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Re-examination for Effect of Ball Race Conformity on Life of Rolling Element Bearing using Metaheuristic

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Abstract

Most important criteria in design of rolling element bearing consist Long fatigue life. Factors like fatigue, lubrication, thermal traits etc. have a great impact on life of bearing. The present work specifically objectify the optimization of the dynamic load capability ,life factors and life of bearing using optimization algorithms Particle Swarm Optimization (PSO) and Genetic Algorithm. Reliability, materials and processing along with operating conditions are taken as some factors can represent the life factor of bearing. Strict series system is considered represents reliability which depicts the total bearing system. The design outcome shows the comparative effectiveness and efficiency of algorithms.

Keywords: Particle swarm optimization, Genetic Algorithm, life factors, Ball race conformity

1. Introduction

The design parameters for rolling element bearing have much affect on the performance and fatigue life of bearings .Thus the effective design of bearing can affect the high quality operation of machinery. The accountability of choosing a most beneficial design from all feasible design parameters is a tedious job for a bearing designer. This leads to the requirement of optimal design of rolling element bearings for effective bearing life.

Palmgren [1] depicted about bearing life measure and an analytical formula i.e L_{10} life. Lundberg and Palmgren [2] modeled the principal relation between bearing life and geometry of bearing, relating to variables viz. ball diameter, pitch diameter, conformities of raceways of inner and outer , ball numbers, also contact angle. The formulation includes ball life to their analysis for bearing life prediction relating to the inner and outer races lives . The Lundberg-Palmgren theory depicts relation between the Hertz stress with fatigue life as inverse 9^{th} power for the ball bearings. Zaretsky [3] calculated the ball set life related to the races for a ball bearing depend upon the relative contact (Hertz) stresses at the respected races. Analysis reported by Zaretsky, et al. [4] determined bearing life as affected by race conformity and incorporate the life factors using the Lundberg-Palmgren theory. He includes calculation to life factors (LF_c) , determines L_{10} life for ball bearing considering series summation of inner and outer race conformity of ball bearing.

A GA based constraint optimization technique is implemented by Chakraverty et al. [5] with five design variables for optimum design of bearing life. Tiwari et al. [6] also formulated methodology for optimization of fatigue life of tapered roller bearing using evolutionary based algorithm. These researchers have considered the optimum designed approach as Changsen[7] predicted design model. Based on the stated review, it is noticeable that soft computing approach are the recent trends of the present researches but they have not emphasized their work basing on Lundberg and Palmgren theory. The aim of this proposed work is the extension the proposed of Zaretsky et al. [4] who include relation between bearing fatigue life and maximum Hertz stress as 9^{th} power , hence to find agreement of the results as using soft computing method as particle swarm optimization and Genetic Algorithm considering the total bearing system as a series system where inner race and outer race considered to be in series.

2. Bearing Geometry Formulation

The finish geometry (Fig.1) of a deep score ball bearing is characterized by the different geometric variables viz. , bore"diameter (d),outer"diameter (D),bearing width (w),ball diameter (D_b),pitch"diameter (D_m),inner"and"outer raceway curvature coefficients (f_i and f_o), and"number"of"rolling"component (Z).

Here design for entire inner geometry (i.e. D_b , D_m , fi , fo and Z) of a bearing, at the same time optimizing its efficiency attributes and global fatigue life is addressed.

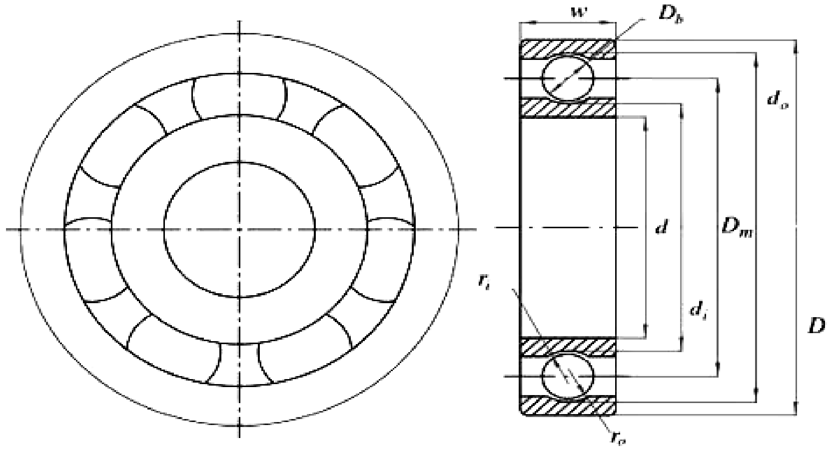

Fig. 1. Radial deep groove ball bearing internal geometries

2.1 Design Variables

The Design variables are fundamentally geometric specifications and different factors, called primary specifications. Stated specifications are to be resolved"in"the bearing outline. The information specifications as,

$$X = [D_b, Z, D_m, f_o, f_i, K_{Dmin}, K_{Dmax}, \varepsilon, e, \zeta] \quad (1)$$

Where, $f_o = r_o/D_b$ and $f_i = r_i/D_b$.

The parameters for bearing interior geometries are D_m, D_b, Z, f_i, and f_o Whereas, K_{Dmin}, K_{Dmax}, ε, ζ, *e* are part of imperatives [6] and are typically saved steady even as designing bearings [6]. For reward work theses are also handled as variables. Assembly attitude (ϕ_0) of a bearing additionally varieties an principal"constraint on the performance of"rolling"elements. Established as analytical induction exhibited in [6], the following formulation as the assembly attitude,

$$\phi_0 = 2\Pi - 2\cos^{-1}\frac{\left[\{(D-d)/2-3(T/4)\}^2+\{D/2-(T/4)-D_b\}^2-\{d/2+(T/4)\}^2\right]}{2\{(D-d)/2-3(T/4)\}\{D/2-(T/4)-D_b\}} \quad (2)$$

Where, $T = D - d - 2D_b$ (3)

2.2 Objective Function

The performance measure of rolling element bearing (deep groove ball bearing) namely dynamic load capacity (C_d) Optimized for best performance of bearing. The dynamic load capacity , which directly influence the exhaustion life of bearing. It is expressed as,

Fatigue life in millions of revolutions, $L = \left(\frac{C_d}{F}\right)^a$ (4)

Where, F is applied load and a = 3 for ball bearings

$$C_d = \begin{cases} max\left[-f_c Z^{2/3} D_b^{1.8}\right] & D_b \leq 25.4mm \\ max\left[-3.647 f_c Z^{2/3} D_b^{1.4}\right] & D_b > 25.4mm \end{cases} \quad (5)$$

$$f_c = 37.91\left\{1+\left[1.04\left(\frac{1-\gamma}{1+\gamma}\right)^{1.72}\left(\frac{f_i(2f_o-1)}{f_o(2f_i-1)}\right)^{0.41}\right]^{10/3}\right\}^{-0.3}\left[\frac{\gamma^{0.3}(1-\gamma)^{1.39}}{(1+\gamma)^{1/3}}\right]\left[\frac{2f_i}{2f_i-1}\right]^{0.41} \quad (6)$$

where $\gamma = D_b\cos\alpha/Dm$ is not an impartial parameter, thus it doesn't show up in aim of"planned"parameters."observed α is the free contact attitude angle(in present case zero) that "relies" on "bearing" geometry. "The" dynamic" load" capacity" is " being "determined" onpremi-se" of "most" extreme" octahedral "stress" developed "between" rolling element and races. Where *i* represent number of rows and it is equals one for unit row deep score rolling bearing.

As scope of design of rolling aspect bearing various practical design requirements are given by scientists so to cut back the parameter space for ease of design optimization. Thus, many constraints conditions[7] are being implemented on the objective function.

2.3 Bearing life prediction

Based on the work of researchers [1],[2], the survival *S* written as a relation of orthogonal shear stress τ_o, life η, depth to the maximum orthogonal shear stress Z_o , and stressed volume *V* Eqn.(7),(8).

$$\ln\frac{1}{S} \sim \tau_o \frac{\eta^e}{Z_o^h} V \quad (7)$$

$$V = aZ_o l \quad (8)$$

Where *a*, Z_o are functions of the maximum Hertz stress S, *l* is the length of rolling path of rolling elements, generally considered same as circumference .

Formulation for the bearing life[3],

$$L_{10} = \left(\frac{C_d}{P_{eq}}\right)^p \tag{9}$$

For deep groove ball bearings exponent p = 3.

Reliability, materials and processing and operating condition may affect the life of bearing ,thus the aforesaid formula can be rewritten as Eqn.(10) considering a_1,$a_2$and a_3 coefficients.

$$L = a_1 a_2 a_3 Z_o L_{10} \tag{10}$$

The relation between ball bearing fatigue life maximum Hertz stress S along with bearing load equivalent P_{eq}.

$$L \sim \left(\frac{1}{P_{eq}}\right)^p \sim \left(\frac{1}{S_{max}}\right)^n \tag{11}$$

where, as per Hertz theory p=n/3and accordance with Lundberg Palmgren hertz sress life exponent n=9.

The fatigue life L of a respected races as inner and outer can be determined as follows,

$$L \sim \left(\frac{1}{S_{max}}\right)^n \left(\frac{1}{l}\right)^{\frac{1}{e}} \left(\frac{1}{N}\right) \tag{12}$$

where N is number of stress cycles per inner race revolution and e is weibull slope generally taken as 1.11.

The ratio X is outer race life to inner race life can be written ,

$$\frac{L_o}{L_i} \approx \left(\frac{S_{maxi}}{S_{maxo}}\right)^n \left(\frac{1}{k}\right)^{\frac{1}{e}} \tag{13}$$

2.4 Bearing Life Factor

The appropriate life factor can be determined based on life factors LF_i & LF_o of respective races conformity after normalizing the value of hertz stress for respected races to a standard conformity of 0.52[6].

$$LF = \left(\frac{S_{max0.52}}{S_{max}}\right)^n \tag{14}$$

Value of ($\mu\nu_{0.52}$) are different for inner and outer races, called as transcendental functions varies with race conformity .

2.5 Series System Reliability

Lundberg and Palmgren [4] expressed the relation among system life & individual component life. A numbers of multiple components compose the bearing system, where each may have different life. Thus system L_{10} life can be formulated using series system of each components fatigue lives Eqn.(15).

$$\frac{1}{L_{10}^{e}}=\frac{1}{L_{10_i}^{e}}+\frac{1}{L_{10_o}^{e}} \tag{15}$$

2.6 Bearing Life Factors And Life Of Bearing

The life factors of inner race life and outer race life as formulated [6],

$$LF_i=\left[\frac{\left(\frac{2}{D_m-D_b}+\frac{4}{D_b}-\frac{1}{0.52D_b}\right)^{2/3}(\mu\nu)_i}{\left(\frac{2}{D_m-D_b}+\frac{4}{D_b}-\frac{1}{f_iD_b}\right)^{2/3}(\mu\nu)_{0.52}}\right]^n \tag{16}$$

$$LF_o=\left[\frac{\left(-\frac{2}{D_m+D_b}+\frac{4}{D_b}-\frac{1}{0.52D_b}\right)^{2/3}(\mu\nu)_o}{\left(-\frac{2}{D_m+D_b}+\frac{4}{D_b}-\frac{1}{f_oD_b}\right)^{2/3}(\mu\nu)_{0.52}}\right]^n \tag{17}$$

Life Factor and life of bearing of the bearing accordance with Lundberg Palmgren approach,

$$LF_c=\left[\frac{(LF_i)^e(LF_o)^e(X^e+1)}{(LF_o)^eX^e+(LF_i)^e}\right]^{1/e} \tag{18}$$

$$L10_m=\frac{(LF_i)(LF_o)XL_i}{\left[(LF_o)^eX^e+(LF_i)^e\right]^{1/e}} \tag{19}$$

Life Factor and life of bearing of the bearing accordance with Zeratesky approach,

$$LF_c=\left[\frac{(LF_i)^e(LF_o)^e(X+2)}{(LF_o)^eX^e+2(LF_i)^e}\right]^{1/e} \tag{20}$$

$$L10_m=\frac{(LF_i)(LF_o)XL_i}{\left[(LF_o)^eX^e+2(LF_i)^e\right]^{1/e}} \tag{21}$$

3 Optimization Algorithm

3.1 Particle Swarm Optimization

A population centered evolutionary algorithm proposed, Particle swarm optimization (PSO) has been developed by Kennedy and Eberhart [8]. Bound to the search space, each and every particle maintains track of its positions, which is associated with the most effective solution (fitness) it has observed up to now, pBest.”Another”best”esteem followed”by”the global”best version of the particle swarm optimizer is the global best value, gBest and its position, obtained thus far”by any”particle “in”the “population. “The “strategy “for “imposing “the “PSO “is, “Initialize “a “population of particles, evaluation the fitness worth of each and every particle, evaluation of each and every particle’s evaluated”fitness”and the”fitness evaluation with the population’s total prior pleasant, update the velocity and role of the particle as Eqn.(22),Eqn.(23), once more evaluation of fitness value of each and every particle until the stopping criterion is met commonly as the highest number of iterations.

$$v[] = v[] + c1 * rand() * \left(pBest[] - present[]\right) + c2 * rand() * (gBest[] - present[]) \quad (22)$$

$$present\,[] = present\,[] + v\,[] \quad (23)$$

3.2 Genetic Algorithm

Genetic algorithms [9] evaluate the target function to be optimized at some randomly selected points of the definition domain. Taking this information into account, a new set of points (a new population) is generated. Gradually the points in the population approach local maxima and minima of the function .Genetic algorithms can be used when no information is available about the gradient of the function at the evaluated points. The function itself does not need to be continuous or differentiable. Genetic algorithms can still achieve good results even in cases in which the function has several local minima or maxima. These properties of genetic algorithms have their price: unlike traditional random search, the function is not examined at a single place, constructing a possible path to the local maximum or minimum, but many different places are considered simultaneously. The function must be calculated for all elements of the population. The creation of new populations also requires additional calculations. In this way the optimum of the function is sought in several directions simultaneously and many paths to the optimum are processed in parallel. The calculations required for this feat are obviously much more extensive than for a simple random search.

Flow diagram as shown (Fig.2).There are six steps in GA and are Problem representation, Initialization of population, Evaluation of fitness function, Constraint handling, Generation of new population, Stopping/termination criteria.

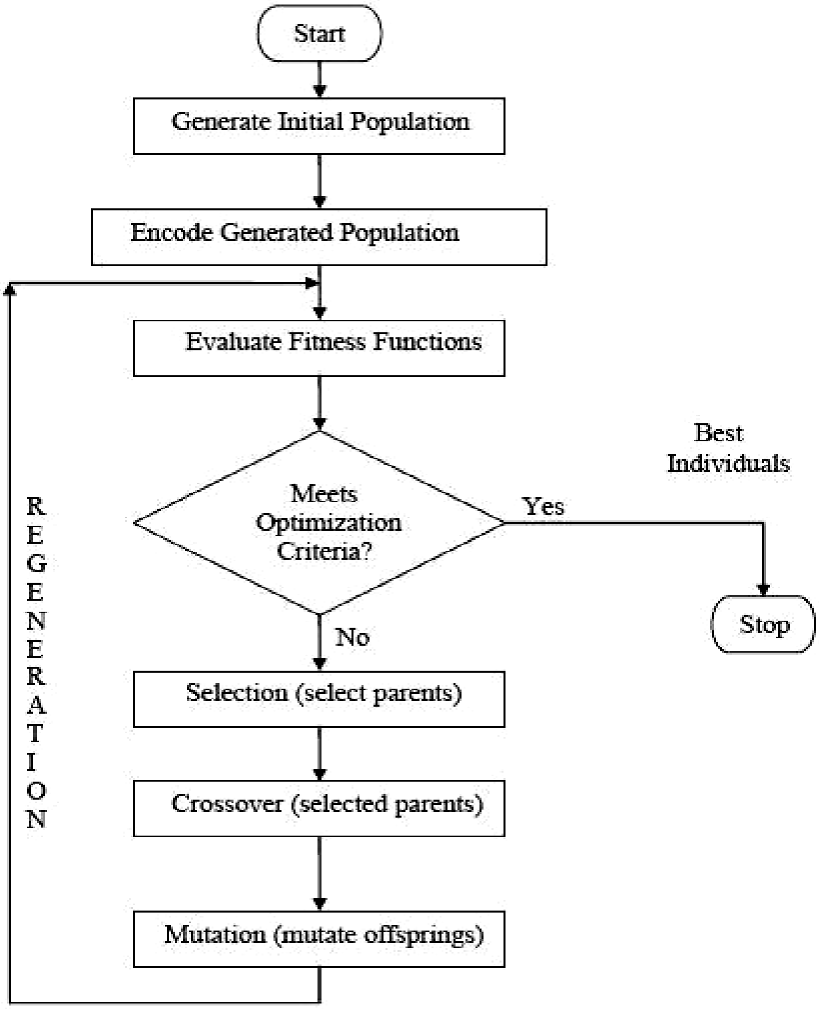

Fig. 2.Flow Diagram of Genetic Algorithm

4 RESULTS AND ANALYSIS

Table 1. Optimization Outcomes (PSO)

D	**d**	**w**	D_b	D_m	**Z**	f_i	f_o	Φ_0	K_{Dmin}	K_{Dmax}	**ε**	***e***	**β**	C_g
30	10	9	6.2	20.05	7	0.515	0.515	3.77	0.4296	0.6482	0.3	0.0659	0.743	5822.7

LF_i	LF_o	X_{life}	LF_c	LF_{cz}	L_{10m}	L_{10mz}
1.1998	1.2333	5.42	1.2116	1.2116	$1.464*10^3$	$1.4643*10^3$

Table 2. Optimization Outcomes (GA)

D	**d**	**w**	D_b	D_m	**Z**	f_i	f_o	Φ_0	K_{Dmin}	K_{Dmax}	**ε**	***e***	**β**	C_g
30	10	9	6.4	20.02	6	0.515	0.515	3.27	0.4462	0.658	0.3	0.0459	0.786	5762.4

LF_i	LF_o	X_{life}	LF_c	LF_{cz}	L_{10m}	L_{10mz}
1.1978	1.2246	5.41	1.2101	1.2101	$1.452*10^3$	$1.4521*10^3$

Table-1,2 gives optimum design of parameters for maximum dynamic load capacity of bearing utilizing PSO and GA under constraint conditions[6] respectively. The dynamic capacity value using PSO and GA was found to be 5822.70 and 5762.4 which is higher than the catalogue value i.e 3508 and hence it indicates better design. The value of Life ratio is found to be 5.42 and 5.41 which are less than the value in Lundberg-Palmgren thus life of inner race is more which indicates better design. Life factor for inner race is found to be 1.1998 and 1.1978 which indicates that inner race is under more stress than outer race. The life factor of bearing system & mean life as resulted are minorly deviating which shows a close agreement of soft computing approach for bearing desing. It shows the life prediction approach is agreement with lundberg palmgren approach.

6. Conclusions

The PSO and Genetic algorithm is applied to the constraint optimization problem involving dynamic load capacity along with life factors and life of bearing for deep groove ball bearing. The algorithms successfully handle mixed integer variables. The reported result indicates the effective implementation of proposed PSO and Genetic algorithm over design based problems in prospects to rolling element bearing. Thus The work of Zaretsky et.al. for calculating life of bearing and this proposed metaheuristic approach are in close agreement. The prospects of this paper include the life of race conformity in designing of bearing life for rolling element bearing.

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