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Optimal design parameters to improve the dynamic capacity of NU303 cylindrical roller bearings using GA

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Abstract.

A NU303 is a single-row cylindrical roller bearing (CRB) with a NU design. This bearing features two rigid ribs on its outer ring and none on its inner ring. As a result, NU bearings can only accommodate radial forces. This kind of bearing is frequently utilized as a floating bearing, enabling the shaft to move axially in either direction with respect to the housing. This is necessary in situations when temperature fluctuations cause the shaft material to shrink or expand. These bearings are quite simple to install because it is straightforward to separate inner and outer rings. CRBs are used in electric motors, gearboxes, pumps, compressors, and agricultural equipment. By making design improvements, CRBs can operate and last longer. In earlier research, design constraints have been adequately simplified in order to get an optimal solution for the CRB. In this research, the optimal design variables are obtained by applying Genetic Algorithm (GA) and increase the dynamic capacity of NU303 CRB. The improvement of dynamic capacity quoted in the SKF catalogue is noticed when the C_d is evaluated based on the optimal design parameters (such as roller effective length, number of rolling elements, bearing mean roller diameter, bearing pitch diameter).

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Keywords: Bearing bore diameter; Bearing outer diameter; Chamfer height; Chamfer width; Roller effective length; Number of rollers; Optimization; Pitch diameter; Roller diameter.

1. Introduction

Every rotating piece of equipment has a bearing at its core. Single-row cylindrical roller bearings (CRBs) belong to the N, NU, NJ, NUP, RNU, and NF series depending on the design; double-row CRBs belong to the NNU series. While the NU-series has two fixed ribs on the outer ring and a plain inner ring, the N-series has two fixed ribs on the inner ring that holds the rollers and cage and a plain (smooth) outer ring. Within specific limits of the shaft in relation to the housing, they permit axial movement. They are essentially incapable of producing thrust and are utilized in non-locating bearing units. Two fixed ribs on the outer ring and one fixed rib on the inner ring of the NJ-series provide one-way (axial) shaft guidance. One fixed rib and a support washer are located on the inner ring of the NUP-series, while two fixed ribs are located on the outer ring. They can guide the shafts axially in either direction and be used to find bearings. There are no inner rings on the RNU-series and two fixed ribs on the outer ring. As an alternate raceway, it makes use of the shaft. The NF-series can withstand unintentional thrust stresses because it contains one rib on the outer ring and two integral ribs on the inner ring. The outer ring of the NNU-series double row CRB features three fixed ribs, while the inner ring is smooth. Within specific bounds, the design permits axial displacement of the shaft with respect to the housing. As a result, non-locating bearing units use rolling bearings from the NU series. Furthermore, the NNU-series bearings are almost incapable of thrust.

CRBs are essential components in many industrial applications. Upgrading the design of CRBs can significantly increase their performance and increase their lifetime [1]. Realizing them with advanced technology can substantially increases bearing life and reduces maintenance costs [2]. CRBs with plastic cage bearings offer reduced vibration, lower noise, higher load capacity, and improved limit speed and bearing life [3]. To improve bearing life, it is important to minimize radial load, angular misalignment, or axial offset error [4].

The NU303 bearing (see Figure-1) is a single-row CRB that is designed to operate at high speeds and can handle high radial loads, making it a versatile component in many different

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types of machinery [5]. In order to use Genetic Algorithm (GA) to optimize the design of NU303 CRBs, a methodical approach that comprises specifying design variables, an objective function, and design constraints must be followed. The Genetic Algorithm (GA) is employed to identify the optimal combination of design variables that maximizes the objective function while adhering to specified constraints.

Figure-1: NU303 SKF Cylindrical roller bearing [6]

NSGA-II is employed to determine the optimal design of spherical roller bearings [7]. To extend the fatigue life of NP1092, various optimization techniques were applied [8, 9]. In order to reduce the stress concentration, Kumar and Tiwari [10] used crowned contours and refined edges. They applied GA to extend the bearing life. In order to improve the load carrying capacity, Dragoni [11] suggested an ideal design for radial CRBs.

Improvement in CRB life was demonstrated by Tiwari et al. [12], Kumar and Reddy [13], using EAs. To optimize CRB while taking into account more design variables, Dandagwhal and Kalyan Kumar [14], and others used the TLBO technique. By properly minimizing the design constraints and utilizing GA, a straightforward optimal design has been suggested for the NU202 CRB [15]. Motivated by the previous research, an attempt is made here to use GA to determine the optimal design parameters for NU303 CRB.

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2. Methodology

2.1 Geometry of the bearing

The procedure for obtaining the optimal design of the NU303 CRB is briefly presented in this section. More design variables, such as pitch diameter- D_m , roller diameter- Dr, number of

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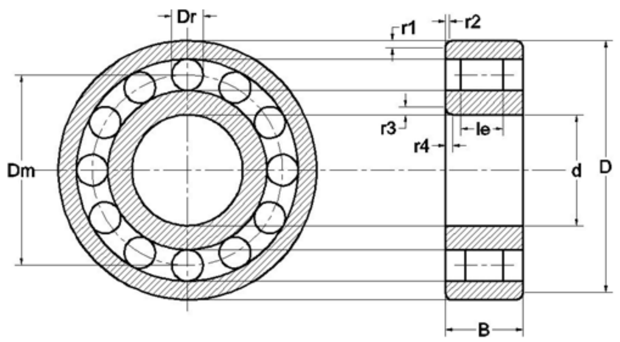
rollers- Z , minimum ball diameter limit- K_{Dmin}, maximum ball diameter limit- K_{Dmax}, outer ring consideration parameter- ε, parameter for mobility conditions-e, and roller effective length parameter-β, are included in the complex internal geometry of the profile shown in Figure-2. Only 7 design variables are taken into account because D_m and D_r determine the number of rollers (Z). As a result, the design becomes simpler.



Design Variables

B	Width
D	Bearing outer diameter
D_m	Pitch diameter
D_r	Roller diameter
d	Bearing bore diameter
le	Effective length
r_1, r_3	Chamfer height
r_2, r_4	Chamfer width
Z	Number of rollers

Figure-2: Internal profile of CRB

2.2 Objective function

For the optimal internal geometry of single-row NU303 CRB, D_m, D_r and Z are the main design parameters. The limits of the parameters are controlled by: $0.4 \le K_{Dmin} \le 0.5$; $0.6 \le K_{Dmax} \le 0.7$; $0.03 \le e \le 0.08$; $0.3 \le \varepsilon \le 0.4$; and $0.7 \le \beta \le 0.85$. The design constraints for improving C_d are in [15], and the expression for C_d is [15]

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

Here,

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

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

$$Z = \text{int}\left[\pi\left\{\sin^{-1}\gamma\right\}^{-1}\right]; \qquad (4)$$

"*le*" is the effective length (mm); "*i*" is the number of rows in the rolling elements; λ = 0.61, is the reduction factor; ν = 1.36 for edge loading; and b_m =1, is the geometric precision factor.

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The bearing life (L_{10}) with 90% reliability in revolutions is [16]:

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

The equivalent radial load, P is measured in Newton; and load-life exponent n = 3.33 for line contact. The standard dimensions for NU303 CRB are [5]:

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

Name of the dimension	**Symbols**	**Input dimension**
Bearing outer diameter (mm)	D	47
Bearing bore diameter (mm)	d	17
Width (mm)	B	14
chamfer height (mm)	r_1	1.0
chamfer width (mm)	r_2	1.0
chamfer height (mm)	r_3	0.6
chamfer width (mm)	r_4	0.6
Standard dynamic capacity (kN)	C_d	24.60
Limiting speed (rpm)	η_o	20,000

C_d is increased for increasing the bearing life (L_{10}). While optimizing C_d for CRBs, expressions and relevant constraints for C_d are arranged as in [17]. The constraints are simplified as in [15] to quickly obtain an optimal solution for CRBs. Table-2 shows the bounds of design variables for NU303 CRB.

Table-2: The range of design variables for NU303 CRB.

CONSTRAINT	DESIGN VARIABLE	RANGE OBTAINED
1&2	D_m	18.2 to 45
9&10	D_m	30.08 to 33.92
13	D_m	≥ 32

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4	Dr	$\leq$13.4
7&8	Dr	7.5 to 9

The applicable range of D_m and D_r obtained are as follows. D_m varies from 33.5 to 33.92 mm; and D_r varies from 8.175 to 9 mm; this is after satisfying the constraint-11 and the limits of ε . Z from equation (3) satisfies the constraints of 5, 6 and 16 when D_m and D_r are used within their applicable range. All of the design constraints are satisfied by these finalized design variables.

3. Results and Discussion

The dynamic capacity (C_d) of NU303 CRB is maximized using MATLAB genetic algorithm. The optimal design variables obtained are: D= 47 mm; d=17 mm; B= 14 mm; D_m= 33.91 mm; D_r= 8.77 mm; Z= 12; K_{dmin}= 0.4698; K_{dmax}= 0.6412; ε = 0.3288; e= 0.069; β= 0.85; and l_e=11.9 mm. Maximum dynamic capacity for the above optimal design variables, C_d= 38.35 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.

Table-3: Comparison of C_d for NU303 CRB using different optimization schemes.

CRB	Dynamic Capacity, C_d (kN)			
	Standard	GA	ABC	Present Design
NU303	24.6	31.87	37.41	38.35

Conclusions

The optimal dynamic capacity (C_d) of NU203 cylindrical roller bearings is the subject of this paper. The optimal C_d was obtained by simplifying the design constraints. Using a Genetic Algorithm (GA) the optimal solution is found after a small number of iterations and a short computation time. The diameters of pitch and roller (D_m and D_r) play a significant role in obtaining optimum C_d. The value found in SKF catalogue is 55% lower than the optimal C_d obtained in the current design. The service life of bearings can be increased, guaranteeing the stability and safety of mechanical equipment, by comprehending the failure mode and implementing preventive measures.

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