PLANNING

Designing dry bearings, Part 1

1. What are dry bearings?

Dry bearings are designed to be used under dry operating conditions with no additional lubricant and have been developed to help simplify the construction of the device they are used in and to be suitable for maintenance-free operation.
In recent years, a wide variety of dry bearings have been developed in response to advances in design technology and demands for greater reliability.

2. Types of sliding bearings

Lubrication regimes

Sliding bearings are used under four different lubrication regimes: hydrodynamic, elastohydrodynamic, boundary, and non-lubricated. Dry bearings fall under the non-lubricated regime.

①Hydrodynamic lubrication
Liquid lubrication provides an axle with support from a thin film of liquid lubricant, thereby eliminating wear and providing a semi permanent service life. The service life is determined by fatigue that is a result of dynamic loading. In general, there are no limits on PV or V values, but it is necessary to take care with maximum pressure (Pmax), maximum temperature (Tmax), and the minimum thickness (Hmin) to which the lubricating film is subject.

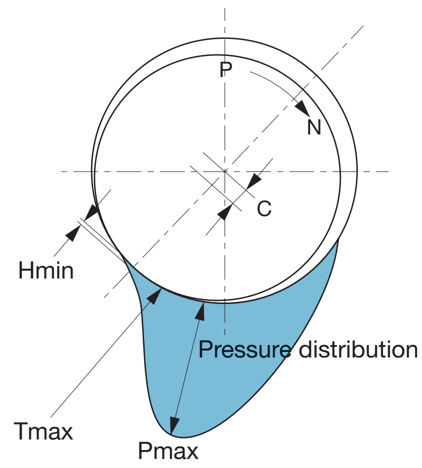


Fig. 1: Formation of lubricating film by liquid lubricants

②Elastohydrodynamic lubrication
This is a field that can still be understood in terms of fluid mechanics. There are limitations placed on PV values, however, because of contact between raised solid features, also called asperities, along the sliding surface. This results in wear and the need to be aware of the potential for seizing.

③Boundary lubrication (semidry)
Loss of lubricating film results in contact between solids, with lubricant remaining in the depressions between asperities. This results in restrictions on PV values and V values, especially. Wear becomes the deciding factor in determining service life.

④Non-lubricated (dry)
Dry friction in the absence of any lubrication except for solid lubricants, which is to say, dry bearings.
PV and V values must be very small and wear determines service life.

Comparison of sliding bearings and rolling bearings

Here is a comparison of sliding bearings with rolling bearings in each of the four lubrication regimes.

①Hydrodynamic lubrication
Resistance to heavy loading

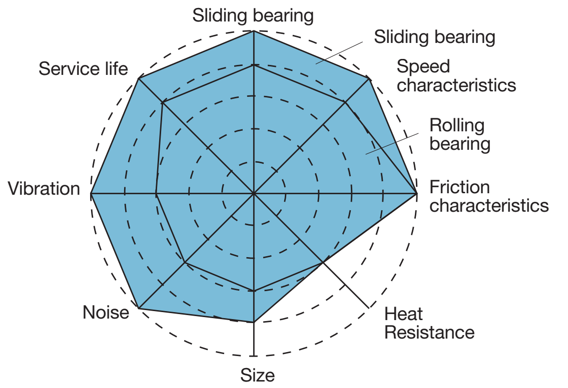


Fig. 2: Comparison under hydrodynamic lubrication

②Elastohydrodynamic lubrication
Example of a DAIDYNE DDK02 sliding bearing

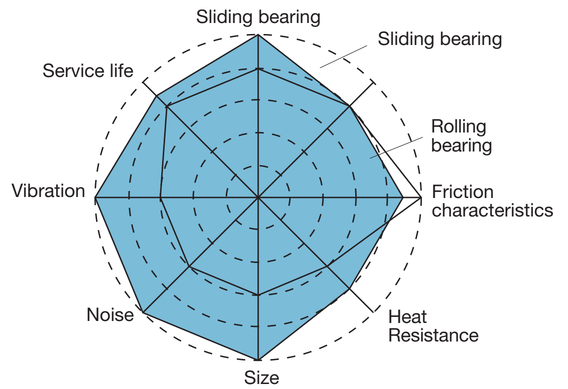


Fig. 3: Comparison under elastohydrodynamic lubrication

③Boundary lubrication

Example of a DAIBEST DBX01 grease-lubricated sliding bearing

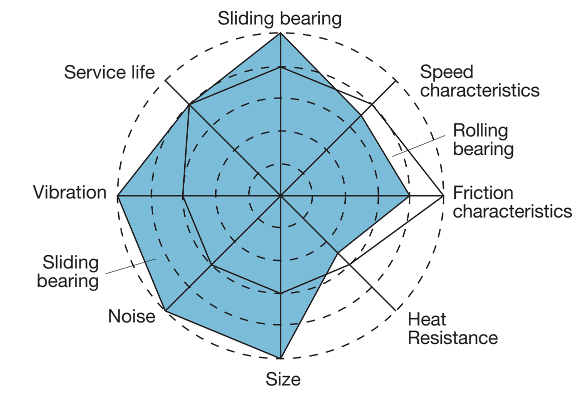


Fig. 4: Comparison under boundary lubrication

④Non-lubricated (dry)

Example of a DAIDYNE DDK05 sliding bearing

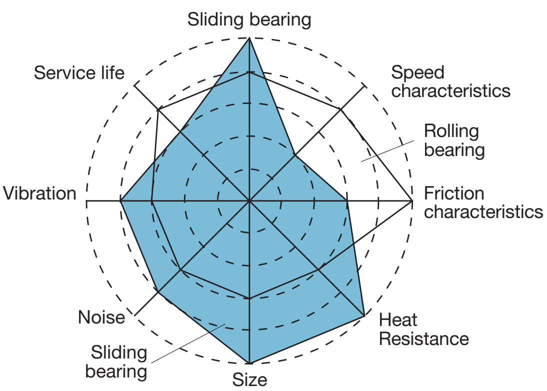


Fig. 5: Comparison under non-lubricated (dry) conditions

Table 1: Comparison of sliding bearings and rolling bearings

Characteristics	Sliding bearing	Rolling bearing
Impact resistance	Superior	Inferior
Corrosion resistance	Generally superior, depending upon type	Inferior
Water resistance	Generally superior, depending upon type	Inferior
Oscillating motion	Significantly superior	Inferior
Reciprocating motion	Superior	Only with linear or stroke ball bearings
Intermittent motion	Superior	Superior
Contamination acceptance	Superior, depending upon selection of materials and processing	Inferior
Weight	Light	Heavy
Availability	Some standard models available.	Standard models available.
Geometry	High degree of freedom	Very low degree of freedom
Price	Standard models are generally less costly than rolling bearings	——

NB: The above stated comparisons are of typical performance levels. Careful design and selection of materials will improve the performance of any type of for sliding bearing.
Please fill out the Bearing Specification Sheet found at the end of this catalog and direct your inquiry to Daido Metal.

Designing dry bearings, Part 2

3. Design of sliding bearings

Design procedure and study items

The procedures and study items necessary to the design of a sliding bearing suitable for the intended application are shown below.

Procedure	Study items
1 Determine specifications for the area surrounding the sliding bearing.	
2 Determine a basic layout for the sliding bearing.	Specify target values for axle diameter, bearing width, outer diameter, housing materials, lubrication regime, and other parameters, as suitable for the object of the design and development.
3 Determine the dimensions of the sliding bearing.	Validate P・V and the maximum allowable PV value. Determine necessity for external lubrication.
4 Determine materials for the sliding bearing.	Operating temperature Ambient conditions for the sliding bearing
5 Compare with existing products and similar products.	Refer to detailed specifications for similar products, if available.
6 Detailed design of sliding bearings	Verify outer diameter of sliding bearing. Validate minimum lubricating film thickness, power loss, heat generation, and other parameters. (lubrication model) Validate necessity for oil grooves, lubrication channels, indents, etc. (lubrication model) Validate clearances.
7 Validate the area around the sliding bearing.	Validate the materials, roughness, rigidity, and other aspects of the housing. Validate materials, roughness, hardness, surface finish, and other aspects of mating surfaces. Validate countermeasures for contamination.
8 Complete design of sliding bearings	

P, V, PV value, and maximum allowable PV value

Here is a comparison of sliding bearings with rolling bearings in each of the four lubrication regimes.

①Specific Load (P)
The term surface pressure refers to the load per unit area applied to a sliding surface.

$$P(MPa) = \frac{W}{d \cdot L} \quad \text{(Equation. 1)}$$

W: the load applied to the bearing in N
d: diameter of the axle in mm, L: width of the bearing in mm

The value d · L is a projected area and larger than the actual area of contact, but is used for practical convenience.

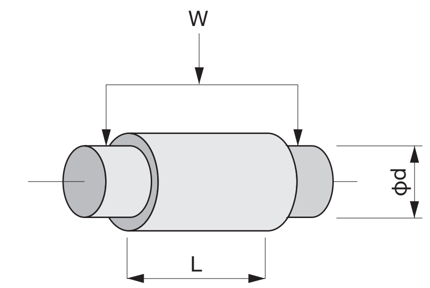


Fig. 6: Projected area

Example:
Find the surface pressure P for a standard K5B2015 bearing to which a load of 6 kN is applied.
Answer:
Axle diameter: 20 mm, axle length: 15 mm

$$P = \frac{6000}{20 \times 15} = 20(MPa)$$

②Sliding speed (V)
The term sliding speed refers to speed of the bearing surface relative to the mating surface.

$$V(m/min) = \frac{\pi \cdot d \cdot N}{1000} \quad \text{(Equation. 2)}$$

V: speed in m/min d: diameter of the axle in mm
N: rotational speed in rpm

Example:
Find the sliding speed for an axle with a 20-mm diameter rotating at a speed of 60 rpm.
Answer:

$$V = \frac{\pi \times 20 \times 60}{1000} \approx 3.8(m/min)$$

③**PV value and maximum allowable PV value**

Selection of a suitable sliding bearing requires more than just satisfying requirements for P and V. The product of P × V, or PV value, is the key to selecting the right sliding bearing.

Lubrication regimes	PV values in MPa·m/sec	P values in MPa	PV values in MPa·m/sec
Hydrodynamic lubrication	100	High	10
Elastohydrodynamic lubrication	10	↑ 10	1
Boundary lubrication	1	↓	0.1
Non-lubricated (dry)	0.1	Low	0.01

Table 2: Order of PV, P, and V values per lubrication regime

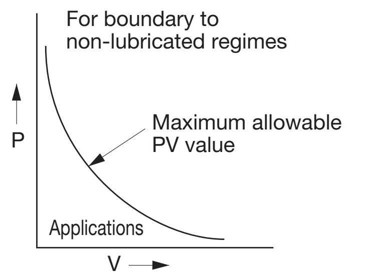


Fig. 7 Maximum allowable PV value

④**Slide plate specific Load (P) and sliding speed (V)**

$$P\ (MPa) = \frac{W}{B \cdot L}\ \text{(Equation. 3)}$$

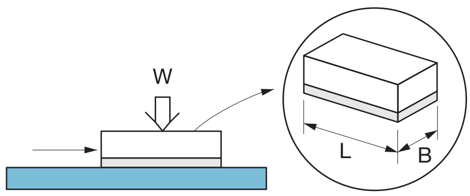


Fig. 8 Slide plate

$$V(m/min) = \frac{S}{T} \cdot \frac{60}{1000}\ \text{or}\ V = \frac{2SC}{1000}\ \text{(Equation. 4)}$$

V: speed in m/min
W: the load applied to the slide plate in N
B: slide plate width
L: slide plate length
S: stroke in mm
T: time to complete one stroke in seconds
C: number of cycles completed per minute

Example:
Find the surface pressure P for a 50 mm by 30 mm slide plate to which a load of 5 kN is applied.
Answer:

$$P(MPa) = \frac{5000}{50 \times 30} \approx 3.3(MPa)$$

Example:
Find the sliding speed V for a slide plate with a stroke of 20 mm sliding along a mating surface at a rate of 50 cycles per minute.
Answer:

$$V = \frac{2 \times 50 \times 20}{1000} = 2(m/min)$$

⑤**Thrust washer specific Load (P) and sliding speed (V)**

$$P(MPa) = \frac{W}{\frac{\pi}{4}(D^2 - d^2)}\ \text{(Equation. 5)}$$

$$V(m/min) = \frac{\pi \cdot \frac{D+d}{2} \cdot N}{1000}\ \text{(Equation. 6)}$$

NB: The thrust washer sliding speed is calculated based on the mean of the inner and outer diameters.

P: pressure in MPa
V: speed in m/min
W: the load applied to the thrust washer in N
D: outer diameter of the thrust washer in mm
d: inner diameter of the thrust washer in mm

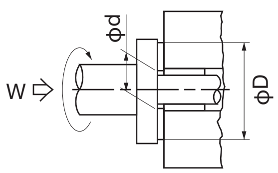


Fig. 9: Thrust washer

Example:
Find the specific Load (P) and sliding speed (V) for a standard K5T20 thrust washer to which a load of 10 kN is applied at 20 rpm.
Answer:

$$P = \frac{10000}{\frac{\pi}{4}(38^2 - 22^2)} \approx 13.3(MPa)$$

$$V = \frac{\pi \times \frac{(38+22)}{2} \times 20}{1000} \approx 1.9(m/min)$$

Designing dry bearings, Part 3

Housing

①All Daido bearings are designed to be press fit into tolerance class H7 housings.
②To prevent scoring during press fitting, chamfer the press fit side as shown in the diagram below.

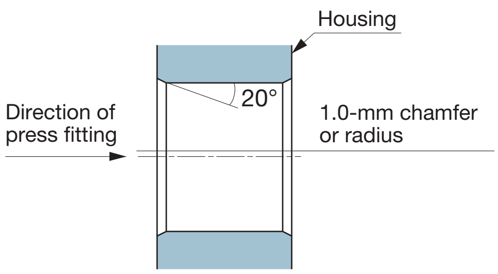


Fig. 10: Housing

③We recommend a normal housing surface roughness of 6.3s, but a roughness of up to 12.5s is acceptable.
④In order to maintain rigidity, the outer diameter of a steel housing is ordinarily at least 150% of the axle diameter, but for aluminum or other light alloys, this should be at least 200%.

Axle (mating surface)

①We recommend a normal axle surface roughness of 0.8-1.6s, but a roughness of up to 3.2s is acceptable. Typical data showing the relationship between surface mating surface roughness and wear for DDK05 dry bearings is shown in Fig. 11.

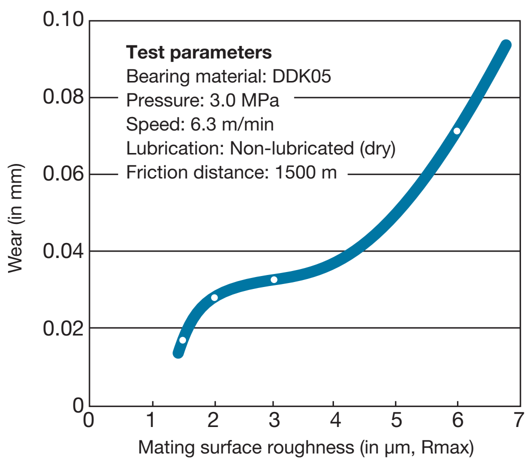


Fig. 11: Surface mating surface roughness and wear

②Do not use the kinds of axles described below.

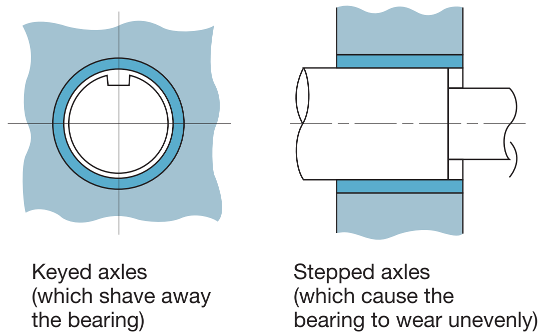


Fig. 12: Axles

Thickness

Thickness for all standard products can be found by referring the related pages for that product.
In general, bearings are classified as shown below.

Table 3: The Ratio of Thickness (T) to Outer Diameter (D)

Form	T/D
Thin-walled	0.03 to 0.06
Thick-walled metallic solid	0.08 to 0.12
Thick-walled plastic solid	0.1 to 0.15

Press-fitting margin

Prior to being press fit, the outer diameter of the bushing is larger than the inner diameter of the housing.
This differential is called a press-fitting margin, and the stress produced by pressing the bushing into the housing prevents the bushing from rotating or slipping out of the housing.
Minimum press-fitting margin = Bushing Dmin - Housing dmax
Maximum press-fitting margin = Bushing Dmax - Housing dmin
(Equation. 7)

Example:
Find the press-fitting margin for a standard DDK05 bushing K5B2015 with a $\phi 23H7^{+0.021}_{0}$ housing.
Answer:

Bushing Dmax = ϕ23.081
Bushing Dmin = ϕ23.046
Housing dmax = ϕ23.021
Housing dmin = ϕ23.000
Minimum press-fitting margin = ϕ23.046-ϕ23.021 = 0.025
Maximum press-fitting margin = ϕ23.046-ϕ23.000 = 0.081

Inner diameter after assembly

Knowing the inner diameter after assembly is necessary to obtaining an accurate clearance between the axle and the bushing inner diameter.

❶For bushings that give dimensions for outer diameter and thickness

To ensure that the housing has sufficient rigidity to prevent it from expanding after the press fitting:

Assembled dmin = housing dmin-2·Tmax
Assembled dmax = housing dmax-2·Tmin (Equation. 8)

Example:

Find the assembled inner diameter (d) after press-fitting a standard DDK05 bushing K5B2015 to a housing with an inner diameter of $\phi 23H7^{+0.021}_{0}$.

Answer:

Housing dmax = ϕ23.021
dmin = ϕ23.000
DDK05 bushing thickness Tmax = 1.500
Tmin = 1.470
Assembled dmin = ϕ23.000 - 2×1.500 = ϕ20.000
Assembled dmax = ϕ23.021 - 2×1.470 = ϕ20.081
Assembled d = $\phi 20^{+0.081}_{0}$

❷For bearings that give dimensions for outer diameter and inner diameter

To ensure that the housing has sufficient rigidity to prevent it from expanding after the press fitting:

Assembled dmin = housing dmin - maximum press-fitting margin
Assembled dmax = housing dmax - minimum press-fitting margin (Equation. 9)

Example:

Find the assembled inner diameter (d) after press-fitting a standard THERMALLOY D type bushing DM20815 to a housing with an inner diameter of $\phi 28H7^{+0.021}_{0}$.

Answer:

D type bushing Dmax = ϕ28.041
Dmin = ϕ28.028
D type bushing dmax = ϕ20.131
dmin = ϕ20.110

Per Equation. 7
Minimum press-fitting margin = ϕ28.028-ϕ28.021 = 0.007
Maximum press-fitting margin = ϕ28.041-ϕ28.000 = 0.041
Assembled dmin = ϕ20.110 - 0.041 = ϕ20.069
Assembled dmax = ϕ20.131 - 0.007 = ϕ20.124
Assembled d = $\phi 20^{+0.124}_{+0.069}$

Clearance

①Calculating clearances

Minimum clearance =
assembled dmin - maximum axle diameter
Maximum clearance =
assembled dmax - minimum axle diameter (Equation. 10)

Example:

Find the clearance for a standard DDK05 bushing K5B2015 press-fitted to a $\phi 23H7^{+0.021}_{0}$ housing and equipped with a $\phi 20^{-0.025}_{-0.046}$ axle.

Answer:

The assembled d is $\phi 20^{+0.081}_{0}$, per Formula No. 8.
Clearancemin = ϕ20.000 - 19.975 = 0.025
Clearancemax = ϕ20.081 - 19.954 = 0.127
Clearance is between 0.025 to 0.127.

Service life

The service life of a dry bearing is generally determined by wear to the bearing. Specific Load (P), sliding speed, lubrication parameters, surface roughness of the mating material, operating conditions, ambient conditions, and other factors have a major impact, which makes accurate calculation of wear extremely difficult.

The following formula is commonly used to approximate wear.
W = kPVT (Equation. 11)

W: wear in μm
P: specific Load (P) in MPa
k: coefficient of wear, equivalent to μm · cm^2 · min/N · m · H
V: sliding speed in m/min
T: service life in hours

The factors that contribute to wear are shown in Fig. 13, and should be given thorough consideration when designing a sliding bearing.

Designing dry bearings, Part 4

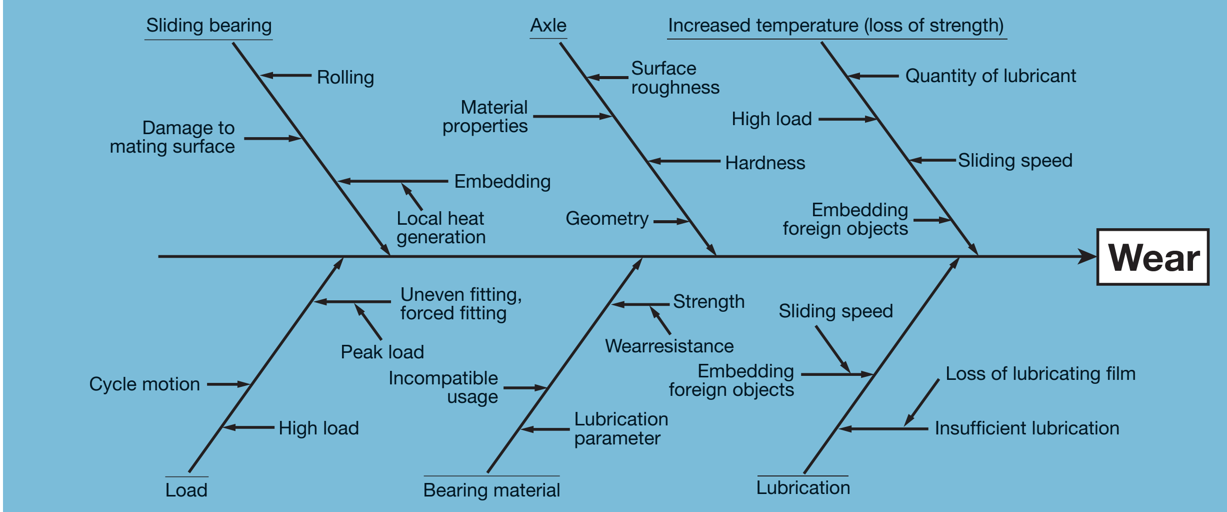


Fig. 13: General wear cause and effect diagram

Coefficient of friction

As shown in the diagram below, the coefficient of friction is the ratio of the force F needed to move the sliding surface to the weight W applied to the sliding surface.

Coefficient of friction: $\mu = \frac{F}{W}$ (Equation. 12)

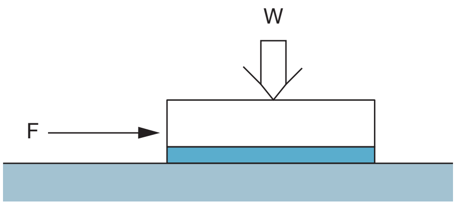


Fig. 14: Coefficient of friction

Obviously, the coefficient of friction for bearings under hydrodynamic lubrication (0.002 to 0.01) is lowest and increases progressively through boundary lubrication (0.01 to 0.08) and non-lubricated (0.08 to 0.3) conditions.

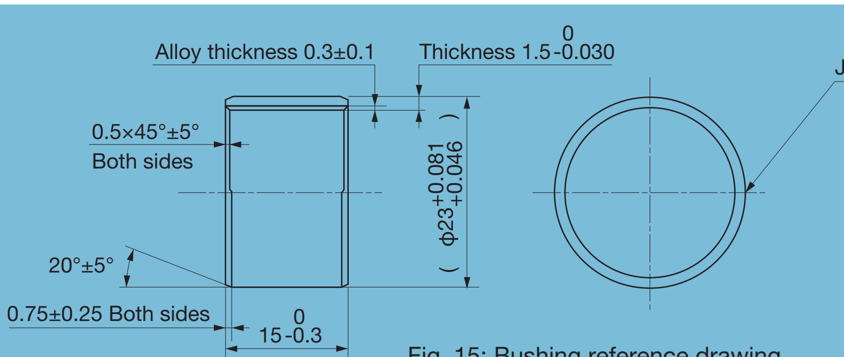
Heat generation

Although friction surfaces are constantly generating heat, this can be ignored when the heat itself is low or heat dissipation is high. The amount of heat generated is equivalent to the friction loss of the bearing: Calorific value = the coefficient of friction · PV value · k (Equation. 13).

For bearings under hydrodynamic lubrication, the lubricant carries away almost all of the generated heat, but for boundary lubrication and non-lubricated bearing, it is necessary to find a way either to reduce the amount of heat generated or improve heat dissipation. Also, it is important to be aware that bearing performance tends to deteriorate as the temperature rises.

Basic production drawings for sliding bearings

A typical production drawing for a sliding bearing detailing parameters finalized per the above is shown in Fig. 15.



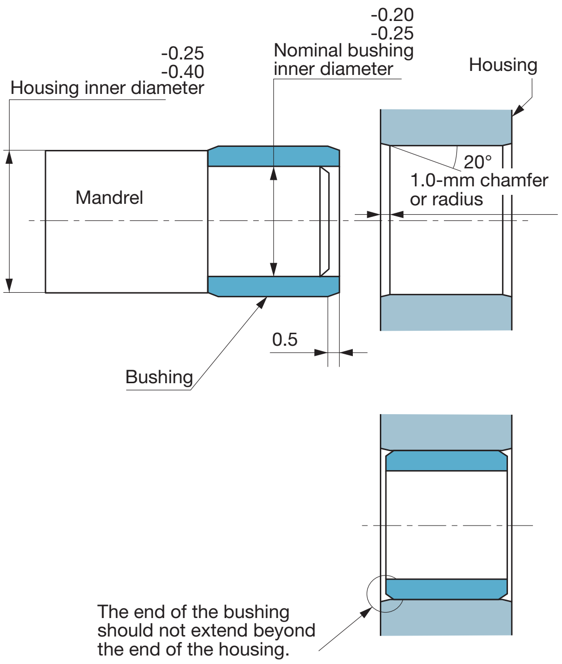
HOUSING	DIAMETER	$\phi 23^{+0.021}_{0}$
	MATERIAL	
SHAFT	DIAMETER	$\phi 20^{-0.025}_{-0.046}$
	MATERIAL	
	HARDNESS	
OIL CLEARANCE		0.025 to 0.127

Fig. 15: Bushing reference drawing

Bushing mounting techniques

❶Press-fitting of bushings

Using a vice or an arbor press, set the bushing in a suitable mandrel and press fit smoothly into the housing. It is extremely important that a bushing be perpendicular to the housing as it is press fit. To facilitate press-fitting of bushing, chamfer the edge of the inner diameter at the end of the housing and lubricate slightly with oil. Also, use a stepped mandrel, as shown in Fig. 16, and take care not to damage the soft bearing surface as the busing is press fit. Never press fit a bushing by hitting it on the end with a hammer. We recommend using a mandrel and chamfer dimensions, as shown in Fig. 16.



NB: In cases where a long housing is press fit with two or more bushings, ensure that adjacent bushings do no contact each other by press fitting the first bushing all the way to its final position and leaving a small clearance between it and the following bushing.

Fig. 16: Press-fitting of bushings

❷Calculating the force F required for press-fitting

F = 0.9tLϕ (δ/D) (Formula No. 14)

F: force in newtons
T: thickness of the backing in mm
L: width of the bushing in mm
ϕ: Coefficient of stress or 1.9 × 105 MPa
δ: fitting margin in mm
D: outer diameter of the bushing in mm

NB: The coefficient of friction for the back of the bushing and the housing is assumed to be 0.15

Example:

Find the force F required for press-fitting a standard K5B2015 into a $23^{+0.021}_{0}$ diameter housing.

Answer:

Thickness = 1.5
Alloy thickness = 0.3, therefore thickness of the backing T is 1.5 - 0.3 = 1.2
Bushing length = 15
Fitting marginmin = 0.025
Fitting marginmax = 0.081 (per Formula No. 7)
Bushing Dmin = ϕ23
$F_{min} = 0.9 \times 1.2 \times 15 \times 1.9 \times 10^5 \times (0.025 \div 23) \approx 3{,}350$ (N)
$F_{max} = 0.9 \times 1.2 \times 15 \times 1.9 \times 10^5 \times (0.081 \div 23) \approx 10{,}840$ (N)

Mounting solid plastic bearings

Solid plastic bearings are subject to extreme fluctuations in temperature, thermal expansion and contraction could result in the bearing separating from the housing.

In such cases, apply the following countermeasures:

①Use a flanged bushing and fix the flange in place.
②Provide the outer diameter with a geometry that prevents rotation.
③Fix in place with an adhesive.

Designing dry bearings, Part 5

Mounting slide plates

❶Using flat head screws
The head of the screw must be sunk below the surface of the bearing alloy.

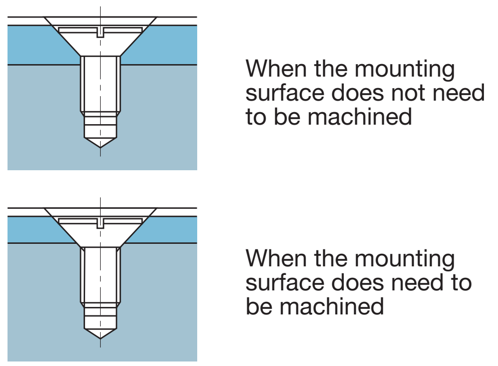


Fig. 17: flat head screws

❷Using Allen head bolts or cheese head screws
We recommend rounding or a 10 to 30° chamfer at A.

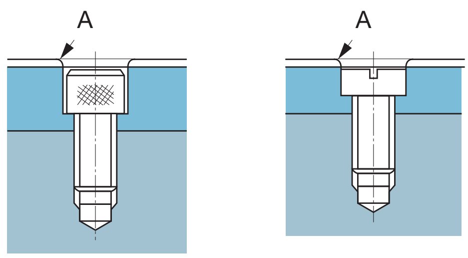


Fig. 18: Attachment bolts

❸Using dowel pins
The hole should be countersunk and the head of the pin caulked to ensure it is fixed in place.

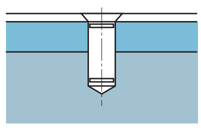


Fig. 19: Dowel pin

❹Using adhesives
Although a variety of adhesives are permissible, we recommend the used of epoxy glue. Also, be sure to select an adhesive suitable for the ambient conditions of the application.

Mounting thrust washers

❶Using flat head screws
Just as with slide plates, the head of the screw must be sunk below the surface of the bearing alloy.

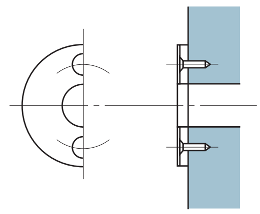


Fig. 20: Mounting washers 1

❷Using dowel pins
Just as with slide plates, the hole should be countersunk and the head of the pin caulked to ensure it is fixed in place.

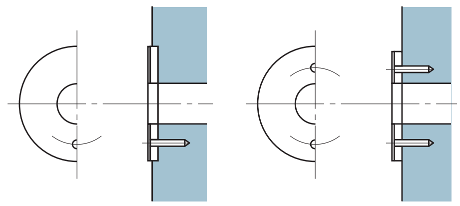


Fig. 21: Mounting washers 2

❸Using adhesives
Although a variety of adhesives are permissible, we recommend the used of epoxy glue. Also, be sure to select an adhesive suitable for the ambient conditions of the application.

Breaking in bearings

We recommend breaking in the bearings as described below prior to full time use.
①Be sure that the surface of the sliding bearing and its mating surface are both smooth.
②Able to alleviate localized interference due to misalignment.

Storing sliding bearings

Avoid the following when storing sliding bearings.
①Avoid exposure to direct sunlight.
②Avoid exposure to high temperatures or humidity.
③Avoid exposure to moisture, alkaline, or acid.
④Avoid exposure to dust or other foreign substances.

Plastic flow analysis

Plastic flow analysis is performed using computer software to simulate the flow of plastic during injection molding.
This simulation predicts the behavior of molten plastic inside the mold and is useful in analyzing the molding process in order to select materials, verify product geometry, and design the placement of gates and runners as well as to determine suitable manufacturing parameters and design countermeasures for short shots, weld lines, warping, sink marks, and other defects.
Also, structural analysis software enables evaluation of warping in parts made by insert molding processes.

A typical analysis

This is an analysis of a tip seal used in a scroll compressor.
The product was modeled using 3D CAD.
The STL and IGES data for the model was then read into the plastic flow analysis software and to create a mesh.
Material and forming parameters were input and an analysis performed.
The results included a filling analysis, a cooling analysis, a contraction and warping analysis, and a stress analysis.

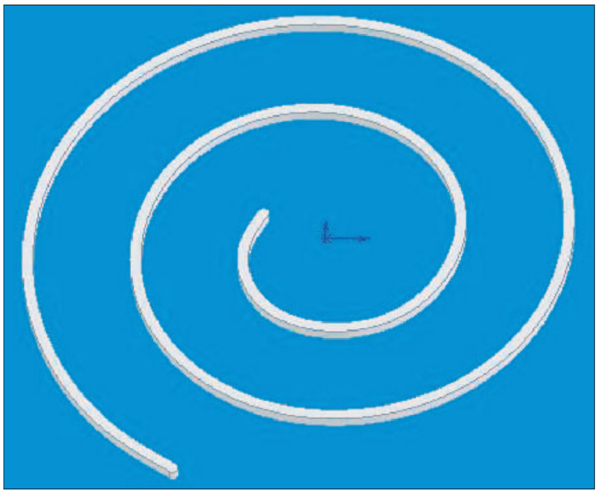


Fig. 1: 3D model of the tip seal

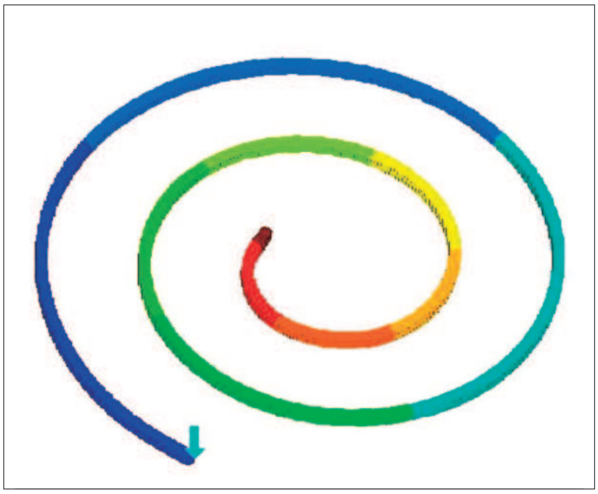


Fig. 2: Filling analysis results (filling pattern)

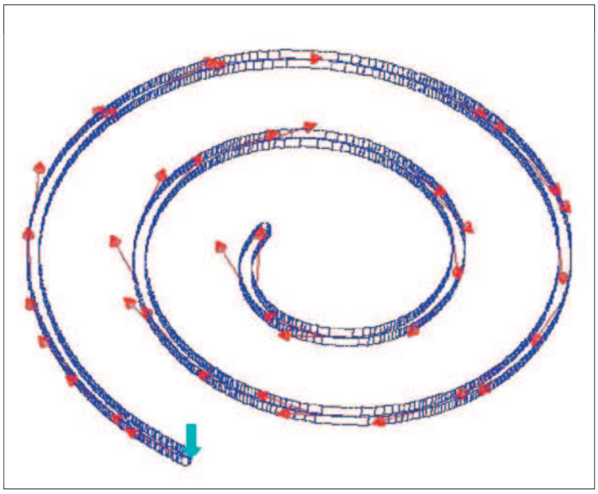


Fig. 3: Filling analysis results (fiber orientation)

Designing dry bearings, Part 6

4. Approximate conversion values for Vickers hardness of steel

Vickers hardness	Brinell hardness 10-mm ball, 3000 kgf		Rockwell hardness			Superficial Rockwell hardness Diamond pyramid			Shore hardness
	Standard ball	Tungsten carbide ball	A-scale, 60 kgf Diamond pyramid	B-scale, 100 kgf 1.6-mm (1/16") ball	C-scale, 150 kgf Diamond pyramid	15N scale, 15 kgf	30N scale, 30 kgf	45N scale, 45 kgf	
940	–	–	85· 6	–	68· 0	93· 2	84· 4	75· 4	97
920	–	–	85· 3	–	67· 5	93· 0	84· 0	74· 8	96
900	–	–	85· 0	–	67· 0	92· 9	83· 6	74· 2	95
880	–	(767)	84· 7	–	66· 4	92· 7	83· 1	73· 6	93
860	–	(757)	84· 4	–	65· 9	92· 5	82· 7	73· 1	92
840	–	(745)	84· 1	–	65· 3	92· 3	82· 2	72· 2	91
820	–	(733)	83· 8	–	64· 7	92· 1	81· 7	71· 8	90
800	–	(722)	83· 4	–	64· 0	91· 8	81· 1	71· 0	88
780	–	(710)	83· 0	–	63· 3	91· 5	80· 4	70· 2	87
760	–	(698)	82· 6	–	62· 5	91· 2	79· 7	69· 4	86
740	–	(684)	82· 2	–	61· 8	91· 0	79· 1	68· 6	84
720	–	(670)	81· 8	–	61· 0	90· 7	78· 4	67· 7	83
700	–	(656)	81· 3	–	60· 1	90· 3	77· 6	66· 7	81
690	–	(647)	81· 1	–	59· 7	90· 1	77· 2	66· 2	–
680	–	(638)	80· 8	–	59· 2	89· 8	76· 8	65· 7	80
670	–	630	80· 6	–	58· 8	89· 7	76· 4	65· 3	–
660	–	620	80· 3	–	58· 3	89· 5	75· 9	64· 7	79
650	–	611	80· 0	–	57· 8	89· 2	75· 5	64· 1	–
640	–	601	79· 8	–	57· 3	89· 0	75· 1	63· 5	77
630	–	591	79· 5	–	56· 8	88· 8	74· 6	63· 0	–
620	–	582	79· 2	–	56· 3	88· 5	74· 2	62· 4	75
610	–	573	78· 9	–	55· 7	88· 2	73· 6	61· 7	–
600	–	564	78· 6	–	55· 2	88· 0	73· 2	61· 2	74
590	–	554	78· 4	–	54· 7	87· 8	72· 7	60· 5	–
580	–	545	78· 0	–	54· 1	87· 5	72· 1	59· 9	72
570	–	535	77· 8	–	53· 6	87· 2	71· 7	59· 3	–
560	–	525	77· 4	–	53· 0	86· 9	71· 2	58· 6	71
550	(505)	517	77· 0	–	52· 3	86· 6	70· 5	57· 8	–
540	(496)	507	76· 7	–	51· 7	86· 3	70· 0	57· 0	69
530	(488)	497	76· 4	–	51· 1	86· 0	69· 5	56· 2	–
520	(480)	488	76· 1	–	50· 5	85· 7	69· 0	55· 6	67
510	(473)	479	75· 7	–	49· 8	85· 4	68· 3	54· 7	–
500	(465)	471	75· 3	–	49· 1	85· 0	67· 7	53· 9	66
490	(456)	460	74· 9	–	48· 4	84· 7	67· 1	53· 1	–
480	448	452	74· 5	–	47· 7	84· 3	66· 4	52· 2	64
470	441	442	74· 1	–	46· 9	83· 9	65· 7	51· 3	–
460	433	433	73· 6	–	46· 1	83· 6	64· 9	50· 4	62
450	425	425	73· 3	–	45· 3	83· 2	64· 3	49· 4	–
440	415	415	72· 8	–	44· 5	82· 8	63· 5	48· 4	59
430	405	405	72· 3	–	43· 6	82· 3	62· 7	47· 4	–
420	397	397	71· 8	–	42· 7	81· 8	61· 9	46· 4	57

Excerpted from SAE J 417

Excerpted from JISB0401 (1986)

Vickers hardness	Brinell hardness 10-mm ball, 3000 kgf		Rockwell hardness			Superficial Rockwell hardness Diamond pyramid			Shore hardness
	Standard ball	Tungsten carbide ball	A-scale, 60 kgf Diamond pyramid	B-scale, 100 kgf 1.6-mm (1/16") ball	C-scale, 150 kgf Diamond pyramid	15N scale, 15 kgf	30N scale, 30 kgf	45N scale, 45 kgf	
410	388	388	71·4	–	41·8	81·4	61·1	45·3	–
400	379	379	70·8	–	40·8	81·0	60·2	44·1	55
390	369	369	70·3	–	39·8	80·3	59·3	42·9	–
380	360	360	69·8	(110·0)	38·8	79·8	58·4	41·7	52
370	350	350	69·2	–	37·7	79·2	57·4	40·4	–
360	341	341	68·7	(109·0)	36·6	78·6	56·4	39·1	50
350	331	331	68·1	–	35·5	78·0	55·4	37·8	–
340	322	322	67·6	(108·0)	34·4	77·4	54·4	36·5	47
330	313	313	67·0	–	33·3	76·8	53·6	35·2	–
320	303	303	66·4	(107·0)	32·2	76·2	52·3	33·9	45
310	294	294	65·8	–	31·0	75·6	51·3	32·5	–
300	284	284	65·2	(105·5)	29·8	74·9	50·2	31·1	42
295	280	280	64·8	–	29·2	74·6	49·7	30·4	–
290	275	275	64·5	(104·5)	28·5	74·2	49·0	29·5	41
285	270	270	64·2	–	27·8	73·8	48·4	28·7	–
280	265	265	63·8	(103·5)	27·1	73·4	47·8	27·9	40
275	261	261	63·5	–	26·4	73·0	47·2	27·1	–
270	256	256	63·1	(102·0)	25·6	72·6	46·4	26·2	38
265	252	252	62·7	–	24·8	72·1	45·7	25·2	–
260	247	247	62·4	(101·0)	24·0	71·6	45·0	24·3	37
255	243	243	62·0	–	23·1	71·1	44·2	23·2	–
250	238	238	61·6	99·5	22·2	70·6	43·4	22·2	36
245	233	233	61·2	–	21·3	70·1	42·5	21·1	–
240	228	228	60·7	98·1	20·3	69·6	41·7	19·9	34
230	219	219	–	96·7	(18·0)	–	–	–	33
220	209	209	–	95·0	(15·7)	–	–	–	32
210	200	200	–	93·4	(13·4)	–	–	–	30
200	190	190	–	91·5	(11·0)	–	–	–	29
190	181	181	–	89·5	(8·5)	–	–	–	28
180	171	171	–	87·1	(6·0)	–	–	–	26
170	162	162	–	85·0	(3·0)	–	–	–	25
160	152	152	–	81·7	(0·0)	–	–	–	24
150	143	143	–	78·7	–	–	–	–	22
140	133	133	–	75·0	–	–	–	–	21
130	124	124	–	71·2	–	–	–	–	20
120	114	114	–	66·7	–	–	–	–	–
110	105	105	–	62·3	–	–	–	–	–
100	95	95	–	56·2	–	–	–	–	–
95	90	90	–	52·0	–	–	–	–	–
90	86	86	–	48·0	–	–	–	–	–
85	81	81	–	41·0	–	–	–	–	–

Excerpted from SAE J 417

Designing dry bearings, Part 7

5. Dimensional tolerances for holes used for normal fit

Dimensions (in mm)		Hole tolerance class																	
more than	or less	B10	C7	C8	C9	C10	D8	D9	D10	E7	E8	E9	F6	F7	F8	G6	G7	H6	H7
–	3	+180 +140	+70 +60	+74 +60	+85 +60	+100 +60	+34 +20	+45 +20	+60 +20	+24 +14	+28 +14	+39 +14	+12 +6	+16 +6	+20 +6	+8 +2	+12 +2	+6 0	+10 0
3	6	+188 +140	+82 +70	+88 +70	+100 +70	+118 +70	+48 +30	+60 +30	+78 +30	+32 +20	+38 +20	+50 +20	+18 +10	+22 +10	+28 +10	+12 +4	+16 +4	+8 0	
6	10	+208 +150	+95 +80	+102 +80	+116 +80	+138 +80	+62 +40	+76 +40	+98 +40	+40 +25	+47 +25	+61 +25	+22 +13	+28 +13	+35 +13	+14 +5	+20 +5	+9 0	+15 0
10	14	+220 +150	+113 +95	+122 +95	+138 +95	+165 +95	+77 +50	+93 +50	+120 +50	+50 +32	+59 +32	+75 +32	+27 +16	+34 +16	+43 +16	+17 +6	+24 +6	+11 0	+18 0
14	18																		
18	24	+244 +160	+131 +110	+143 +110	+162 +110	+194 +110	+98 +65	+117 +65	+149 +65	+61 +40	+73 +40	+92 +40	+33 +20	+41 +20	+53 +20	+20 +7	+28 +7	+13 0	+21 0
24	30																		
30	40	+270 +170	+145 +120	+159 +120	+182 +120	+220 +120	+119 +80	+142 +80	+180 +80	+75 +50	+89 +50	+112 +50	+41 +25	+50 +25	+64 +25	+25 +9	+34 +9	+16 0	+25 0
40	50	+280 +180	+155 +130	+169 +130	+192 +130	+230 +130													
50	65	+310 +190	+170 +140	+186 +140	+214 +140	+260 +140	+146 +100	+174 +100	+220 +100	+90 +60	+106 +60	+134 +60	+49 +30	+60 +30	+76 +30	+29 +10	+40 +10	+19 0	+30 0
65	80	+320 +200	+180 +150	+196 +150	+224 +150	+270 +150													
80	100	+360 +220	+205 +170	+224 +170	+257 +170	+310 +170	+174 +120	+207 +120	+260 +120	+107 +72	+126 +72	+159 +72	+58 +36	+71 +36	+90 +36	+34 +12	+47 +12	+22 0	+35 0
100	120	+380 +240	+215 +180	+234 +180	+267 +180	+320 +180													
120	140	+420 +260	+240 +200	+263 +200	+300 +200	+360 +200	+208 +145	+245 +145	+305 +145	+125 +85	+148 +85	+185 +85	+68 +43	+83 +43	+106 +43	+39 +14	+54 +14	+25 0	+40 0
140	160	+440 +280	+250 +210	+273 +210	+310 +210	+370 +210													
160	180	+470 +310	+270 +230	+293 +230	+330 +230	+390 +230													
180	200	+525 +340	+286 +240	+312 +240	+355 +240	+425 +240	+242 +170	+285 +170	+355 +170	+146 +100	+172 +100	+215 +100	+79 +50	+96 +50	+122 +50	+44 +15	+61 +15	+29 0	+46 0
200	225	+565 +380	+306 +260	+332 +260	+375 +260	+445 +260													
225	250	+605 +420	+326 +280	+352 +280	+395 +280	+465 +280													
250	280	+690 +480	+352 +300	+381 +300	+430 +300	+510 +300	+271 +190	+320 +190	+400 +190	+162 +110	+191 +110	+240 +110	+83 +56	+108 +56	+137 +56	+49 +17	+69 +17	+32 0	+52 0
280	315	+750 +540	+382 +330	+411 +330	+460 +330	+540 +330													

Excerpted from JISB0401 (1986)

Dimensions (in mm)		Hole tolerance class																	
more than	or less	H8	H9	H10	JS6	JS7	K6	K7	M6	M7	N6	N7	P6	P7	R7	S7	T7	U7	X7
–	3	+14 0	+25 0	+40 0	±3.0	±5	0 -6	0 -10	-2 -8	-2 -12	-4 -10	-4 -14	-6 -12	-6 -16	-10 -20	-14 -24	–	-18 -28	-20 -30
3	6	+18 0	+30 0	+48 0	±4.0	±6	+2 -6	+3 -9	-1 -9	0 -12	-5 -13	-4 -16	-9 -17	-8 -20	-11 -23	-15 -27	–	-19 -31	-24 -36
6	10	+22 0	+36 0	+58 0	±4.5	±7	+2 -7	+5 -10	-3 -12	0 -15	-7 -16	-4 -19	-12 -21	-9 -24	-13 -28	-17 -32	–	-22 -37	-28 -43
10	14	+27 0	+43 0	+70 0	±5.5	±9	+2 -9	+6 -12	-4 -15	0 -18	-9 -20	-5 -23	-15 -26	-11 -29	-16 -34	-21 -39	–	-26 -44	-33 -51
14	18																		-38 -56
18	24	+33 0	+52 0	+84 0	±6.5	±10	+2 -11	+6 -15	-4 -17	0 -21	-11 -24	-7 -28	-18 -31	-14 -35	-20 -41	-27 -48	–	-33 -54	-46 -67
24	30																-33 -54	-40 -61	-56 -77
30	40	+39 0	+62 0	+100 0	±8.0	±12	+3 -13	+7 -18	-4 -20	0 -25	-12 -28	-8 -33	-21 -37	-17 -42	-25 -50	-34 -59	-39 -64	-51 -76	–
40	50																-45 -70	-61 -86	
50	65	+46 0	+74 0	+120 0	±9.5	±15	+4 -15	+9 -21	-5 -24	0 -30	-14 -33	-9 -39	-26 -45	-21 -51	-30 -60	-42 -72	-55 -85	-76 -106	–
65	80														-32 -62	-48 -78	-64 -94	-91 -121	
80	100	+54 0	+87 0	+140 0	±11.0	±17	+4 -18	+10 -25	-6 -28	0 -35	-16 -38	-10 -45	-30 -52	-24 -59	-38 -73	-58 -93	-78 -113	-111 -146	–
100	120														-41 -76	-66 -101	-91 -126	-131 -166	
120	140	+63 0	+100 0	+160 0	±12.5	±20	+4 -21	+12 -28	-8 -33	0 -40	-20 -45	-12 -52	-36 -61	-28 -68	-48 -88	-77 -117	-107 -147	–	–
140	160														-50 -90	-85 -125	-119 -159		
160	180														-53 -93	-93 -133	-131 -171		
180	200	+72 0	+115 0	+185 0	±14.5	±23	+5 -24	+13 -33	-8 -37	0 -46	-22 -51	-14 -60	-41 -70	-33 -79	-60 -106	-105 -151	–	–	–
200	225														-63 -109	-113 -159			
225	250														-67 -113	-123 -169			
250	280	+81 0	+130 0	+210 0	±16.0	±26	+5 -27	+16 -36	-9 -41	0 -52	-25 -57	-14 -66	-47 -79	-36 -88	-74 -126	–	–	–	–
280	315														-78 -130				

Reference: The upper figure in each cell indicates the upper tolerance and the lower figure in each cell indicates the lower tolerance for the given class.

Designing dry bearings, Part 8

6. Dimensional tolerances for shafts used for normal fit

Excerpted from JISB0401 (1986)

Units: μm

Dimensions (in mm)		Shaft tolerance class																
more than	or less	b9	c9	d8	d9	e7	e8	e9	f6	f7	f8	g5	g6	h5	h6	h7	h8	h9
–	3	-140 -165	-60 -85	-20 -34	-20 -45	-14 -24	-14 -28	-14 -39	-6 -12	-6 -16	-6 -20	-2 -6	-2 -8	0 -4	0 -6	0 -10	0 -14	0 -25
3	6	-140 -170	-70 -100	-30 -48	-30 -60	-20 -32	-20 -38	-20 -50	-10 -18	-10 -22	-10 -28	-4 -9	-4 -12	0 -5	0 -8	0 -12	0 -18	0 -30
6	10	-150 -186	-80 -116	-40 -62	-40 -76	-25 -40	-25 -47	-25 -61	-13 -22	-13 -28	-13 -35	-5 -11	-5 -14	0 -6	0 -9	0 -15	0 -22	0 -36
10	14	-150 -193	-95 -138	-50 -77	-50 -93	-32 -50	-32 -59	-32 -75	-16 -27	-16 -34	-16 -43	-6 -14	-6 -17	0 -8	0 -11	0 -18	0 -27	0 -43
14	18																	
18	24	-160 -212	-110 -162	-65 -98	-65 -117	-40 -61	-40 -73	-40 -92	-20 -33	-20 -41	-20 -53	-7 -16	-7 -20	0 -9	0 -13	0 -21	0 -33	0 -52
24	30																	
30	40	-170 -232	-120 -182	-80 -119	-80 -142	-50 -75	-50 -89	-50 -112	-25 -41	-25 -50	-25 -64	-9 -20	-9 -25	0 -11	0 -16	0 -25	0 -39	0 -62
40	50	-180 -242	-130 -192															
50	65	-190 -264	-140 -214	-100 -146	-100 -174	-60 -90	-60 -106	-60 -134	-30 -49	-30 -60	-30 -76	-10 -23	-10 -29	0 -13	0 -19	0 -30	0 -46	0 -74
65	80	-200 -274	-150 -224															
80	100	-220 -307	-170 -257	-120 -174	-120 -207	-72 -107	-72 -126	-72 -159	-36 -58	-36 -71	-36 -90	-12 -27	-12 -34	0 -15	0 -22	0 -35	0 -54	0 -87
100	120	-240 -327	-180 -267															
120	140	-260 -360	-200 -300	-145 -208	-145 -245	-85 -125	-85 -148	-85 -185	-43 -68	-43 -83	-43 -106	-14 -32	-14 -39	0 -18	0 -25	0 -40	0 -63	0 -100
140	160	-280 -380	-210 -310															
160	180	-310 -410	-230 -330															
180	200	-340 -455	-240 -355	-170 -242	-170 -285	-100 -146	-100 -172	-100 -215	-50 -79	-50 -96	-50 -122	-15 -35	-15 -44	0 -20	0 -29	0 -46	0 -72	0 -115
200	225	-380 -495	-260 -375															
225	250	-420 -535	-280 -395															
250	280	-480 -610	-300 -430	-190 -271	-190 -320	-110 -162	-110 -191	-110 -240	-56 -88	-56 -108	-56 -137	-17 -40	-17 -49	0 -23	0 -32	0 -52	0 -81	0 -130
280	315	-540 -670	-330 -460															

Dimensions (in mm)		Shaft tolerance class													
more than	or less	js5	js6	js7	k5	k6	m5	m6	n6	p6	r6	s6	t6	u6	x6
–	3	±2.0	±3.0	±5	+4 0	+6 0	+6 +2	+8 +2	+10 +4	+12 +6	+16 +10	+20 +14	–	+24 +18	+26 +20
3	6	±2.5	±4.0	±6	+6 +1	+9 +1	+9 +4	+12 +4	+16 +8	+20 +12	+23 +15	+27 +19	–	+31 +23	+36 +28
6	10	±3.0	±4.5	±7	+7 +1	+10 +1	+12 +6	+15 +6	+19 +10	+24 +15	+28 +19	+32 +23	–	+37 +28	+43 +34
10	14	±4.0	±5.5	±9	+9 +1	+12 +1	+15 +7	+18 +7	+23 +12	+29 +18	+34 +23	+39 +28	–	+44 +33	+51 +40
14	18														+56 +45
18	24	±4.5	±6.5	±10	+11 +2	+15 +2	+17 +8	+21 +8	+28 +15	+35 +22	+41 +28	+48 +35	–	+54 +41	+67 +54
24	30												+54 +41	+61 +48	+77 +64
30	40	±5.5	±8.0	±12	+13 +2	+18 +2	+20 +9	+25 +9	+33 +17	+42 +26	+50 +34	+59 +43	+64 +48	+76 +60	–
40	50												+70 +54	+86 +70	
50	65	±6.5	±9.5	±15	+15 +2	+21 +2	+24 +11	+30 +11	+39 +20	+51 +32	+60 +41	+72 +53	+85 +66	+106 +87	–
65	80										+62 +43	+78 +59	+94 +75	+121 +102	
80	100	±7.5	±11.0	±17	+18 +3	+25 +3	+28 +13	+35 +13	+45 +23	+59 +37	+73 +51	+93 +71	+113 +91	+146 +124	–
100	120										+76 +54	+101 +79	+126 +104	+166 +144	
120	140	±9.0	±12.5	±20	+21 +3	+28 +3	+33 +15	+40 +15	+52 +27	+68 +43	+88 +63	+117 +92	+147 +122	–	–
140	160										+90 +65	+125 +100	+159 +134		
160	180										+93 +68	+133 +108	+171 +146		
180	200	±10.0	±14.5	±23	+24 +4	+33 +4	+37 +17	+46 +17	+60 +31	+79 +50	+106 +77	+151 +122	–	–	–
200	225										+109 +80	+159 +130			
225	250										+113 +84	+169 +140			
250	280	±11.5	±16.0	±26	+27 +4	+36 +4	+43 +20	+52 +20	+66 +34	+88 +56	+126 +94	–	–	–	–
280	315										+130 +98	–			

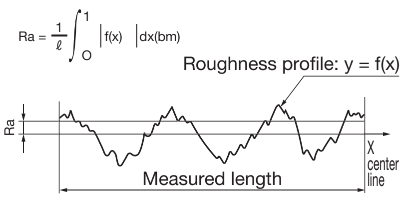
Excerpted from JISB0401 (1986)

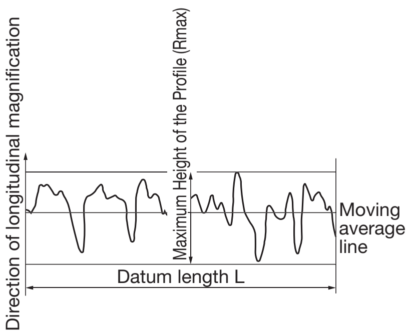
Reference: The upper figure in each cell indicates the upper tolerance and the lower figure in each cell indicates the lower tolerance for the given class.

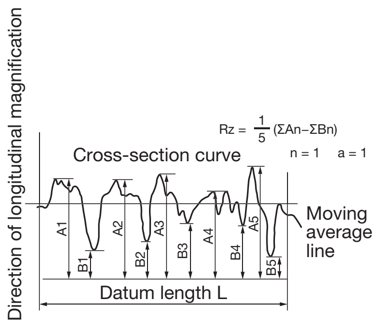
7. Defining and indicating surface roughness

Excerpted from JISB0601

Center Line Average Roughness (Ra)	Maximum Height of the Profile (Rmax)	Ten Point Average Roughness (Rz)
A value in micrometers (μm) found using the formula below when sampling along the center line of a roughness profile with the center line taken as the x-axis and the longitudinal magnification taken as the y-axis to display the roughness profile y = f(x). $Ra = \frac{1}{\ell}\int_{0}^{\ell} \lvert f(x) \rvert \, dx$	A value in micrometers (μm) found by measuring the distance between two straight lines that are parallel to the moving average line when sampling along a datum length of the cross-section curve, and which are respectively tangent to the highest peak and the lowest valley of the cross-section curve.	A value in micrometers (μm) found by averaging the height of the five highest peaks and the five lowest valleys when sampling along the datum length, as measured from the moving average line.







8. Standard sequences and datum lengths for surface roughness

Center Line Average Roughness (Ra)		Maximum Height of the Profile (Rmax)		Ten Point Average Roughness (Rz)	
Standard sequences	Cutoff value (mm)	Standard sequences	Datum length L (mm)	Standard sequences	Datum length L (mm)
0.013a 0.025a 0.05a 0.1a 0.2a		0.05s 0.1s 0.2s 0.4s 0.8s	0.25	0.05z 0.1z 0.2z 0.4z 0.8z	0.25
0.4a 0.8a 1.6a	0.8	1.6s 3.2s 6.3s	0.8	1.6z 3.2z 6.3z	0.8
3.2a 6.3a		12.5s 25.0s	2.5	12.5z 25.0z	2.5
12.5a 25.0a		50.0s 100.0s	8.0	50.0z 100.0z	8.0
50.0a 100.0a	2.5	200.0s 400.0s	25.0	200.0z 400.0z	25.0
Measurement length: At least 300% of the cutoff value.					

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9. International System of Units (SI)

The world's industries presently use the International System of Units as a common system of measurement. This catalog utilizes SI units almost exclusively, but also presents units from earlier systems of measurement side by side for convenience.

(Showing only related units)

Classification	Conventional units	SI units*
Weight or Force	1.0kgf	9.8N
Specific load	1.0kgf/cm^2	9.8×10^{-2}MPa
	1.0kgf/cm^2	9.8×10^{-2}N/mm^2
PV value	1.0kgf/cm^2 · m/min	9.8×10^{-2}MPa · m/min
Stress	1.0kgf/mm^2	9.8MPa
	1.0kgf/mm^2	9.8N/mm^2

*NB: Figures are rounded to two decimal places.

Other SI units

A.1 Force

To convert from kgf to N: 1 kgf = 9.80665 N
To convert from N to kgf: 1 N = 0.101972 kgf
Ref: to convert from dyn to kN: 1 dyn = 1×10^{-2} kN

A.2 Pressure

To convert from mm H_2O to Pa: 1 mm H_2O = 9.80665 Pa
To convert from Pa to mm H_2O: kPa = 0.101972 mm H_2O
To convert from kgf/cm^2 to MPa: 1 kgf/cm^2 = 0.0980665 MPa
To convert from MPa to kgf/cm^2: 1 MPa = 10.1972 kgf/cm^2
To convert m H_2O to kPa: 1 m H_2O = 9.80665 kPa
To convert kPa to m H_2O: 1 kPa = 0.101972 m H_2O
To convert atm to MPa: 1 atm = 0.101325 MPa
To convert MPa to atm: 1 MPa = 9.86923 atm
To convert mm Hg to kPa: 1 mm Hg = 0.133322 kPa
To convert kPa to mm Hg: 1 kPa = 7.50062 mm Hg
Ref: to convert bar to Pa: 1 bar = 1×105 Pa

A.3 Stress

To convert kgf/cm^2 to MPa: 1 kgf/cm^2 = 0.0980665 MPa
To convert MPa to kgf/cm^2: 1 MPa = 10.1972 kgf/cm^2
To convert kgf/mm^2 to MPa: 1 kgf/mm^2 = 9.80665 MPa
To convert MPa to kgf/mm^2: 1 MPa = 0.101972 kgf/mm^2
Ref: to convert N/mm^2 to MPa: 1 N/mm^2 = 1 MPa

A.4 Work and Energy

To convert from kgf · m to J: 1 kgf · m = 9.80665 J
To convert J to kgf · m: 1 J = 0.101972 kgf· m/s

A.5 Power

To convert kgf · m/s to W: 1 kgf · m/s = 9.80665 W
To convert W to kgf · m/s: 1 W = 0.101972 kgf · m/s

B.1 Work and Energy

To convert kW·h to MJ: 1 kW · h = 3.6 MJ
To convert MJ to kW · h: 1 MJ = 0.277778 kW · h

B.2 Power

To convert PS to kW: 1 PS = 0.7355 kW
To convert kW to PS: 1 kW = 1.35962 PS

B.3 Heat

To convert kcal to kJ: 1 kcal = 4.18605 kJ
To convert kJ to kcal: 1 kJ = 0.238889 kcal

B.4 Heat flow

To convert kcal/h to W: 1 kcal/h = 1.16279 W
To convert W to kcal/h: 1 W = 0.860 kcal/h

B.5 Thermal conductivity

To convert kcal/h (h · m · °C) to W/(m · K):
1 kcal/h (h · m · °C) = 1.16279 W/(m · K)
To convert W/(m · K) to kcal/h(h · m · °C):
1 W/(m · K) = 0.860 kcal/(h · m · °C)

B.6 Coefficient of heat transfer

To convert kcal/(h · m · °C) to W/(m · K):
1 kcal/(h · m · °C) = 1.16279 W/(m · K)
To convert W/(m · K) to kcal/(h · m · °C):
1 W/(m · K) = 0.860 kcal/(h · m · °C)

B.7 Specific heat

To convert kcal/(kg · °C) to kJ/(kg · K):
1 kcal/(kg · °C) = 4.18605 kJ/(kg · K)
To convert kJ/(kg · K) to kcal/(kg · °C):
1 kJ/(kg · K) = 0.238889 kcal/(kg · °C)

Reference **1. Viscosity**
1 cP = 1×10^{-3}Pa · s (1 Pa · s = 1×10^3 cP)
1 P = 1×10^{-1}Pa · s (1 Pa · s =10 P)
2. Dynamic viscosity
1 cSt = 1×10^{-6}m^2/s (1 m^2/s = 1×10^6 cSt)
1 St = 1×10^{-4}m^2/s (1 m^2/s = 1×10^4 cSt)