Complements of Machine Elements
Formulary Rolling Bearings

Carlos M. C. G. Fernandes

1 Rolling bearings

1.1 Static load safety factor

$$S_0 = \frac{C_0}{P_0}$$

The equivalent static load is the greatest of the following values:

$$P_0 = X_0 \cdot F_{0r} + Y_0 \cdot F_{0a}$$

$$P_0 = F_{0r}$$

- C_0 - Basic static load ration (Rolling Bearing Catalog) / N;
- P_0 - Equivalent static load / N;
- F_{0r} - radial static load / N;
- F_{0a} - axial static load / N;
- X_0 - radial factor (Rolling Bearing Catalog);
- Y_0 - axial factor (Rolling Bearing Catalog).

The recommended static safety factors are given on Table 1.

Table 1: Static safety factor S_0.

Type of operation	Characteristics	Ball bearings	Roller bearings
Quiet running applications	smooth-running vibration-free high rotational accuracy	2	3
Normal-running applications	smooth-running vibration-free normal rotational accuracy	1	1.5
Applications subjected to shock loads	pronounced shock loads[a]	1.5	3

[a] If the magnitude of the load is not known, $S_0 > 1.5$.
If the magnitude of the shock loads is known exactly $S_0 > 1.5$ can be applied.

1.2 Basic rating life

$$L_{10} = \left(\frac{C}{P}\right)^p \cdot 10^6$$

$$L_{10\ h} = \frac{10^6}{60 \cdot n} \cdot \left(\frac{C}{P}\right)^p$$

$$P = X \cdot F_r + Y \cdot F_a$$

- L_{10} - basic rating life;
- $L_{10\ h}$ - basic rating life in hours
- C - Basic dynamic load rating (Rolling Bearing Catalog) / N
- P - Equivalent dynamic load / N
- n - operating speed / rpm
- p - exponent depending on the bearing type:
  - roller bearings: $p = 10/3$
  - ball bearings: $p = 3$

1.3 Adjusted rating life

$$L_{10} = \left(\frac{C}{P}\right)^p \cdot 10^6$$

$$L_{na} = a_1 \cdot a_2 \cdot a_3 \cdot L_{10}$$

- a_1 – Life adjustment factor for reliability [1]
- a_2 – Life adjustment factor for special bearing properties [1]
- a_3 – Life adjustment factor for operating conditions [1]

1.4 Expanded adjusted rating life

$$L_{nm} = a_1 \cdot a_{ISO} \cdot L_{10}$$

- a_1 – Life adjustment factor for reliability [2] (Table 2)
- a_{ISO} – Life adjustment factor for operating conditions (Figure 1) [2].

The a_{ISO} is function of the following factors (Figure 1, 2, 3 and 4):

$$a_{ISO} = f\left(\frac{e_C \cdot C_u}{P}, \kappa\right)$$

- e_C – life adjustment factor for contamination (Table 3);

- C_u - fatigue limit load;
- $\kappa = \frac{\nu}{\nu_1}$ is the viscosity ratio.
- ν - actual operating viscosity of the lubricant / $\mathrm{mm^2\,s^{-1}}$
- ν_1 - rated viscosity, function of the mean bearing diameter and rotational speed (Figure 5) / $\mathrm{mm^2\,s^{-1}}$

Table 2: Life adjustment factor for reliability a_1 [2].

Reliability %	L_{nm}	a_1
90	$L_{10\ m}$	1
95	$L_{5\ m}$	0.64
96	$L_{4\ m}$	0.55
97	$L_{3\ m}$	0.47
98	$L_{2\ m}$	0.37
99	$L_{1\ m}$	0.25
99.2	$L_{0.8\ m}$	0.22
99.4	$L_{0.6\ m}$	0.19
99.6	$L_{0.4\ m}$	0.16
99.8	$L_{0.2\ m}$	0.12
99.9	$L_{0.1\ m}$	0.093
99.92	$L_{0.08\ m}$	0.087
99.94	$L_{0.06\ m}$	0.080
99.95	$L_{0.05\ m}$	0.077

Table 3: Contamination factor e_C ($dm = \frac{D+d}{2}$) [2].

Level of contamination	$d_m < 100\,\mathrm{mm}$	$d_m \geq 100\,\mathrm{mm}$
Extreme cleanliness	1	1
High cleanliness	0.8–0.6	0.9–0.8
Normal cleanliness	0.6–0.5	0.8–0.6
Slight contamination	0.5–0.3	0.6–0.4
Typical contamination	0.3–0.1	0.4–0.2
Severe contamination	0.1–0	0.1–0
Very severe contamination	0	0

The a_{ISO} in the SKF bearing manufacturer catalog is defined as $a_{SKF} = f\left(\frac{\eta_C \cdot P_u}{P}, \kappa\right)$

2 Coulomb model for rolling bearings

$$M_t = \mu \cdot F \cdot \frac{d}{2}$$

$$F = \sqrt{{F_r}^2 + {F_a}^2}$$

- M_t – total friction torque / N mm
- μ – coefficient of friction (Table 4)
- d – bearing inner diameter / mm
- F – bearing load / N
- F_r – radial load / N
- F_a – axial load / N

Table 4: Coulomb coefficient of friction values for different rolling bearing types.

Bearing type	Coefficient of friction $\mu \times 10^{-3}$
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
Self-aligning roller bearings	2.0–2.5
Thrust ball bearings	1.0–1.5
Thrust roller bearings	2.0–3.0

3 Arvrid Palmgren model for rolling bearings

$$M_t = M_0 + M_1$$

$$M_0 = f_0 \cdot 10^{-7} \cdot (\nu \cdot n)^{2/3} \cdot d_m^3$$

$$M_1 = \mu_1 \cdot f_1 \cdot F \cdot \frac{d_m}{2}$$

$$F = \sqrt{{F_r}^2 + {F_a}^2}$$

$$d_m = \frac{D + d}{2}$$

- μ_1 – coefficient of friction depending on load and bearing type [3]

- ν – kinematic viscosity of the lubricant at the operating temperature / $\mathrm{mm^2\,s^{-1}}$
- d – bearing inner diameter / mm
- D – bearing outer diameter / mm
- d_m – bearing mean (or pitch) diameter / mm
- f_0 – coefficient taking into account the bearing type and lubrication method [3, 4]
- f_1 – coefficient that considers the direction of load application [3, 4]
- F – bearing load / N
- F_r – radial force / N
- F_a – axial force / N
- M_0 – no-load bearing friction torque / N mm
- M_1 – load-dependent bearing friction torque / N mm
- M_t – total friction torque / N mm
- n – bearing speed / rpm

References

[1] ISO 281:1990: *Rolling bearings - Dynamic load ratings and rating life*. International Organization for Standardization, 2nd edition, 2007.

[2] ISO 281:2007: *Rolling bearings - Dynamic load ratings and rating life*. International Organization for Standardization, 2nd edition, 2007.

[3] Harris, Tedric A. and Michael N. Kotzalas: *Advanced Concepts of Bearing Technology*. CRC Press, 2007, ISBN 9788578110796.

[4] Brändlein, J., U. Merkle-Eschmann, P. Eschmann, L. Hasbargen, and K. Weigand: *Ball and Roller Bearings: Theory, Design and Application*. Wiley, 1999, ISBN 9780471984528.

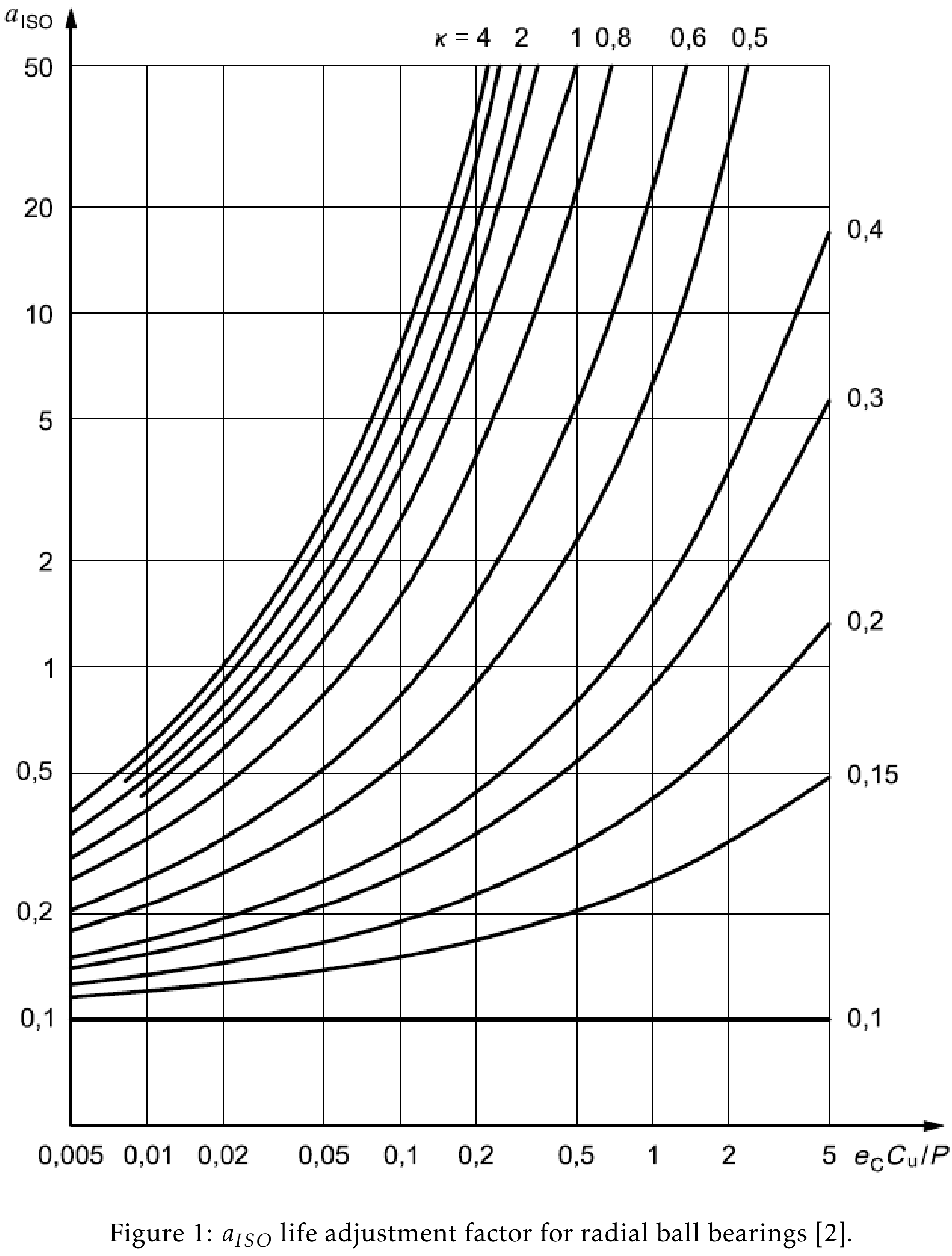

Figure 1: a_{ISO} life adjustment factor for radial ball bearings [2].

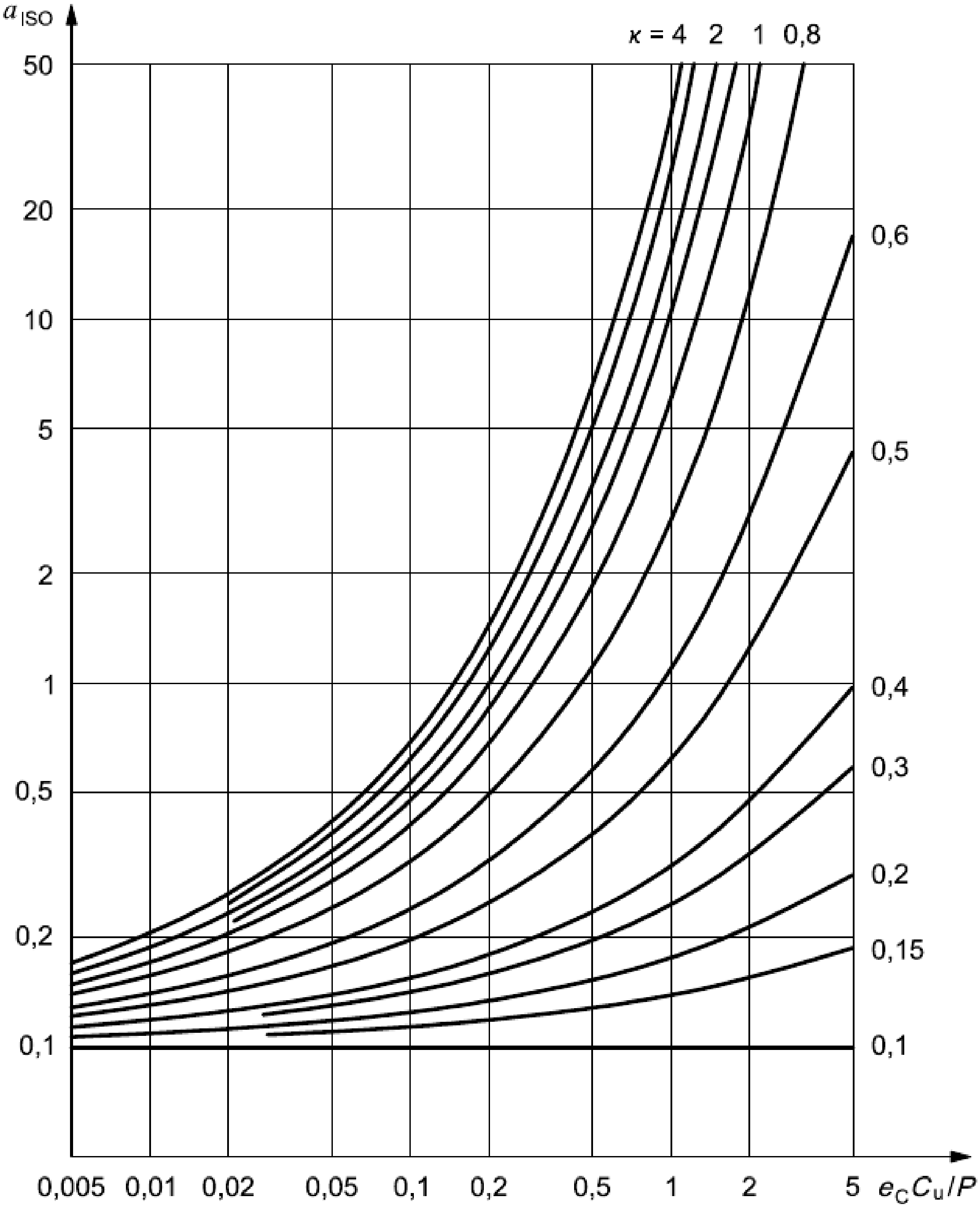

Figure 2: a_{ISO} life adjustment factor for radial roller bearings [2].

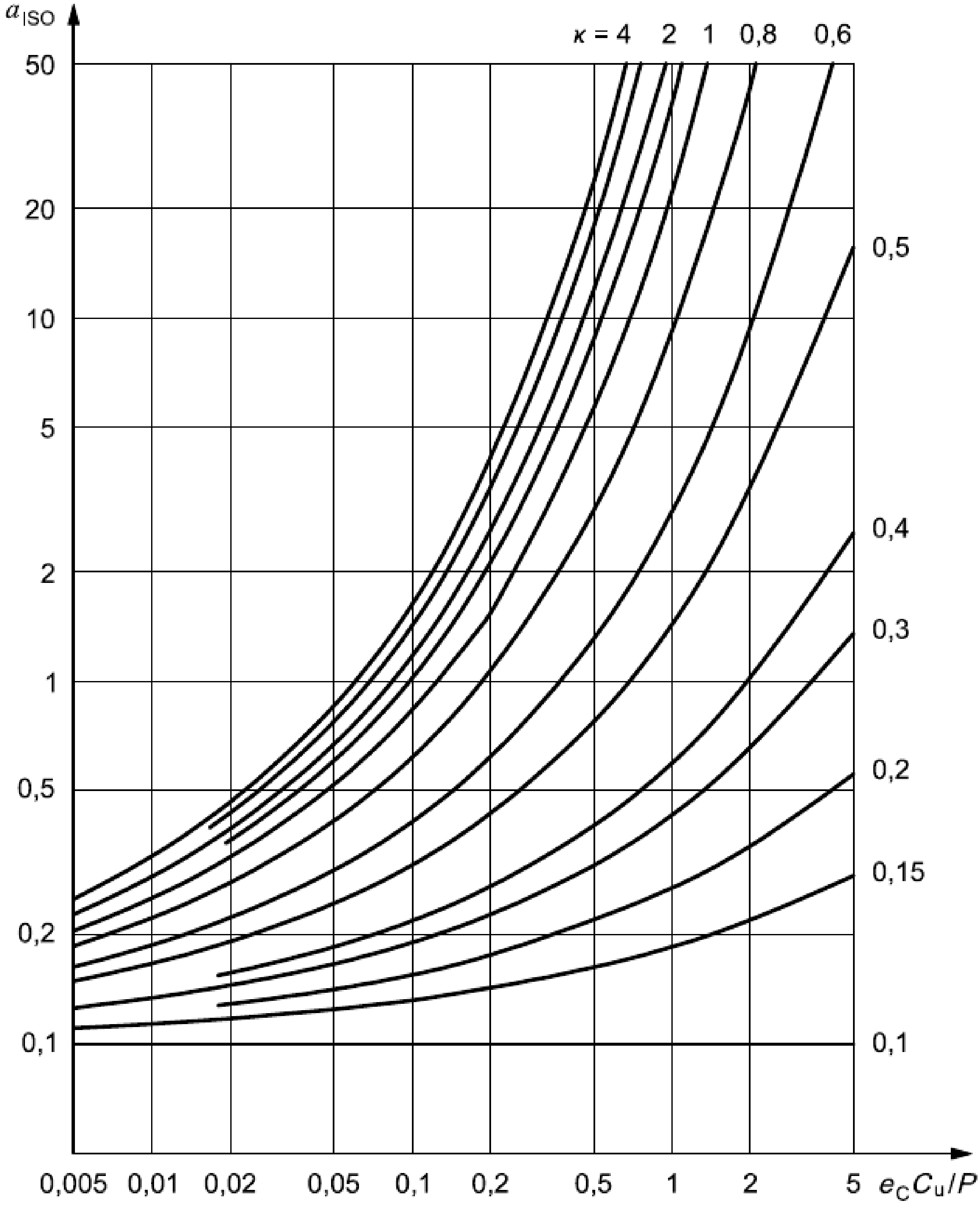

Figure 3: a_{ISO} life adjustment factor for thrust ball bearings [2].

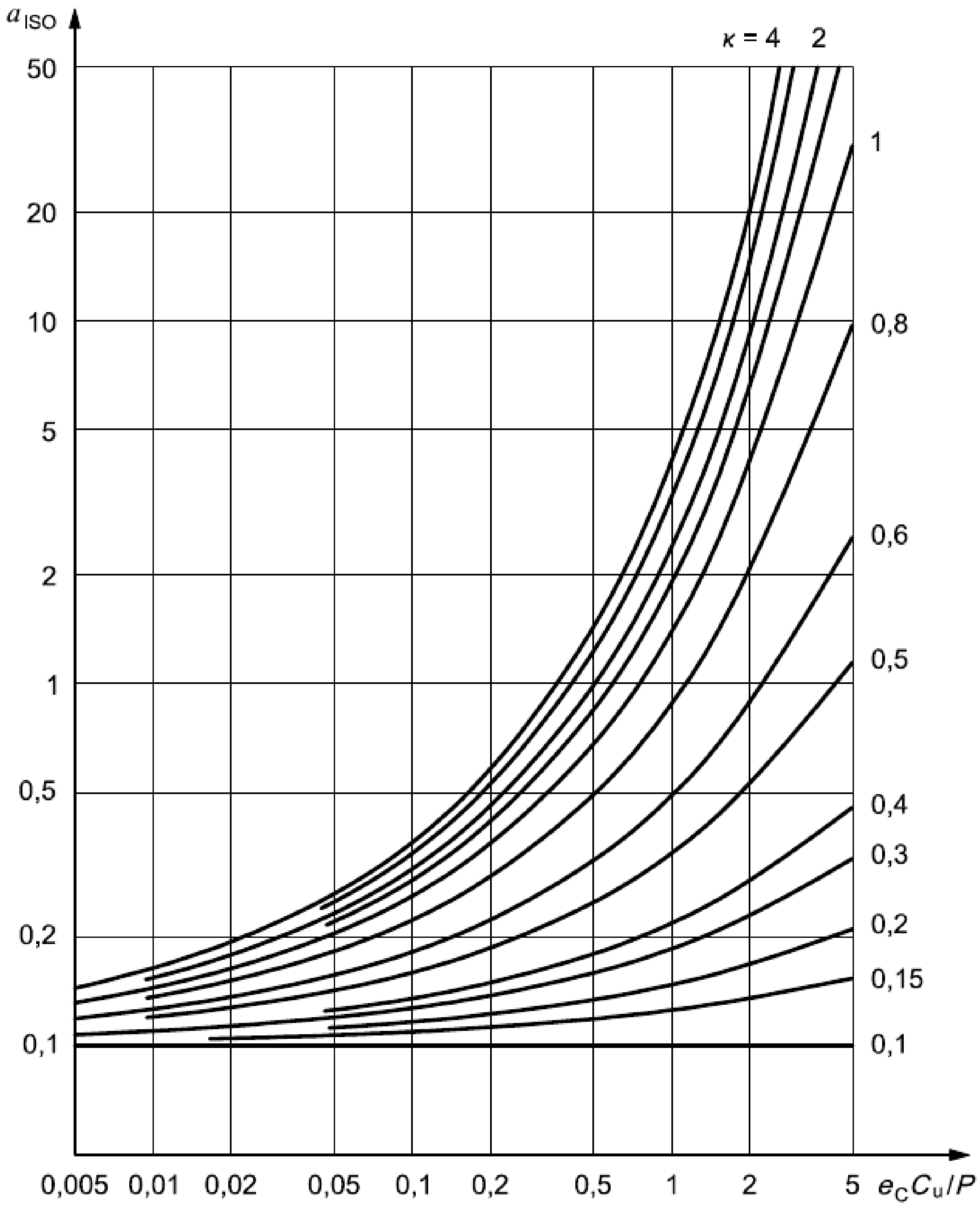

Figure 4: a_{ISO} life adjustment factor for thrust roller bearings [2].

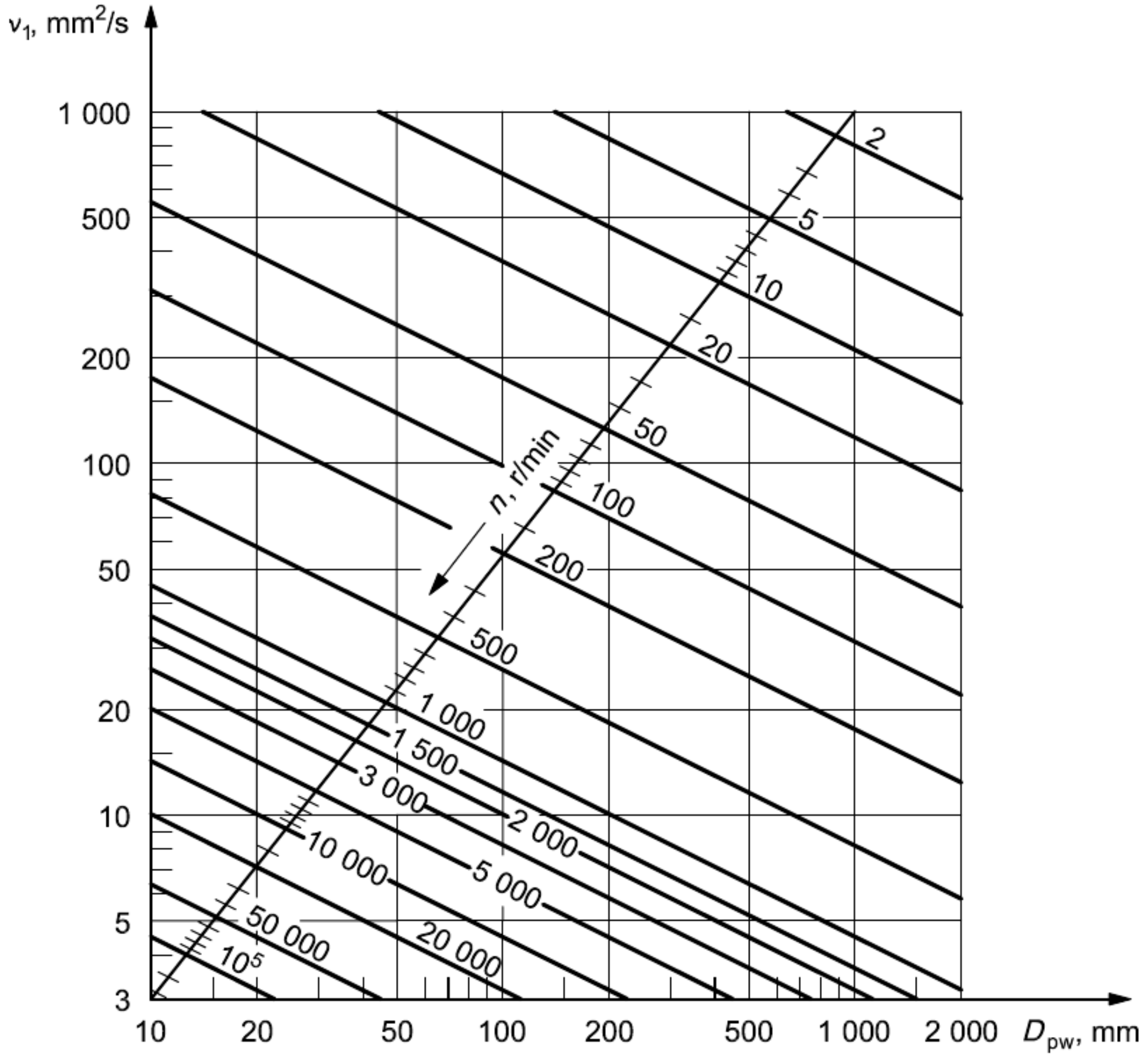

Figure 5: Rated viscosity ν_1 ($D_{pw} = dm = \frac{D+d}{2}$) [2].