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On the possibility of improving the life of NU204 cylindrical roller bearings by design optimization using genetic algorithm in MATLAB

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Abstract

The NU series of single-row cylindrical roller bearings (CRBs) are designed to withstand high speeds and heavy radial loads. It consists of inner ring, outer ring, cylindrical rollers, and cage. They are suitable for use as non-locating bearings because they can accommodate axial displacement of the shaft relative to the housing in both directions. Electric motors and conveyor systems are just two of the many applications in which it is frequently used. Many bearings prematurely fail due to wear, so their design needs to be re-evaluated. Bearing life is directly related to dynamic capacity (C_d). Design involves numerous variables and complex constraints. Here, an attempt is made to use genetic algorithm (GA) of MATLAB to optimize the life of NU204 CRB by reducing the number of constraints and design variables. A comparison is made between its life expectancy and current best practices. The optimal design C_d is 60% more than the value shown in the SKF standard catalogue.

Keywords: Cylindrical roller bearings, Genetic algorithm, Dynamic capacity, optimization.

1. Introduction

A prominent feature of the NU204 CRBs (see Figure-1) is their ability to handle loads. They are excellent for supporting large radial loads with little friction. A single-row NU204 CRB configuration consists of inner and outer rings with cylindrical rollers separated by a cage [1]. They are widely used in conveyor systems and electric motors. Numerous works have been

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documented in the literature. Dragoni [2] proposed an optimal design of CRBs to improve load carrying capacity. Evolutionary algorithms (EAs) were used by Tiwari et al. [3] and Kumar et al. [4] to extend the life of the CRB, but the design is complex and requires more iterations. A thorough investigation of rolling bearings analysis is reported in [5-7]. Dandagwhal and Kalyan Kumar [8] attempted to use the TLBO technique to increase the dynamic capacity (C_d) of CRB and deep groove ball bearings. These methods, however, require more design constraints, which increase the computational time and iterations. The main reasons for this are inclusion of some tolerance-based constraints and the treatment of geometric design variables as independent.

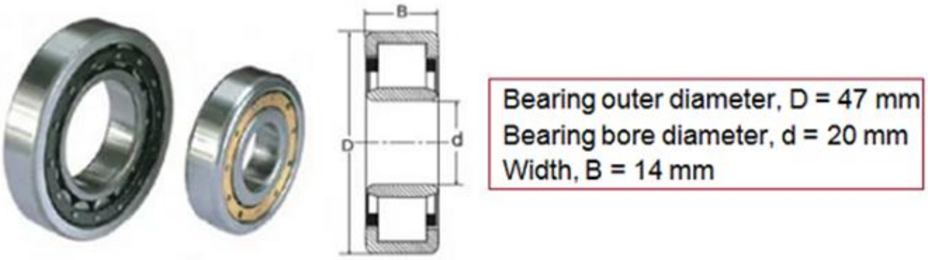

Figure-1: NU204 CRB Internal profile

The present work uses MATLAB' GA to obtain optimal design variables that minimize constraints and optimize dynamic capacity (C_d). The results are compared with the values reported in a SKF standard catalogue, and it is observed that the life is increased by 60%.

2. Design/Methods/Modelling

Figure-2 shows the internal profile of single-row cylindrical roller bearings (CRBs) with design variables of the NU series.

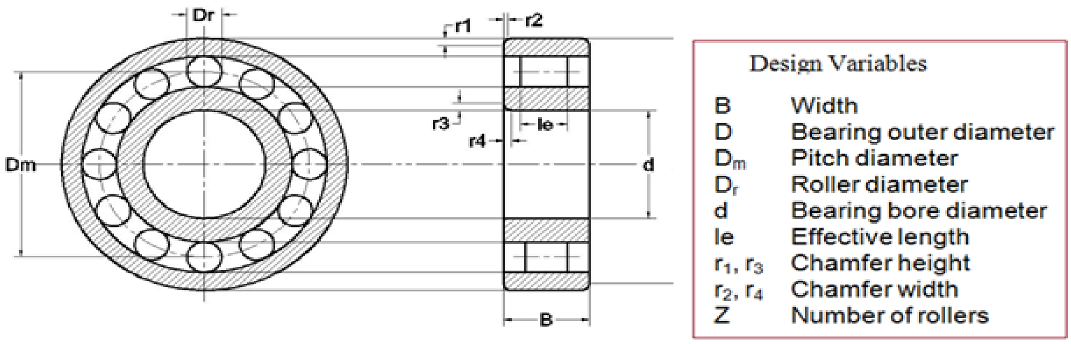

Figure-2: Internal profile of CRB

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The design variables D_m, D_r, Z, β present in equation (1) for the dynamic capacity (C_d) of CRBs. This serves as an objective function in the present study [5].

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

Here,

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

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

$$Z = \operatorname{int}\left\{ \frac{\pi}{\sin^{-1}(\gamma)} \right\}, \quad (4)$$

"le" is the effective length (mm); *"i"* is the number of rows in the rolling elements; $\lambda = 0.61$ is the reduction factor; $\nu = 1.36$ for edge loading; and the geometrical precision factor, $b_m = 1$ *[6]*. *Z* in equation (4) is dependent on D_m and D_r [9], which reduces the number of constraints.

Fatigue affects bearing life. It can be described as [5]:

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

L_{10}, is the 90 % reliable bearing life (in revolutions); "P" represents equivalent radial load in Newton; and for line contact the load-life exponent *n* = 3.33. The bearing life increases with increasing C_d.

Table-1 presents the design constraints. The minimum and maximum ball diameter limiters are denoted by K_{Dmin} and K_{Dmax}. β is the roller effective length parameter. The parameter "e" is for mobility conditions. Table-2 provides the SKF catalogue design variables. Following the simplified design approach [9], the range of parameters in Table-3 are obtained and used while optimizing the dynamic capacity (C_d) of NU204 CRB.

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Table 1: *Design Constraints* ***[5]***

Constraint(s)	Range of design variables
1&2	$(d+2r_{3_{min}}) \le D_m \le (D = 2r_{1_{min}})$
3&4	$268.71\frac{\sqrt{Q_{max}}}{\sigma_{c_{max}}} \le D_r \le \frac{1}{2}\{(D-2r_{1\,min})-(d+2r_{3\,min})\}$, where, $Q_{max}=\frac{5F_r}{z}$ and $\sigma_{c_{max}}$, is the maximum contact stress.
5&6	$K_{D_{min}}\frac{(D-d)}{2} \le D_r \le K_{D_{max}}\frac{(D-d)}{2}$
7&8	$\left(\frac{1}{2}-e\right)(D+d) \le D_m \le \left(\frac{1}{2}+e\right)(D+d)$
9	$\frac{1}{2}(D-D_m-D_r)-\varepsilon D_r \ge 0 \Rightarrow D_r \le \left(\frac{D-D_m}{1+2\varepsilon}\right)$
10	$\frac{1}{2}(D-D_0)-2r_{1_{min}} \ge 0 \text{ in which } D_0 = D_m + D_r$
11	$\frac{1}{2}(D_i-d)-\frac{1}{2}(D-D_0) \ge 0 \text{ in which } D_i = D_m - D_r \Rightarrow D_m \ge \frac{(D+d)}{2}$
12	$\sigma_{c_{safe}}-\sigma^{i}_{c_{max}} \ge 0$, where $\sigma^{i}_{c_{max}} = 2\frac{Q_{max_i}}{\pi l_e b_i}$; $b_i = 3.35\times10^{-3}\sqrt{\frac{Q_{max_i}}{l_e\sum\rho_i}}$; and $\sum\rho_i = \frac{2}{D_r}+\frac{2}{D_i}$
13	$\sigma_{c_{safe}}-\sigma^{o}_{c_{max}} \ge 0$, where $\sigma^{o}_{c_{max}} = 2\frac{Q_{max_o}}{\pi l_e b_0}$; $b_o = 3.35\times10^{-3}\sqrt{\frac{Q_{max0}}{l_e\sum\rho_0}}$; and $\sum\rho_0 = \frac{2}{D_r}-\frac{2}{D_0}$
14	$\beta B - l_e \ge 0 \Rightarrow l_e \le \beta B$
15	$(B-l_e)-2r_1 \ge 0 \Rightarrow l_e \le (B-2r_1)$
16	$\frac{1}{2}(D-D_0)-3Z_{static} \ge 0 \text{ in which } Z_{static} = 0.626\, b_0$

Table 2: NU204 CRB design input from SKF catalogue [1].

Dimensions (mm)							C_d (kN)	n_o (rpm)
D	d	B	r_{1min}	r_{2min}	r_{3min}	r_{4min}		
47	20	14	1.0	1.0	0.6	0.6	25.10	19000

Table 3: Range of design parameters for optimizing the NU 204 CRB

Design parameters	Dimensions (mm)		K_{Dmin}	K_{Dmax}	ε	e	β
	D_m	D_r					
Lower limit	34.85	7.18	0.4	0.6	0.3	0.03	0.75
Upper limit	35.51	8.1	0.5	0.7	0.4	0.08	0.85

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3. Results and Discussion

Using the GA of MATLAB [10] and the range of design parameters for NU204 CRB, the maximum dynamic capacity (C_d) is determined. The results are compared with the values reported in a SKF standard catalogue, and it is observed that the life is increased by 60%. Figure-3 shows a comparison of C_d obtained using different optimization techniques.

Table 4: Optimum design variables and C_d of NU204 CRB

Dimension (mm)						Z	Design parameters					C_d (kN)
D	d	B	D_m	D_r	l_e		K_{dmin}	K_{dmax}	ε	e	β	
47	20	14	35.17	7.82	11.9	14	0.469	0.639	0.398	0.0504	0.85	38.8

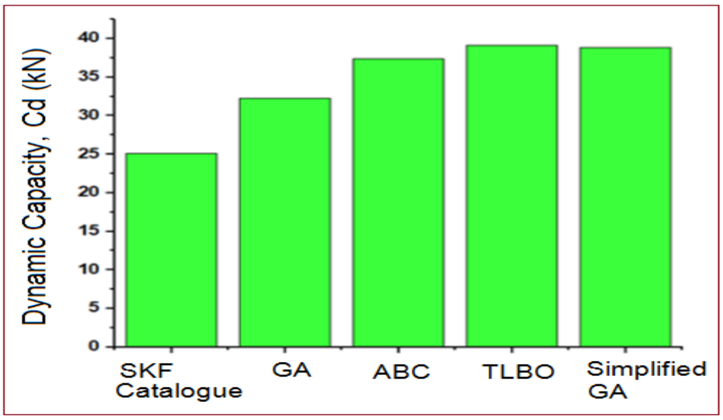

Figure3: Comparison of maximized C_d for NU204 CRB using different optimization techniques

4. Conclusions

In order to maximize a bearing's dynamic capacity (C_d), and achieve high performance, reliability, and efficiency in mechanical systems, a number of variables and complex constraints must be taken in to account. To determine optimal set of design parameters, optimization techniques such as RSM (response surface methodology), FEA (finite element analysis), and GA (genetic algorithms) can be applied. In this paper, the life of NU204 CRB is optimized by maximizing C_d using MATLAB's GA. A comparative analysis of various optimization schemes (such as GA, ABC, and TALBO techniques) is conducted to determine

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the optimal solution of the current design problem. The value in the SKF standard catalogue is 60% lower than the optimal design value of C_d, which is 38.8 kN. Inadequate installation, contamination, lubrication problems, and high loads can all lead to different kinds of CRB failures. It is possible to reduce CRB failures through routine maintenance and monitoring, which will enhance bearing life and performance.

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