Mancais de Rolamento

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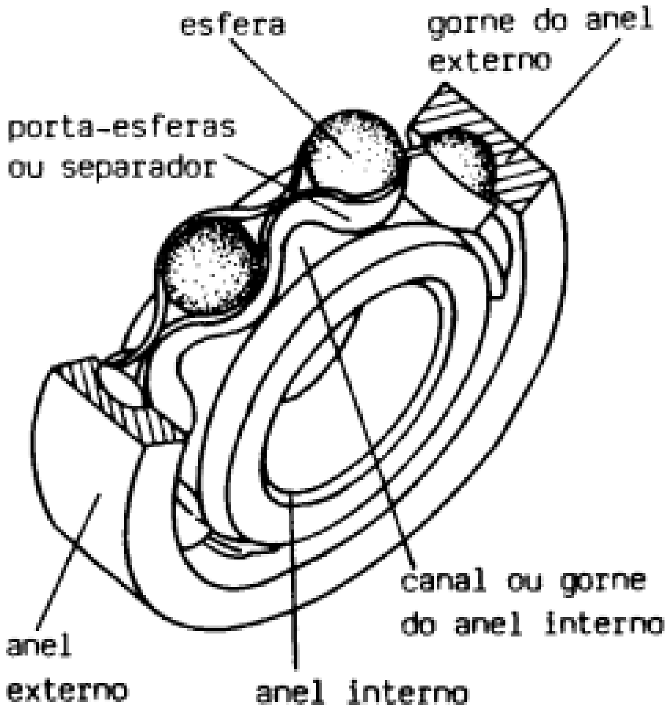
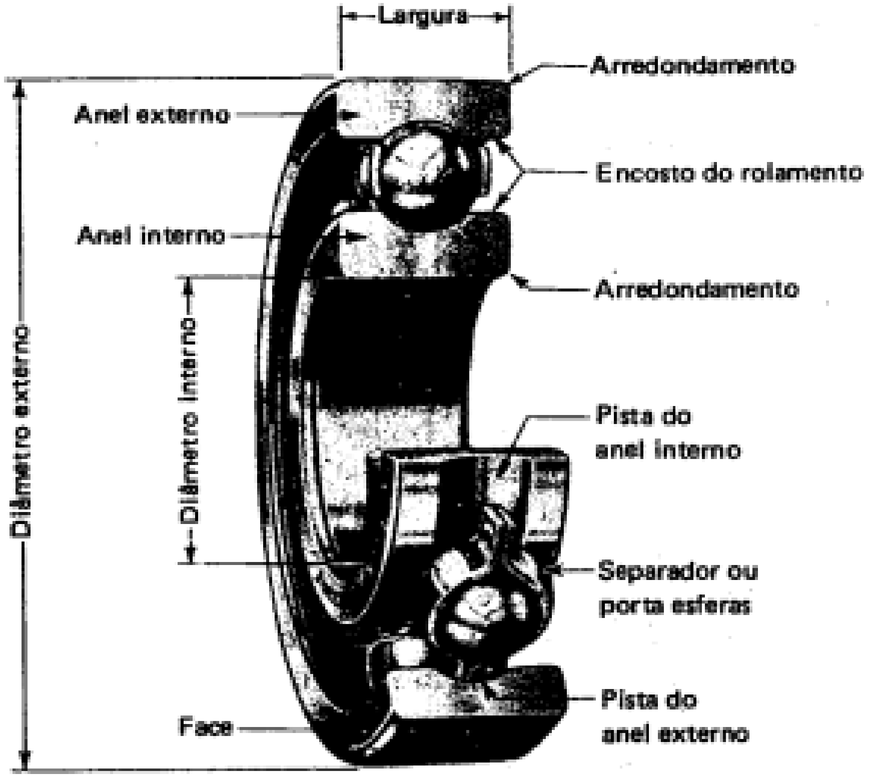
O que são?

- Mancais de apoio onde o esforço principal é transmitido através de um elemento de contato rolante,
- O atrito inicial e o atrito de serviço são aprox. iguais;
- Os efeitos de carga, velocidade e temperatura são pequenos.
- A especificação dos rolamentos é feita a partir das forças de serviço, limite de velocidade, tipo específico de lubrificação, etc.

Nomenclatura


esfera
gorne do anel externo
porta-esferas ou separador
anel externo
anel interno
canal ou gorne do anel interno


Largura
Arredondamento
Anel externo
Encosto do rolamento
Anel interno
Arredondamento
Diâmetro externo
Diâmetro interno
Pista do anel interno
Separador ou porta esferas
Face
Pista do anel externo

Classificacao dos rolamentos quanto à série

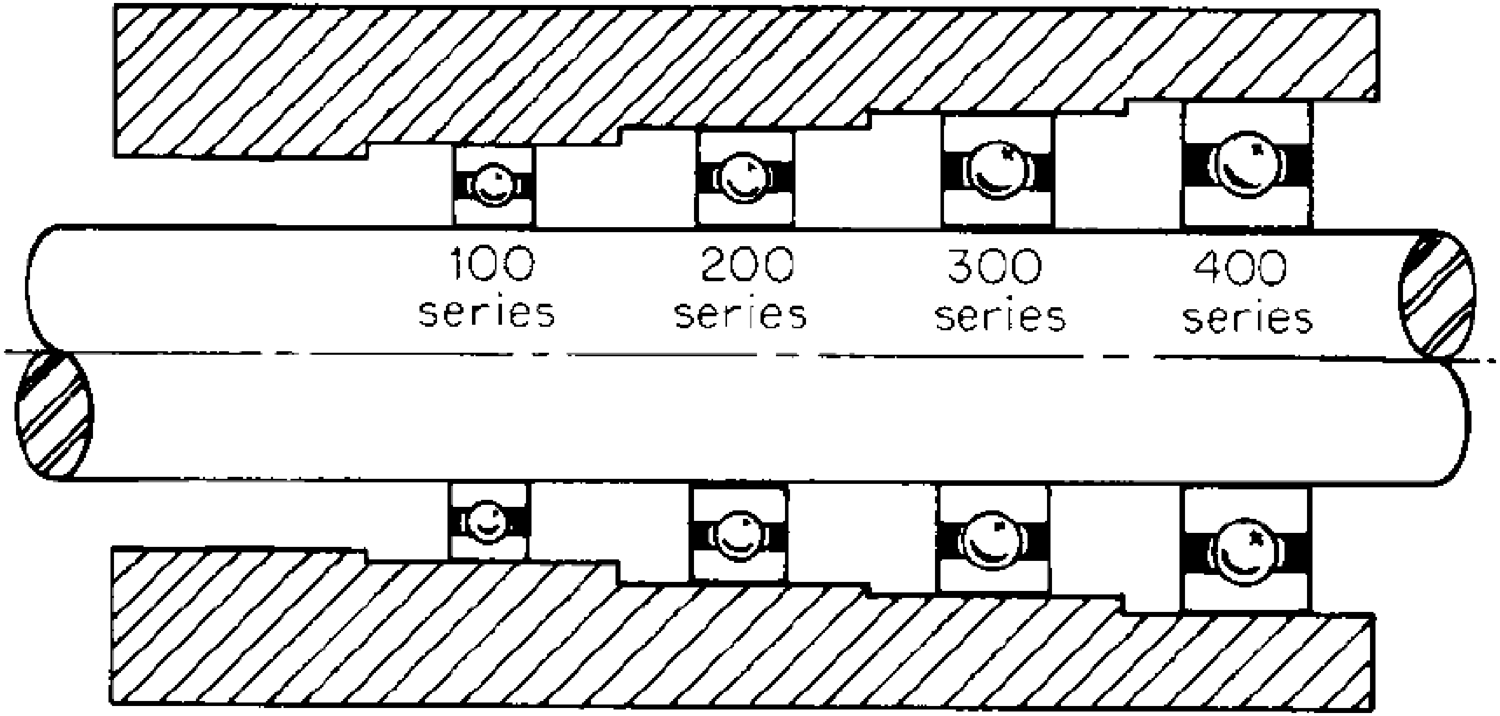
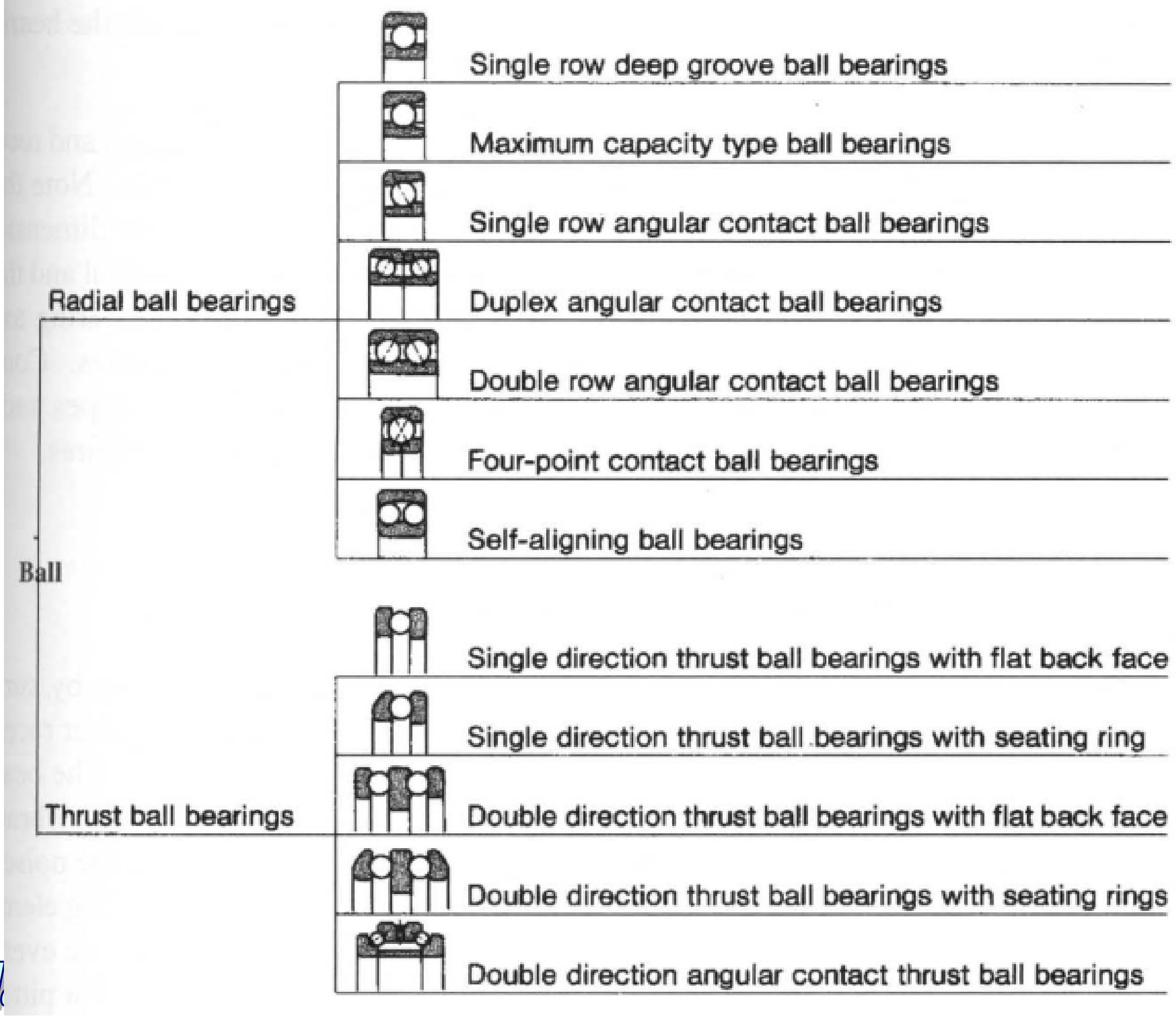

100
series
200
series
300
series
400
series

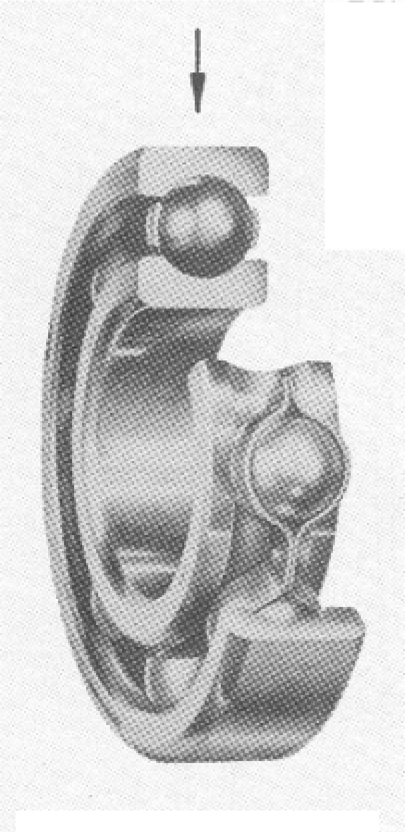
Fig. 8.5.2 Bearing standard series.

Classificação dos rolamentos
Elemento rolante - Esferas

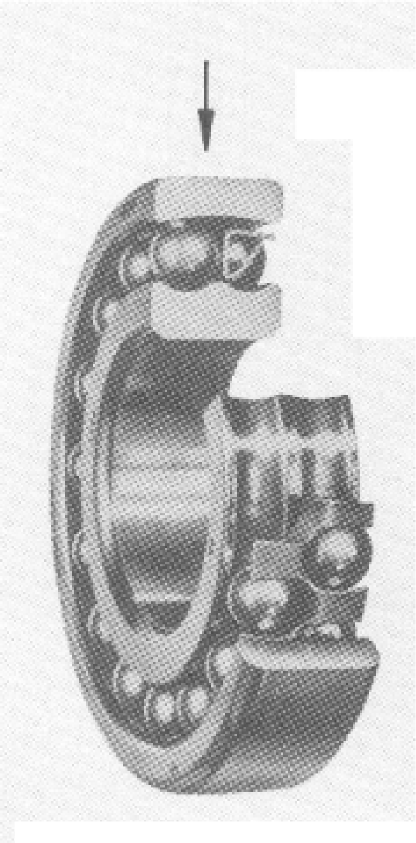


- Ball
  - Radial ball bearings
    - Single row deep groove ball bearings
    - Maximum capacity type ball bearings
    - Single row angular contact ball bearings
    - Duplex angular contact ball bearings
    - Double row angular contact ball bearings
    - Four-point contact ball bearings
    - Self-aligning ball bearings
  - Thrust ball bearings
    - Single direction thrust ball bearings with flat back face
    - Single direction thrust ball bearings with seating ring
    - Double direction thrust ball bearings with flat back face
    - Double direction thrust ball bearings with seating rings
    - Double direction angular contact thrust ball bearings

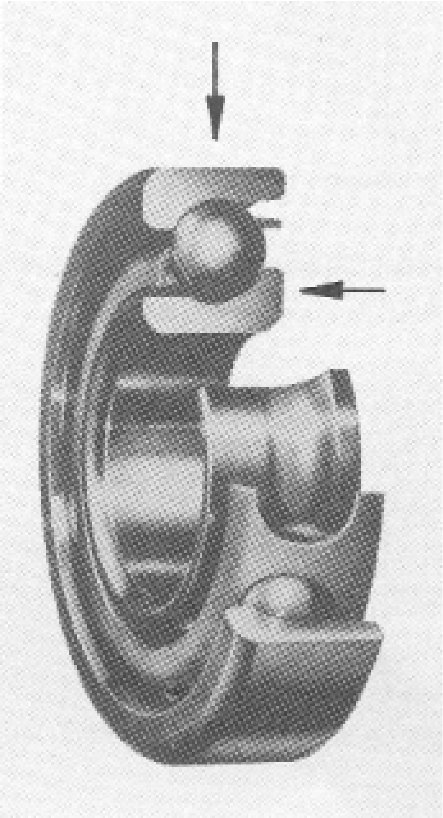
Rolamentos de esferas



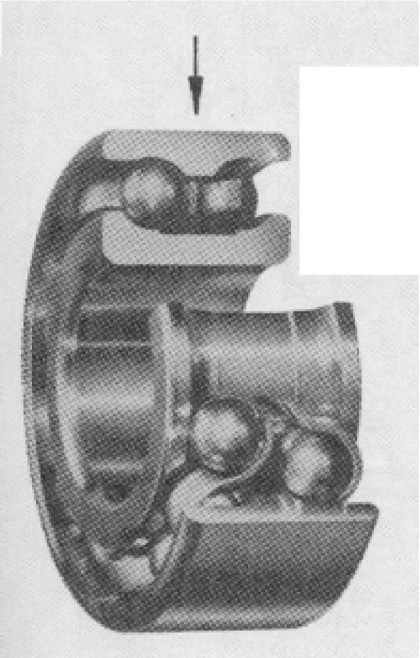
Rolamento uma carreira de esferas



Rolamento autocompensador de esferas

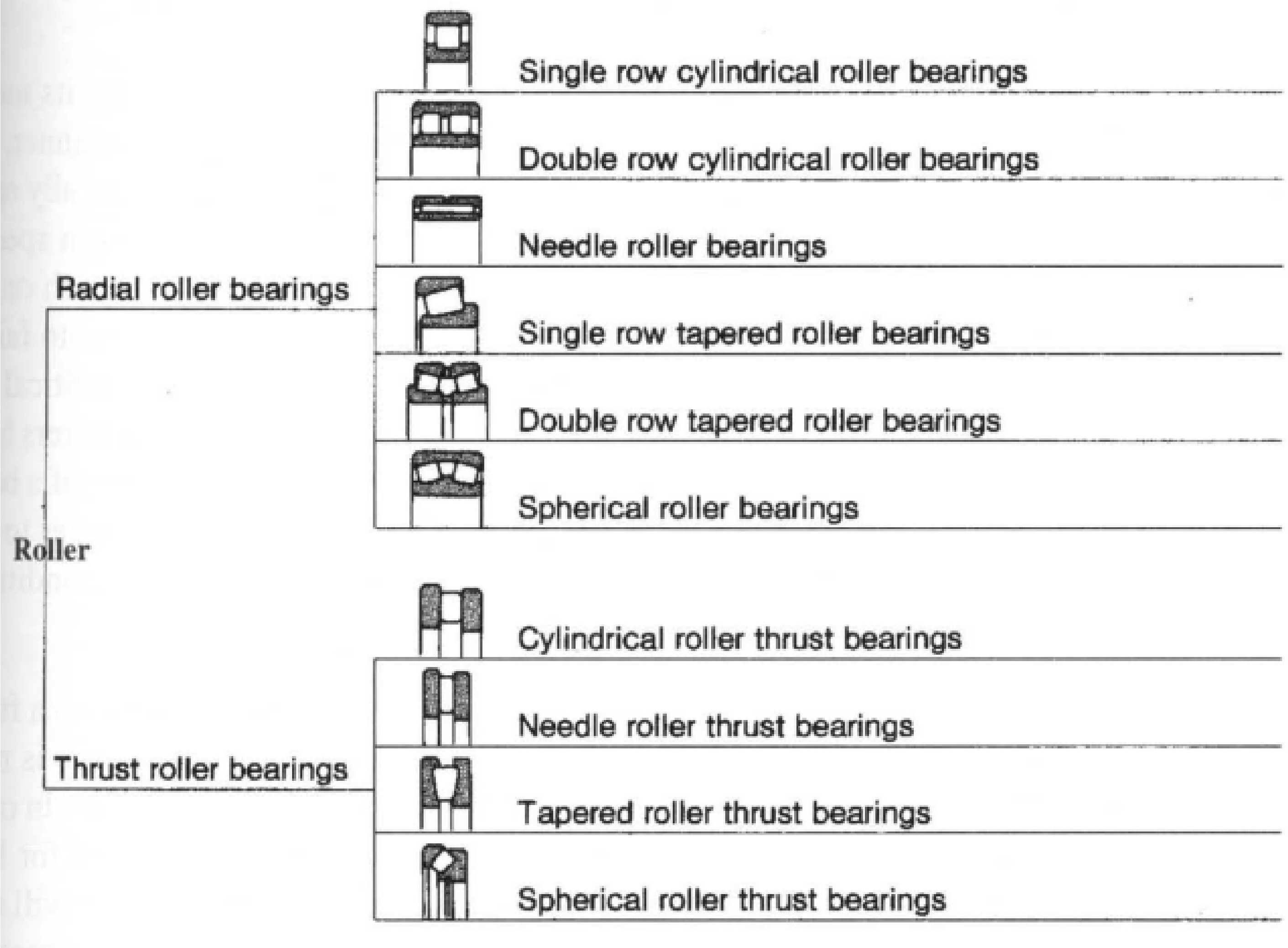


Rolamento de contato angular



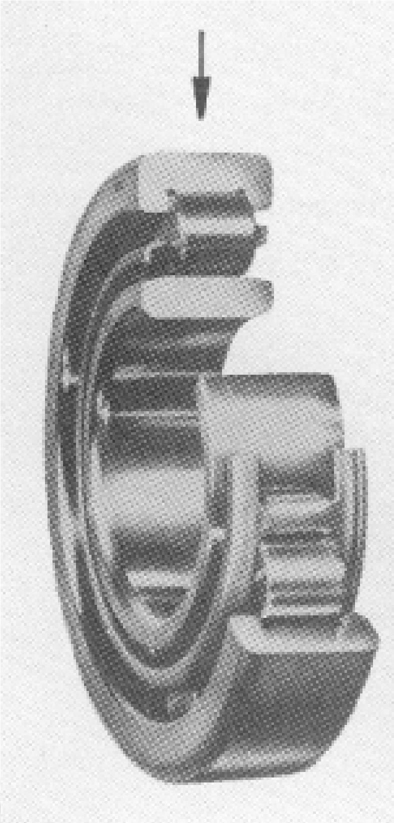
Rolamento de contato angular de duas carreiras de esferas

Rolamentos de rolos

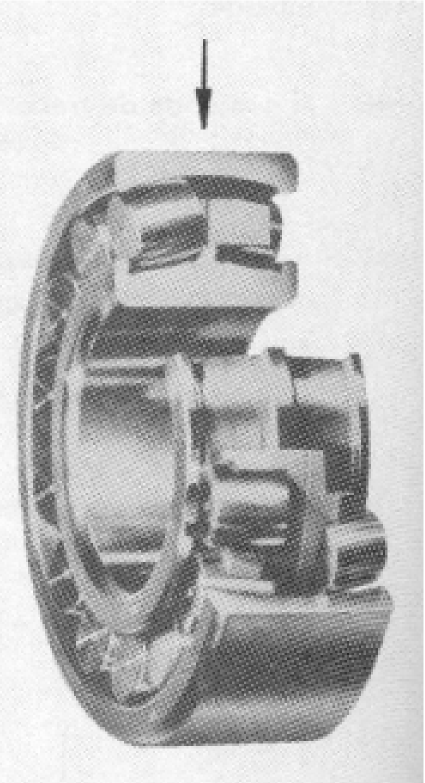


- **Roller**
  - Radial roller bearings
    - Single row cylindrical roller bearings
    - Double row cylindrical roller bearings
    - Needle roller bearings
    - Single row tapered roller bearings
    - Double row tapered roller bearings
    - Spherical roller bearings
  - Thrust roller bearings
    - Cylindrical roller thrust bearings
    - Needle roller thrust bearings
    - Tapered roller thrust bearings
    - Spherical roller thrust bearings

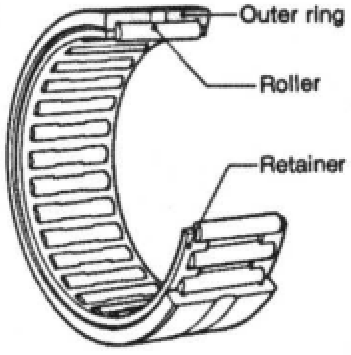
Rolamentos de rolos



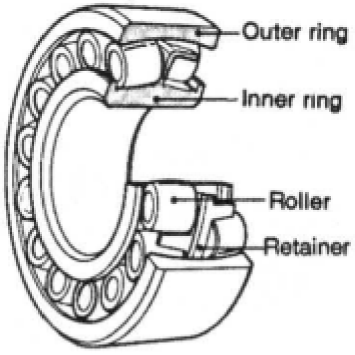
Rolamento de rolos cilíndricos



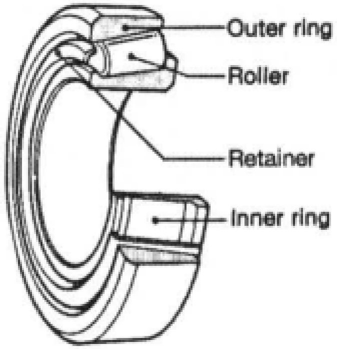
Rolamento autocompensador de rolos


Outer ring
Roller
Retainer

(*b*) Needle roller bearing

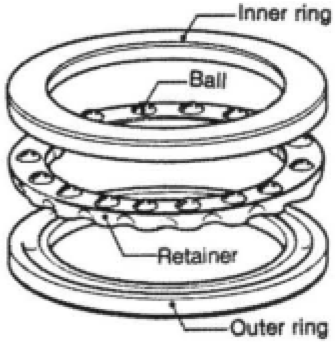

Outer ring
Inner ring
Roller
Retainer

(*d*) Spherical roller bearing

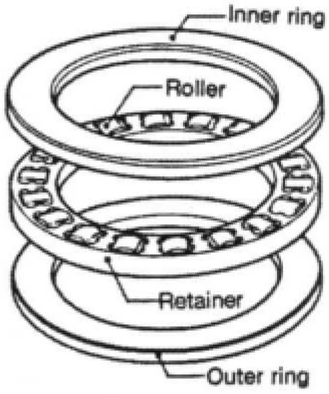

Outer ring
Roller
Retainer
Inner ring

(*c*) Tapered roller bearing

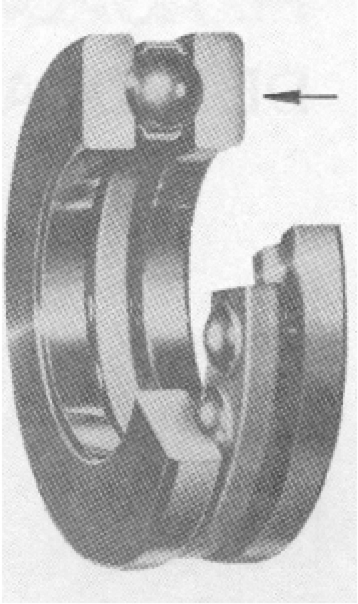
Mancais de escora (axiais)


Inner ring
Ball
Retainer
Outer ring

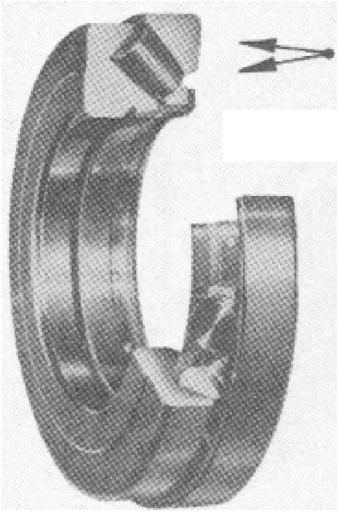
(*a*) Ball thrust bearing


Inner ring
Roller
Retainer
Outer ring

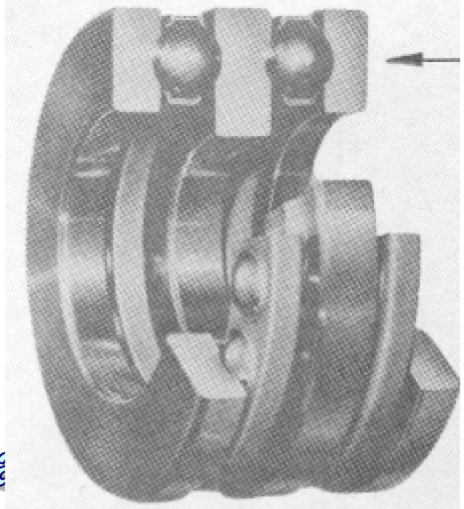
(*b*) Roller thrust bearing



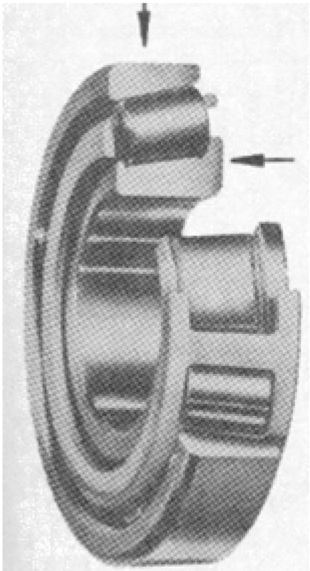
Rolamento axial de esferas



Rolamento axial autocom-pensador de rolos

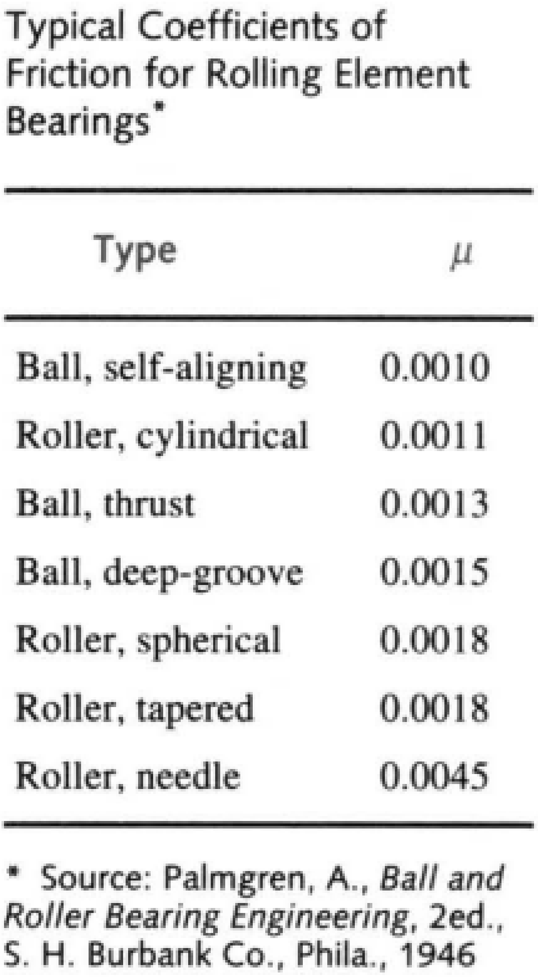


Rolamento axial de esferas de escora dupla



Rolamento de rolos cônicos

Coeficiente de atrito para rolamentos

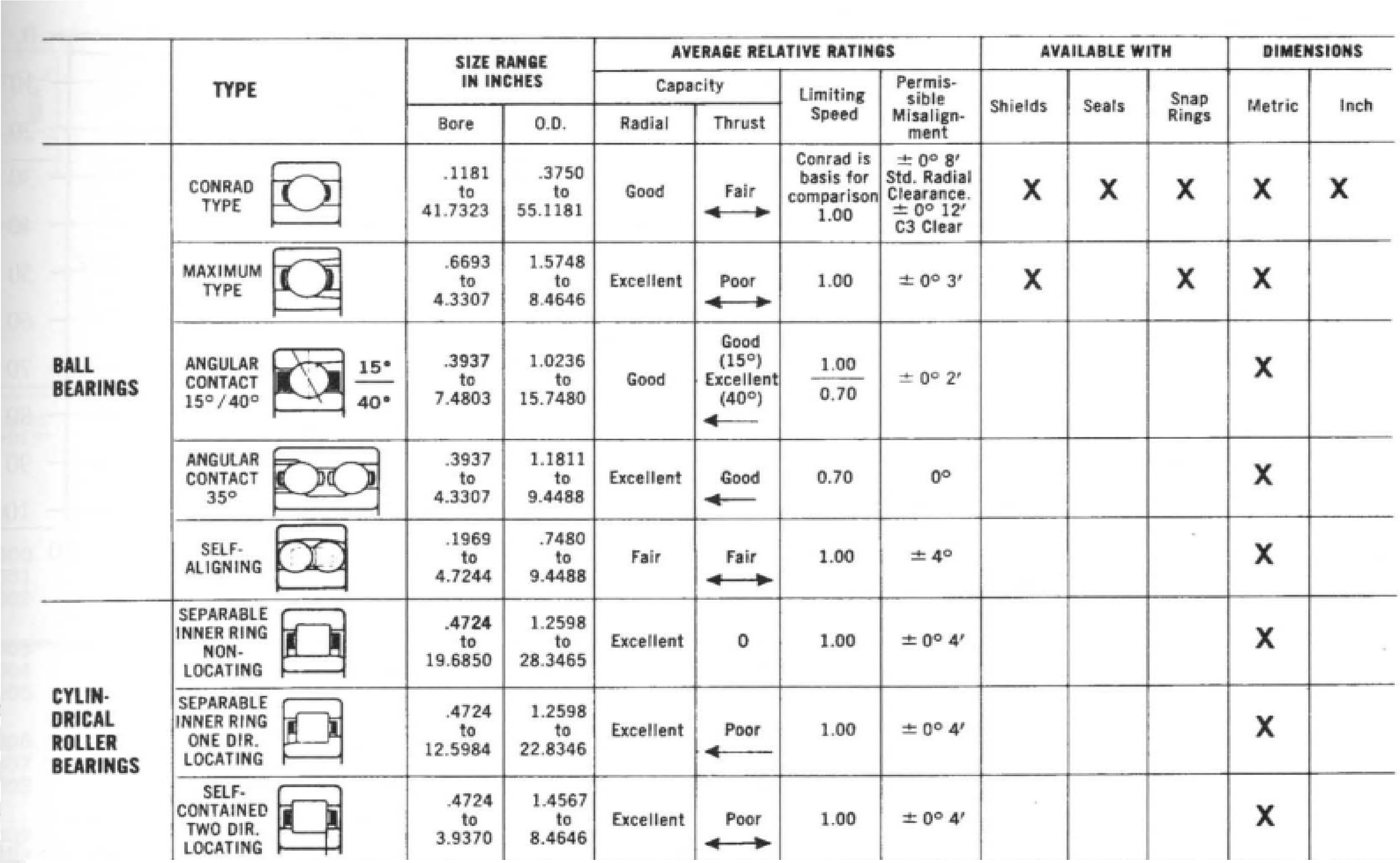


Typical Coefficients of Friction for Rolling Element Bearings*

Type	μ
Ball, self-aligning	0.0010
Roller, cylindrical	0.0011
Ball, thrust	0.0013
Ball, deep-groove	0.0015
Roller, spherical	0.0018
Roller, tapered	0.0018
Roller, needle	0.0045

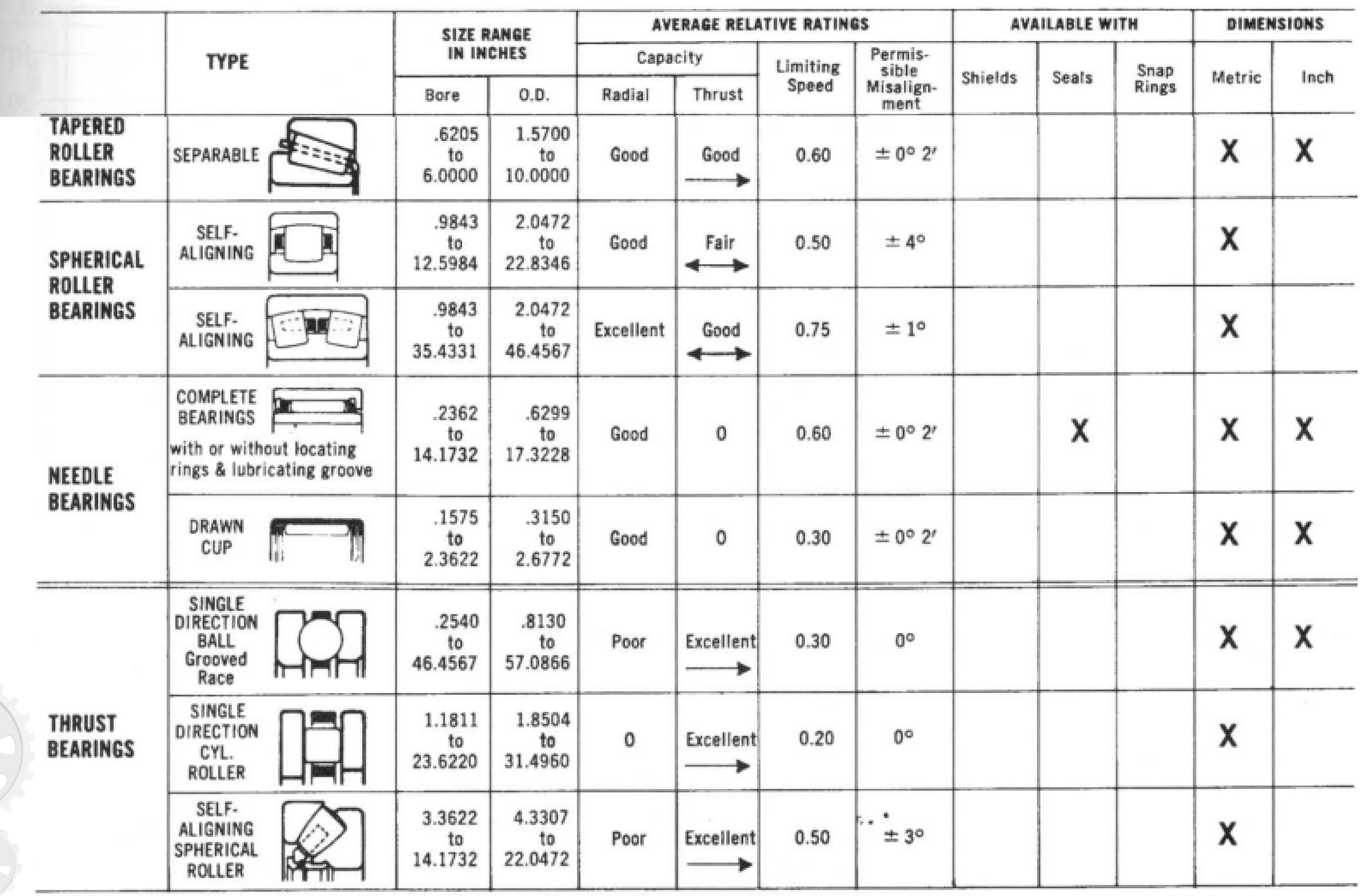
* Source: Palmgren, A., *Ball and Roller Bearing Engineering*, 2ed., S. H. Burbank Co., Phila., 1946

Características dos rolamentos comerciais (FAG)



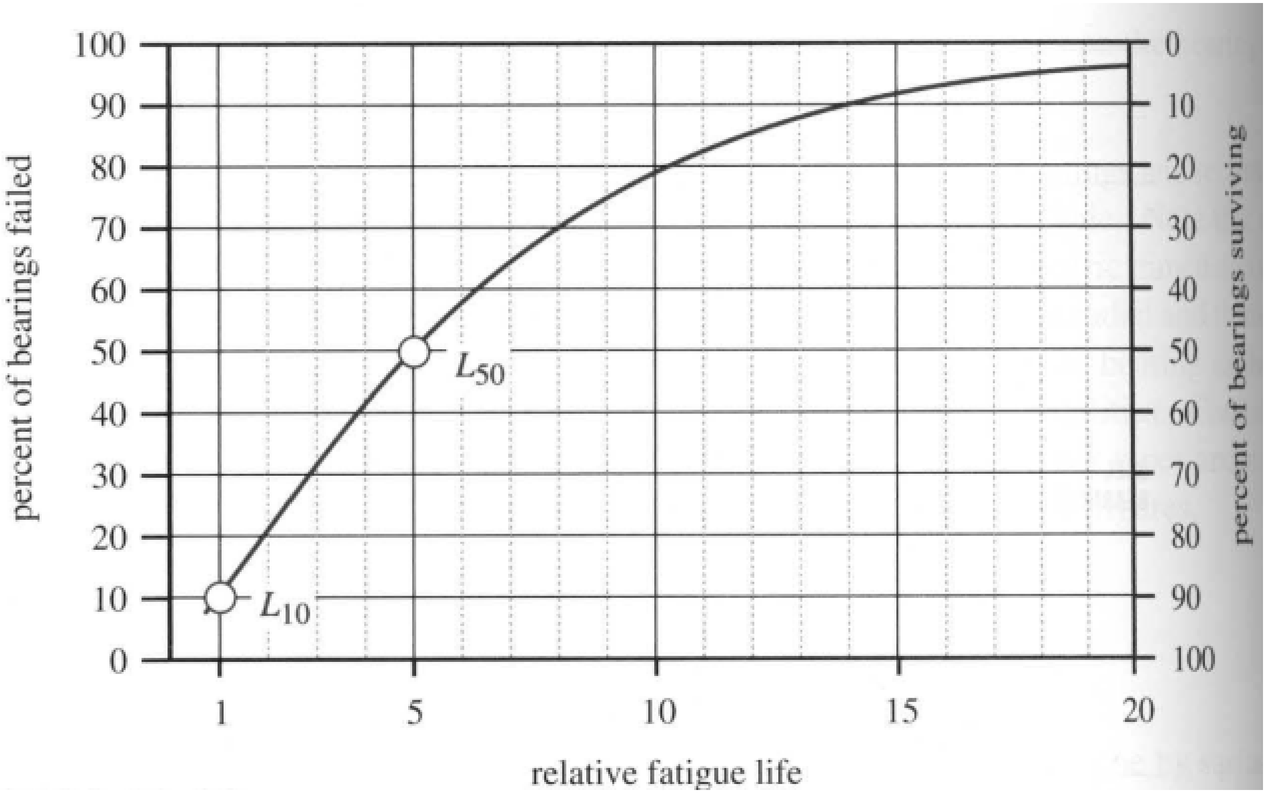
	TYPE	SIZE RANGE IN INCHES		AVERAGE RELATIVE RATINGS				AVAILABLE WITH			DIMENSIONS	
		Bore	O.D.	Capacity: Radial	Capacity: Thrust	Limiting Speed	Permissible Misalignment	Shields	Seals	Snap Rings	Metric	Inch
BALL BEARINGS	CONRAD TYPE	.1181 to 41.7323	.3750 to 55.1181	Good	Fair ↔	Conrad is basis for comparison 1.00	± 0° 8′ Std. Radial Clearance. ± 0° 12′ C3 Clear	X	X	X	X	X
	MAXIMUM TYPE	.6693 to 4.3307	1.5748 to 8.4646	Excellent	Poor ↔	1.00	± 0° 3′	X		X	X	
	ANGULAR CONTACT 15°/40° 15° / 40°	.3937 to 7.4803	1.0236 to 15.7480	Good	Good (15°) Excellent (40°) ←	1.00 / 0.70	± 0° 2′				X	
	ANGULAR CONTACT 35°	.3937 to 4.3307	1.1811 to 9.4488	Excellent	Good ←	0.70	0°				X	
	SELF-ALIGNING	.1969 to 4.7244	.7480 to 9.4488	Fair	Fair ↔	1.00	± 4°				X	
CYLINDRICAL ROLLER BEARINGS	SEPARABLE INNER RING NON-LOCATING	.4724 to 19.6850	1.2598 to 28.3465	Excellent	0	1.00	± 0° 4′				X	
	SEPARABLE INNER RING ONE DIR. LOCATING	.4724 to 12.5984	1.2598 to 22.8346	Excellent	Poor ←	1.00	± 0° 4′				X	
	SELF-CONTAINED TWO DIR. LOCATING	.4724 to 3.9370	1.4567 to 8.4646	Excellent	Poor ↔	1.00	± 0° 4′				X	

Características dos rolamentos comerciais (FAG)

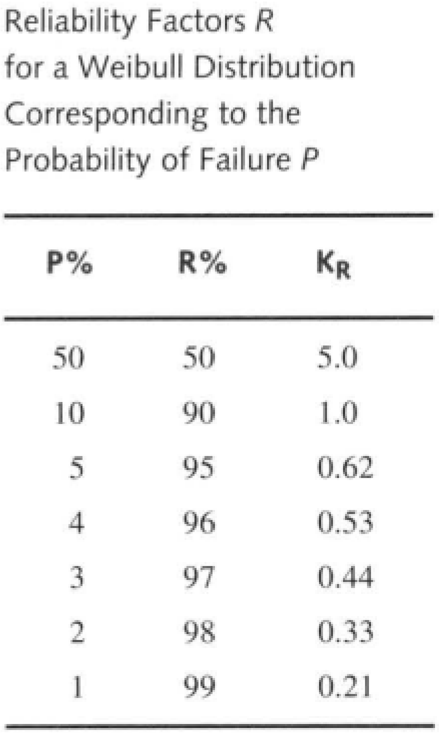


	TYPE	SIZE RANGE IN INCHES		AVERAGE RELATIVE RATINGS				AVAILABLE WITH			DIMENSIONS	
		Bore	O.D.	Capacity Radial	Capacity Thrust	Limiting Speed	Permissible Misalignment	Shields	Seals	Snap Rings	Metric	Inch
TAPERED ROLLER BEARINGS	SEPARABLE	.6205 to 6.0000	1.5700 to 10.0000	Good	Good →	0.60	± 0° 2′				X	X
SPHERICAL ROLLER BEARINGS	SELF-ALIGNING	.9843 to 12.5984	2.0472 to 22.8346	Good	Fair ↔	0.50	± 4°				X	
	SELF-ALIGNING	.9843 to 35.4331	2.0472 to 46.4567	Excellent	Good ↔	0.75	± 1°				X	
NEEDLE BEARINGS	COMPLETE BEARINGS with or without locating rings & lubricating groove	.2362 to 14.1732	.6299 to 17.3228	Good	0	0.60	± 0° 2′		X		X	X
	DRAWN CUP	.1575 to 2.3622	.3150 to 2.6772	Good	0	0.30	± 0° 2′				X	X
THRUST BEARINGS	SINGLE DIRECTION BALL Grooved Race	.2540 to 46.4567	.8130 to 57.0866	Poor	Excellent →	0.30	0°				X	X
	SINGLE DIRECTION CYL. ROLLER	1.1811 to 23.6220	1.8504 to 31.4960	0	Excellent →	0.20	0°				X	
	SELF-ALIGNING SPHERICAL ROLLER	3.3622 to 14.1732	4.3307 to 22.0472	Poor	Excellent →	0.50	± 3°				X	

Avaliação da vida de um rolamento



$$L_P = K_R L_{10}$$

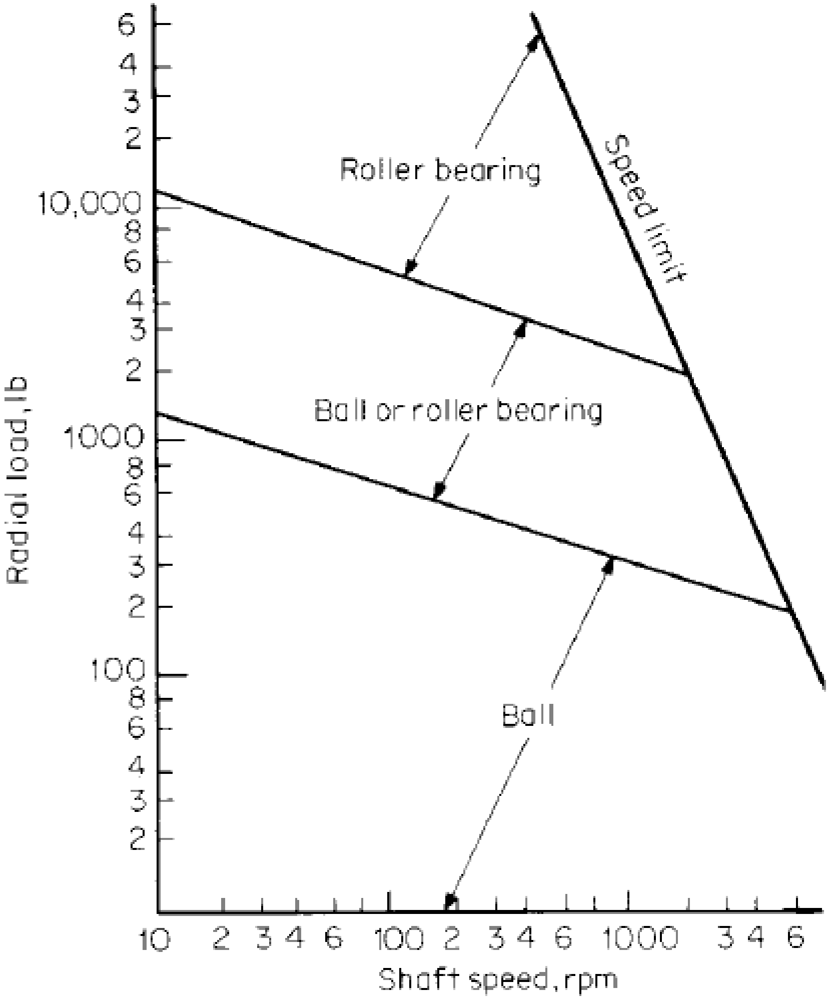


Reliability Factors *R* for a Weibull Distribution Corresponding to the Probability of Failure *P*

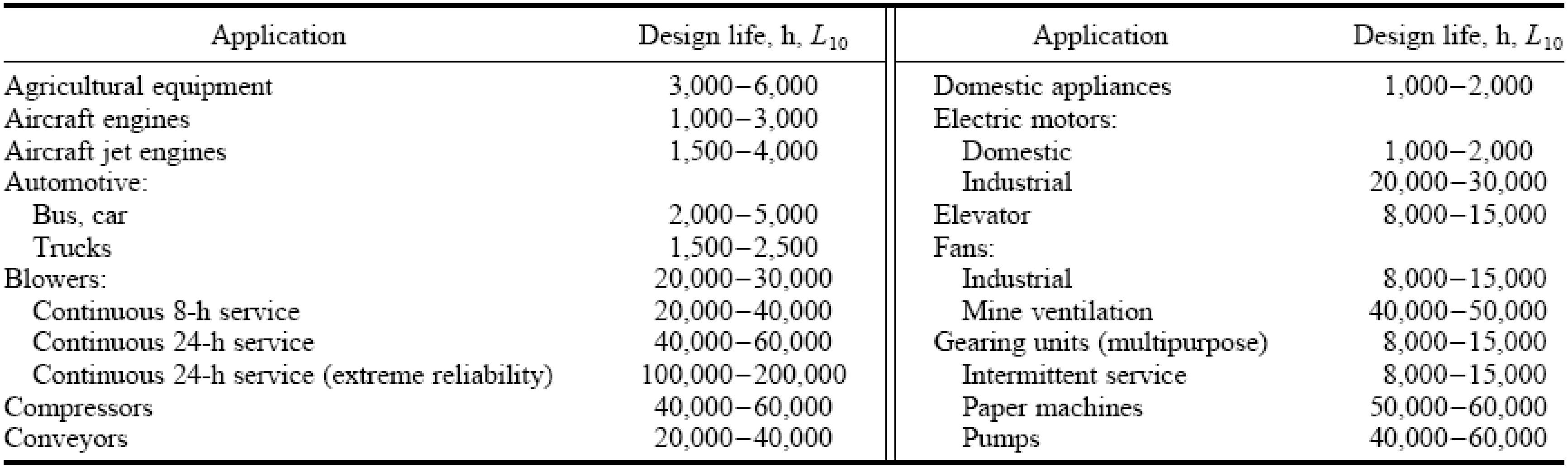
P%	R%	K_R
50	50	5.0
10	90	1.0
5	95	0.62
4	96	0.53
3	97	0.44
2	98	0.33
1	99	0.21

Avaliação da vida de um rolamento

Vida
X
Elemento rolante



Guia prático para selecao da vida do rolamento



Application	Design life, h, L_{10}	Application	Design life, h, L_{10}
Agricultural equipment	3,000–6,000	Domestic appliances	1,000–2,000
Aircraft engines	1,000–3,000	Electric motors:	
Aircraft jet engines	1,500–4,000	Domestic	1,000–2,000
Automotive:		Industrial	20,000–30,000
Bus, car	2,000–5,000	Elevator	8,000–15,000
Trucks	1,500–2,500	Fans:	
Blowers:	20,000–30,000	Industrial	8,000–15,000
Continuous 8-h service	20,000–40,000	Mine ventilation	40,000–50,000
Continuous 24-h service	40,000–60,000	Gearing units (multipurpose)	8,000–15,000
Continuous 24-h service (extreme reliability)	100,000–200,000	Intermittent service	8,000–15,000
Compressors	40,000–60,000	Paper machines	50,000–60,000
Conveyors	20,000–40,000	Pumps	40,000–60,000

Oberg, 2004

Relação entre a carga e a vida de um rolamento

ball bearings : $$L_{10} = \left(\frac{C}{P}\right)^{3}$$

roller bearings : $$L_{10} = \left(\frac{C}{P}\right)^{10/3}$$

Onde:

L_{10} é a vida à fadiga em milhões de revoluções;

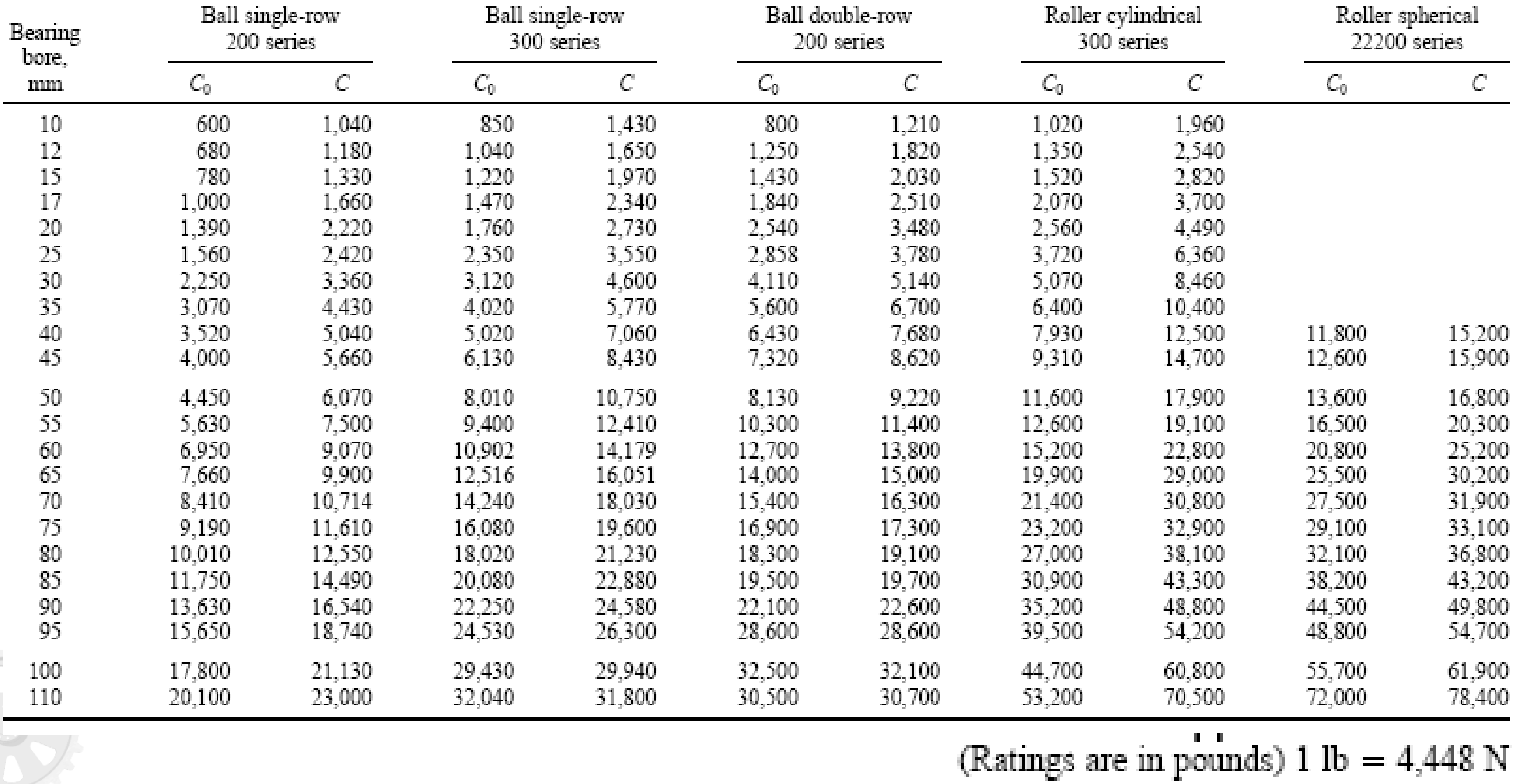
P é a carga aplicada constante

C é carga dinâmica básica para cada rolamento (a carga que irá promover uma carga de 1 milhão de rotações)

Carga estática do rolamento

- C_0 é a chamada carga estática de um rolamento que seria a carga teórica capaz de produzir uma deformação plástica de 0,0001*d* em algum dos elementos rolantes do rolamento.
- Estas cargas podem muitas vezes ser excedidas sem falha principalmente se as velocidades forem baixas.

Cargas dinâmicas e estáticas x tamanho e tipo do rolamento



Bearing bore, mm	Ball single-row 200 series		Ball single-row 300 series		Ball double-row 200 series		Roller cylindrical 300 series		Roller spherical 22200 series	
	C_0	C	C_0	C	C_0	C	C_0	C	C_0	C
10	600	1,040	850	1,430	800	1,210	1,020	1,960		
12	680	1,180	1,040	1,650	1,250	1,820	1,350	2,540		
15	780	1,330	1,220	1,970	1,430	2,030	1,520	2,820		
17	1,000	1,660	1,470	2,340	1,840	2,510	2,070	3,700		
20	1,390	2,220	1,760	2,730	2,540	3,480	2,560	4,490		
25	1,560	2,420	2,350	3,550	2,858	3,780	3,720	6,360		
30	2,250	3,360	3,120	4,600	4,110	5,140	5,070	8,460		
35	3,070	4,430	4,020	5,770	5,600	6,700	6,400	10,400		
40	3,520	5,040	5,020	7,060	6,430	7,680	7,930	12,500	11,800	15,200
45	4,000	5,660	6,130	8,430	7,320	8,620	9,310	14,700	12,600	15,900
50	4,450	6,070	8,010	10,750	8,130	9,220	11,600	17,900	13,600	16,800
55	5,630	7,500	9,400	12,410	10,300	11,400	12,600	19,100	16,500	20,300
60	6,950	9,070	10,902	14,179	12,700	13,800	15,200	22,800	20,800	25,200
65	7,660	9,900	12,516	16,051	14,000	15,000	19,900	29,000	25,500	30,200
70	8,410	10,714	14,240	18,030	15,400	16,300	21,400	30,800	27,500	31,900
75	9,190	11,610	16,080	19,600	16,900	17,300	23,200	32,900	29,100	33,100
80	10,010	12,550	18,020	21,230	18,300	19,100	27,000	38,100	32,100	36,800
85	11,750	14,490	20,080	22,880	19,500	19,700	30,900	43,300	38,200	43,200
90	13,630	16,540	22,250	24,580	22,100	22,600	35,200	48,800	44,500	49,800
95	15,650	18,740	24,530	26,300	28,600	28,600	39,500	54,200	48,800	54,700
100	17,800	21,130	29,430	29,940	32,500	32,100	44,700	60,800	55,700	61,900
110	20,100	23,000	32,040	31,800	30,500	30,700	53,200	70,500	72,000	78,400

(Ratings are in pounds) 1 lb = 4,448 N

Combinação de cargas radiais e axiais

$$P = XVF_r + YF_a$$

$$\text{if} \quad \frac{F_a}{VF_r} \le e \qquad \text{then } X = 1 \text{ and } Y = 0$$

P = equivalent load

F_r = applied constant radial load

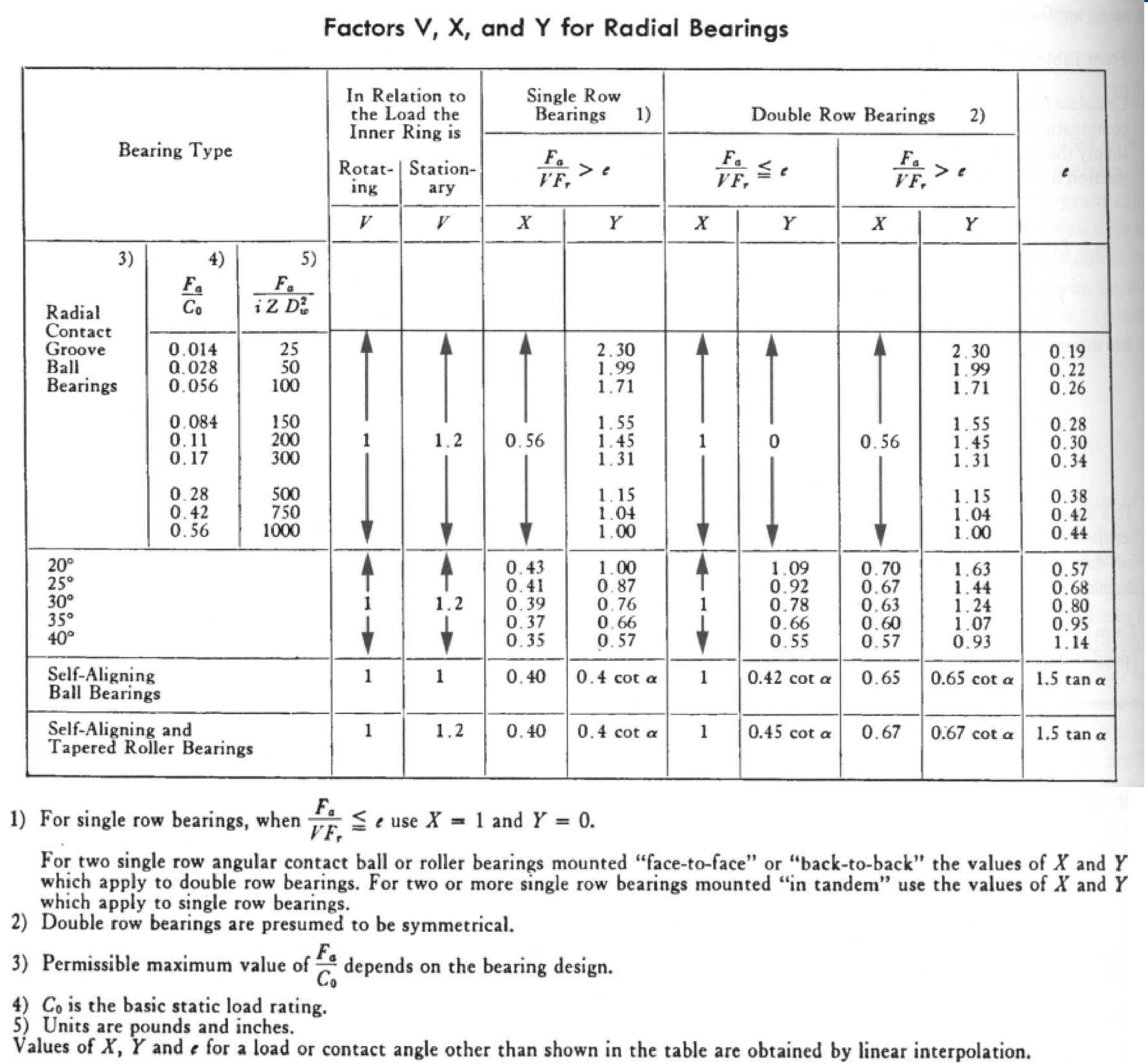
F_a = applied constant thrust load

V = a rotation factor (see Figure 10-24)

X = a radial factor (see Figure 10-24)

Y = a thrust factor (see Figure 10-24)

As cargas axiais são consideradas desprezíveis



Factors V, X, and Y for Radial Bearings

Bearing Type			In Relation to the Load the Inner Ring is: Rotating	Stationary	Single Row Bearings 1) $\frac{F_a}{VF_r} > e$		Double Row Bearings 2) $\frac{F_a}{VF_r} \leq e$		$\frac{F_a}{VF_r} > e$		e
			V	V	X	Y	X	Y	X	Y	
3) Radial Contact Groove Ball Bearings	4) $\frac{F_a}{C_0}$	5) $\frac{F_a}{iZD_w^2}$									
	0.014	25	1	1.2	0.56	2.30	1	0	0.56	2.30	0.19
	0.028	50				1.99				1.99	0.22
	0.056	100				1.71				1.71	0.26
	0.084	150				1.55				1.55	0.28
	0.11	200				1.45				1.45	0.30
	0.17	300				1.31				1.31	0.34
	0.28	500				1.15				1.15	0.38
	0.42	750				1.04				1.04	0.42
	0.56	1000				1.00				1.00	0.44
20°			1	1.2	0.43	1.00	1	1.09	0.70	1.63	0.57
25°					0.41	0.87		0.92	0.67	1.44	0.68
30°					0.39	0.76		0.78	0.63	1.24	0.80
35°					0.37	0.66		0.66	0.60	1.07	0.95
40°					0.35	0.57		0.55	0.57	0.93	1.14
Self-Aligning Ball Bearings			1	1	0.40	0.4 cot α	1	0.42 cot α	0.65	0.65 cot α	1.5 tan α
Self-Aligning and Tapered Roller Bearings			1	1.2	0.40	0.4 cot α	1	0.45 cot α	0.67	0.67 cot α	1.5 tan α

1) For single row bearings, when $\frac{F_a}{VF_r} \leq e$ use $X = 1$ and $Y = 0$.

For two single row angular contact ball or roller bearings mounted "face-to-face" or "back-to-back" the values of X and Y which apply to double row bearings. For two or more single row bearings mounted "in tandem" use the values of X and Y which apply to single row bearings.

2) Double row bearings are presumed to be symmetrical.

3) Permissible maximum value of $\frac{F_a}{C_0}$ depends on the bearing design.

4) C_0 is the basic static load rating.

5) Units are pounds and inches.

Values of X, Y and e for a load or contact angle other than shown in the table are obtained by linear interpolation.

Vida a fadiga modificada

$$L_{10} \text{ modified} = A_1 A_2 A_3 \frac{16{,}700}{N} \left(\frac{C}{P} \right)^K$$

Table 8.5.5 Reliability Factor A_1 for Various Survival Rates

Survival rate, %	Bearing life notation	Reliability factor A_1
90	L_{10}	1.00
95	L_5	0.62
96	L_4	0.53
97	L_3	0.44
98	L_2	0.33
99	L_1	0.21

Table 8.5.6 Life-Modifying Factor A_2

Material	Factor A_2
A1S1 440C, Air Melted	0.025
SAE 52100, Vacuum Processed	1.0
M50 VIM-VAR Melted	2.0

A_3 varia de 1 à 3 dependendo da qualidade da lubrificacao

Limite de velocidade

- Para limitar a velocidade limite do rolamento devem ser avaliados vários fatores como.
  - Tamanho, rotacao, tolerancias, carga de contato, tipo e material da gaiola, temperatura lubrificacao, etc.
- Uma verificacao direta pode ser feita avaliandose o valor dn value.

Valor d_n

$$dn = \text{bore (mm)} \times \text{speed (r/min)}$$

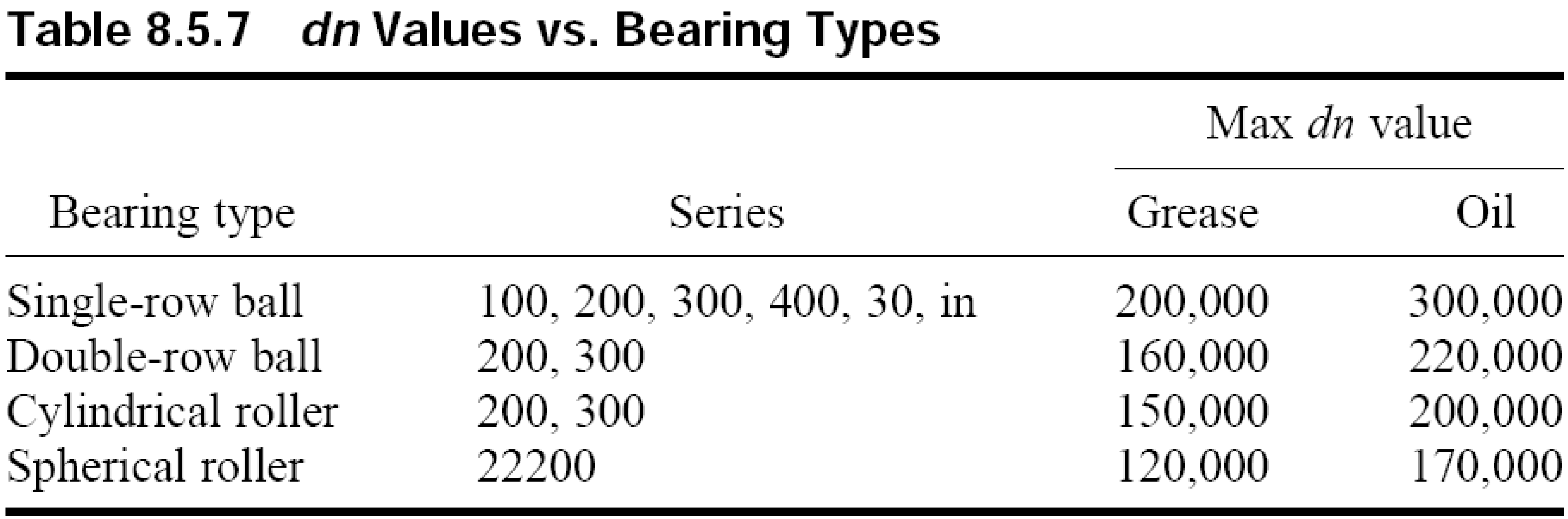


Table 8.5.7 ***dn* Values vs. Bearing Types**

		Max *dn* value	
Bearing type	Series	Grease	Oil
Single-row ball	100, 200, 300, 400, 30, in	200,000	300,000
Double-row ball	200, 300	160,000	220,000
Cylindrical roller	200, 300	150,000	200,000
Spherical roller	22200	120,000	170,000

Procedimento de selecao de rolamento

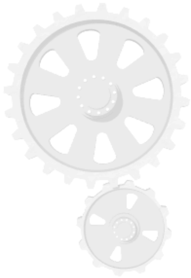
- Selecao do tamanho do rolamento, conhecidos tipo e série:
  - Seleciona a vida de projeto;
  - Calcular a carga radial equivalente, P;
  - Calcular a carga necessária, Cr;
  - Comparar Cr com os valores de C, e selecione o diametro interno.
  - Checar a velocidade limite.

Procedimento de selecao de rolamento

- Selecao do tipo do rolamento conhecidos o tamanho do furo e a vida;
  - Selecionar o tipo de elemento do rolamento;
  - Calcular a carga equivalente, P;
  - Calcular a carga necessária, Cr;
  - Comparar Cr com os valores de C, e selecione o diametro interno.
  - Checar a velocidade limite.

Procedimento de selecao de rolamento

- Determinacao da vida do rolamento, conhecendo o tamanho do rolamento
  - Selecionar o tipo de elemento do rolamento;
  - Calcular a carga radial equivalente, P;
  - Calcular a carga necessária, Cr;
  - Comparar Cr com os valores de C, e selecione o diametro interno.
  - Checar a velocidade limite.



Tipos diferentes de rolamentos

- Rolamentos plásticos:
  - Elementos rolantes feitos de resina de acetato;
  - Usados em aplicacoes de difícil lubrificacao, condicoes excessivamentes abrasivas e corrosivas.
  - Menores condicoes de carga e maiores coeficientes de atrito.
  - Resistencia a identacoes devidas ao choque.

Material

- Acos liga completamente endurecidos;
- Gaiola:
  - Aplicacoes convencionais: Acos de baixo carbon sulfurados, aco estampado com ou sem fosfatacao.
  - Aplicacoes de alta velocidade ou com lubrificacao intermitente: Iron-silicon-bronze, laminated phenolics, silver-plating, over-lays, solid-film baked-on coatings, carbon-graphite.
  - Casos extremos: materiais sinterizados e impregnados.
- Sendo a lubrificacao e a velocidade adequados entao torna-se o projeto da gaiola de importancia secundaria quando relacionado com os elementos rolantes.

Lubrificacao

Viscosidade de Aplicacao

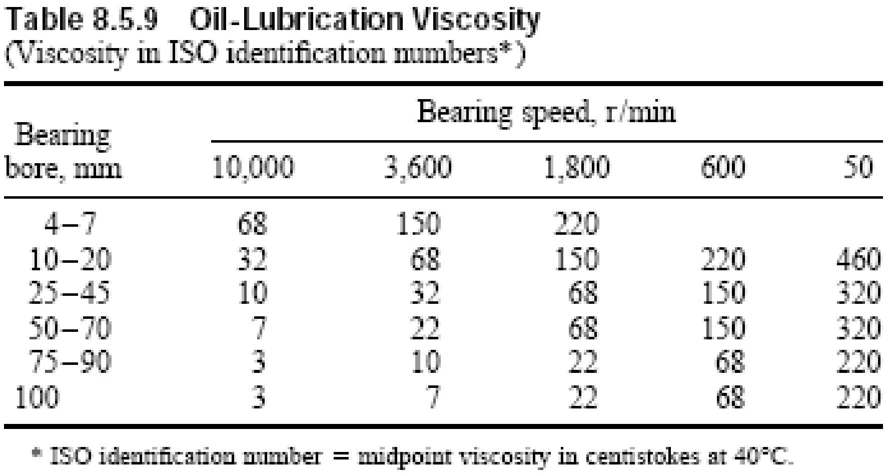


Table 8.5.9 Oil-Lubrication Viscosity
(Viscosity in ISO identification numbers*)

Bearing bore, mm	Bearing speed, r/min				
	10,000	3,600	1,800	600	50
4–7	68	150	220		
10–20	32	68	150	220	460
25–45	10	32	68	150	320
50–70	7	22	68	150	320
75–90	3	10	22	68	220
100	3	7	22	68	220

* ISO identification number = midpoint viscosity in centistokes at 40°C.

Períodos de Lubrificacao

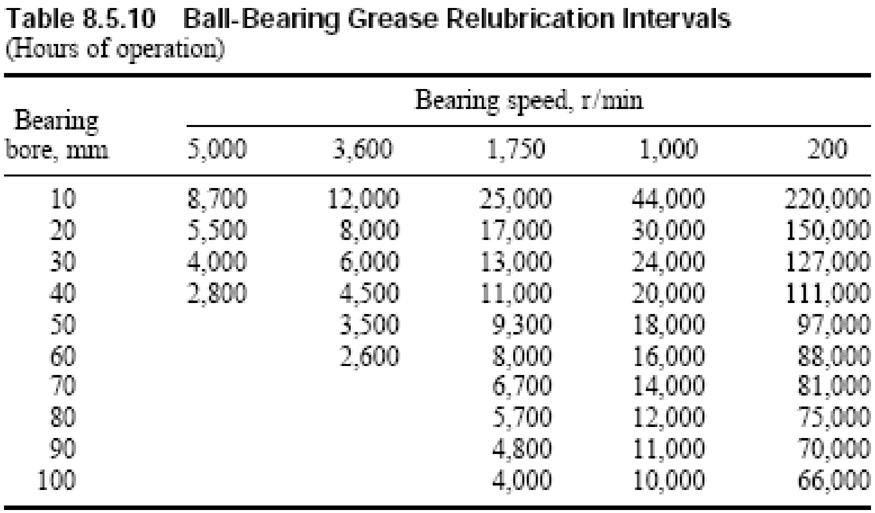


Table 8.5.10 Ball-Bearing Grease Relubrication Intervals
(Hours of operation)

Bearing bore, mm	Bearing speed, r/min				
	5,000	3,600	1,750	1,000	200
10	8,700	12,000	25,000	44,000	220,000
20	5,500	8,000	17,000	30,000	150,000
30	4,000	6,000	13,000	24,000	127,000
40	2,800	4,500	11,000	20,000	111,000
50		3,500	9,300	18,000	97,000
60		2,600	8,000	16,000	88,000
70			6,700	14,000	81,000
80			5,700	12,000	75,000
90			4,800	11,000	70,000
100			4,000	10,000	66,000

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