SICK AG WHITEPAPER

SERVICE LIFE OF DEEP GROOVE BALL BEARINGS (SUPPLEMENTARY IN-FORMATION TO THE DATA SHEET SPECIFICATIONS)

AUTHORS

Josef Maier
Development Engineer Mechanik, Encoder, SICK AG

Rolf Wehrle
Development Engineer Mechanik, Motor-Feedback-Systeme, SICK AG

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CONTENT

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Introduction

Deep groove ball bearings are used in encoders and motor feedback systems. For the sake of simplicity, encoders as well as motor feedback systems will be referred to as encoders in the following text.

The service life of the deep groove ball bearings is usually the determining factor for the limited operating life of encoders. The theoretically determined service life specified in the data sheet and the actual service life of the deep groove ball bearings in operation may vary on a case by case basis. This is due to a variety of influencing factors such as speed, temperature, axial and radial forces, as well as contamination that affect the encoder over time. Depending on the application, actual values and the values used in the calculation may differ.

This paper therefore discusses the specific calculation details.

Basic construction of an encoder bearing system

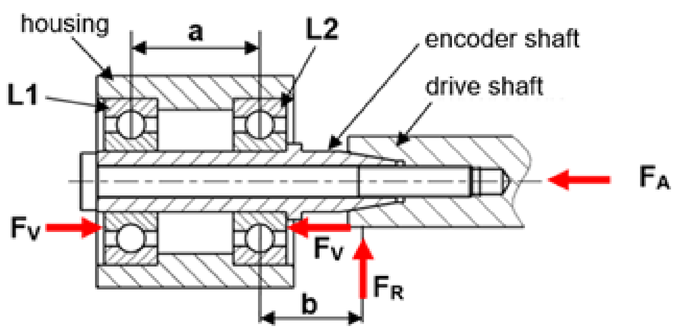

Figure 1

An encoder has 2 deep groove ball bearings L1 and L2, which are axially preloaded with the force FV in an O arrangement to produce zero backlash. The separation a between the deep groove ball bearings depends on the type of encoder. During operation, an additional axial force FA and a radial force FR act on the deep groove ball bearings at a distance b apart. Figure 1 shows a basic design with a conical connection to the drive shaft.

Calculation of the bearing service life

The service life of the bearing is calculated according to ISO/TS 16281 (Formula 1). In the data sheets, a modified reference service life L10mr is calculated for the encoders. The number 10 stands for a failure probability of 10% according to ISO 281 (Formula 2).

Modified reference service life Lnmr, in 10^6 revolutions

$$Lnmr = a1 * a_{ISO} * \left(\frac{Cr}{Pref,r}\right)^3$$

Formula 1

Life modification factor for reliability a1

The life modification factor for reliability a1 represents the failure probability of deep groove ball bearings. The values of a1 can be used to derive other bearing service life values, see Table 1.

Reliability %	L_{nm}	a_1
90	L_{10m}	1
95	L_{5m}	0,64
96	L_{4m}	0,55
97	L_{3m}	0,47
98	L_{2m}	0,37
99	L_{1m}	0,25
99,2	$L_{0,8m}$	0,22
99,4	$L_{0,6m}$	0,19
99,6	$L_{0,4m}$	0,16
99,8	$L_{0,2m}$	0,12
99,9	$L_{0,1m}$	0,093
99,92	$L_{0,08m}$	0,087
99,94	$L_{0,06m}$	0,080
99,95	$L_{0,05m}$	0,077

Table 1

Life modification factor a_{ISO}

The life modification factor a_{ISO} takes into account the operating conditions as well as the lubricant and the cleanliness.

$$a_{ISO} = f\left(\frac{ec * Cu}{P}, k\right)$$

Formula 2

The value for a_{ISO} can be determined graphically using Figure 2.
For practical reasons, the modification factor is limited to $a_{ISO} \leq 50$. This limit shall also apply when:

$$\frac{e_C * c_U}{P} > 5$$

is.

For values Werte k > 4 the value k = 4 is used.

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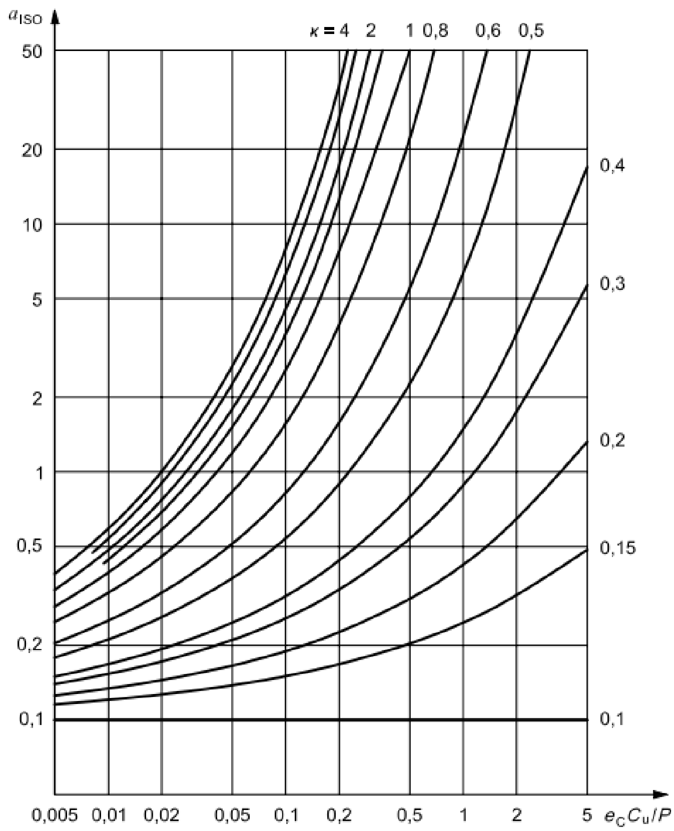

Figure 2

Contamination factor e_c

The contamination factor e_c takes into account the effect of contamination. A value of $e_c = 0.6$ is used for deep groove ball bearings of encoders, see Table 2.

Level of contamination	e_C	
	$D_{pw} < 100$ mm	$D_{pw} \geqslant 100$ mm
Extreme cleanliness Particle size of the order of lubricant film thickness; laboratory conditions	1	1
High cleanliness Oil filtered through extremely fine filter; conditions typical of bearing greased for life and sealed	0,8 to 0,6	0,9 to 0,8
Normal cleanliness Oil filtered through fine filter; conditions typical of bearings greased for life and shielded	0,6 to 0,5	0,8 to 0,6
Slight contamination Slight contamination in lubricant	0,5 to 0,3	0,6 to 0,4
Typical contamination Conditions typical of bearings without integral seals; course filtering; wear particles and ingress from surroundings	0,3 to 0,1	0,4 to 0,2
Severe contamination Bearing environment heavily contaminated and bearing arrangement with inadequate sealing	0,1 to 0	0,1 to 0
Very severe contamination	0	0

Table 2

Fatigue load limit C_u

The fatigue load limit C_u is defined as the load at which the limit fatigue stress is reached at the most heavily loaded raceway contact [2]. This complex calculation is not shown here.

Dynamic equivalent reference load P

The dynamic equivalent reference load P is calculated from the radial bearing load Fr and the axial bearing load Fa.

$$P = X * Fr + Y * Fa$$

Formula 3

The values for X and Y are shown in Table 3.

Bearing type	$\frac{F_a}{F_r} \leqslant e$		$\frac{F_a}{F_r} > e$		e
	X	Y	X	Y	
Single-row, $\alpha \neq 0°$	1	0	0,4	$0,4 \cot\alpha$	$1,5 \tan\alpha$
Double-row, $\alpha \neq 0°$	1	$0,45 \cot\alpha$	0,67	$0,67 \cot\alpha$	$1,5 \tan\alpha$

Table 3

Viscosity ratio κ

$$k = \frac{v}{v_1}$$

Formula 4

$$\nu_1 = 45\,000 * n^{-0,83} * D_{pw}^{-0,5} \text{ for } n < 1\,000 \text{ r/min}$$

Formula 5

$$\nu_1 = 4\,500 * n^{-0,5} * D_{pw}^{-0,5} \quad \text{for } n \geq 1\,000 \text{ r/min}$$

Formula 6

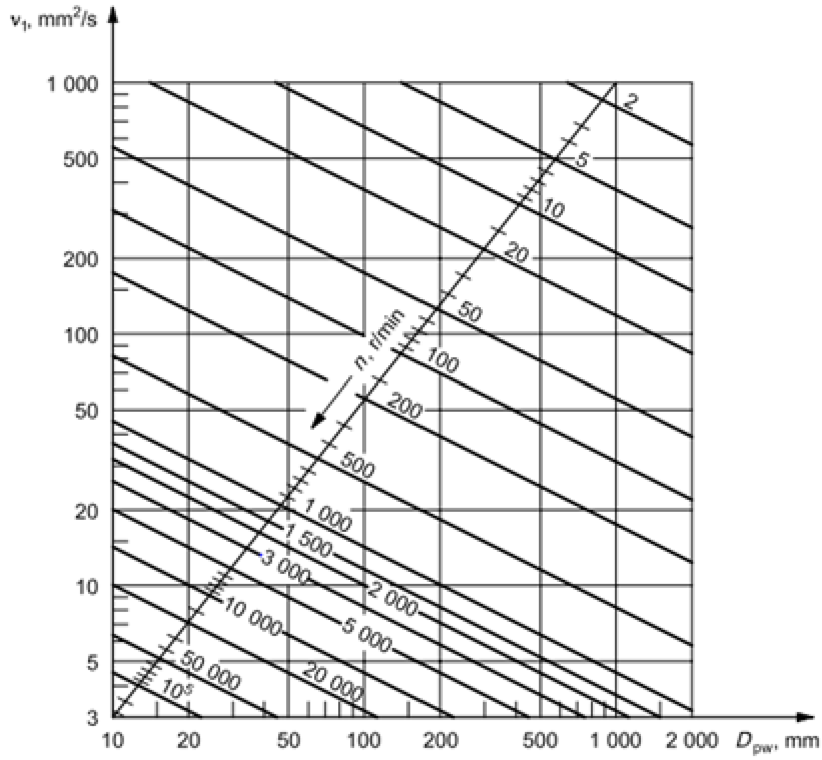

Figure 3

The reference viscosity can be calculated using the formula 5 or 6 or determined graphically see Figure 3.

Theoretical service life of grease F_{10q}

$$F_{10q} = F_{10} * K_n * K_B * F_1 * F_2 * F_3 * F_4 * F_5 * F_6$$

Formula 7

Expected grease service life F_{10}

Values for the grease service life F_{10} can be found in the data sheets of the grease manufacturer.

Speed factor K_n

Values for the speed factor K_n can be found in the data sheets of the grease manufacturer.

Bearing type K_B

$$K_{B=} K_f(test\ bearing)/K_f(application)$$

Formula 8

Bearing design	K_r
Single row deep groove ball bearing	0.9 to 1.1
Double row deep groove ball bearing	1.5
Single row angular contact ball bearing	1.6
Double row angular contact ball bearing	2
Spindle bearing a = 15°	0.75
Spindle bearing a = 25°	0.9
Four-point bearing	1.6
Self-aligning ball bearing	1.3 to 1.6
Thrust deep groove ball bearing	5 to 6
Thrust double row angular contact ball bearing	1.4
Single row cylindrical roller bearing	3 to 3.5
Double row cylindrical roller bearing	3.5
Full complement cylindrical roller bearing	25
Thrust cylindrical roller bearing	90
Needle bearing	3.5
Tapered roller bearings	4
Barrel roller bearing	10
Spherical roller bearing without flange "E"	7 to 9
Spherical roller bearing with centre flange	9 to 12

Table 4: Table bearing type K_r

Correction factors F_1 to F_6

F1: Effect of dust and humidity on the functional bearing surfaces

moderate	F_1 = 0,7 to 0,9
significant	F_1 = 0,4 to 0,7
very significant	F_1 = 0,1 to 0,4

F2: Influence of shock loads, vibrations and oscillation

moderate	F_2 = 0,7 to 0,9
significant	F_2 = 0,4 to 0,7
very significant	F_2 = 0,1 to 0,4

F3: Effect of high loads

C/P = 10 to 7	F_3 = 1,0 to 0,7
C/P = 7 to 4	F_3 = 0,7 to 0,4
C/P = 4 to 3	F_3 = 0,4 to 0,1

F4:	Effect of air flowing through the bearing		
	weak flow	F_4 = 0,5 to 0,7	
	Starke Strömung	F_4 = 0,1 to 0,5	[3]
F5:	Rotating outer ring		
	Significant	F_5 = 0,5	[3]
F6:	Vertical shaft		
	depending on sealing provided	F_6 = 0,5 to 0,7	[3]

For factors 1 – 6 having no effect, insert 1 [3].

Application factors for typical applications

Life modification factor for reliability a_1 = 1

Contamination factor e_C = 0.6

Bearing type factor K_B = 1

Correction factors F_1 to F_6 = 1

Calculations for the modified reference life L_{10mr} and the theoretical service life of grease F10q are independent of each other. The smallest value is used for the specification in the datasheet.

Symbols

a	Distance between deep groove ball bearing 1 and deep groove ball bearing 2
a1	Life modification factor for reliability
a_{ISO}	Life modification factor
b	Distance of radial force application to deep groove bearing 2
Cu	Fatigue load limit, in newtons
Dpw	Pitch diameter of ball or roller set, in millimetres
eC	Contamination factor
F_A	Axial force, in newtons
Fa	Bearing axial load (axial component of actual bearing load), in newtons
FR	Radial force, in newtons
Fr	Bearing radial load (radial component of actual bearing load), in newtons
FV	Preload, in newtons
F_1 bis F_6	Correction factors
F_{10}	Service life to be expected, in h
F_{10q}	Theoretical service life of grease, in h
K_B	Bearing type
K_n	Speed factor
L_{nmr}	Modified reference service life, in 10^6 revolutions
L1	Deep groove ball bearings 1
L2	Deep groove ball bearings 2
n	Speed, in rpm
P	Dynamic equivalent load, in newtons
X	Dynamic radial load factor
Y	Dynamic axial load factor
κ	Viscosity ratio
v	Viscosity at operating conditions, in mm^2/s
v_1	Reference viscosity required to achieve an adequate lubricating state, in mm^2/s

REFERENCES

[1] ISO/TS 16281: 2008-06 Rolling bearings — Methods for calculating the modified reference rating life for universally loaded bearings

[2] ISO 281: 2007-02 Rolling bearings — Dynamic load ratings and rating life

[3] Klüber Lubrication. The element that rolls the bearing. Tips and tricks for the lu-brication of rolling bearings. B010000502/ Edition 12.20

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