Table 5-10(1) Preload and Rigidity (DB and DF Arrangement) of HTA A standard series

Bearing Number	Bore d (mm)	Bearing Preload、Rigidity			
		M		H	
		Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)	Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)
HTA010A DB	50	325	190	650	243
HTA011A DB	55	347	212	695	272
HTA012A DB	60	352	219	704	280
HTA013A DB	65	421	240	841	307
HTA014A DB	70	492	260	984	332
HTA015A DB	75	499	268	998	343
HTA016A DB	80	653	301	1306	384
HTA017A DB	85	663	310	1326	396
HTA018A DB	90	686	329	1372	421
HTA019A DB	95	848	352	1695	449
HTA020A DB	100	861	362	1722	463

Table 5-10(2) Preload and Rigidity (DB and DF Arrangement) of HTA B standard series

Bearing Number	Bore d (mm)	Bearing Preload、Rigidity			
		M		H	
		Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)	Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)
HTA010B DB	50	540	339	1080	431
HTA011B DB	55	576	378	1152	481
HTA012B DB	60	582	390	1165	496
HTA013B DB	65	697	427	1393	543
HTA014B DB	70	815	463	1630	589
HTA015B DB	75	826	478	1651	607
HTA016B DB	80	1082	536	2164	681
HTA017B DB	85	1098	553	2196	702
HTA018B DB	90	1134	587	2269	745
HTA019B DB	95	1404	627	2808	797
HTA020B DB	100	1426	646	2851	821

Table 5-10(3) Preload and Rigidity (DB and DF Arrangement) of BS standard series

Bearing Number	Bore d (mm)	Bearing Preload、Rigidity	
		Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)
BS2047	20	2060	635
BS2562	25	3250	980
BS3062	30	3250	980
BS3572	35	3800	1130
BS4072	40	3800	1130

6 Lubrication of Bearings

The purpose of bearing lubrication is to prevent direct metal to metal contact between the various rolling and sliding elements. This is accomplished through the formation of a thin oil(or grease) film on contact surfaces. Lubrication also helps to reduce friction and wear, dissipate friction heat, keep away from dust. In order to achieve the above advantages and prolong the bearing life, the most effective lubrication method and lubricant has to be selected for each individual operating conditions.

The main spindle of a machine tool usually uses an extremely low volume of lubricant so heat generation from stirring of the lubricant is minimal. Fig. 6.1 summarizes the relationships between oil volume, friction loss, and bearing temperature.

The lubrication methods available for bearings in a machine tool include grease lubrication, oil mist lubrication, air-oil lubrication, and jet lubrication. Each method has unique advantages. Therefore, the lubricating system that best suits the lubrication requirements should be used. Tables 6.1 and 6.2 summarize the features of various lubrication methods.

Fig. 6.1 Oil volume, friction loss and bearing temperature

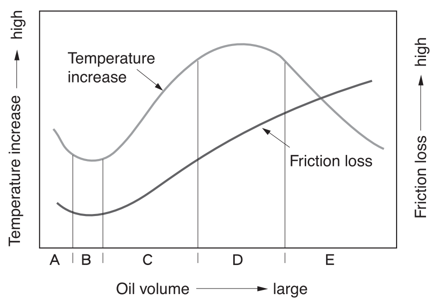


Table 6.1 Different Zone(Fig. 6.1) and its lubrication method

Zone	Features	Typical lubrication method
A	With an extremely low volume of oil, partial metal-to-metal contact occurs between the rolling elements and raceway surface, possibly leading to abnormal wear and bearing seizure.	—
B	A uniform, uninterrupted oil film is formed. Friction is minimal and bearing temperature is kept low.	Grease lubrication Oil mist lubrication Air-oil lubrication
C	Even with a greater oil volume, heat generation and cooling are in balance.	Circulating lubrication

Zone	Features	Typical lubrication method
D	Temperature increase is constant regardless of oil volume.	Circulating lubrication
E	A further increase in oil volume contributes to a significant cooling effect, and the bearing temperature drops.	Forced circulating lubrication Jet lubrication

Table 6.2 Evaluation of various lubricating systems

Lubrication method / Criterion	Grease lubrication	Oil mist lubrication	Air-oil lubrication	Jet lubrication
Handling	☆☆☆☆	☆☆☆	☆☆☆	☆☆
Reliability	☆☆☆	☆☆	☆☆☆	☆☆☆☆
Temperature increase	☆☆	☆☆	☆☆☆	☆☆☆☆
Cooling effect	☆	☆☆	☆☆☆	☆☆☆☆
Sealing structure	☆☆	☆☆☆	☆☆☆	☆
Power loss	☆☆☆	☆☆☆	☆☆☆	☆
Environmental contamination	☆☆☆	☆	☆☆	☆☆☆
Allowable dmN value①	$140X10^4$	$220X10^4$	$250X10^4$	$400X10^4$

Legend ☆☆☆☆：Excellent ☆☆☆：Good
☆☆：Fair ☆：Poor

①The permissible dmN values are approximate values:
dmN: pitch circle diameter across rolling elements, mm multiplied by speed, min^{-1}

6.1 Grease lubrication and its life prediction

Lubricating grease are composed of either a mineral oil base or a synthetic oil base. To this base a thickener and other additives are added. Thickening agents are compounded with base oils to maintain the semi-solid state of the grease.

Usually, a bearing for the main spindle of a machine tool requires that grease volume be low so heat generated by the stirring of the grease during high speed operation is minimal. A guideline for the amount of grease used for a main spindle bearing is given below.

・Angular contact ball bearing:
(dmn value ≦ 650×103); 15% of bearing free space
(dmn value ＞ 650×103); 12% of bearing free space
・Cylindrical roller bearing:10% of bearing free space
・Tapered roller bearing: 15% of bearing free space

The space in the bearing typically used for main spindles are listed in dimension tables. Determine a fill amount by referring to the relevant bearing table.

For ball screw support applications, support bearings are generally lubricated by grease. The recommended grease is listed in Table 6.3 and amount of grease is 25% of bearing free space.

The prediction of grease life can be calculated according to the method of Kawamura et al. The calculated life L50 (50% reliability life) of grease can be expressed as follows:

For urea-based grease：

$$\log L = -2.02\times10^{-6}\times K\times V - 2.95\times10^{-2}T - 8.36F + 8.50 + K_1$$

Table 6.3 Typical greases for machine tool main spindle bearings

Code	Grease brand	Soup	Base oil	Base oil viscosity (40℃) mm2/S	Dropping point (℃)	NLGI	Operating temperature range (℃)	Characteristics
5K	Multemp SRL	Li	ester	26	201	2	-40~+150	General used, low noise
15K	Isoflex NBU 15	Ba Complex	ester+ PAO+mineral	20	>200	2	-40~+130	High speed
L712	Kluberspeed BF 72-22	Urea	ester+ PAO	22	220	2	-50~+120	High speed
L433	Asonic Q 74-73	Urea	ester+ PAO	68	>250	3	-40~+160	High speed
L559	Turmogrease Highspeed L252	Li	ester	25	>250	2	-40~+150	High speed
2AS	Alvania Grease S2	Li	mineral	130	>200	2	-25~+120	Ball screw support

where,

$10 \leqq dm \leqq 100,\ 70 \leqq T \leqq 180,\ T \leqq 70,$

$T=70;\ V \geqq 7x10^6,\ V=7x10^6$

For Li-based grease：

$$\log L = -1.58\times10^{-6}\times K\times V$$
$$-2.18\times10^{-2}T - 9.84F + 6.33 + K_1$$

where,

$10 \leqq dm \leqq 100,\ 70 \leqq T \leqq 150,\ T \leqq 70,$

$T=70;\ V \geqq 7x10^6,\ V=7x10^6$

在此，

L：L_{50} grease life, hour

K：compensation factor for outer ring rotation(if inner ring rotation: K=1; if outer ring rotation: K= inner ring rotating speed calculated from the cage orbital speed when inner ring rotation condition is assumed/ outer ring rotating speed)

V：*dmn value* (Definition refer to 9.2)

dm：*pitch diameter* $\approx \dfrac{d+D}{2}$

D：*outside diameter mm*

T：*bearing temperature* ℃

F：*load ratio P/Cr*

$K1$：*compensation factor for base oil type (Table 6.4, 6.5)*

Table 6.4 K1 value for urea based grease

Base oil type	compensation factor K1
mineral	-0.08
PAO	-0.05
ester	-0.21
ether	0.18
mineral +PAO	-0.06
mineral + ester	-0.16
PAO+ ester	0
PAO+ ether	0
ester + ether	0.07

Table 6.5 K1 value for Lithium based grease

Base oil type	compensation factor K1
mineral	-0.29
PAO	-0.05
ester	0.42
diester	-0.5
silicon	0.54

6.2 Air-oil lubrication

Air-oil lubrication employs a method by which compressed air is used to provide lubricating oil in precisely controlled amounts. Generally, an air-oil lubrication unit a volumetric piston-type distributor that accurately meters the required minimum amount of lubricating oil and provides it at optimal intervals controlled by a timer. The recommended oil viscosity is 10 to 32 mm2/s.

A nozzle with a hole diameter of 1.0 to 1.5 mm and a length 4 to 6 times the hole diameter is recommended. Air-oil lubrication requires a specialized nozzle because it supplies the lubricating oil to the inside of the bearing by means of compressed air. Fig. 6.2 illustrates the feed system for air-oil lubrication when lubricant is supplied between the cage and inner ring. Table 6.6 shows the Air-oil/oil mist nozzle spacer dimension.

Fig. 6.2 Feed system for air-oil lubrication

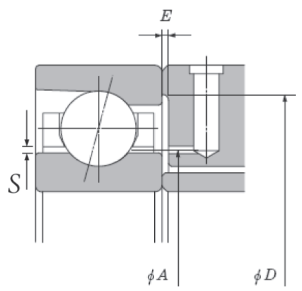


Table 6.6 Air-oil/oil mist nozzle spacer dimensions

Unit：mm

Bearing No.	S	ϕA
HSE000CE1	0.80	19.15
HSE001CE1	1.15	22.20
HSE002CE1	1.10	25.65
HSE003CE1	1.00	28.00
HSE004CE1	1.20	33.10
HSE005CE1	1.20	38.10
HSE006CE1	1.20	42.30
HSE007C E1	1.38	48.33
HSE008C E1	1.33	53.68
HSE009CE1	1.33	59.68
HSE010CE1	1.58	64.93
HSE011CE1	1.58	72.43
HSE012CE1	1.58	77.43
HSE013CE1	1.68	82.33
HSE014CE1	1.68	89.33
HSE015CE1	1.88	94.93
HSE016CE1	2.28	102.63
HSE017CE1	2.28	107.63
HSE018CE1	2.28	115.13
HSE019CE1	2.47	119.82
HSE020CE1	2.47	124.82

Air-oil lubrication uses a large volume of air to feed lubricating oil to the bearing. Therefore, it is essential that the air fed into the bearing be allowed to escape. If the air is not smoothly exhausted, the lubricating oil will remain in the bearing and possibly contribute to bearing seizure. In the design stage, remember to allow ample space on the exhaust side of the bearing in order to increase exhaust efficiency and provide a larger oil drain hole to ensure smooth airflow. In addition, for types that allow for repositioning of the spindle, it is recommended that the shoulder dimensions of all parts is designed to prevent lubricating oil from flowing back into the bearing after a change in the attitude of the main spindle. Unnecessary dimensional differences can also contribute to stagnancy of the lubricating oil.

6.3 Jet lubrication

With this lubricating system, a high-speed jet of lubricant is injected into the bearing from the side. This is the most reliable lubricating technique and is typically used on the main spindle bearings of jet engines and gas turbines.

When used as a lubricating system for the main spindle of a machine tool, it can minimize the temperature increase of the bearing. However, the resultant torque loss is great, as a large amount of oil which is low viscosity oil (2-3 mm2/s) is supplied to each bearing. Therefore, this arrangement requires a powerful motor to drive the main spindle.

7 Bearing Limiting Speed

7.1 Bearing Limiting Speed

Angular contact ball bearings feature the highest rotational speed capabilities of all precision bearings. The limiting speeds listed in the precision bearing tables are guideline values. They are based on a single bearing that is lightly spring preloaded and subject to both grease and oil air lubrication. In situations where the lubricant is used as a mean to remove heat, higher speed can be achieved. Limiting temperature for grease lubricated bearings is lower than that for oil because of greater lubricant deterioration. Therefore, limiting speed for grease lubrication is consequently about 65% of the value achievable with oil.

Achievement of maximum speed is affected by internal configuration and correct assembly of the bearings. For bearing internal configuration, bearing arrangement, preload, bearing precision, contact angle and way of lubrication may influence bearing speed. Also, tolerance limits of shaft, housing, and spindle components, proper dynamic balancing of rotating parts, and efficient lubrication are external.

Accordingly, the limiting speed calculation can be performed based on the above consideration and the speed n_{max} is calculated as follows:

$$n_{max} = f_1 \cdot f_2 \cdot f_3 \cdot n_L \ min^{-1}$$

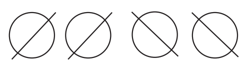
where， f_1 : Speed factor for bearing arrangement v.s. preload, refer to Fig. 7.1

f_2 : Speed factor for bearing precision, refer to Table 7.1

f_3 : Speed factor for contact angle, refer to Table 7.2

n_L : The limiting speed for grease and oil lubrications, refer to Precision Bearing Tables

Fig. 7.1 Speed factor for bearing with various arrangement and preload f_1

Bearing arrangement		L	N	M	H
	DB	0.85	0.80	0.65	0.55
	DBT	0.75	0.70	0.55	0.40
	DTBT	0.80	0.75	0.60	0.45