of oil which must pass through the bearing to maintain the viscosity within the range of operating temperatures.

Precision-Groove Applications: The groove width (W) should be taken as .06 times the bearing bore diameter and the depth (D) to (.5W).

Medium-Groove Applications: The groove width (W) should be taken as .08 times the bearing bore and depth (D) to (.5W).

Loose-Groove Applications: The groove width (W) can be taken as .10 times the bearing bore and depth (D) to (.5W).

Although the generally-accepted print tolerances are usually given as plus-or-minus .005 to plus-or-minus .010, the width and depth can be specified in less restricted tolerances.

In general, the suggested widths and depths of oil-lubricated grooves can be taken as follows:

Bearing ID	Groove Width	(W)	Groove Depth	(D)
0.5	1/16	0.062	1/32	0.032
1	1/8	0.125	1/16	0.062
2	5/32	0.156	5/64	0.078
3	3/16	0.188	3/32	0.094
4	1/4	0.25	1/8	0.125
5	5/16	0.312	5/32	0.156
6	3/8	0.375	3/16	0.188
7	7/16	0.437	7/32	0.219
8	1/2	0.5	1/4	0.25
9	9/16	0.562	9/32	0.281
10	5/8	0.625	5/16	0.312
11	11/16	0.687	11/32	0.344
12-20	3/4	0.75	3/8	0.375

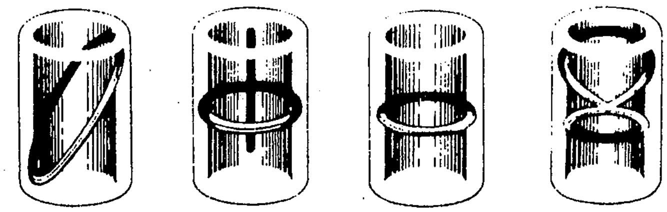
Typical Operating Range for Oil Film Lubrication

Example SAE 660 Alloy

Condition	Recommended Limitations
Surface Speed	70 fpm or over
Unit Load	3,000 psi or less
Lubrication	High Speeds— Over 1200 fpm: SAE 10 High Loads— Over 250 psi: SAE 30
Shaft Hardness	Rc20 min. High Speeds (low loads): Rc25 Low Speeds (high loads): Rc35
Shaft Finish	32 RMS or better

With Oil Film Lubrication, grooves are required when bearing's length to diameter ratio is greater than 1.

Used when oil reservoir is at end of Bearing. — Used with pressure lubrication and unidirectional load. — Used with unidirectional load. — Used with oil inlet at center.



OVAL — ONE STRAIGHT AND ONE CIRCULAR — CIRCULAR GROOVE — FIGURE EIGHT

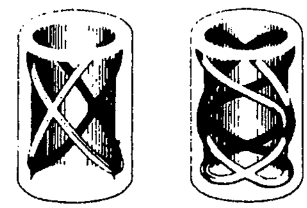
Typical Operating Range for Grease Lubrication

Grooved Bearings

Condition	Recommended Limitations
Surface Speed	Below 70 fpm
Unit Load	Up to 8,600 psi.
Lubrication	Low Loads— Under 3000 psi: SAE 40 High Loads— Over 3000 psi: 90-EP
Shaft Hardness	Rc20 min. Low Loads: Rc25 High Loads: Rc35 or higher
Shaft Finish	20 to 63 RMS max.

With Grease Film Lubrication, grooves are required when bearing's length to diameter ratio is greater than 1.5. Two popular designs are described:

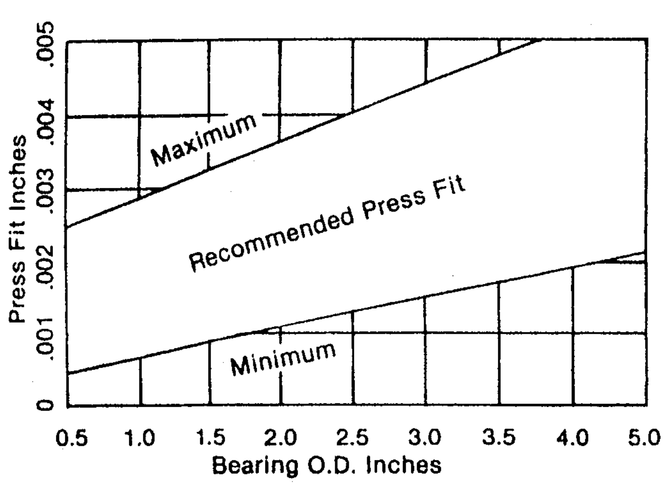
Used with high load, low speed range (under 30 fpm). — Used with low load, high speed range (over 30 fpm).



DOUBLE OVAL — DOUBLE FIGURE EIGHT

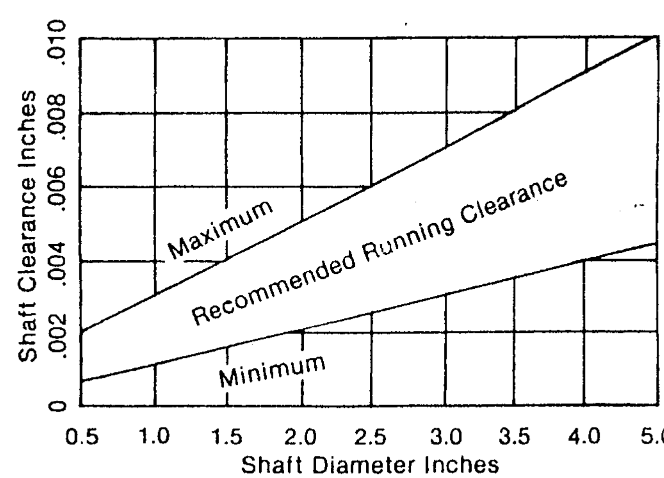
Press Fit

Generally a .001 minimum interference fit per inch of diameter is adequate at room temperature.



Clearance

If exceptionally high speeds or loads are involved, increase the clearance allowance to the next size.



CHAPTER EIGHT
GROOVES FOR GREASE AND GRAPHITE-FILLED BEARINGS

The groove width (W) for grease lubricated bearings should be increased by 1/32" of that of oil grooves with depth (D) remaining the same or slightly deeper by 1/64".

The wider grooves permit the shaft a longer contact period with the less mobile grease supply and permit a greater surface coverage of graphite filled grooves.

The suggested groove width (W) and depth (D) as shown below:

Bearing ID	Groove Width	(W)	Groove Depth	(D)
0.5	3/32	0.094	3/64	0.046
1	5/32	0.156	5/64	0.078
2	3/16	0.188	3/32	0.094
3	1/4	0.25	1/8	0.125
4	9/32	0.281	9/64	0.14
5	5/16	0.312	5/32	0.156
6	13/32	0.406	13/64	0.205
7	15/32	0.469	15/64	0.234
8	17/32	0.531	17/64	0.265
9	19/32	0.593	19/64	0.296
10	21/32	0.656	21/64	0.328
11	23/32	0.719	23/64	0.36
12-20	25/32	0.781	25/64	0.39

Since these grooves are not as critical as oil grooves, they can be toleranced looser to plus-or-minus 1/64 to plus-or-minus 1/32.

In grease lubricated bearings where exposed to contaminants such as dirt, ash or other debris, it is advisable to provide an annular or circular groove near the end of the bearing within 1/8" to 1/4" to create a dam effect. Such an effect will act as a reasonable seal, preventing contaminants from entering the bearing surface.

CHAPTER NINE
GRAPHITED AND SOLID LUBRICATED BEARINGS

Solid lubricated bearings such as graphite or molybdenum disulfides are used in severe environmental situations where normal fluid or grease lubricants cannot be used because of abnormal temperatures which would tend to carbonize or freeze the lubricant to brittle solids.

They find usage constantly in chemically-reactive environments, in nuclear radiation and vacuum environments and where normal lubricants cannot be tolerated. They also are used where there is limited access to resupplying the lubricant or where it can be neglected.

These solid lubricants can be used in form of collodial powders in suspension of a grease carrier or held and bonded by various binders.

Graphite itself, although one of the most popular solid lubricants, requires some absorbable gases, moisture or hydrocarbon vapors to develop low-shear strength.

The gases and water vapor in the normal atmosphere are usually sufficient to ensure an adequate supply of absorbable medium but a brief immersion in a heated oil eliminates chance.

Graphite in excellent through temperatures ranges through 1000 degrees F but are generally not satisfactory in high altitudes nor in a vacuum conditions since desorption occurs.

Molybdenum disulfide is an excellent solid lubricant below 750 degrees F or in a vacuum since it does not require presence of adsorbable vapors. However, above 750 degrees F in the presence of air or oxygen, it deteriorates and becomes an abrasive. It is also more expensive than graphite so it has limited usage.

As with graphite, molybdenum disulfide and the other solid lubricants require a binder to make it adhere to the bearing surface. There are various binders available that can be formulated.

The thermoplastic resins such as cellulesic or acrylic resins are easily sprayed, fast drying, requiring no baking but are limited to 150 degrees F.

The thermosetting phenolics have a service temperature of 400 degrees F with good adherence.

The epoxy resins adhere well and are safer than phenolics being stable through 600 degrees F but requiring heat-curing.

Some inorganic binders such as sodium silicate would exceed the 750 degrees F and would be suitable for graphite but limited to a lower temperature for molybdenum disulfide.

For an economical solid lubricant containing bearings, the standard available sintered powdered metal bearing with 18% porosity offers an excellent surface for retaining graphite or molybdenum disulfide formulation that would require a burnish operation of the lubricant into the surface.

CHAPTER TEN
GRAPHITED BEARING WALL THICKNESS CALCULATION

Since the solid lubricant must be held in form of grooved configurations, plugs or sticks in a series of drilled holes, they require a substantial depth to be retained properly.

The minimum wall thickness of groove-filled solid lubricated bearings can follow the width (W) and depth (D) described in Chapter VIII. Plug lubricated bearings with a .5 diameter should be held to 3/16" minimum wall thickness and then increased 1/32" for each nominal half-size above. That is, for a 1" ID bearing, a wall thickness of 7/32" should be considered for plug graphited bearings.

A general rule of thumb: wall thickness = .08D + 1/8" (where D is the bearing ID.)

The overall length on solid lubricated sleeve bearings can range in various lengths depending on the load, speed, and type of the application. The normal recommended L/D ratio is 1.5. This is to minimize possible shaft deflection and to offer greater stability and surface area. The maximum L/D ratio recommended should rarely exceed a ratio of 3 since misalignment edge-loading and frictional heat can be appreciably increased.

The accepted standard solid lubricant coverage should average 30 to 35% of the surface area. However, the calculation of plug size and lubricant coverage is shown below. The plug diameter and drill size should be no larger than the wall thickness but no less than half.

CALCULATION OF LUBRICANT COVERAGE AND PLUG SIZE:
Percentage of Graphite or Solid Lube Coverage

Drill Size	10%	15%	20%	25%	30%	35%	40%	45%	50%
3/16	8.95	13.43	17.9	22.38	26.85	31.33	36.81	40.28	44.5
1/4	5.03	7.54	10.05	12.57	15.08	17.6	20.11	22.62	25
5/16	3.22	4.83	6.44	8.05	9.66	11.27	12.88	14.49	16.1
3/8	2.23	3.35	4.47	5.59	6.7	7.82	8.94	10.06	11.1
7/16	1.64	2.46	3.28	4.1	4.92	5.75	6.57	7.39	8.2
1/2	1.26	1.89	2.51	3.14	3.77	4.4	5.03	5.66	6.28

1. Choose the appropriate drill or plug size.
2. Locate the desired solid lubricant coverage
   Use factor number opposite drill or plug size
3. Multiply bushing ID x bushing length.
   Multiply factor number to obtain the number of holes or plugs.

Example: 2" ID x 2 1/2 OD x 2" length

1. 1/4 plug diameter
2. 35% coverage from chart 17.6
3. 2 x 2" length x 17.6 = 70 drilled holes or plugs.

CHAPTER ELEVEN
GRAPHITED BEARING RUNNING CLEARANCE ALLOWANCE

The running clearances for solid lubricated bearings must be substantially greater than in oil and grease lubricated bearings because the frictional heat generated is not dissipated.

An allowance of .002 minimum per inch of diameter should be considered. Further, since solid lubricated bearings are not generally machined or bored after assembly "close in" of the ID must be allowed for. This allowance must be increased further if the bearing is to be used in abnormal temperature service to allow for expansion or contraction of the shaft.

For more specific clearance allowances, use the attached calculation sheet either for normal temperatures or for abnormal temperature service. (Reference Chapter 6.)

Surfaces Finishes: Solid lubricated sleeve bearings do not require the high degree of surface finishes of oil lubricated bearings. The slightly rougher bearing ID finish is desireable to permit the solid lubricant to coat its surface. Therefore, a bearing surface ID finish of 63 RMS to 125 RMS should be satisfactory. The shaft finish, however, should be ground or polished smooth to approximately 32 RMS.

Upon installation of the solid lubricated bearing, there will be instant wear until the shaft and bearing become coated with the solid lubricant. It would be adviseable to submerge the graphited bearing in an oil bath of slightly heated oil to penetrate the plugs or filled graphite grooves to enhance its initial "running in" or "bedding in" to reduce this initial wear to an acceptable minimum.

Note that the drilled and plugged holes do reduce the strength and structure of the bearing while adding to the cost.

Many times it would be more economical to utilize filled groove configurations since they do not weaken the bearing to any noticeable degree.

Although a solid lubricant can be retained in a serrated ID which can be broached for economy, tests have shown that such a structure weakens the lands in the bearing ID and limits the load and speed capabilities to less than 50 PSI and 30 fms.

General Information: Some commercially available solid lubricants containing compounds of graphite and molybdenun disulphide are sold by Lubriplate and Emhart Companies as Never-Seize and Dri-Slide.

The coefficient of friction for solid lubricated bearings are appreciably higher than those for oil and grease ranging from .15 to .35 initially then reduced to a lower acceptable level.

CHAPTER TWELVE
RECOMMENDED SHAFTING AND JOURNAL MATERIAL

The shaft or journal is the mating part of any bearing application and, therefore, requires ample consideration when mated with one of the many bronze alloys which have varying mechanical properties compatibility and hardnesses.

The designer must first choose a shaft or journal material that will satisfy the applications requirements of torque, shear stress, fatigue strength, fracture toughness, rigidity, wear resistance, corrosion resistance and have the ability to provide a good surface finish and sufficient hardness.

Various type of shaft or journal materials such as cast gray iron, modular iron, forged steel, induction hardened steel, case hardened, chrome-plated and polished steels are used.

The cast iron, gray and modular iron shafts offer low cost but since they do not pose all of the desireable shaft properties of steel, they have somewhat limited useage. Futher, they require specific grinding and polishing instructions.

The more popular shafting steels are mild SAE 1020 and low-carbon steels of SAE 1040. The higher carbon steels - AISI 1045, 1060, 4140, 4340, 52100 and M 50 tool steels and stress-proof steels are used after hardening, grinding and polishing finish.

The general range of such shafts are classified by hardness as follows:

Soft 165 BHN to 290 BHN
Medium 300 BHN to 390 BHN
Hard 400 BHN to 1000 BHN

There are commercially available standard shafts which have soft cores but a sub-surface which is case hardened to various depths, chrome-plated and polished.

Tests have proven that various hard bronze alloys, when mated with a soft shaft, will tend to seize or weld to the shaft at substantially lesser loads than when mated with a hard shaft.

The harder shaft will permit an appreciably higher unit load to be sustained with a lower wear rate resulting in extending the life of the assembly.

With the **high leaded bronze alloys**, which range in hardness of 50 to 70 BHN, a soft or mild steel, or cold-rolled steel shaft ranging in hardnesses of 165 BHN to 290 BHN are a suitable combination.

Shafts mated with the **high copper-tin alloys** which contain little or no lead having a range of hardnesses of 70 BHN to 80 BHN, would be adequately served by the medium shaft hardness range of 300 minimum.

The **aluminum bronze alloys**, not heat-treated, with average hardness of 140 BHN to 170 BHN are best combined with the hard shaft category of 400 BHN minimum.

Heat-treated aluminum bronze alloys, including the manganese bronzes with hardness ranges from 180 BHN to 240 BHN, require the shaft hardness range to be above 500 BHN or recommended to be used with shafts RC60 minimum being preferred.

In bearing tests conducted by various sources, the results indicated that the harder shafts with the highest polished finishes offer the best combination for improved load carrying ability over the speed ranges tested with the lowest wear rate.

Initially, most bronze alloys will show a high wear rate while "bedding" or "running in" but will level off to a more constant lower value.

The surface finishes of the shaft have a profound effect in any bearing application on the lubricating mode.

In full hydrodynamic conditions, the bronze bearing alloy should have a RMS finish in the range of 25 to 32 RMS and the shaft or journal held to polished to 6 RMS to 12 RMS.

In mixed film conditions, the bronze bearing alloy can range between 32 RMS to 43 RMS and the journal polished to 8 RMS to 16 RMS. Since the bearing goes in and out of full hydrodynamic mode, the better the finish the less the initial wear.

For boundary conditions wehre the surface speed is much lower, the relative roughness of the bearing and journal are not as critical. However, it is best to maintain at least a 43 RMS to 63 RMS finish on the bronze bearing and the journal to 32 maximum.

A hardened and super finished shaft has the ability to double the load before seizure when compared to a soft shaft finished to 10 RMS under the same conditions. In loads over 3000 PSI, a 10 RMS shaft finish is recommended.

In the case of sintered powdered metal self-lubricating bearings, a cold-rolled steel or mild steel shaft would be acceptable. However, a hardened carbon steel shaft such as C1137 with chrome-plating will double the PV factor while reducing shaft and bearing wear.

Whenever a stainless steel shaft must be considered because of corrosion conditions, it is not recommended that the 303 austenitic stainless series be used in combination with sintered bronze bearings unless it is chrome-plated or the sintered bearing is reimpregnated with a special lubricant containing oxidation and corrosion inhibiting additives.

If a stainless steel shaft is necessary, it is recommended the 400 SS Series with the 440 C being the preferred shaft since it does not require the special lubes.

Remember, in all cases, that the harder the shaft, the greater the load-capability and the better the surface finishes, the less the wear rate with longer bearing life. Shaft roundness and shaft size control without nicks, gouges or sharp edges will offer the most satisfactory performance.

CHAPTER THIRTEEN
LUBRICATION AND LUBRICANTS

The importance of an oil depends mainly on its film forming ability which depends further on its viscosity.

An oil of lowest viscosity is generally more suitable for an application since a higher viscosity oil will waste power to overcome the internal friction of the oil itself.

There are many ways to supply a lubricant to a bearing.

Pressure lubrication is probably the most positive and efficient means to provide lubricant to a bearing. In addition to offering a more copious supply of oil lubricant, up to an average pressure of 50 PSI, it coats the bearing, maintaining a more stable viscosity range and it assists in flushing out dirt and wear debris from the bearing surface.

Oil bath lubrication is where the bearing is submerged in oil which makes it the next reliable method to the pressure-fed oil. The shaft speed should not be so great as to cause excessive churning of the oil.

Splash-fed lubrication involves the oil being splattered onto the bearing surface by movement of other adjacent parts. The housing should be reasonably oil-tight to prevent excessive loss and leakage of the lubricant.

Oil ring lubrication involves a revolving or processing ring on a shaft in contact with the oil sump. When the shaft is at low speed, sufficient oil may not be brought to the bearing surface or if the shaft speed is too great, the oil will be centrifuged beyond where it is needed. It also may not keep pace with the oil required.

For best results, it has been proposed that the peripheral speed should be in the range of 200 to 2000 feet per minute. The safe load based on full hydrodynamic lubrication mode should be reduced by one half of pressure lubricated bearings.

Wick or waste-pack lubrication delivers oil to a bearing surface by capillary action of a wick or waste-pack as done in many old railroad axles using bobbitted bronze backed partial sleeve bearings.

The safe load when compared with pressure-fed full hydrodynamic load should be reduced to 1/4 of the load.

Grease-packed bearings: Grease is generally packed to surround the bearing and although is substantially less effective than oil, it is much more permanent but the bearing will generally operate in boundary conditions.

CHAPTER FOURTEEN
LUBRICANT SELECTION

The selection of a lubricant is based on various factors such as the type of operation, whether full hydrodynamic, mixed film or boundary film conditions in addition to the surface speed and bearing load involved.

Various lubricant articles suggest some recommended viscosities for specific services.

As a rule of thumb, the following suggested viscosities should be considered on the basis of surface speed with a qualified load.

Speed (fpm)	Viscosity (sus)	SAE Oil
30 or less	1200-1800	80
70	800-1200	70
150	500-800	60
300	300-500	50
600	150-300	40
1200	120-150	30
2400	90-120	20
5000	40-90	10
over 5000	5-40	5

As a general rule of thumb, heavier oils are recommended for high loads and lighter oils for high speeds.

In order to obtain a quick conversion of viscosity (sus) to centistokes (cSt), multiply the (cSt) value by 5. The multiple will be the approximate (sus) value.

To obtain the (cSt) value, divide the (sus) value by 5.

These results are reported to be accurate within 7% in the range of 75 to 7000 (sus) and 15 to 1500 (cSt).

But also be cautioned that this assumption should not be used below 75 (sus) or 15 (cSt).

For more explicit lubrication data, we suggest you refer to the CBBI manual or to the Machine Design article of March 10, 1966.

CHAPTER FIFTEEN
COMPARATIVE CASTING METHODS

There are various casting methods available for casting ferrous and non-ferrous metals. A brief description of each follows with a listing of advantages and disadvantages as well as other pertinent data.

Sand Casting: Moist bonded sand or resin coated sand is packed around a wood or metal pattern of the item or items to be cast. The pattern is removed and the cavity or cavaties are filled with the molten bronze.

Following the air cooling of the mold, the casting or castings are removed to be cut or sheared off from the gate and runner as individual castings.

Advantages: Any metal can be cast - ferrous or non-ferrous - without limitations to size, weight or shape. It is one of the most versatile and low-cost methods available including tooling costs. This method is economical and suitable for low to unlimited quantities.

Disadvantages: Close tolerances are difficult to achieve and some machining may always be necessary. Interconnected porosity is generally inherent to this process and a fairly rough surface finish averaging 1000 RMS is obtained. The typical tolerances range from plus-or-minus 1/32 to as much as plus-or-minus .090 and greater across parting lines.

Permanent Mold Casting: The mold cavities are machined out of a nickel steel or cast-iron die blocks since they are designed for repetitive use. Generally, steel cores are used although sand cores of intricate design can be used. Because of the casting heat, the sand cores are expended while the steel cores can be expected to give reasonable life before they are replaced. The mold halves are clamped together and the molten bronze poured into the cavity by gravity without turbulence or under a low-vacuum pressure.

The mold is opened within a few seconds following approximately a 50-degree drop from casting temperature with aluminum bronze or manganese bronze alloys. The casting with gate and riser is ejected immediately.

Advantages: Good dimensional accuracy is obtained, good grain size and structure results from the rapid chill. Casting tolerances possible range from plus-or-minus .010 to plus-or-minus .015 per side or surface and parting lines can be h eld to about plus-or-minus .030.

Casting variations from casting are rarely existent except after tooling begins to show signs of wear.

Disadvantages: This method is normally limited to non-ferrous alloys. Size, shape and intricacies also are somewhat limited, although many sections can be cast thinner than sand castings. To justify this method, a moderate volume of 1,000 through 50,000 pieces yearly would be necessary to offset expensive tooling costs. Each individual casting must have a gate and riser which reduces the effectiveness of the yield.

Centrifugal Casting: In this process of casting, steel or cast-iron dies are used and the molten metal is poured into the rotating or spinning die. After pouring, a water spray is directed onto the rotating die, cooling it more rapidly.

Advantages: Since the molten metal is forced by centrifugal action of the rotating die, the metal thus centrifuged is free of porosity, more dense with a structure designed to carry heavy loads with impacts. The alloy cast in this method can withstand substantial hydraulic pressures without leaking. This method is suitable for ferrous and non-ferrous alloys.

Disadvantages: Although a controlled stock allowance is set by the die, a maching operation is generally required to remove the rough surface finish and excess stock.

Continous Cast Method: In this process, the die is made out of carbon graphite which is surrounded by a cooling jacket through which water flows to chill and solidify the cast tube, bar or shape. As it exits from the furnace proper by gravity, the casting solidifies. It is pulled out slowly by pull rolls or pinch rolls. This rapid cooling reduces the grain size and as the casting exits from the lower section of the holding furnace, a homogenuous micro-structure is obtained.

Advantages: A minimum of stock allowance can be controlled to plus-or-minus .015 reducing the amount of machining necessary as in other methods. Various shapes are cast reasonably to size without need for precision machining. The resulting structure is generally suitable for acceptance by radiographic tests and will withstand a substantial hydraulic pressure without leaking.

Disadvantages: Initial high unit cost investment and space; graphite dies must be replaced after each run and each size requires a cooling jacket.

Die Casting: Molten metal is forced into closed steel dies at high velocities by application of pressure.

Advantages: Excellent dimensional accuracy is obtained across parting lines plus-or-minus .005 and plus-or-minus .001 to plus-or-minus .003 across extremities and surface finishes 100 RMS or less.

Disadvantages: This process requires high volumes of 20,000 to a million pieces or more since the relative die cast is extensively high. It also is limited to non-ferrous metals and porosity may be encountered as a result of entrapped air in the die. Size is limited to 3 feet square and under 15.0 pounds.

Investment Casting: Various ferrous and non-ferrous materials are used to make a wax or thermoplastic pattern which is expendable in the process. Hot wax or plastic is injected to make a pattern under pressure into the die and multiple patterns are mounted on a common sprull made of the same material. The assembly, called a tree, is dipped into a liquid surry followed by several immersions in dry fluidized bed of fine sand. Each dipping operation requires drying time. As many as five to eight dippings are required to build a shell around the tree. For wax removal, the tree is placed into a steam autoclave. Before pouring, the molds are kiln-dried and tongued from the furnace to the pouring box and poured while cherry red.

Advantages: There is no parting line and no draft. The surface finishes are less than 125 RMS and shapes are cast which couldn't be produced by other methods. This process becomes most economical when two or three machining operations can be eliminated. The typical tolerances are usually plus-or-minus .005 and high volume is not a criterion. Tooling is less costly than pressure-die casting.

Disadvantages: Although this method has the fewest design limitations of shapes, size or design, pound for pound the cost of this process is comparatively high.

There are several other methods of casting which include shell molding as a modified sand casting which offers closer tolerances as plus-or-minus .007 to .015. The surface finish is much better than sand casting and there is better definition of details such as lettering, etc. The cost of pattern equipment is higher than for sand casting and the process necessitates higher quantities.

Plaster molding and ceramic mold casting are similar to investment casting. But the molding material is more expensive and the processes have never been suitably automated to reduce the labor intensity of making the molds. The casting tolerances are reasonably close to investment casting.

CHAPTER SIXTEEN
EFFECT OF THE CASTING METHOD ON BRONZE ALLOYS

The casting method shold not be ignored but given consideration of the type of service the bronze alloy will be subjected to.

In particular, the type of load - whether steady and continuous, intermittent or with shock impact or pounding loads - the surface speeds to be encountered and other important features required to be met.

The casting method has a definite impact on the bronze alloy such as the resulting grain size, density, hardness, mechanical and physical properties, soundness and structure.

In general, the slower chilled or cooled casting will give rise to coarser and larger grain size. These have a profound effect on the surface qualities, coefficient of friction, wear rate or wear resistance and loads.

The faster cooled or chilled castings result in greater density, hardness, finer grain size, improved soundness and structure.

Referring to the illustrations on the following page, please note the finer grain sizes developed by each method of casting.

Sand Casting: Since molten bronze is poured into a sand mold, the sand or silica having thermal insulating characteristics, will cause slow cooling or chilling of the casting in air. This slow cooling permits the grain size to grow larger, the density, the soundness and structure to be less than by other casting methods.

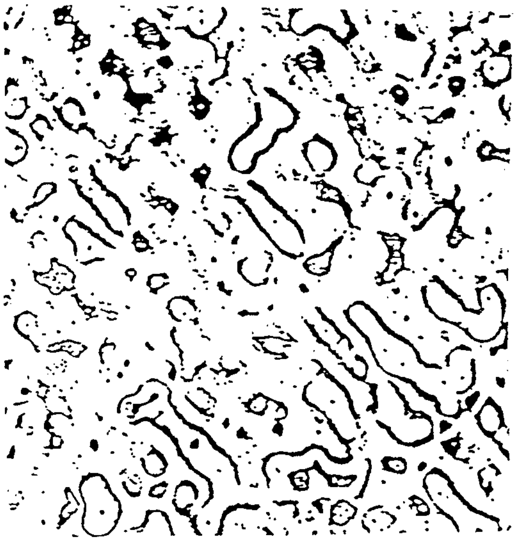
Permanent Molded or Chill Casting: The thermal insulating sand is replaced by nickel steel or cast-iron dies. The metal mold quickly chills the casting and this faster solidification results in finer grain size, no interconnected porosity, finer surface finish and improved physical and mechanical properties.

Centrifugal Casting: Molten metal is poured into a rotating steel or cast-iron die. The centrifugal force impacts the molten metal against the inside of the die, eliminating any porosity. the rotating or spinning die is then sprayed with water coolant to obtain a faster chill than the first two methods discussed the finer grain size further improves the physical and mechanical properties still further.

Continous Casting: The molten metal flows by gravity through a graphite die which is chilled immediately by the cooling jacket surrounding the die. This faster cooling further reduces the grain size and results in still higher physical and mechanical strength.

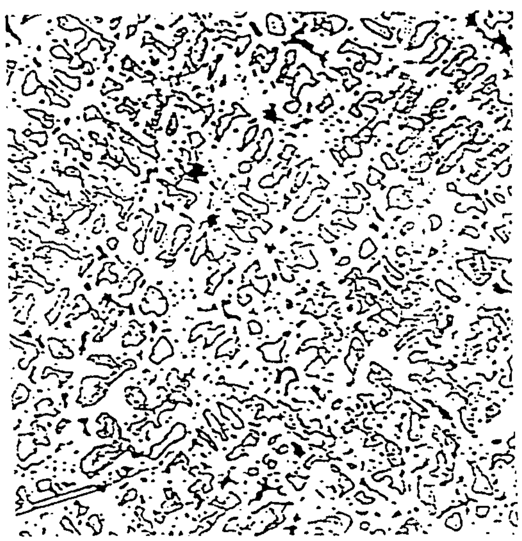
The average increase progressively in the tensile and yield strengths is about 5000 to 10,000 PSI and hardness is increased by 10 to 20 points of Brinell hardness.

Remarks: To further enhances the physical and mechanical properties of the bronzes, extrusion and forging operations can reduce the grain size additionally. These are special processes and the four methods of casting described earlier in this chapter cannot achieve comparable mechanical and physical strength.

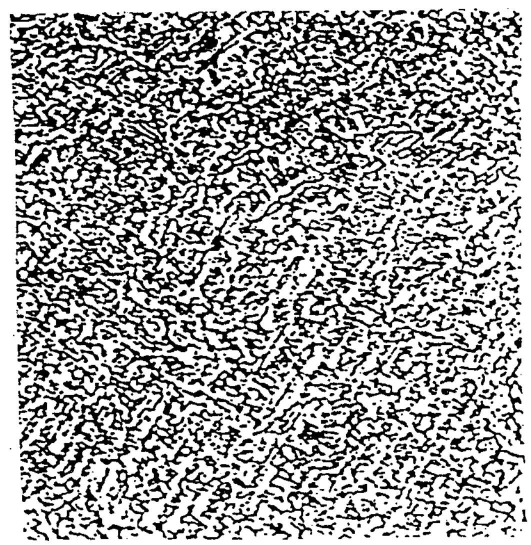


SAND CASTING
100 X MAGNIFICATION

CHILL CAST AND PERMANENT MOLD
100 X MAGNIFICATION



CENTRIFUGAL CASTING
100 X MAGNIFICATION



CONTINUOUS CAST
100 X MAGNIFICATION

Casting Effect On Grain Size and Density

CHAPTER SEVENTEEN
WEAR RESISTANCE OF BRONZE BEARING MATERIALS

Although most sleeve bearings are designed to operate in a film lubricant separating the mating parts, this does not always happen. Generally, the mated surfaces will deteriorate gradually by wear of hard particles infiltrating the surface area along with breakdown of lubricant. Lubricant starvation also may occur.

Many wear tests have been performed to determine the comparisons that various alloys exhibit under the same conditions of lubrication, shaft and material hardnesses and surface finishes.

In comparison tests, the results were reported to be as follows:

Aluminum bronze CDA 954 exhibited the highest wear resistance.

CDA 954 performed better than 3.9 times alloy CDA 938.

CDA 863 performed better than 2.5 times CDA 938.

CDA 905 showed a better wear resistance over CDA 938 by 1.9 times.

CDA 932 alloy was found to be more wear resistant than CDA 938 by 1.2 times.

CHAPTER EIGHTEEN
IMPORTANT FEATURES OF ALUMINUM BRONZES

Non-sparking: The non-sparking characteristics make the aluminum bronzes suitable for manufacturing of tools, equipment for petroleum and chemical processing, in mine service, handling explosives and in gas equipment.

Cold Working Capability: The aluminum bronzes with less than 8% aluminum content are most suitable for cold working into tube sheets, flats, wires and other modified configurations.

Hot Working Capability: The aluminum bronzes with 8 to 10 % aluminum content result in progressively increased mechanical strength and hardness of the alloy, requiring them to be hot worked. The hot working temperatures range from 1300 degrees F and up.

Corrosion Resistance: The aluminum bronzes have outstading corrosion resistance for marine, chemical and in atmospheric service because of its rapid formation of an aluminum oxide film. If the film is damaged, scratched or abraded, this oxide film is self-healing and reforms almost immediately. The aluminum bronze alloys are resistant to exposure, to chlorides and similar other chemicals and to many acids. (See art -- re: corrosion.)

Oxidation Resistance: The aluminum bronzes are suitable for all air and steam and in temperature service up to 750 degrees F. They do not lose their mechanical strength as rapidly as the manganese bronzes or other leaded and tin bronze alloys. They are generally considered for temperature service.

Magnetic Permeability: The aluminum bronzes have magnetic permeability often less than 1.07 at 200 oersteds. They are used in highly-stressed, rotating, non-magnetic parts.

Electrical Conductivity: The aluminum bronzes have a relatively low value of electrical conductivity compared to copper. The IACS percentage drops as much as 75% of the original value.

Since aluminum bronzes contain elements of aluminum, manganese, iron and nickel, the aluminum bronzes have an average of 13% IACS at 20 degrees C value of copper.

Thermal Conductivity: Metals with high electrical conductivity usually transfer heat well, too. The aluminum bronzes, as other copper-based alloys, have better heat dissipation properties required for bearing service than steel, cast iron and other ferrous metals. The average aluminum bronze thermal conductivity value is about 15% of that of copper taken as 226 BTU/square foot/hour/degree F 68 degrees F.

Thermal Expansion: Copper-based alloys have higher thermal expansion and contraction values than many other metals. Their approximate average expansion and contraction values are twice that of steel or cast-iron. This is why it is necessary to adjust mating sizes if higher or lower than normal ambient temperature service is involved.

The aluminum bronzes have an average coefficient of linear thermal expansion inch per inch per degree F as shown in the comparison below:

Aluminum bronze	.000009 or 9 x 10 to the minus sixth power
Manganese bronze	.000012 or 12 x 10 to the minus sixth power
Leaded bronze	.0000108 or 10.8 x 10 to the minus sixth power
Tin bronzes	.00010 or 10.0 x 10 to the minus sixth power
Steel	.0000633 or 6.33 x 10 to the minus sixth power
Cast Iron	.0000655 or 6.55 x 10 to the minus sixth power

Heat Treatment of Aluminum Bronzes: The aluminum bronzes with more than 9.5% aluminum content with small additions of iron, nickel or manganese which are added for specific properties (such as higher strength hardness, wear resistance, fatigue strength, etc.) can be heat-treated to enhance these properties more. Heat treatment increases the tensile and yield strength and hardness of the alloy but the elongation is somewhat reduced. The heat treatment of aluminum bronzes involve bringing the casting up to 1650 degrees F (900 degrees C) for two hours per inch of section thickness with a water or oil quench followed by a tempering treatment, the temperature of which must be selected in correct combination of strength hardness and ductility. This second treatment generally is done at 1000 to 1150 degrees F for one hour of section thickness.

Stress Relieving: Stress relieving may be required when the copper-based alloy is used for bearings that are split longitudinally or when the stresses in the alloy from casting or other operation must be removed so as not to cause dimensional changes after machining the split. Such stresses may be removed or minimized by heating the casting, or semi-finished part at 1000 degrees F for an hour per inch of section thickness, followed by cooling in air (without quenching). For stress relieving leaded and tin bronzes, this temperature should be reduced to 600 degrees F.

Wear Resistance: Tests have proven that aluminum bronzes have better wear resistance than the leaded tin bronzes, tin bronzes and manganese bronzes. (See Chapter XVII)

CHAPTER NINETEEN
HEAT TREATMENT OF ALUMINUM BRONZE ALLOYS

The cast aluminum bronzes consist of copper and aluminum with lesser additions of iron, nickel or manganese elements, primarily to enhance the tensile strength, yield strength, hardness, wear resistance, fatigue resistance and corrosion.

The more popular aluminum bronzes contain from 8 to 13 % aluminum, up to 5% iron, nickel and manganese in various combinations.

As the aluminum content increases, the tensile strength, yield strength and hardness also increase but ductility decreases.

The aluminum bronze alloys with 10% or more aluminum content can be heat-treated successfully to further increase the physical and mechanical properties of the alloy.

The normal heat treatment sequence of aluminum bronze alloys with 10% or more aluminum content is to solution heat soak the alloy at 1650 degrees F for at least two hours, then quenching rapidly in water. Slow cooling results in "self-annealing" and produces a coarse structure with greatly-reduced properties.

Following the heat-treatment sequence, a tempering treatment is required by reheating the casting to 1000 to 1150 degrees F for one hour then quenching in water.

The heat-treatment changes the "as cast" alloy's micro-structure to a finer grain, resulting in substantial increases in tensile strength, yield strength and hardness but with a fairly high reduction in ductility.

The wear resistance also is greatly improved by heat treatment without correlation to hardness. It does not seem to cause increased damage to steel shafts.

CHAPTER TWENTY
THRUST BEARINGS OR WASHERS

There are three basic types of thrust washers which are defined by their mode of operation. Thrust bearings designed correctly to operate under either one of the following modes have theoretical justification for their load capacities.

1. **Flat boundary lubricated** 100 PSI.
2. **Flat thermal wedge**, hydrodynamically lubricated 1200 PSI.
3. **Contoured wedge**, hydrodynamically lubricated 5000 PSI.

However, in actual practice, these values are not achieved other than in theoretical design. In practice, the load capacity of each reduce to about 60% of theoretical values of 60 PSI, 700 PSI and 3000 PSI.

For the greater majority of flat thrust washers, it is impossible to prevent some degree of hydrodynamic lubrication so that even in the worst design, the allowable loading will be greater than 60 PSI.

In conditions of a sparse oil supply mated with steel, the high leaded tin bronze alloys (20% or greater lead content) are much more capable of satisfactory service providing their is no large amount of dirt or debris.

If there is a fair amount of dirt present which is fairly coarse in particle size and movement or motion is infrequent or slow, the lower content leaded tin bronze alloys (20% or less) are preferred.

For unlubricated applications against steel, the preferred thrust washer materials are the sintered powdered bronze oil impregnated or Teflon-coated and plastic materials.

For applications in which the non-lubricating film such as water or silicone fluids are present, the preference should be for Teflon-coated or impregnated bronzes or plastics.

Oil Distribution Grooves: These are grooves that separate each sector of the thrust washers. The grooves must not go completely across the thrust face of the washer unless the thrust washer is completely immersed in the lubricant.

If the lubricant is supplied at the ID of the washer, then the grooves should extend from the ID going outward covering about 80% of the distance to the outer edge.

If the direction of rotation can be in either direction, the grooves should be radial; but if the direction of the rotation is fixed, the grooves should be slanted so that the viscous drag of the rotation will pull the lubricant into the groove in the direction of movement. The slanted angle should be between 10 to 40 degrees to the diameter.

If the lubricant is supplied from the outer circumference (which is an undesirable condition) then the grooves must be slanted 20 to 60 degrees; but if the grooves are in the stationery member, they should be pointed in the direction of the rotation; if the grooves are on the moving member, they should be pointed against the direction of the rotation.

Oil Collection Grooves: These grooves, like spreading grooves, should only go part way across the surface from 50 to 80% of the distance is suitable. They also should be slanted in the same direction as the oil-spreading grooves. These grooves are positioned just before the oil distribution grooves if the washer is supplied with oil from the ID.

Oil Groove Dimension: The length of the groove is controlled by the degree of slant and should go about 80 to 90 % of the way across the annular surface.

The groove cross-section should be in the form of a wide **"V"** to promote the formation of an oil film or a **tear-drop design** which blends into the surface.

The thrust washer with grooves such as through grooves, **tear-drop** (or stopped off) and **tapered land grooves** are superior to a plain washer. By adding four through grooves to the plain washer, the oil flow increases across the thrust surface and the load-carrying capacity increases by 30%.

While restricting total oil flow through the washer with **tear-drop grooves**, an 85% increase can be obtained.

With the **tapered land groove** which promotes an oil wedge, the increase in load-carrying capacity increases to 300% of a plain washer.

According to theory, if the plain washer is perfectly flat, it would have no load capacity so surface waviness is not undesirable if it is fitted into a rigid aligned housing.

The speed of operation of a thrust washer is not generally a problem if the surface speed is at least 25 fpm. At very high speeds - above 2000 to 4000 fpm - it may become a problem to supply ample lubricant although there is a compensating advantage of realizing a higher unit load. There also is the possibility of the oil carbonizing at this high speed, depending upon the load.

Lubricant is important since the higher viscosity lubes such as SAE 50 offer greater chances that hydrodynamic film formation will be realized.

The normal hydrocarbon oil lubricants are suitable for washers but the non-polymer modified oils are preferred for their higher viscosity.

CHAPTER TWENTY-ONE
CORROSION RESISTANCE OF SOME BRONZES

Corrosion is defined as the eroding of a metal as a result of a reaction with its environment, or exposure to various liquids or gases.

Some metals and alloys are naturally resistant to certain corrosive environments. The product of a corrosive film which forms when metals are subjected to corrosive attack protects them from speedy damage by virtue of this protective oxide film.

Corrosion can occur in bronzes as a result of slow dissolution of copper and copper alloys either because no protective film is formed or because as fast as a film is formed, it enters into solution in the corroding medium.

Outdoors, copper and copper alloys develop a relatively protective skin of sulfides, oxides or soot. The sulfides form as a result of a reaction with sulfuric acid in the atmosphere and oxides as a result of a reaction with oxygen in the air. These reactions speed up in humid and rainy climates. They would cease entirely in the absence of water.

Galvanic corrosion is caused by compounds which are electrical conductors when in solution in water and are known as electrolytes. The ions in these electrolytes are ever ready to conduct electricity if an anode (the positive ion) and cathode (the negative ion) of any type are present.

Solutions of carbon dioxide, sulfur dioxide, oxygen, chlorides and fluorides are condensed or precipitated from the atmosphere. When a metal is to be used where there is an electrolytes as in sea water, the coupling of metals must be close together in the EMF series; to reduce the tendency to corrode the least nobler (cathodic) material.

Galvanic corrosion often can be prevented by separating the less noble material by insulating it with rubber or synthetic resins.

Although aluminum alone as a base material possesses good corrosion resistance to dry atmospheres, it actually corrodes very rapidly until a surface film forms. The surface film arrests further action to sea water, many fresh waters, chemicals and foods.

This oxide film is extremely thin and, when damaged or scratched, corrosion will reform another thin film. Aluminum, therefore, depends on the resistance of the formed oxide film to attack rather than to the base metal.

If aluminum is coupled with a copper-based alloy as bronze in a wet atmosphere, such as in marine environments, corrosion of the aluminum will continue unabated and would be an unfavorable galvanic couple. However, in a dry atmosphere, there is no precipitable galvanic action encountered.

The high-leaded tin bronzes, leaded tin bronzes and tin bronzes have poor resistance to most acids but good resistance to sea water, fresh water, gasolines, fuel oils, alcohols, Freons and many other mediums. But it is recommended that the copper alloys be tin-coated or plated.

For the most corrosive resistant alloys, the aluminum bronze alloys offer the greatest protection. The aluminum bronze alloys are used for their strength primarily and extensively used in general outdoors, marine service and exposure to many acids.

A brief list follows showing the acceptable and non-acceptable exposure to various corrosive medium by aluminum bronzes.

GOOD	FAIR	POOR
Acetic acid	Aluminum chloride	Acetylene
Aluminum hydroxide	Ammonium sulfate	Ammonia, moist gas
Aluminum sulfate	Barium sulfide	Ammonium hydroxide
Ammonia, dry	Calcium hypochlorite	Ammonium chloride
Atmosphere, marine	Chlorine, moist	Ammonium nitrate
Barium chloride	Copper nitrate	Chromic acid
Calcium chloride	Ferrous chloride	Ferric chloride
Calcium hydroxide	Ferrous sulfate	Ferric sulfate
Chloride, dry	Hyrdrochloride acid	Hydrocyanic acid
Copper sulfate	Hydrofluoric acid	Hydrogen sulfide, moist
Hydrogen sulfide, dry	Phosphuric acid	Nitric acid
Magnesium chloride	Potassium hydroxide	Potassium cyanide
Magnesium hydroxide	Sodium hydroxide	Sodium cyanide
Magnesium sulfate	Sodium sulfide	
Potassium chloride	Sulfuric acid	
Potassium sulfate	Zinc chloride	
Sodium chloride		
Sodium nitrate		
Sodium sulfate		
Sulfur dioxide		
Zinc sulfate		
Water, fresh, sea		

In the case of manganese bronzes, which contain less than 80% copper, zinc is selectively removed from the alloy by most acids when diluted in water. Manganese bronzes can be used for marine applications, water pump rotors and in sea water.

CHAPTER TWENTY-TWO
SOLDERING, BRAZING AND WELDING OF BRONZE ALLOYS

Copper-based alloys, like other metals, occasionally require joining by soldering, brazing and welding. The following is intended to assist in those procedures.

In soft soldering, the low melting solders of tin and lead, in varying proportions, are used to join bronzes at relatively low temperatures well below the melting point of the bronze alloy or its lead content (if the lead content is 3% or less). The solders most generally used are the 60 tin and 40 lead solder which melts at 374 degrees F and the 50 tin and 50 lead solder which melts at 477 degrees F.

Soldering is used to provide a convenient joint that does not require any great mechanical strength. It is used in combination with mechanical staking, crimping or folding and used to seal against leakage or to assure electrical contact.

Fluxes for soldering: Soldering requires the metals being joined to be clean and fluxes clean the surface by removing the oxide coating present, keep the area clean by preventing formation of oxide films and lower the surface tension of the solder by increasing its wetting properties.

Rosin, tallow and stearic acid are mild fluxes but are not too effective in removing oxides present. Zinc chloride and ammonium chloride used separately or in combination will remove oxide films readily, however, this flux residue must be removed or neutralized to prevent their corrosive effects. Washing with water or with commercial water soluble detergents will neutralize any further corrosive effects.

Methods of application: Soldering can be done with a soldering iron, a torch, electric induction or resistance heating.

There are no special techniques used to solder except the usual precautions of cleanliness and fit of mating surfaces. The advantage of soldering is a low-temperature process, good manual application, no fusion of parent metals, and, therefore, no warpage. It is applicable to most copper-based alloys (with less than 3% lead) with minimum finishing requirements being necessary.

Brazing is a method of joining two metals through the use of heat and a filler metal below the melting point of the metals being joined. Brazing creates a metallurgical bond between the filler metal and the surfaces of the two metals being joined.

Again, here in order to obtain a sound joint, the surfaces in the join and around it must be free from oil, dirt and oxides. Cleaning can be achieved by chemical means such as using trisodium phosphate, carbon tetrachloride and trichlorethlene for chemical method and the use of filing, grinding, machining or sand-blasting for mechanical means of cleaning.

Fluxes are used mainly to prevent formation of oxides and to remove oxides from the base and filter metals and to promote free flow of the filler metal.

CHAPTER TWENTY-THREE
CBBI MANUAL BEARING PROCEDURE AND NOTES

1. Identify the particular application from Fig. 6 through 10 in the CBBI Manual.

2. Pick up the recommended value for M from the type of machinery application.

3. A = M(squared)W / D(squared)Z N

W = load in pounds
D = diameter of shaft or bush ID
Z = absolute viscosity (centipoises)
N = RPM
A = characteristic number

a. Assume an operating temperature

b. Z can be determined for the lube at assumed temperature T(2)

c. A fair approximate of lubricant temperature rise can be made.
Forced feed or pressure lubrication, temperature rise will average between 5 and 10 degrees F, if less oil is supplied bearing will run hotter, thus for other lubricating techniques, such as oil bath, splash feed and ring oiling, lubricant may rise from 10 to 100 degrees F.

d. After substitution, if "A" falls in the range of .0005 and .50, practical full-film lubrication is possible.

ANALYSIS:

A large value for "A" indicates a heavily-loaded or slow-speed bearing.

Conversely, light loads and high speeds, a very low "A" number will be obtained.

With a light load or no load, eccentricity ratio "e" will be zero and centered.

As the load increases, the journal moves eccentrically.

While eccentricity "e" is increasing, the minimum film thickness (Ho) is decreasing.
Ho = c-e = c (i-e)

If the load becomes great enough, the journal may eventually touch the bearing for this condition:
"e" = c, (Ho) = 0.

Once the bearing characteristic number is determined, a suitable length for the bearing can be determined.

LUBRICATING CONDITIONS

Hydrodynamic Mode:
1. Surface velocity in excess of 25 FPM
2. Coefficient of friction is .001-.005
3. Proper viscosity of lube
4. Proper lube flows
5. Proper design methods

Mixed film/Lubrication Mode:
1. Surface velocity in excess of 10 FPM
2. Coefficient of friction .02-.08
3. Journal BRG goes through all three modes

Boundry Lubrication Mode:
1. Generally slow rotary motion, less than 10 FPM
2. Oscillating motion
3. Coefficient of friction .08-.14
4. Generally grease lubricated

Press Fits or Shrinkage Fits:
1. Generally .001" minimum press fit should be sufficient for ODS up to 3" OD
2. Adjust press fit for bearings through 6" OD to about .002 minimum
3. Following a press fit or shrinkage fit, the bearing ID will close in on the ID by 100% of the press fit allow. Heavier wall bearings will average 60 to 80% close in based on the interference fit allowance.

Bearing Retention Methods:
1. Press fit or shrinkage fit
2. Set screws
3. Woodruff keys
4. Bolted through flange
5. Threaded/screwed bearing

Clearance Allowances:
1. Machined bearings with ground journals for use in steam turbines, generators, etc., usually have a running clearance of .001 per inch of shaft diameter.
2. Clearances of .0015 through .0035/ inch of diameter are used for grease and solid lube conditions.

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