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Simplified design constraints for optimal NU203 Cylindrical roller bearings using GA

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Abstract

Design constraints have been simplified in previous studies to quickly obtain an optimal solution for cylindrical roller bearings (CRBs). This article presents an optimal design to increase the life of NU203 CRB by facilitating smooth and efficient rotation of machine parts in the mechanical system. So improving the life of CRBs is very much essential. A non-traditional optimization approach (known as Genetic Algorithm, GA) is used and the optimal design of NU203 CRB is obtained with few iterations and minimal computation time. Optimal design variables (such as pitch diameter of the bearing, bearing mean roller diameter, the number of rolling elements, and roller effective length) were identified to maximize the dynamic capacity of the CRB. The optimal design solution of NU203 CRB confirms the SKF catalogue.

Keywords: Cylindrical roller bearings; Genetic algorithm; Dynamic capacity; Optimization.

1. Introduction

Cylindrical roller bearings (CRBs) are key components in various mechanical systems, providing support for rotating machinery. These bearings operate under dynamic loads and high-speed rotation that are susceptible to fatigue failure.

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NSGA-II (so-called non-dominated sorting genetic algorithm) is used in the optimal design of the spherical roller bearings [1]. Several optimization schemes were used to improve the fatigue life of NP1092 [2, 3]. Kumar and Tiwari [4] used GA to increase the bearing life by modelling edges with crowned contours and reducing stress concentrations. Dragoni [5] proposed an optimal design of radial CRBs and showed improvement in load carrying capacity. Using EAs, Tiwari et al. [6], also Kumar and Reddy [7] showed improvement in CRBs life. Studies on rolling bearings can be found in [8-10]. Inspired by the above work, the optimization of CRB is studied here.

The design process for a CRB is inherently complex, characterized by complex internal geometry and numerous constraints. Designers and engineers bear the responsibility of carefully selecting and optimizing the design parameters of CRBs to maximize their dynamic load-bearing capacity. In response to these challenges, the use of optimization techniques emerges as a suitable and effective method to determine the most favourable design parameters. The purpose of this study is to streamline the design process by reducing the number of independent variables when using GA.

In particular, the primary objective is to identify optimal design variables that can maximize dynamic capacity (a critical performance parameter) for CRBs. By doing so, this research not only advances the understanding of these indispensable components but also seeks to achieve significant enhancements in their functional capabilities.

2. Design and methodology

2.1 Objective function:

The complex internal structure of a cylindrical roller bearing (CRB) affects the distribution of loads, stresses, and deflections. It is important to note that the alignment of the bearing significantly influences its durability. This geometry consists of a cage consisting of an inner ring, an outer ring, and a set of rollers, as shown in Figure 1.

Standard specifications for the NU202 model include specific parameters. These dimensions include an outer bearing diameter (D) of 35mm, a bore diameter (d) of 15mm, and a bearing width (B) of 11mm. In addition, there are defined chamfering parameters: chamfer height, r_1 = 0.6 and chamfer width, r_2 = 0.6, while r_3=0.3 and r_4 =0.3 correspond to chamfer height and chamfer width, referenced in [11].

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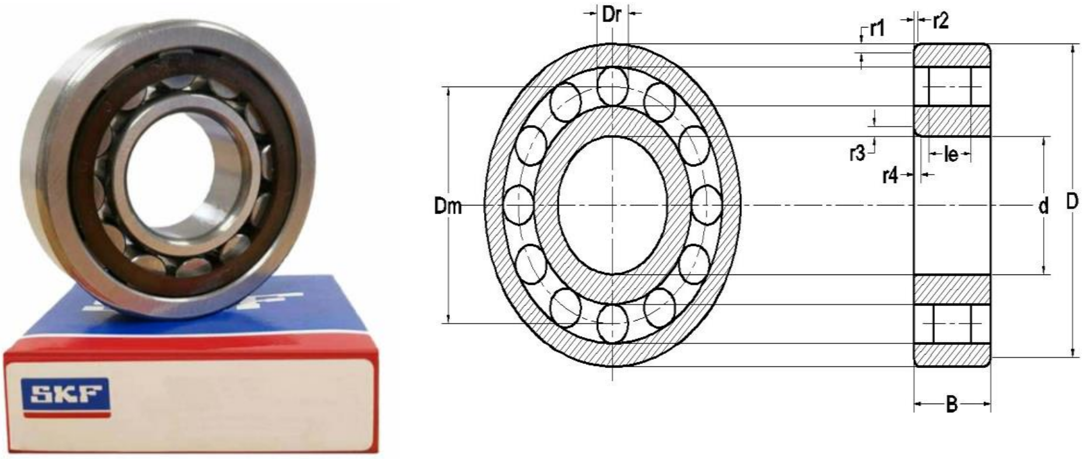

Figure-1:NU203 Single row CRB

(https://www.qualitybearingsonline.com/nu203-ecp-c3- skf-cylindrical-roller-bearing/)

The optimal internal geometry of NU203 single row CRB is obtained as follows. The main parameters in the design are the pitch and roller diameters, and number of rollers, designated by D_m, D_r and Z. The limits of the minimum and maximum ball diameters (K_{Dmin} and K_{Dmax}) are: $0.4 \leq K_{Dmin} \leq 0.5$, and $0.6 \leq K_{Dmax} \leq 0.7$. The mobility condition parameter (e) is: $0.03 \leq e \leq 0.08$. The outer ring consideration parameter (ε) is: $0.3 \leq \varepsilon \leq 0.4$. The effective length parameter (β) of roller is: $0.7 \leq \beta \leq 0.85$.

For optimal internal geometry of the CRB, the dynamic capacity (C_d) is maximized [12]:

$$C_d = b_m \, f_c \left(i\, l_e\right)^{\frac{7}{9}} Z^{\frac{3}{4}} D_r^{\frac{29}{27}} \qquad (1)$$

Here,

$$f_c = 207.9\,\lambda\,\nu\,\gamma^{\frac{2}{9}} \frac{(1-\gamma)^{\frac{29}{27}}}{(1+\gamma)^{\frac{1}{4}}} \left[1 + \left\{1.04\left(\frac{1-\gamma}{1+\gamma}\right)^{\frac{143}{108}}\right\}^{\frac{9}{2}}\right]^{-\frac{2}{9}} \qquad (2)$$

$$\gamma = \frac{D_r}{D_m}, \qquad (3)$$

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$$Z = \text{int}\left\{ \frac{\pi}{\sin^{-1}\left(\frac{D_r}{D_m}\right)} \right\} \quad (4)$$

Effective length, le measured in mm; the number of rows in the rolling elements designated by "i"; reduction factor, λ = 0.61; ν = 1.36 for edge loading; and geometric precision factor, b_m =1.

Fatigue affects bearing life. The bearing life (L_{10}) with 90% reliability in revolutions is [12]:

$$L_{10} = \left(\frac{C_d}{P}\right)^n \times 10^6 \quad (5)$$

The equivalent radial load, P is measured in Newton; and load-life exponent n = 3.33 for line contact. For increasing the bearing life (L_{10}), it is necessary to increase the C_d. In the optimization problem for CRBs, expressions and relevant constraints for C_d are arranged as suggested in [13]. The constraints are simplified as in [12] to quickly obtain an optimal solution for CRBs.

2.2 Finalization of bounds

Following the procedure in [12], the bounds of design variables for NU203 CRB are finalized. GA is applied by arranging the expressions and relevant constraints for C_d as in [13]. Basic design input for NU203 CRB model is from SKF catalogue [11] (see Table 1). Table 2 gives the finalised bounds for optimization.

Table 1: Standard values chosen from bearing catalogue-Input dimensions [11]

Bearing number	D	d	B	r_{1min}	r_{2min}	r_{3min}	r_{4min}	C_d (kN)	n_o (rpm)
	(mm)								
NU203	40	17	12	0.6	0.6	0.3	0.3	17.20	22000

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Table 2: For bearing size NU 203, calculated range of design parameters for optimization

Design parameters	D_m (mm)	D_r	K_{Dmin}	K_{Dmax}	ε	e	β
Lower limit	29.65	6.11	0.4	0.6	0.3	0.03	0.7
Upper limit	30.21	6.9	0.5	0.7	0.4	0.08	0.85

3. Results and Discussion

The dynamic capacity (C_d) of NU203 CRB is maximized using MATLAB genetic algorithm. The optimal design variables obtained are: D= 40 mm; d=17 mm; B= 12 mm; D_m= 30.21 mm; D_r= 6.72 mm; Z= 13; K_{dmin}= 0.4356; K_{dmax}= 0.6817; ε = 0.3319; e= 0.0602; β= 0.85; and le=10.2mm. Maximum dynamic capacity for the above optimal design variables, Cd= 29.28 kN. Table-3 gives comparison of the maximum C_d obtained using other optimization schemes. The main contribution to achieve the optimum C_d is by D_m and D_r. Common causes of bearing failures include wear, fatigue, fracture, corrosion, deformation and manufacturing defects [14, 15]. To avoid such failures, the quality, accuracy, and service life of bearings are necessary during selection and ensure proper installation; routine maintenance (including lubrication and inspection); monitoring; and design considerations such as radial clearance, load distribution, and material selection [16-18].

Table 3 Comparison of C_d for NU203 CRB obtained using different optimization schemes.

CRB	Dynamic Capacity, C_d (kN)			
	Standard	GA	ABC	Present Design
NU203	17.2	23.58	27.41	29.28

4. Conclusions

This paper deals with the simplification of design constraints for NU203 cylindrical roller bearings to obtain optimal dynamic capacity (C_d) rapidly to increase their life by facilitating

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smooth and efficient rotation of machine parts in a mechanical system. Genetic Algorithm (GA) is used and the optimal solution is obtained with few iterations and minimal computation time. Pitch and roller diameters (D_m and D_r) are major contributors to achieving optimum C_d. The optimal C_d obtained in the current design is 90% higher that the value in SKF catalogue. By understanding the failure mode and applying preventive measures, the service life of bearings can be improved, ensuring the safety and stability of the mechanical equipment

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