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Intelligent Optimization technique for Design of Ball Bearings

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Abstract:

In the engineering design, a best possible design is achieved by comparing alternative design solutions by using previous problem information. Optimization algorithms provide systematic and efficient ways of creating and comparing new design solutions in order to achieve an optimal design. An optimum design is to minimize the various undesirable values and to maximize the most significant enviable effect. Optimization plays an imperative role in various engineering applications. In order to increase the design efficiency and get the most excellent design effect, in this paper Ball bearing design is considered as an application and the evolutionary algorithm is used for evaluation. Ball bearings are universally used mechanical elements in a variety of area likes automobiles, machine tools and aircrafts etc. The major problem for the mechanical engineer is in the field of design and innovation. Ball bearing design can be defined as the selection of material and geometry, which satisfies individual and implied efficient requirements. In this paper, the artificial bee colony is used to maximize the dynamic capacity. There is an excellent improvement found in optimized bearing designs.

Keywords — **Optimum design; Ball bearings; Artificial bee colony algorithm; Genetic algorithm; Sensitivity analysis.**

I. INTRODUCTION

Designing is the process where the products are made attractive, suitable, highly efficiency but there are certain difficulties in making the perfect, best, desired product. Optimization Algorithm helps the Engineer to design and to obtain the best solution for complex problems. Evolutionary algorithm is an optimum algorithm used to reduce the complicity of the design and it is a subset of evolutionary computation, Evolutionary algorithms named Artificial Bee Colony algorithm is proposed by D. Karaboga *et al* [1], it is based on the intelligent foraging behavior of honey bee swarm. Several research works have been reported on optimization of various machine elements, however, very few literatures are available on the optimization of rolling bearings. Asimow [1] used the Newton-Raphson method for the optimum design of the length and the diameter of a journal bearing supporting a given load at a given speed. The objective function was to minimize a weighted sum of the frictional loss and the shaft twist. Seireg *et al* [2] utilized a gradient-based search to optimised the bearing length, the radial clearance and the average viscosity of the lubricant. The objective function was chosen to minimize a weighted sum of the quantity of lubricant fed to the bearing and its temperature rise. Maday [3] and Wylie *et al* [4] used bounded variable methods of the calculus of variable to determine the optimum configuration for hydrodynamic bearings. The design criterion was chosen to maximize the load carrying capacity of the bearing.

The present paper is organized as follows; section 2 briefs the geometry of rolling bearings. The mathematical modelling of the problem as a set of objective functions, design parameters and constraints are described in section 3. Section 4 introduces the concept of the multi-objective optimisation and goes on to discuss whether a deterministic or a stochastic approach is more appropriate for this problem. Section 5 details the application and results. Section 6 concludes the present work, followed by important references. Results obtained are satisfactory, and give a good insight into the trade-offs between the performances measures of rolling bearings. Apart from the numerical significance of the obtained optimal solution, these results can help us better understand parameters behind the effective designing of rolling bearings.

II. Rolling Bearing

Rolling bearings appear to have a simple outer geometry, but their internal geometry can have varying effects on the amount of stresses, deflections and load distributions it can handle. Therefore the internal geometry has a direct effect on the performance and the life of a bearing. Figure 1 shows the common nomenclature of a typical rolling bearing. In the crudest form, the geometry of a bearing can be defined by three *boundary dimensions*, namely, the bore diameter (d), the outer diameter (D) and the bearing width (B_w). These boundary dimensions have been standardized. Parameters that help to define the complete internal geometry of a given rolling bearing (i.e. for a given boundary dimensions) are the ball diameter (D_b), the pitch diameter of the bearing (D_m), the inner and outer raceway curvature coefficients (f_i and f_o), and number of rolling elements (Z).

III. Problem Formulation

We seek to find out the complete internal geometry (i.e. the ball and pitch diameter, the inner and outer raceway curvature coefficients, and number of rolling elements) of a given bearing (i.e. the bore and outer diameters and the bearing width) while optimizing its performance characteristics and overall life. Presence of more than one objective makes the problem come into the domain of multi-objective optimisation.

Any constrained multi-optimisation optimisation problem is essentially composed of three components, namely, *design parameters*, *objective functions*, and *constraints* (for defining feasible design parameter space). We discuss in brief these components of the present problem in following sections.

A. Design Parameters

The design parameter vector can be written as:

$$X=[D_m, D_b, Z, f_i, f_o, K_{D\min}, K_{D\max}, \varepsilon, e, \zeta]^{\mathrm{T}}, \qquad (1)$$

Where,

$$f_i = r_i / D_b; \qquad f_o = r_o / D_b. \qquad (2)$$

Parameters that define bearing internal geometries are D_m, D_b, Z, f_i, and f_o (refer Appendix A for the nomenclature). Whereas, K_{Dmin}, K_{Dmax}, ε, e, and ζ are part of constraints [11] (refer subsection 3.2 and 3.3 for details) and do not directly represent any measurement of bearing internal geometries. Usually these are kept as constant while designing bearings [7]. For the present case these secondary parameters are considered as variable and it is possible due the Genetic Algorithm based approach that has been adopted. All angles are measured in radians, distances in millimetres - taking the exception of the minimum film thickness (H_{min}) that is measured in micrometers, and forces in Newton (N). Assembly angle (ϕ_o) of a bearing (see Figure 2) is also an important geometrical constraint. Based on the geometrical derivation, one could arrive at the following formula for the assembly angle [11],

$$\phi_o = 2\Pi - 2\cos^{-1}\frac{[\{(D-d)/2-3(T/4)\}^2+\{D/2-(T/4)-D_b\}^2-\{d/2+(T/4)\}^2]}{2\{(D-d)/2-3(T/4)\}\{D/2-(T/4)-D_b\}}, \qquad (3)$$

$$T = D - d - 2D_b. \qquad (4)$$

B. Objective Functions

As discussed earlier, we have three objective functions for simultaneous optimisation. These are the dynamic capacity (C_d), the minimum film thickness (H_{min}), and the static capacity (C_s). All three have to be maximized.

*1) **Dynamic Capacity (C_d):*** Among different objectives for rolling bearings, the dynamic capacity (C_d) is the most important one, as this directly forms the basis for longest *fatigue life* of a bearing. The dynamic capacity, also known as the dynamic load rating, is defined as the constant radial load which a group of apparently identical bearings can endure for a rating life of one million revolutions of the inner ring (for a stationary load and the stationary outer ring). It is given as [7]:

$$C_d = \begin{cases} f_c Z^{2/3} D_b^{1.8} & D_b \le 25.4\,\text{mm} \\ 3.647 f_c Z^{2/3} D_b^{1.4} & D_b > 25.4\,\text{mm} \end{cases} \quad (5)$$

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

$$\gamma = D_b \cos\alpha / D_m \quad (7)$$

2) ***Constraints:*** Constraints reduce the parameter space to the feasible parameter space. This section summarises the nine problem constraints. Apart from geometrical constraints, we also maintain an intuitive constraint on the number of balls in a given bearing. The first constraint for the maximum allowance on the assembly angle is [11]

$$\frac{\phi_0}{2\sin^{-1}(D_b/D_m)} - Z + 1 \ge 0. \quad (8)$$

$$2D_b - K_{D\min}(D-d) \ge 0, \quad (9)$$

$$K_{D\max}(D-d) - 2D_b \ge 0. \quad (10)$$

$$\zeta B_w - D_b \ge 0. \quad (11)$$

$$D_m - 0.5(D+d) \ge 0 \quad (12)$$

$$(0.5+e)(D+d) - D_m \ge 0. \quad (13)$$

$$0.5(D-D_m-D_b) - \varepsilon D_b \ge 0. \quad (14)$$

$$f_i \ge 0.515, \quad (15)$$

$$f_o \ge 0.515. \quad (16)$$

3) Artificial Bee Colony Algorithm

In ABC algorithm, the colony of artificial bees contains three groups of bees: employed bees, onlookers and scouts. First half of the colony consists of the employed artificial bees and the second half includes the onlookers. For every food source, there is only one employed bee. In other words, the number of employed bees is equal to the number of food sources. The employed bee of an abandoned food source becomes a scout. The search carried out by the artificial bees can be summarized as follows: - Employed bees determine a food source within the neighbourhood of the food source in their memory. - Employed bees share their information with onlookers within the hive and then the onlookers select one of the food sources. - Onlookers select a food source within the neighbourhood of the food sources chosen by them. - An employed bee of which the source has been abandoned becomes a scout and starts to search a new food source randomly.

Initialize
REPEAT
Move the employed bees onto their food sources
Move the onlookers onto the food sources and
Determine their nectar amounts.
Move the scouts for searching new food sources.
Memorize the best food source found so far.
UNTIL (requirements are met)

IV. *IMPLEMENTATION AND RESULTS*

The work on the design optimisation of ball bearings is a very active area of research. Some contribution on the design of ball bearings was made by earlier work of Chakraborty et al. [10] and Rao and Tiwari [11], where GA was used to optimize dynamic capacity for rolling bearings.

Problem parameters were given strict upper and lower bounds (Table 1) to reduce the solution space.

D_m	~	{0.5 (*D*+*d*), 0.6 (*D*+*d*)}
D_b	~	{0.15(*D*-*d*), 0.45(*D*-*d*)}
Z	~	(4, 50)
f_i	~	(0.515, 0.6)
f_o	~	(0.515, 0.6)
K_{Dmin}	~	(0.4, 0.5)
K_{Dmax}	~	(0.6, 0.7)
ε	~	(0.3, 0.4
E	~	(0.02, 0.10)
ζ	~	(0.6, 0.85)

Table 1. Parametric bounds

S. N.	Standard bearing Dynamic capacity(N) (SKF)	bearing Dynamic capacity(N) (SKF) in ABC	% increment in dynamic capacity
1	3580	6036.770439	0.11992
2	5870	7064.509981	0.09337
3	9430	12108.80555	0.08187
4	14900	18127.6276	0.08684
5	22500	27165.89450	0.10021
6	26900	29198.45632	0.69475
7	40300	43656.84015	0.11406
8	47600	52499.70286	0.10755
9	55600	64441.69275	0.10173
10	73900	81929.43753	0.10525

Dynamic capacity

V. CONCLUSIONS

In the present paper, a procedure for the optimum design of ball bearings has been proposed. The design has been optimized using the artificial bee colony. Optimum design from algorithm is compared and it is concluded that artificial bee colony is better than the Standard for the present optimum design. The dynamic capacity of the bearing is taken as the objective function and is subjected to non-linear constraints. A convergence study has been carried out to ensure the global optimum point in the design. There is good agreement between the optimized and standard bearings in respect of the C_d. The proposed optimum design methodology could be considered as a basic step towards more advance design.

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