outer ring. 2)The contact surface pressure on the raceway surface reaches 4200Mpa or 428kgf/mm2 in either the inner or outer ring raceway. The allowable axial load for each bearing is found in the precision bearing tables.

4.5 Bearing life for high speed application

For high speed applications, the effects of ball centrifugal forces and gyroscopic moments needs to be included. The force and moment equilibrium equations for the bearing inner ring are solved for the bearing axial, radial, and angular deflections. If the bearing has a complement of Z balls, then a system of 4Z+5 equations is solved numerically using the Newton-Raphson method.

For the analysis including the determination of ball friction forces and speeds, in addition to the 5 force and moment load equilibrium equations for the inner ring, the torques acting on the cage in the plane of bearing rotation is balanced, and cage speed is determined. In this case a system of 9Z+6 equations are solved numerically. TPI's HSE high speed type angular contact ball bearings are optimally designed with their internal configuration to accommodate both low frictional 24 heat or ball skidding effect and high rigidity by using TH-BBAN.

4.6 Life for hybrid bearings

When calculating the rating life for hybridbearings, the same life values can be used as for all-steel bearings. The ceramic balls in hybrid bearings are much harder and stiffer than the all-steel bearings. Although this increased level of hardness and stiffness creates a higher degree of contact stress between the ceramic ball and the steel raceway, extensive experience and testing shows that in typical machine tool applications, the service life of a hybrid bearing is significantly longer life than that of an all-steel bearing. The reasons for this are: 1) low density minimizes centrifugal and inertial forces; 2) low surface adhesive wear is reduced by the lower affinity to steel; and 3) better surface finish enables the bearing to maximize the effects of the lubricant.

References：

R. Barnsby, T. Harris, E. Ioannides, W. Littmann, T. Loesche, Y. Murakami, W. Needelman, H. Nixon, and M. Webster, "Life Ratings for Modern Rolling Bearings", ASME Paper 98-TRIB-57 (October 26, 1998).

T. A. Harris and M. H. Kotzalas, "Rolling Bearing Analysis: Advanced Concepts of Bearing technology", pp.209~258, 5th Ed., CRC Press, (2007).

5 Bearing Preload and Rigidity

5.1 Stiffness of spindle

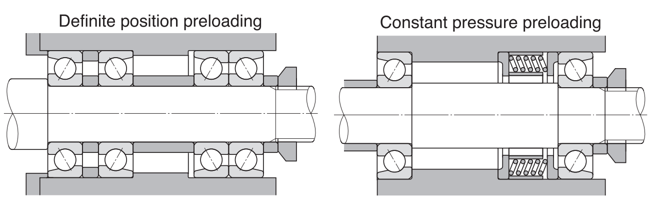
System rigidity in machine tool applications is extremely important because the magnitude of deflection under load determines machining accuracy. Bearing stiffness is only one factor that influences system stiffness, others include shaft diameter, tool overhang, housing stiffness number, position and type of bearings. For axial stiffness of spindles, bearing stiffness plays an important role of it. Giving preload to a bearing results in the rolling element and raceway surfaces being under constant elastic compressive forces at their contact points. This has the effect of making the bearing extremely rigid so that even when load is applied to the bearing, radial or axial shaft displacement does not occur.

If high radial rigidity of bearing is needed, cylindrical roller bearings are normally used. In contrast to angular contact ball bearing, they provide more surface contact and gross sliding and are not suitable for very high speed applications. For axial loading applications, angular contact ball bearings are normally used. Their larger contact angle type provide higher axial rigidity. The stiffness of this type also depends on number and size of balls. Recently, the ceramic material silicon nitride Si_3N_4 is used for precision ball bearings. The radial rigidity of this hybrid bearings is approximately 15% higher because of the higher Young' s modulus. As mentioned in 4.5, TPI' s HSE type angular contact ball bearings are optimally designed with their internal configuration to accommodate both low ball skidding effect and high rigidity by using TH-BBAN.

5.2 Bearing preload

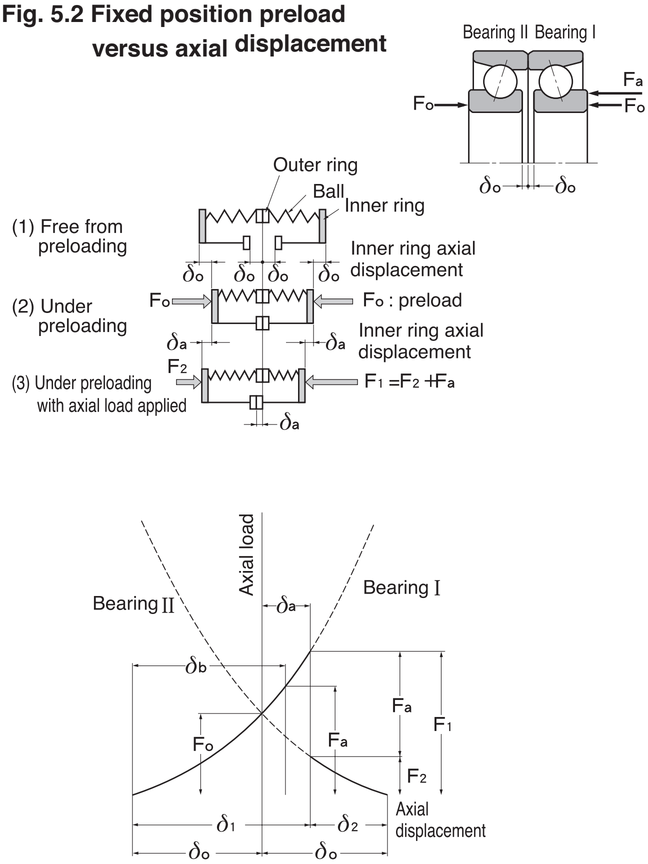
The preload method is divided into fixed position preload and constant pressure preload as shown in Fig. 5.1. The fixed position preload is effective for positioning the two bearings and also for increasing the rigidity. Due to the use of a spring for the constant pressure preload, the preloading amount can be kept constant, even when the distance between the two bearings fluctuates under the influence of operating heat and load.

Fig. 5.1 Preloading methods for bearings



The increased rigidity effect preloading has on bearings is shown in Fig. 5.2. When the offset inner rings of the two paired angular contact ball bearings are pressed together, each inner ring is displaced axially by the amount δ_o and is thus given a preload, F_0, in the direction. Under this condition, when external axial load F_a is applied, bearing I will have an increased displacement by the amount δ_a and bearing II's displacement will decrease. At this time the loads applied to bearing I and II are F_I and F_{II}, respectively. Under the condition of no preload, bearing I will be displaced by the amount δ_b when axial load F_a is applied. Since the amount of displacement, δ_a, is less than δ_b, it indicates a higher rigidity for δ_a.. When external axial load F_a keeps increasing until δ_b equals to δ_0, that is, F_{II}=0 or F_I=2.83 F_0. Now, bearing II becomes released from preload while bearing I is loaded with 2.83 times of given preload F_0. This amount of load is called the limiting axial load and it may depend on bearing arrangement and contact angle.

Fig. 5.2 Fixed position preload versus axial displacement



5.2.1 Bearing standard preload

Universal combination bearings and matched bearing sets are produced in four different standard preload to meet the varying requirements including rotational speed, rigidity and heat generation. It is also needed to be aware that the proper preload during high speed operation is important. Fig. 5.3 shows the factors may lead to preload change after installation and during operation. Among those factors, TPI may provide face side offset increase due to interference fit between inner and shaft. Please contact TPI for further information. There are four standard preloads :L(Light preload), N(Normal preload), M(Medium preload), and H(Heavy preload). These preload from light to heavy have certain ratio of dynamic basic load rating C_r. Table 5.1 is the preload comparison table of TPI bearings with other brand bearings for 7014C angular contact ball bearings. It is noted that preload setting methods may be different for other brand bearings. Table 5.9 shows standard preload, rigidity ,and measured face side offset in DB and DF arrangement of various series of angular contact ball bearings. To stabilize the measurement of face side offset, measuring load is usually axially applied and listed in Table 5.2. As shown in Fig. 5.2, the true face side offset is -2 δ_0 , while the measured face side offset in DB and DF arrangement as shown in Table 5.9 is compensated with measuring load. The positive and negative signs are defined in Appendix IV.

Table 5.10 shows standard preload and rigidity in DB and DF arrangement of HTA and BS series of angular contact ball bearings.

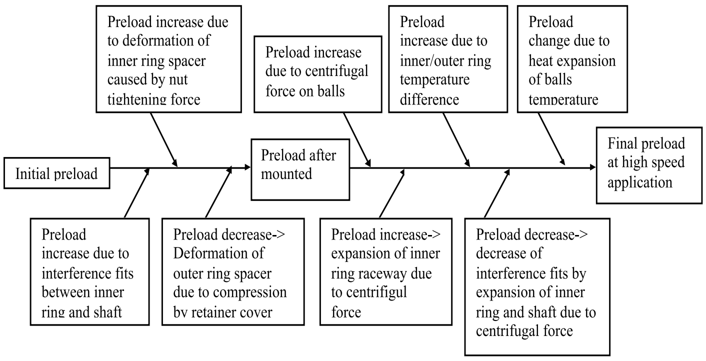


Fig. 5.3 Preload setting study flow

Table 5.1 preload comparison table of TPI bearings with other brand bearings for 7014C

Brand / Preload	TPI	NTN	NSK	FAG	SKF	Remark
Light	L(0.3)	L(0.2)	EL(0.3)	—	A(0.3)	
Mormal	N(0.6)	N(0.6)	L(0.6)	L(0.6)	B(0.8)	7014C for instance, 0.3 in ( ) means 0.3% C_r
Medium	M(1.6)	M(1.2)	M(1.6)	M(1.8)	C(1.5)	
Heavey	H(3.1)	—	H(3.1)	H(3.8)	—	

Table 5.2 Measuring load of face side offset

Nominal Outside Diameter (mm) D		Measuring load (N)
Over	Incl.	
10(incl.)	50	24.5
50	120	49
120	200	98

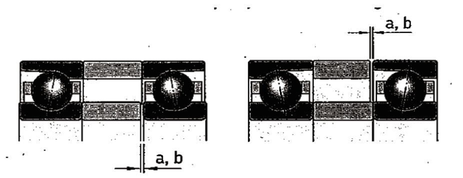
5.2.2 Individual adjustment of preload

In case where universal combination bearings or matched bearing sets are used, preload is determined at the factory during production. In some cases, however, it may be necessary to optimize the preload to accommodate operating conditions. It is possible to increase or decrease preload by using spacer rings between the bearings. For instance, in DB arrangement, reduce width of outer spacer rings should decrease preload while reduce width of inner rings should increase preload. In DF arrangement, reduce width of outer spacer rings should increase preload while reduce width of inner rings should decrease preload as shown in Fig. 5.4. By grinding the side face of the inner or outer spacer the preload in the bearing set can be changed. In these cases, the bearings should not be modified, as this requires special tools, and the bearings could be damaged. Table 5.3 provides information about which of the equal-width spacer ring side faces must be ground and what effect it will have. Table 5.9 contains the necessary dimensional deviation for the overall width of the spacer rings from deviation of measured face side offsets between two different standard preloads(positive value).

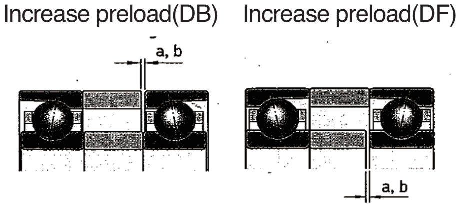
Table 5.3 Necessary spacer ring width reduction

Preload change	Width reduction (positive value)	Effect
N(Normal preload)-> L(Light preload)	I(L preload)-(N preload)I	Decrease preload
N(Normal preload)-> M(Medium preload)	I(M preload)-(N preload)I	Increase preload
N(Normal preload)-> H(Heavy preload)	I(H preload)-(N preload)I	Increase preload

Fig. 5.4 Increase or decrease preload by adjusting spacer ring width



Increase preload(DB) Increase preload(DF)



Decrease preload(DB) Decrease preload(DF)

In the case of DT arrangement, it is necessary to remember that axial deflection δ a of the combination bearings under preload is less that of in DB and DF arrangement. Therefore, this difference has to be considered to the value of width reduction of spacer for altering preload as shown in Table 5.4.

Table 5.4 Axial deflection for No. of row in DT arrangement

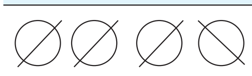
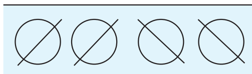
No. of row in DT	1	2	3	4
Axial deflection	δ_a	0.63 δ_a	0.48 δ_a	0.40 δ_a

However, it is not necessary to determine axial deflection although it can be calculated once bearing arrangement and contact angle(including mixed contact angle) are designated for applications. As long as the bearing preload provides sufficient system stiffness, the resulting preload can be determined by a factor for its bearing arrangement as shown in Table 5.5. The value of resulting preload P_r is

$$P_r = P_1 \cdot P_{ro} \quad \text{N}$$

where P_{ro} can be obtained in Table 5.9

Table 5.5 Preload Factor P_1 for different bearing arrangements

Arrangement		Factor P_1
	DB	1.00
	DBT	1.35
	DTTB	1.60
	DTBT	2.00

5.3 Rigidity of angular contact ball bearing

$$\delta_r = 5.848 \times 10^{-3} \cdot F_r^{2/3} \cdot (iZ)^{-2/3} \cdot D_w^{-1/3} \cdot \cos\alpha^{-5/3}$$

$$\delta_a = 2 \times 10^{-3} \cdot F_a^{2/3} \cdot (iZ)^{-2/3} \cdot D_w^{-1/3} \cdot \sin\alpha^{-5/3}$$

Elastic deformation in rolling bearings results in the rings being displaced relative to each other. For angular contact ball bearings, the following formula is used to calculate this relative displacement in a radial and axial direction:

where， δ_r :radial displacement under pure radial load, mm

δ_a :axial displacement under pure axial load, mm
F_r : pure radial load, kgf
F_a : pure axial load, kgf
i : No. of row
Z : No. of balls per row
D_w : ball pitch diameter, mm
α : contact angle, degrees

In Table 5.9, the (axial) rigidity is defined as the external axial load of a bearing set in DB or DF arrangement, which causes a deflection of 1 micron of the bearing rings to each other. Before reaching to limiting axial load, bearing rigidity can is consistently measured and the result is close to the calculated value under light and normal preload. However, for bearings under medium and heavy preload, the calculated value becomes doubtable because change of initial and final contact angles. The above formula for radial and axial displacements is not valid under heavy load and need more rigorous analytical computer program such as TH-BBAN program to solve it.

Radial rigidity varies with contact angle and preload. In contrast to the axial rigidity, radial rigidity decreases as contact angle increases and changes markedly as a function of the ratio between axial and external loads applied to the bearing. In practical manner, the radial and axial rigidity are determined as follows. Rigidity factors with various arrangements, contact angle, and preload in the formula can be obtained in Table 5.6 and 5.7.

$$R_r = q_1 \cdot q_2 \cdot R_a \qquad \text{N/}\mu\text{m}$$
$$R_a = q_1 \cdot R_{ao}$$

where, q_1 : rigidity factor for bearing arrangement, please refer to Table 5.6
q_2 : rigidity factor for contact angle and preload, please refer to Table 5.7

Table 5.6 Rigidity factor for bearings with various arrangements q_1

Arrangement	Radial factor q_1	Axial factor q_1
DB	1.00	1.00
DBT	1.54	1.48
DTBT	2.00	2.00

Table 5.7 Rigidity factor for bearings with various arrangement and preload q_2

Contact angle \ Preload	L	N	M	H
15°	6.5	6.0	5.0	4.5
18°	4.5			—
25°	2.0			
30°	1.4			

5.4 Limiting Axial Load

Limiting axial load is the external axial load of a preloaded bearing pair or set that causes loss of contact between the balls and race in preload bearings. This effect may lead to balls skidding against the raceways and surface damage.

In some machine tools applications, where the working axial load is predominantly in one direction, limiting axial load can be increased by using a bearing set with a mixed contact angle. The axially more rigid bearing withstands the work load and the less rigid one is the reaction element. Table 5.8 is a example to address the above concept. Compared to the bearing set with same contact angle, the bearing set with a mixed contact angle of 15 and 25 degrees withstands higher 5.9 times of axial preload load (compared to 2.83 times of preload). Furthermore, it could be consider that increasing their contact angle by 3~5 degree, bearings withstand their axial load may have 16 ~32% more limiting axial load and axial stiffness as well.

Table 5.8 Limiting axial load of bearings with an equal/a mix contact angle and various arrangements

Unit : P_{ro}(N)

Arrangement (α contact angle; 1:bearing withstands axial load; 2:bearing paired to bearing 1)	Limiting axial load $\alpha_1 = \alpha_2$: P_{d1}	$\alpha_1 = \alpha_2$: P_{d2}	α_1=25°, α_2=15°: P_{d1}	α_1=25°, α_2=15°: P_{d2}
DB	2.83	2.83	5.90	1.75
DBT	4.16	2.08	9.85	1.45
DTBB	5.40	1.80	13.66	1.33
DTBT	2.83	2.83	5.90	1.75

Table 5-9(1) Preload and Rigidity (DB and DF Arrangement) of 70C standard series

Bearing Number	Bore d (mm)	Bearing Preload、Rigidity、and Measured Face Side Offset											
		L			N			M			H		
		Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)	Measured Offset (μm)	Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)	Measured Offset (μm)	Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)	Measured Offset (μm)	Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)	Measured Offset (μm)
7000C	10	15	14	(2)	30	19	(-2)	85	30	(-10)	165	43	(-19)
7001C	12	15	14	(2)	35	19	(-2)	85	31	(-10)	170	43	(-19)
7002C	15	20	17	(1)	40	23	(-3)	100	37	(-11)	195	51	(-19)
7003C	17	20	19	(1)	40	25	(-3)	105	39	(-11)	205	55	(-19)
7004C	20	35	24	(-2)	65	32	(-6)	180	51	(-17)	345	71	(-28)
7005C	25	35	26	(-2)	70	35	(-6)	185	54	(-17)	360	76	(-28)
7006C	30	45	31	(0)	90	41	(-5)	240	64	(-16)	470	90	(-28)
7007C	35	55	36	(-1)	115	48	(-6)	305	75	(-19)	595	104	(-32)
7008C	40	60	40	(-1)	125	53	(-7)	330	83	(-19)	640	115	(-31)
7009C	45	75	44	(-2)	145	58	(-8)	390	90	(-21)	755	125	(-35)
7010C	50	80	48	(-3)	155	63	(-8)	415	99	(-21)	805	137	(-34)
7011C	55	100	53	(-5)	205	71	(-11)	545	110	(-26)	1060	152	(-42)
7012C	60	105	56	(-5)	210	74	(-11)	560	115	(-26)	1085	159	(-41)
7013C	65	110	61	(-5)	225	80	(-11)	595	124	(-26)	1150	172	(-41)
7014C	70	140	67	(-7)	280	88	(-14)	750	136	(-30)	1455	188	(-48)
7015C	75	145	69	(-7)	290	92	(-14)	770	141	(-30)	1490	195	(-47)
7016C	80	175	75	(-5)	350	99	(-13)	940	153	(-32)	1820	211	(-51)
7017C	85	180	78	(-5)	360	103	(-13)	965	158	(-31)	1865	218	(-50)
7018C	90	215	83	(-7)	430	109	(-16)	1145	169	(-36)	2220	233	(-58)
7019C	95	220	86	(-7)	440	114	(-15)	1175	175	(-36)	2280	241	(-57)
7020C	100	225	90	(-6)	450	118	(-15)	1205	182	(-35)	2335	250	(-56)

(70 series C angle:15° nominal contact angle, steel ball)

Table 5-9(2) Preload and Rigidity (DB and DF Arrangement) of 70AD standard series

Bearing Number	Bore d (mm)	Bearing Preload、Rigidity、and Measured Face Side Offset											
		L			N			M			H		
		Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)	Measured Offset (μm)	Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)	Measured Offset (μm)	Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)	Measured Offset (μm)	Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)	Measured Offset (μm)
7000AD	10	25	34	(0)	45	43	(-2)	140	67	(-9)	270	89	(-16)
7001AD	12	25	34	(0)	45	44	(-2)	140	67	(-9)	275	89	(-16)
7002AD	15	25	40	(0)	55	52	(-3)	160	80	(-9)	315	106	(-16)
7003AD	17	30	44	(0)	55	56	(-3)	170	86	(-9)	335	114	(-16)
7004AD	20	50	57	(-2)	95	73	(-5)	285	112	(-13)	565	149	(-21)
7005AD	25	50	61	(-2)	100	78	(-5)	300	120	(-13)	590	159	(-21)
7006AD	30	65	72	(-1)	130	93	(-4)	390	142	(-13)	765	188	(-22)
7007AD	35	80	85	(-2)	165	109	(-5)	490	166	(-15)	965	220	(-24)
7008AD	40	90	94	(-2)	175	121	(-5)	525	184	(-14)	1035	243	(-24)
7009AD	45	105	103	(-2)	210	132	(-6)	625	201	(-16)	1225	265	(-26)
7010AD	50	110	113	(-2)	220	145	(-6)	665	221	(-16)	1305	290	(-26)
7011AD	55	145	126	(-4)	290	162	(-8)	875	246	(-19)	1715	324	(-31)
7012AD	60	150	131	(-4)	300	169	(-7)	895	257	(-19)	1760	338	(-30)
7013AD	65	160	143	(-4)	315	184	(-7)	945	279	(-18)	1860	366	(-30)
7014AD	70	200	157	(-5)	400	202	(-9)	1200	306	(-22)	2355	402	(-35)
7015AD	75	205	163	(-5)	410	210	(-9)	1225	318	(-21)	2405	418	(-34)
7016AD	80	250	176	(-4)	500	227	(-9)	1500	343	(-23)	2945	451	(-37)
7017AD	85	255	184	(-4)	510	236	(-9)	1535	357	(-22)	3015	469	(-37)
7018AD	90	305	195	(-5)	610	251	(-10)	1830	380	(-26)	3595	499	(-42)
7019AD	95	315	203	(-5)	625	261	(-10)	1875	396	(-25)	3685	519	(-41)
7020AD	100	320	211	(-5)	640	272	(-10)	1920	411	(-25)	3775	538	(-41)

(70 series AD angle:25° nominal contact angle, steel ball)

Table 5-9(3) Preload and Rigidity (DB and DF Arrangement) of 5S-70C standard series

Bearing Number	Bore d (mm)	Bearing Preload、Rigidity、and Measured Face Side Offset											
		L			N			M			H		
		Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)	Measured Offset (μm)	Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)	Measured Offset (μm)	Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)	Measured Offset (μm)	Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)	Measured Offset (μm)
5S1-7000C	10	20	17	(1)	40	23	(-3)	100	36	(-11)	195	51	(-20)
5S1-7001C	12	20	17	(1)	40	23	(-3)	105	37	(-11)	200	52	(-20)
5S1-7002C	15	25	21	(0)	45	28	(-3)	120	44	(-12)	230	61	(-20)
5S1-7003C	17	25	22	(0)	50	30	(-4)	125	47	(-12)	245	66	(-20)
5S1-7004C	20	40	29	(-2)	80	39	(-7)	210	61	(-18)	410	85	(-29)
5S1-7005C	25	45	31	(-3)	85	41	(-7)	220	65	(-18)	430	90	(-28)
5S1-7006C	30	55	37	(-1)	110	49	(-6)	285	76	(-17)	555	107	(-29)
5S1-7007C	35	70	43	(-2)	135	57	(-7)	360	89	(-20)	705	124	(-33)
5S1-7008C	40	75	48	(-2)	145	63	(-8)	390	98	(-20)	755	137	(-32)
5S1-7009C	45	90	52	(-3)	175	69	(-9)	460	107	(-22)	895	149	(-36)
5S1-7010C	50	95	57	(-4)	185	76	(-9)	490	117	(-22)	955	162	(-35)
5S1-7011C	55	125	63	(-5)	245	84	(-12)	645	131	(-27)	1255	181	(-43)
5S1-7012C	60	125	66	(-5)	250	88	(-12)	665	136	(-27)	1290	188	(-42)
5S1-7013C	65	135	72	(-5)	265	96	(-12)	705	147	(-26)	1370	204	(-41)
5S1-7014C	70	170	79	(-7)	335	105	(-15)	890	162	(-31)	1730	224	(-49)
5S1-7015C	75	175	82	(-7)	345	109	(-15)	915	168	(-31)	1775	232	(-48)
5S1-7016C	80	215	89	(-6)	420	118	(-14)	1120	181	(-33)	2170	250	(-52)
5S1-7017C	85	220	92	(-6)	430	123	(-14)	1145	188	(-32)	2225	260	(-51)
5S1-7018C	90	260	98	(-7)	515	131	(-17)	1365	200	(-37)	2645	276	(-58)
5S1-7019C	95	270	102	(-7)	530	136	(-17)	1405	208	(-37)	2715	287	(-58)
5S1-7020C	100	275	106	(-7)	540	140	(-16)	1435	216	(-36)	2780	297	(-57)

(5S-70 series C angle:15° nominal contact angle, ceramic ball)

Table 5-9(4) Preload and Rigidity (DB and DF Arrangement) of HSECE1 standard series

Bearing Number	Bore d (mm)	Bearing Preload、Rigidity、and Measured Face Side Offset											
		L			N			M			H		
		Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)	Measured Offset (μm)	Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)	Measured Offset (μm)	Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)	Measured Offset (μm)	Preload P_{ro} (N)	Rigidity R_{ao} (N/μm)	Measured Offset (μm)
HSE000CE1	10	5	12	(5)	10	15	(3)	30	22	(-1)	60	29	(-5)
HSE001CE1	12	5	12	(5)	10	15	(3)	30	22	(-1)	55	29	(-5)
HSE002CE1	15	10	15	(4)	15	19	(2)	40	28	(-3)	80	36	(-7)
HSE003CE1	17	10	16	(3)	15	20	(2)	40	29	(-3)	80	38	(-7)
HSE004CE1	20	15	21	(2)	25	27	(0)	70	39	(-5)	130	51	(-11)
HSE005CE1	25	15	22	(2)	25	28	(0)	70	41	(-5)	135	53	(-11)
HSE006CE1	30	30	30	(3)	55	38	(-1)	150	55	(-8)	290	72	(-17)
HSE007CE1	35	35	33	(2)	70	43	(-2)	185	61	(-11)	355	80	(-20)
HSE008CE1	40	35	37	(1)	75	47	(-2)	195	67	(-11)	380	88	(-20)
HSE009CE1	45	40	40	(1)	75	52	(-3)	205	73	(-10)	400	95	(-20)
HSE010CE1	50	45	44	(0)	95	57	(-4)	250	81	(-12)	485	105	(-23)
HSE011CE1	55	50	49	(0)	100	62	(-3)	270	90	(-12)	520	117	(-22)
HSE012CE1	60	50	51	(0)	105	64	(-3)	275	93	(-12)	530	121	(-22)
HSE013CE1	65	60	56	(-1)	120	70	(-5)	325	102	(-14)	630	132	(-24)
HSE014CE1	70	70	60	(-1)	145	76	(-5)	380	110	(-15)	740	143	(-27)
HSE015CE1	75	80	68	(-2)	155	86	(-6)	420	125	(-16)	810	163	(-27)
HSE016CE1	80	105	74	(0)	205	96	(-5)	545	140	(-16)	1060	182	(-29)
HSE017CE1	85	105	76	(0)	210	99	(-5)	555	144	(-16)	1080	188	(-29)
HSE018CE1	90	110	81	(0)	215	105	(-5)	575	153	(-16)	1120	199	(-28)
HSE019CE1	95	135	87	(-1)	265	112	(-7)	710	163	(-20)	1375	213	(-34)
HSE020CE1	100	135	89	(-1)	270	116	(-7)	725	168	(-19)	1400	219	(-33)

(HSE series CE1 angle:18° nominal contact angle, steel ball)

Table 5-9(5) Preload and Rigidity (DB and DF Arrangement) of 5S-HSECE1 standard series

Bearing Number	Bore d (mm)	L Preload P_{ro} (N)	L Rigidity R_{ao} (N/μm)	L Measured Offset (μm)	N Preload P_{ro} (N)	N Rigidity R_{ao} (N/μm)	N Measured Offset (μm)	M Preload P_{ro} (N)	M Rigidity R_{ao} (N/μm)	M Measured Offset (μm)	H Preload P_{ro} (N)	H Rigidity R_{ao} (N/μm)	H Measured Offset (μm)
5S1-HSE000CE1	10	5	14	(4)	15	18	(2)	35	26	(-2)	70	34	(-6)
5S1-HSE001CE1	12	5	14	(4)	15	18	(2)	35	26	(-2)	70	34	(-6)
5S1-HSE002CE1	15	10	18	(3)	20	23	(1)	50	33	(-3)	95	43	(-8)
5S1-HSE003CE1	17	10	18	(3)	20	24	(1)	50	34	(-3)	95	45	(-8)
5S1-HSE004CE1	20	15	25	(1)	30	32	(-1)	80	47	(-6)	155	61	(-11)
5S1-HSE005CE1	25	15	26	(1)	30	34	(-1)	80	48	(-6)	160	63	(-11)
5S1-HSE006CE1	30	35	36	(2)	70	46	(-2)	175	65	(-9)	345	86	(-18)
5S1-HSE007CE1	35	40	40	(1)	85	51	(-3)	215	73	(-11)	425	96	(-21)
5S1-HSE008CE1	40	45	44	(0)	90	56	(-3)	230	80	(-11)	455	105	(-21)
5S1-HSE009CE1	45	45	48	(0)	95	62	(-3)	245	87	(-11)	490	115	(-21)
5S1-HSE010CE1	50	55	52	(-1)	115	67	(-4)	300	96	(-13)	580	125	(-24)
5S1-HSE011CE1	55	60	58	(-1)	115	73	(-4)	320	107	(-13)	630	140	(-23)
5S1-HSE012CE1	60	60	60	(-1)	120	75	(-4)	325	111	(-13)	630	143	(-22)
5S1-HSE013CE1	65	75	67	(-1)	145	84	(-5)	385	121	(-14)	745	156	(-25)
5S1-HSE014CE1	70	90	73	(-2)	170	91	(-6)	455	131	(-16)	880	170	(-27)
5S1-HSE015CE1	75	100	82	(-3)	190	102	(-6)	495	148	(-16)	970	195	(-28)
5S1-HSE016CE1	80	120	88	(-1)	245	114	(-6)	650	166	(-17)	1260	217	(-30)
5S1-HSE017CE1	85	125	91	(-1)	250	118	(-6)	660	171	(-17)	1280	223	(-30)
5S1-HSE018CE1	90	125	96	(-1)	260	125	(-6)	685	181	(-17)	1330	237	(-29)
5S1-HSE019CE1	95	160	103	(-2)	315	133	(-7)	840	193	(-20)	1635	253	(-34)
5S1-HSE020CE1	100	160	106	(-2)	325	137	(-7)	860	200	(-20)	1665	260	(-34)

Column group heading: Bearing Preload、Rigidity、and Measured Face Side Offset

(HSE series CE1 angle:18° nominal contact angle, ceramic ball)

Table 5-9(6) Preload and Rigidity (DB and DF Arrangement) of 72C standard series

Bearing Number	Bore d (mm)	L Preload P_{ro} (N)	L Rigidity R_{ao} (N/μm)	L Measured Offset (μm)	N Preload P_{ro} (N)	N Rigidity R_{ao} (N/μm)	N Measured Offset (μm)	M Preload P_{ro} (N)	M Rigidity R_{ao} (N/μm)	M Measured Offset (μm)	H Preload P_{ro} (N)	H Rigidity R_{ao} (N/μm)	H Measured Offset (μm)
7200C	10	15	14	(2)	30	19	(-2)	85	31	(-10)	170	43	(-19)
7201C	12	20	17	(1)	40	22	(-4)	115	35	(-14)	220	49	(-24)
7202C	15	25	19	(-1)	55	25	(-5)	145	40	(-17)	280	56	(-28)
7203C	17	35	21	(-2)	65	28	(-7)	180	44	(-20)	345	62	(-32)
7204C	20	45	25	(-3)	85	34	(-9)	235	53	(-23)	450	75	(-36)
7205C	25	50	30	(0)	100	40	(-6)	265	62	(-19)	515	87	(-32)
7206C	30	70	35	(-2)	140	47	(-9)	370	74	(-24)	715	103	(-40)
7207C	35	90	40	(-5)	180	54	(-12)	485	85	(-30)	940	118	(-48)
7208C	40	110	46	(-6)	220	62	(-14)	580	96	(-33)	1125	134	(-51)
7209C	45	120	49	(-7)	245	66	(-16)	655	102	(-35)	1265	142	(-55)
7210C	50	130	52	(-7)	255	70	(-16)	685	109	(-35)	1325	151	(-55)
7211C	55	160	58	(-9)	320	78	(-18)	845	121	(-40)	1640	167	(-62)
7212C	60	190	64	(-11)	385	86	(-21)	1025	132	(-45)	1985	184	(-69)
7213C	65	210	67	(-12)	420	90	(-23)	1115	138	(-47)	2165	192	(-72)
7214C	70	230	70	(-8)	455	93	(-20)	1215	144	(-45)	2355	200	(-72)
7215C	75	240	74	(-9)	475	99	(-20)	1270	153	(-45)	2460	212	(-71)
7216C	80	280	80	(-10)	555	107	(-22)	1485	165	(-49)	2875	229	(-78)
7217C	85	310	88	(-11)	625	118	(-24)	1665	181	(-51)	3230	251	(-80)
7218C	90	370	92	(-14)	735	124	(-28)	1960	190	(-59)	3800	263	(-91)
7219C	95	415	98	(-16)	835	132	(-31)	2220	203	(-64)	4305	280	(-98)
7220C	100	445	98	(-17)	895	132	(-33)	2385	203	(-69)	4620	280	(-106)

Column group heading: Bearing Preload、Rigidity、and Measured Face Side Offset

(72 series C angle:15° nominal contact angle, steel ball)

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

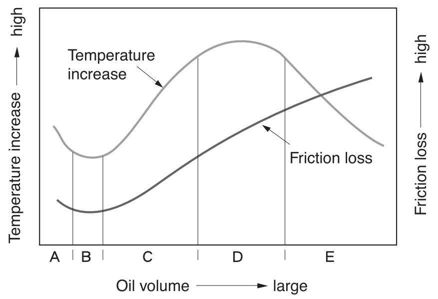


Table 6.1 Different Zone(Fig. 6.1) and its lubrication method

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