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

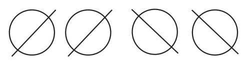
Bearing arrangement		L	N	M	H
	DB	0.85	0.80	0.65	0.55
	DBT	0.75	0.70	0.55	0.40
	DTBT	0.80	0.75	0.60	0.45

Table 7.1 Speed factor for bearing precision f_2

	Factor for precision		
Precision	P2	P4	P5
f_2	1.1	1.0	0.9

Table 7.2 Speed factor for contact angle f_3

	Factor for contact angle		
Contact angle	15°	18°	25°
f_3	1.00	0.97	0.90

When a ceramic ball is used, limiting speed value will be 1.25 times the value of steel ball. If the ball guided polyamide resin cage is used, the limiting speed is limited to 1.4 million dmN value.

The limiting speed for ball screw support BS thrust bearings are different from that for angular contact ball bearings. It accounts for the discrepancy for contact angle and preload between two types of bearings. The speed factor of limiting speed n_{max} for BS bearings are listed in Table 7.3.

Table 7.3 Speed factors for BS bearings f_1, f_2, f_3

Arrangement	DF DB	DFT DBT	DTFT DTBT
f_1	0.58	0.41	0.49
Precision	P4		P5
f_2	1.0		0.9
Contact angle	60°		
f_3	1.00		

Same as BS bearings, high speed thrust HTA bearings have their own limiting speed calculation. The speed factor of limiting speed n_{max} for HTA B DB combined bearings are listed in Table 7.4.

Table 7.4 Speed factors for HTA B DB combined bearings f_1, f_2, f_3

Preload	M	H
f_1	1.00	0.85
Precision	P4	P5
f_2	1.0	0.9
Contact angle	40°	
f_3	1.00	

7.2 Friction

One of the main functions required of a bearing is that it must have low friction. Under normal operating conditions rolling bearings have a much smaller friction coefficient than the slide bearings, especially starting friction.

The friction coefficient for rolling bearings is calculated on the basis of the bearing bore diameters and is expressed by formula

$$M = \mu P \frac{d}{2}$$

where,

M : Friction moment, N · mm or kgf · mm

μ : Friction coefficient, N · mm

P : Load, N or kgf

d : Bearing bore diameter, mm

Although the dynamic friction coefficient for rolling bearings varies with the type of bearings, load, lubrication, speed, and other factors; for normal operating conditions, the approximate friction coefficients for various bearing types are listed in Table 7.5

Table 7.5 Friction coefficient for bearings

Bearing type	Coefficient μx10^{-3}
Deep groove ball bearings	1.0 ~ 1.5
Angular contact ball bearings	1.2 ~ 1.8
Self-aligning ball bearings	0.8 ~ 1.2
Cylindrical roller bearings	1.0 ~ 1.5
Needle roller bearings	2.0 ~ 3.0
Tapered roller bearings	1.7 ~ 2.5
Spherical roller bearings	2.0 ~ 2.5
Thrust ball bearings	1.0 ~ 1.5
Thrust roller bearings	2.0 ~ 3.0