MOTION & CONTROL
NSK

For high-speed machine tool spindles

Precision ceramic angular contact ball bearings

High-precision, light-weight ceramic balls
to meet the demands for higher-speeds, less heat generation
of machine tool spindles.

NSK PRECISION CERAMIC ANGULAR CONTACT BALL BEARINGS HAVING PRECISION, LIGHT-WEIGHT, AND THERMALLY LOW EXPANSIVE CERAMIC (Si_3N_4) BALLS, WHICH ARE DESIGNED TO SUPPORT MACHINE TOOL SPINDLES RUNNING AT HIGHER SPEEDS WITH LOWER HEAT GENERATION

Cutting machine tools, especially machining centers, can have higher machining efficiencies and higher machining accuracies when operated run at higher speeds. For this reason, there have been ever greater demands for higher speed performance of their spindle bearings. In reply to the demand, NSK has developed precision ceramic angular contact ball bearings, consisting of outer and inner rings made of bearing steel, and ceramic (silicon nitride: Si_3N_4) balls having density as light as 40 percent of bearing steel and yet having a high rigidity. The bearings are already used in many machine tools. The high-speed and low-heat performance of NSK ceramic angular contact ball bearings, unattainable by conventional bearings, will surely contribute to greater performance of your machine tool spindles.

NSK can also provide cylindrical roller bearings comprising ceramic rollers, customized to your requirements. Please contact NSK.

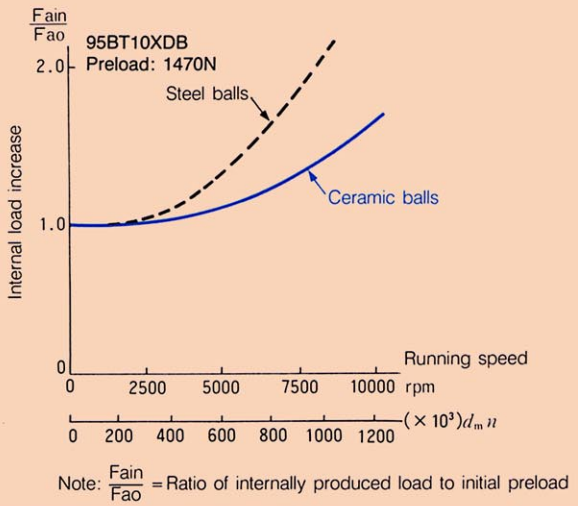
1. Features of precision ceramic angular contact ball bearings

(1) Low heat generation, Ultra-high speed capability

The density of ceramic balls being as light as 40 percent of that of bearing steel balls, the centrifugal force acting on the ceramic balls is smaller. Therefore, the increase of the internal axial load, in a position preload, which is a problem in high-speed revolutions, is also smaller (Fig. 1).

It is also known that, when bearing temperature rises under high-speed revolutions, the preload on ceramic balls is smaller than that on steel balls because the coefficient of linear expansion of the ceramic is smaller than that of bearing steel (Fig. 2). In addition, ceramic balls are less liable to slips (gyroscopic slip and spinning slip) which can be a cause of heat generation, can run with less temperature rise, and can therefore be operated at ultrahigh speeds (Figs. 3 (a), (b) and (c)). Generally, when lubricated in the same way, ceramic ball bearings can be operated at speeds about 1.2 to 1.5 times higher than steel ball bearings, though this depends on operating conditions.

Fig. 1. Increase in internal axial load by centrifugal force



Note: $\frac{Fain}{Fao}$ = Ratio of internally produced load to initial preload

Fig. 2. Preloads at immediately after stop of run

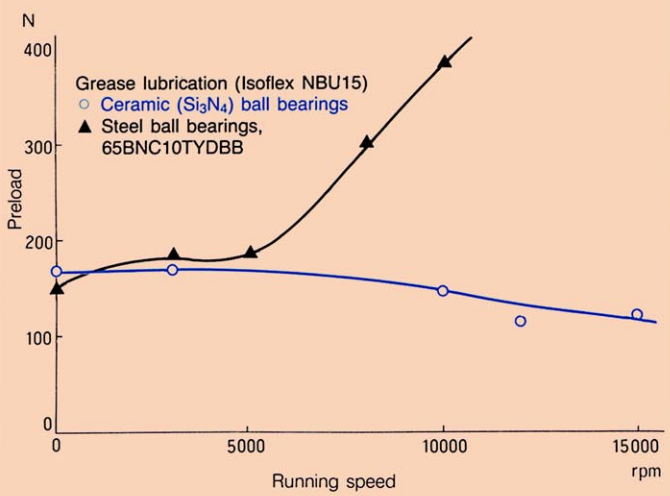
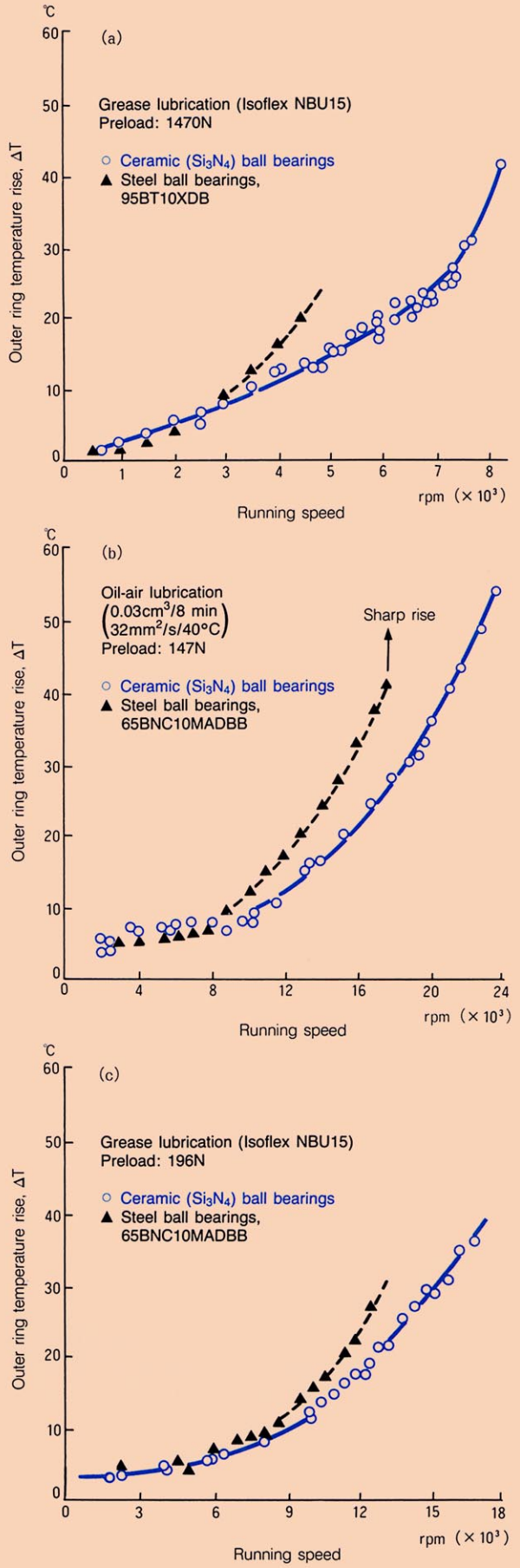


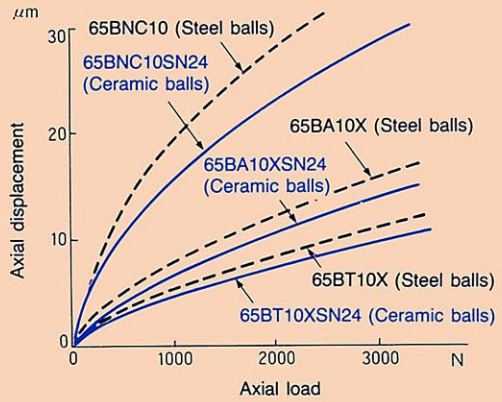
Fig. 3. Temperature rise of ceramic angular contact ball bearings



(2) High rigidity

Ceramic balls have an approximately 50-percent higher modulus of direct elasticity than that of bearing steel balls, and ceramic ball bearings therefore can have a higher rigidity and are ideal for machine tool spindle bearings (Fig. 4).

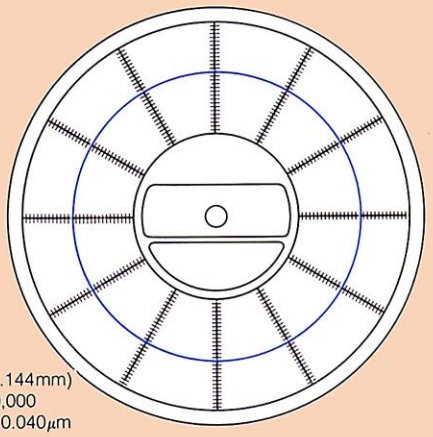
Fig. 4. Axial rigidity of ceramic angular contact ball bearings



(3) High running accuracy

Machine tool spindle bearings are required to run at high speeds with low temperature rise and to have high running accuracy. Based on NSK's many years of precision ball manufacturing experience and technologies, together with the use of improved materials and sintering processes, NSK ceramic balls are made to have the equivalent precision as steel balls (Fig. 5).

Fig. 5. Out-of-roundness of ceramic ball

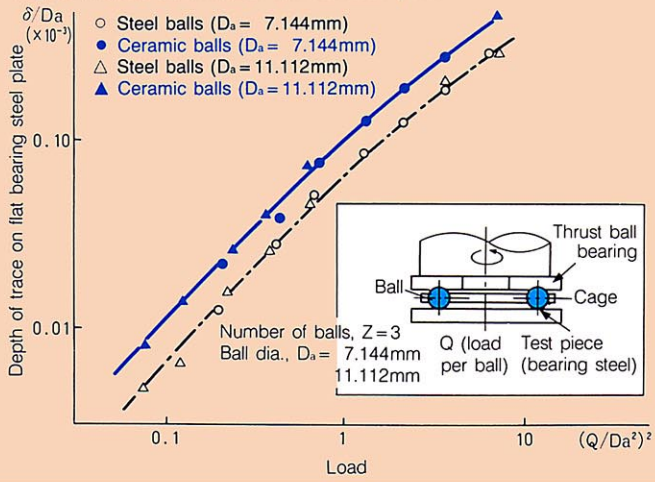


Ball Dia: 9/32″ (7.144mm)
Magnification: X50,000
Out-of-roundness: 0.040μm

2. Static load carrying capacity of ceramic angular contact ball bearings

Fig. 6 shows the measured depths of the traces of ceramic balls and steel balls slowly rolled under pressure on a flat bearing steel plate. For the use of ceramic angular contact ball bearings, it should be borne in mind that their static load carrying capacity is slightly lower than that of steel ball bearings. Since, however, loads on machine tool spindle bearings are usually lower than those on other general bearings, they may be practically considered as not liable to permanent deformation. In applications where bearings are subject to impact loads, the bearings should be treated carefully because such loads may cause indentation on their bearing steel raceway surfaces.

Fig. 6. Plastic deformation on flat steel plate



3. Comparison between ceramic and bearing steel

Table 1. Properties of Ceramic and Bearing Steel

Property	Bearing steel	Ceramic (Si_3N_4)
Density (g/cm³)	7.8	3.2
Coefficient of linear expansion (°C)	12.5×10^{-6}	2.8×10^{-6}
Modulus of direct elasticity (MPa) {kgf/mm²}	208 000 {21 200}	314 000 {32 000}
Poisson's ratio	0.3	0.27
Thermal conductivity (cal/cm·s·°C)	0.1	0.07

1. Durability of ceramic angular contact ball bearings

(1) Rolling fatigue life of ceramic balls

- **Rolling fatigue life test results of ceramic balls (made of HIP, by 6 manufacturers)**

In Fig. 7, the ceramic balls made by the manufacturers A and B are those used in NSK ceramic angular contact ball bearings, which have a life more than twice the calculated life (L_{10}) of bearing steel balls. Recently, NSK has developed ceramic balls having a longer life.

Fig. 7. Fatigue life test results, plotted to Weibull's chart

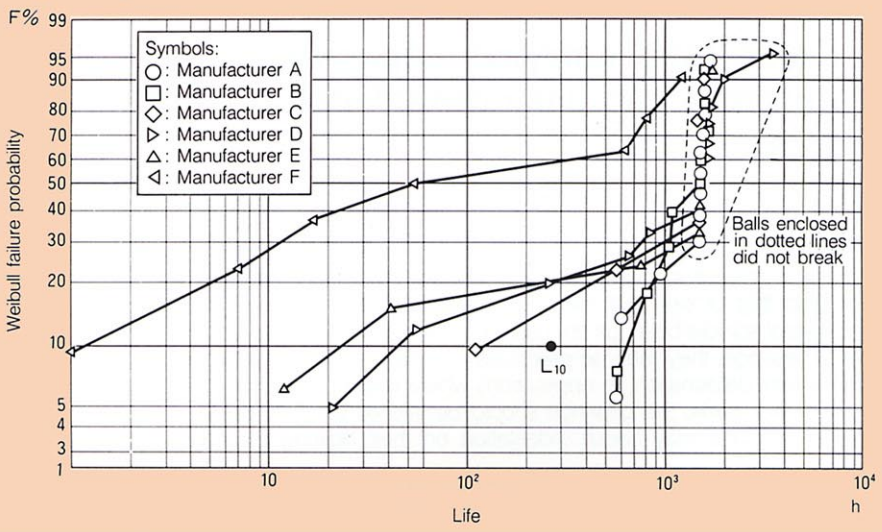


Fig. 8. Schematic views of testing apparatus

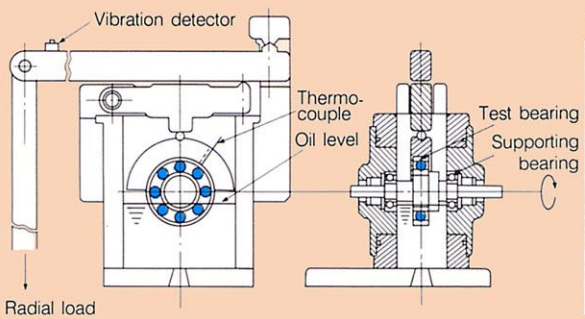


Table 2. Test conditions

Test bearing: 6206 (comprising 8 balls, 3/8″ dia., and a nylon cage)
Supporting bearings: 6304
Radial load: 3.8 kN (Max. contact surface pressure: 2800 MPa)
Running speed: 3000 rpm
Lubrication: FBK oil RO-68 oil bath

(2) Evaluation of endurance at high speeds

● Results of endurance test (12,000 starts-stops cyclic test under load) under oil-air lubrication

This test was conducted simulating typical cutting operation by a machining center. Throughout the endurance test, the bearing temperature rise and the spindle housing vibration were stable, and the running accuracies of the spindle after the test in both the radial and axial directions were within 1 μm as they were before the test.

Table 3. Test bearing and test conditions

Test bearing specification						Lubrication	Running speed (rpm)	Radial load (N)
Bearing No.	Ball dia (mm)	Number of balls	Contact angle (deg.)	Preload (N)	Fit on shaft (μm)			
65BNC10SN24 MADBB (d65xϕ100x 18mm)	7.144	28	15	147	Tight fit, approx. 10	Oil-air lubrication ISOVG32 equivalent mineral oil (0.03cm^3/8 min) bearing	2 000 ~24 000	0~2 940

Fig. 9. Loading test equipment

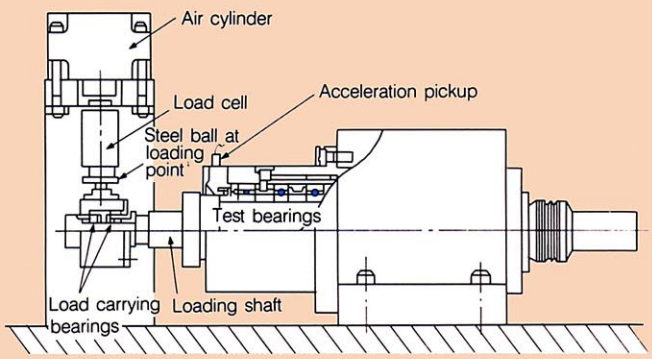


Fig. 10. Loading cycles in endurance test

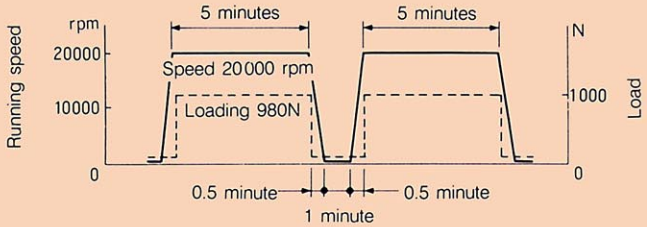
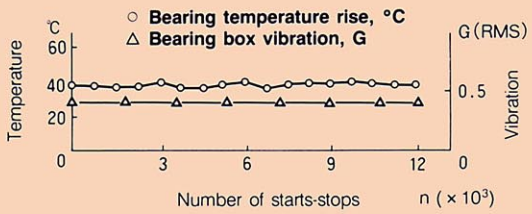


Fig. 11. Temperature and vibration variations during test



● Endurance test under grease lubrication

Fig. 13 shows an example of the results of the endurance test that has been being conducted at NSK under grease lubrication at 11,000 rpm (Dpw x n (dm n) = 900 x 10^3) and 13,500 rpm (Dpw x n = 1.1 x 10^6). At each of the running speeds, the bearing temperature has been stable.

Fig. 12. Endurance test equipment

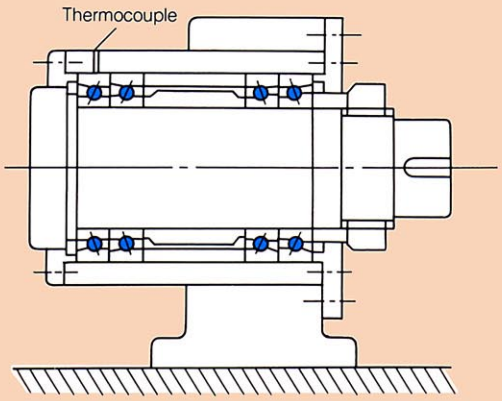
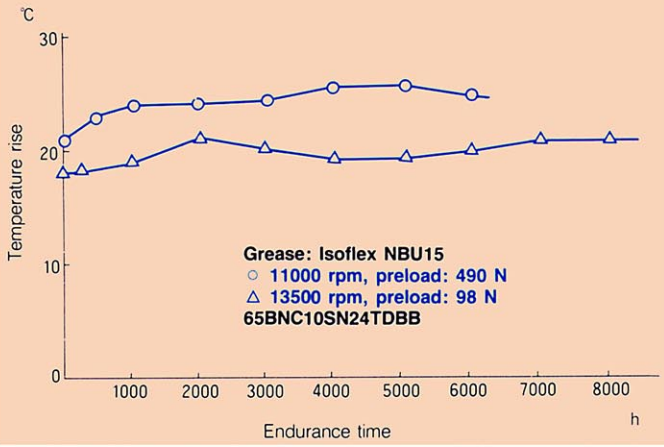


Fig. 13. Endurance test under grease lubrication



2. Dynamic friction analysis of NSK precision ceramic angular contact ball bearings

NSK calculated the dynamic frictional losses of ceramic ball bearings and steel ball bearings in steady-state conditions by computer simulation of the motions of balls and cages. Fig. 14 shows the results of the calculations adjusted to the test conditions shown in Fig. 3 (a) on Page 3. By comparing the dynamic frictional loss curves with the temperature rise curves, we can see that their tendencies under increasing running speeds, agree well with each other. The temperature rise differences between ceramic ball bearings and steel ball bearings in the high-speed region can be regarded as differences of the sliding friction between the balls and the raceways.

Fig. 14. Calculated dynamic frictional losses of bearings

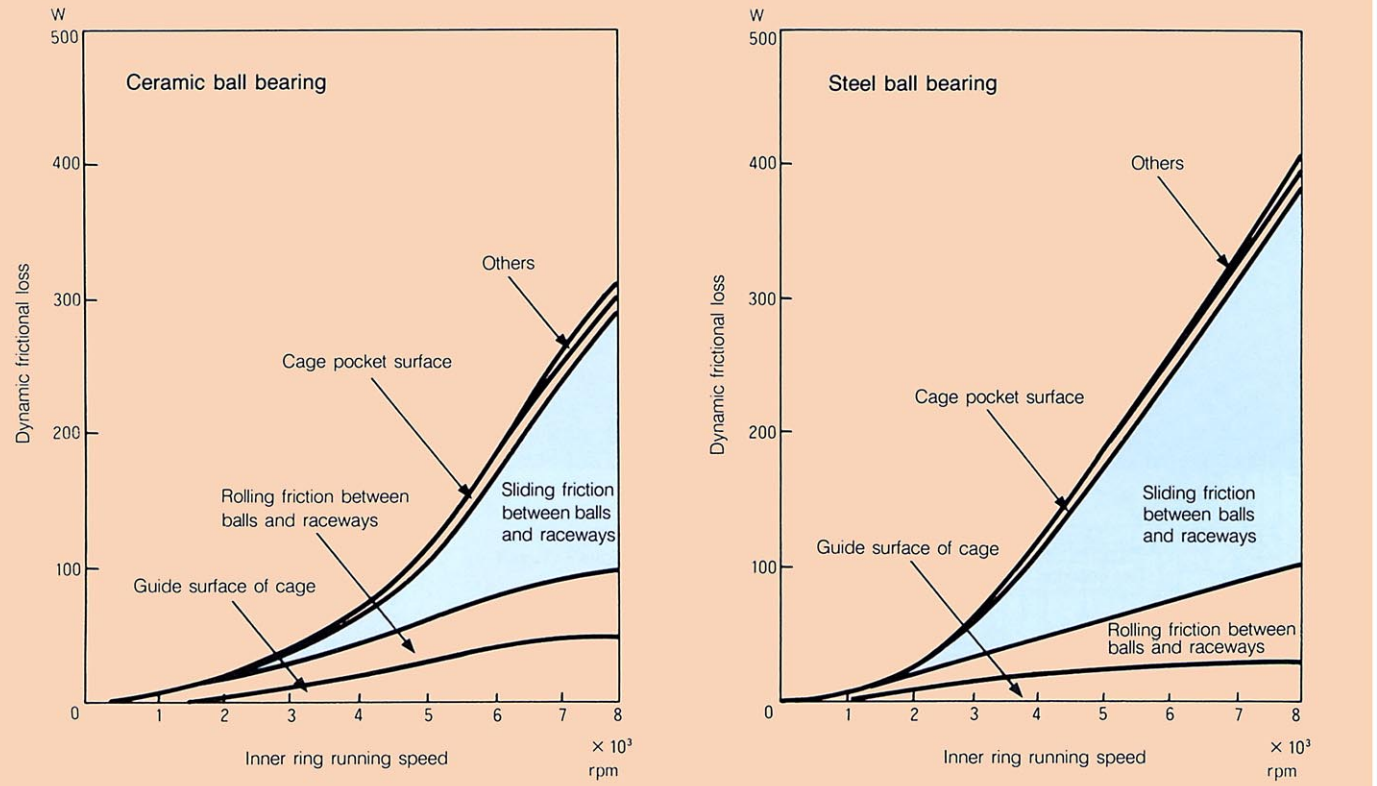


Table 4. Input data for analysis

Bearing	Ball diameter	(mm)	11.112
	Number of balls		27
	Pitch diameter	(mm)	120
	Initial contact angle	(°)	40
Material	Modulus of direct elasticity	(MPa)	Steel 208 000 Ceramic 314 000
	Poisson ratio		Steel 0.3 Ceramic 0.25
	Density	(g/cm^3)	Steel 7.8 Ceramic 3.2
Load	Initial constant position preload	(N)	1470
Lubricant	Kinematic viscosity	mm^2/s (40°C)	20
Speed		(rpm)	500 ~ 8 000

The dimensions of the NSK precision ceramic angular contact ball bearings of the standard series BNC10, BNC19 and BNT10F are listed on this and the following pages. Those bearings of other sizes of other bearing series (series 70, series 72, etc.) are available or manufacturable depending on user's specific requirements. Please contact NSK for such other types or other series.

Formulation of bearing numbers

(Example) 70 | BNC | 10 | SN24 | MA | DB | L | P4

Tolerance classes
P4: ISO Class 4
P2: ISO Class 2

Preload symbols
L: Standard preload
CP: Preload clearance (CP10 = -10μm)
CA: Axial clearance (CA10 = $+10\mu$m)

Combination symbols
DB: Back-to-back combinations
DT: Tandem combinations
DBB: 4-row combinations

Cage symbols
MA: Machined and silver plated brass cage
(D_{pw} x n: 1.4 x 10^6, over)
T: Phenolic cage
(D_{pw} x n: 1.4 x 10^6, max.)
TY: Polyamide cage
(D_{pw} x n: 1.2 x 10^6, max.)

Material symbols
The material of rolling elements is silicon nitride (Si_3N_4)

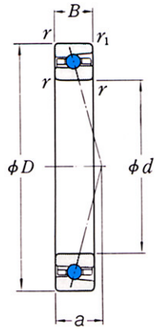
Dimension series symbols
10: Same bore and outside diameters and width as 70 series
19: Same bore and outside diameters and width as 79 series

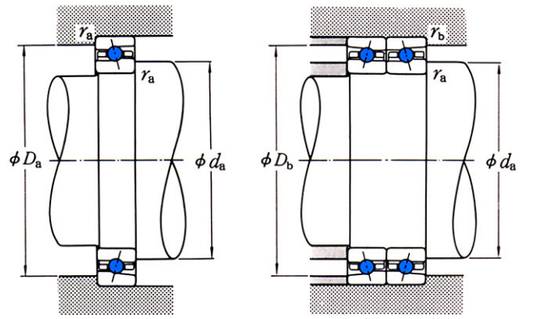
Bearing type symbol

Nominal bore diameter

BNC 10

Nominal contact angle: 15°





Dynamic equivalent load $P = XFr + YFa$

Contact Angle	$if_0 F_a$* / C_{or}	e	Single, DT				DB or DF			
			$F_a/F_r \leqq e$		$F_a/F_r > e$		$F_a/F_r \leqq e$		$F_a/F_r > e$	
			X	Y	X	Y	X	Y	X	Y
15°	0.178	0.38	1	0	0.44	1.47	1	1.65	0.72	2.39
	0.357	0.40	1	0	0.44	1.40	1	1.57	0.72	2.28
	0.714	0.43	1	0	0.44	1.30	1	1.46	0.72	2.11
	1.07	0.46	1	0	0.44	1.23	1	1.38	0.72	2.00
	1.43	0.47	1	0	0.44	1.19	1	1.34	0.72	1.93
	2.14	0.50	1	0	0.44	1.12	1	1.26	0.72	1.82
	3.57	0.55	1	0	0.44	1.02	1	1.14	0.72	1.66
	5.35	0.56	1	0	0.44	1.00	1	1.12	0.72	1.63

* For i, use 2 for DB, DF and 1 for DT.

Static equivalent load $P_o = X_o F_r + Y_o F_a$

Nominal contact angle	Single, DT		DB or DF	
	X_o	Y_o	X_o	Y_o
15°	0.5	0.46	1	0.92

If $F_r > 0.5F + Y_o F_o$, for single or DT, use $P_o = F_r$.

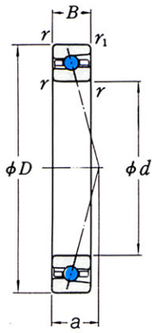
Boundary dimensions (mm) d	D	B	r (min)	r_1 (min)	Basic load ratings (1) (N) C_r	C_{or}	(kgf) C_r	C_{or}	Factor f_0	Bearing numbers
40	68	15	1	0.6	13 900	12 200	1 420	1 240	16.2	**40 BNC 10 SN24**
45	75	16	1	0.6	15 500	14 000	1 580	1 420	16.3	**45 BNC 10 SN24**
50	80	16	1	0.6	16 200	15 400	1 650	1 570	16.5	**50 BNC 10 SN24**
55	90	18	1.1	0.6	20 000	19 500	2 040	1 990	16.5	**55 BNC 10 SN24**
60	95	18	1.1	0.6	20 800	21 300	2 120	2 180	16.6	**60 BNC 10 SN24**
65	100	18	1.1	0.6	21 600	23 200	2 200	2 360	16.8	**65 BNC 10 SN24**
70	110	20	1.1	0.6	29 400	30 500	3 000	3 100	16.5	**70 BNC 10 SN24**
75	115	20	1.1	0.6	29 900	32 000	3 050	3 250	16.7	**75 BNC 10 SN24**
80	125	22	1.1	0.6	35 000	38 000	3 550	3 850	16.6	**80 BNC 10 SN24**
85	130	22	1.1	0.6	35 500	39 500	3 600	4 050	16.7	**85 BNC 10 SN24**
90	140	24	1.5	1	46 500	51 500	4 750	5 250	16.5	**90 BNC 10 SN24**
95	145	24	1.5	1	47 500	53 500	4 850	5 450	16.6	**95 BNC 10 SN24**
100	150	24	1.5	1	48 000	56 000	4 900	5 700	16.7	**100 BNC 10 SN24**

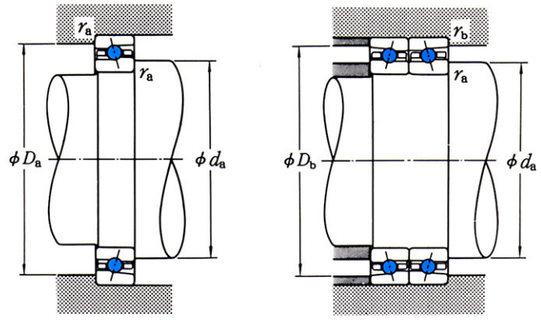
Note (1): The ISO does not provide basic load ratings for bearings containing ceramic balls. Based on the findings obtained by life tests at NSK, ceramic ball bearings have the equivalent life as bearing steel ball bearings. The values listed herein were determined with reference to those calculated by the ISO-specified formulas.

Effective load center (mm) a	Abutment and fillet dimensions (mm) d_a (min)	D_a (max)	D_b (max)	r_a (max)	r_b (max)	Mass (kg) (approx.)	Internal space (cm^3/row)
14.7	46	62	63	1	0.5	0.198	7.5
16.0	51	69	70	1	0.5	0.242	8.9
16.7	56	74	75	1	0.5	0.262	9.9
18.7	62	83	85	1	0.6	0.368	13
19.4	67	88	90	1	0.6	0.419	13
20.0	72	93	95	1	0.6	0.451	15
22.1	77	103	105	1	0.6	0.597	22
22.7	82	108	110	1	0.6	0.630	24
24.7	87	118	120	1	0.6	0.861	29
25.4	92	123	125	1	0.6	0.901	31
27.4	99	131	134	1.5	0.8	1.14	41
28.1	104	136	139	1.5	0.8	1.19	43
28.7	109	141	144	1.5	0.8	1.24	45

BNC 19

Nominal contact angle: 15°





Dynamic equivalent load $P = XFr + YFa$

Contact Angle	$if_0 F_a$* / C_{or}	e	Single, DT				DB or DF			
			$F_a/F_r \leqq e$		$F_a/F_r > e$		$F_a/F_r \leqq e$		$F_a/F_r > e$	
			X	Y	X	Y	X	Y	X	Y
15°	0.178	0.38	1	0	0.44	1.47	1	1.65	0.72	2.39
	0.357	0.40	1	0	0.44	1.40	1	1.57	0.72	2.28
	0.714	0.43	1	0	0.44	1.30	1	1.46	0.72	2.11
	1.07	0.46	1	0	0.44	1.23	1	1.38	0.72	2.00
	1.43	0.47	1	0	0.44	1.19	1	1.34	0.72	1.93
	2.14	0.50	1	0	0.44	1.12	1	1.26	0.72	1.82
	3.57	0.55	1	0	0.44	1.02	1	1.14	0.72	1.66
	5.35	0.56	1	0	0.44	1.00	1	1.12	0.72	1.63

* For i, use 2 for DB, DF and 1 for DT.

Static equivalent load $P_o = X_o F_r + Y_o F_a$

Nominal contact angle	Single, DT		DB or DF	
	X_o	Y_o	X_o	Y_o
15°	0.5	0.46	1	0.92

If $F_r > 0.5F + Y_o F_a$, for single or DT, use $P_o = F_r$.

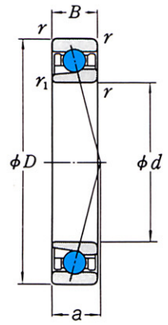
Boundary dimensions (mm) d	D	B	r (min)	r_1 (min)	Basic load ratings (1) (N) C_r	C_{or}	(kgf) C_r	C_{or}	Factor f_0	Bearing numbers
35	55	10	0.6	0.3	11 400	9 000	1 160	920	15.9	**35 BNC 19 SN24**
40	62	12	0.6	0.3	11 900	10 200	1 210	1 040	16.3	**40 BNC 19 SN24**
45	68	12	0.6	0.3	12 700	11 800	1 300	1 210	16.5	**45 BNC 19 SN24**
50	72	12	0.6	0.3	13 200	12 900	1 340	1 320	16.7	**50 BNC 19 SN24**
55	80	13	1	0.6	13 500	14 100	1 380	1 440	16.9	**55 BNC 19 SN24**
60	85	13	1	0.6	13 900	15 200	1 420	1 550	17.0	**60 BNC 19 SN24**
65	90	13	1	0.6	14 300	16 400	1 460	1 670	17.2	**65 BNC 19 SN24**
70	100	16	1	0.6	18 000	20 600	1 830	2 100	17.1	**70 BNC 19 SN24**
75	105	16	1	0.6	18 500	22 100	1 880	2 250	17.2	**75 BNC 19 SN24**
80	110	16	1	0.6	18 900	23 600	1 930	2 400	17.3	**80 BNC 19 SN24**
85	120	18	1.1	0.6	22 700	28 000	2 320	2 860	17.2	**85 BNC 19 SN24**
90	125	18	1.1	0.6	23 400	29 800	2 380	3 050	17.3	**90 BNC 19 SN24**
95	130	18	1.1	0.6	24 000	31 500	2 440	3 250	17.4	**95 BNC 19 SN24**
100	140	20	1.1	0.6	33 500	43 000	3 450	4 400	17.1	**100 BNC 19 SN24**

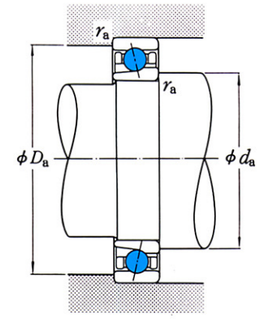
Note (1): The ISO does not provide basic load ratings for bearings containing ceramic balls. Based on the findings obtained by life tests at NSK, ceramic ball bearings have the equivalent life as bearing steel ball bearings. The values listed herein were determined with reference to those calculated by the ISO-specified formulas.

Effective load center (mm) a	Abutment and fillet dimensions (mm) d_a (min)	D_a (max)	D_b (max)	r_a (max)	r_b (max)	Mass (kg) (approx.)	Internal space (cm^3/row)
11.0	40	50	52.5	0.6	0.3	0.066	3.1
12.8	45	57	59.5	0.6	0.3	0.105	4.2
13.6	50	63	65.5	0.6	0.3	0.125	4.5
14.2	55	67	69.5	0.6	0.3	0.126	4.8
15.5	61	74	75	1	0.5	0.179	5.8
16.2	66	79	80	1	0.5	0.190	6.6
16.9	71	84	85	1	0.5	0.206	6.6
19.4	76	94	95	1	0.5	0.345	10
20.1	81	99	100	1	0.5	0.366	11
20.7	86	104	105	1	0.5	0.385	12
22.7	92	113	115	1	0.6	0.564	16
23.4	97	118	120	1	0.6	0.576	17
24.1	102	123	125	1	0.6	0.604	17
26.1	107	133	135	1	0.6	0.796	27

BNT 10F

Nominal contact angle: 12°





Dynamic equivalent load $P = XF_r + YF_a$

Nominal contact angle	$\frac{C_{or}}{iF_a}$ *	e	Single, DT			
			$F_a/F_r \leqq e$		$F_a/F_r > e$	
			X	Y	X	Y
12°	5	0.39	1	0	0.46	1.39
	10	0.36	1	0	0.46	1.53
	15	0.34	1	0	0.46	1.61
	20	0.33	1	0	0.46	1.66
	25	0.32	1	0	0.46	1.70
	30	0.32	1	0	0.46	1.73
	50	0.30	1	0	0.46	1.80

* i: number of rows of bearings

Boundary dimensions (mm) d	D	B	r (min)	r_1 (min)	Basic load ratings (1) (N) C_r	C_{or}	{kgf} C_r	C_{or}	Bearing numbers
8	22	7	0.3	0.15	2 370	795	242	81	**8 BNT 10F SN24**
10	26	8	0.3	0.15	3 300	1 140	335	116	**10 BNT 10F SN24**
12	28	8	0.3	015	3 600	1 340	370	136	**12 BNT 10F SN24**
15	32	9	0.3	0.15	3 950	1 580	405	161	**15 BNT 10F SN24**
17	35	10	0.3	0.15	5 250	2 130	535	217	**17 BNT 10F SN24**
20	42	12	0.6	0.3	6 650	2 800	680	285	**20 BNT 10F SN24**
25	47	12	0.6	0.3	7 550	3 500	770	360	**25 BNT 10F SN24**
30	55	13	1	0.6	9 900	4 900	1 010	500	**30 BNT 10F SN24**

Note (1): The ISO does not provide basic load ratings for bearings containing ceramic balls. Based on the findings obtained by life tests at NSK, ceramic ball bearings have the equivalent life as bearing steel ball bearings. The values listed herein were determined with reference to those calculated by the ISO-specified formulas.

Effective load center (mm) a	Abutment and fillet dimensions (mm) d_a (min)	D_a (max)	r_a (max)	Mass (kg) (approx.)
5.1	10.5	19.5	0.3	0.011
5.9	12.5	23.5	0.3	0.016
6.1	14.5	25.5	0.3	0.018
7.0	17.5	29.5	0.3	0.026
7.8	19.5	32.5	0.3	0.033
9.3	25	37	0.6	0.058
9.8	30	42	0.6	0.067
11.0	36	49	1	0.097