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# BALL BEARING DESIGN THROUGH JAYA ALGORITHM

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## ABSTRACT

*Bearings are the basic components of any machines whose function is to enable rotation or linear movements. The design of rolling element bearings has been a challenging task in the field of mechanical engineering. For proper utilization of the recourses and technologies in a better way, Optimization of bearing is also necessary. Maximization of dynamic capacity is the main objective during designing and optimization of bearing, with considering all necessary constraints. In the present paper, design optimization of rolling element bearing is carried out by taking maximization of dynamic capacity as objective. Jaya algorithm is a new, population based optimization algorithm is used to solved this problem and their results have been compared with the results of the other algorithm proposed by previous researchers. The results obtained using Jaya algorithm is better than the other algorithm. The convergence study is also carried out in all problems.*

***Keywords: Design optimization, Jaya algorithm, Ball bearing, Genetic algorithm, Dynamic capacity.***

## I INTRODUCTION

Design of any product involves several parameters and stages depending upon the design strategy, procedure, depth of design and requirements. In machine element the design is focused on strength, load bearing capacity, wear and deflection, etc. Design optimization of a mechanical system is more complicated and involves a number of design variables and constraints. So it is a good practice to apply optimization approach to individual subassembly level. Rolling elements Bearing is a mechanical component, which is use to support a rotating machine element and confines its motion. It has variety of applications in automobiles, rotating machinery, machine tools, aircraft, household appliances, etc. The basic purpose of optimize designing of bearing is to increase the performance of bearing, better efficiency and to getting more reliable operation under adverse operating condition. Consequently, it also affects the operating quality and economy of machines on which the bearings are used. Bearing designer have the responsibility of selecting an optimum scheme from all possible alternative designs. In all such applications of bearings, the demand of high reliability and dynamic capacity gives a boost to the advancement in design technology of bearings. Design engineers come with various technologies that will optimize the fatigue life of the bearings. There are many numerical techniques available for solving non-linear constrained optimization to optimize objective function. Jaya algorithm is the non-conventional method, is easy and suitable for non-linear constrained problems. We are here discussing the optimizing basic dynamic capacity rolling element bearing.

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## II LITERATURE REVIEW

Research literature available on bearings is mainly concentrated on development of new bearing design, the analysis of load distributions, design of profiles of bearings, and the effect of roller screw; and very few literature is available on optimum design of rolling element bearings. Krzeminski-Freda and Ward [1] presented their study on optimization of the correction of roller generators in the spherical roller bearing. Choi and Yoon [3] used genetic algorithm for design optimization of automobile wheel bearing unit with discrete design variables by considering the maximization of fatigue life as the objective. Chakraborty et al. [4] described the design optimization of radial ball bearings with five design variables by using genetic algorithm for longest fatigue life. The authors presented the optimum design variables and dynamic load capacity of different size of bearings. However, the constraints considered in that model appear unrealistic. Rao and Tiwari [6] described a constraint non- linear optimization problem for designing roller bearings using genetic algorithms. The optimization was performed in two stages. Gupta et al. [7] proposed multi objective optimization procedure for rolling element bearing, with maximization of dynamic load capacity, static load capacity and elestohyderodynamic minimum thickness as the three objectives using NSGA-II (non-dominated sorting based genetic algorithm).

Kumar et al. [8] developed an optimum design methodology of cylindrical roller bearing using genetic algorithm. Waghole and Tiwari [9] proposed optimization of needle roller bearing using various methods. They had solved non-liner optimization problem using the artificial bee colony algorithm (ABCA), differential search algorithm (DSA), grid search method (GSM) and hybrid method (HM, a approach of combination of the ABCA/DSA and GSM. On examination of the available literature, it is notice that various optimization methods are used to optimize fatigue life of different types and sizes of bearings. Results obtained using those advanced optimization methods are better than previously known standard values. However, some degree of constraint violation is always there and that’s why possibilities of getting better results still exist. It can be done by applying other improved optimization algorithm, which able to reduce constraint violence. Rao [10] proposed a new advanced algorithm known as Jaya algorithm. It is a simple and powerful optimization algorithm for solving both constraint and unconstraint problems. This algorithm secures first rank for the best and mean solutions in the Friedman’s rank test for all 24 constrained benchmark problems.

In this paper, Jaya algorithm is applied to optimize design of ball bearings. The results of the present investigation are compared with the results obtained by previous researchers. Dynamic load capacity is taken as main objective and other variables are going to optimized accordingly. The next section describes the newly proposed Jaya algorithm.

## III JAYA ALGORITHM

Jaya algorithm is a newly developed advanced optimization algorithm. It consists a single phase process and quite simpler to apply but gives good results. This algorithm is based on the concept of moving the optimum

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solution of a problem closer to the best solution and moving away from the worst solution. The algorithm can be applied in both constrained and unconstrained type optimization problem. This algorithm requires only some common control parameters and does not require any algorithm specific controls parameter. The description of Jaya algorithm is given below.

Consider a problem where f(x) is the objective function which is to be maximized (or minimized). At any number of iteration 'i', consider 'd' is the number of design variables (i.e. j=1,2,…,d) and 'p' be the number of candidate solution (i.e. population size, k=1,2,…p). Let the best candidate best obtained the best value of f(x) (i.e. $f(x)_{best}$) in the entire candidate solutions and the worst candidate worst obtained the worst value of f(x) (i.e. $f(x)_{worst}$) in the entire candidate solutions. If $X_{j,k,i}$ is the value of the $j^{th}$ variable for the $k^{th}$ candidate during the $i^{th}$ iteration, then this value is modified as per the following equation.

$$X'_{j,k,i} = X_{j,k,i} + r_{1,j,i} (X_{1,best,i} - |X_{j,k,i}|) - r_{2,j,i} (X_{1,worst,i} - |X_{j,k,i}|) \quad (1)$$

where, $X_{j,best,i}$ is the value of the $j^{th}$ design variable for the best candidate and $X_{j,worst,i}$ is the value of the $j^{th}$ design variable for the worst candidate. $X'_{j,k,i}$ is the new improved value of $X_{j,k,i}$ and $r_{1,j,i}$ and $r_{2,j,i}$ are the two random numbers for $j^{th}$ variable during the $i^{th}$ iteration in the range [ 0, 1 ]. The term "$r_{1,j,i} (X_{1,best,i} - |X_{j,k,i}|)$" indicates the tendency of the solution to move towards the best solution and the other term " $- r_{2,j,i} (X_{1,worst,i} - |X_{j,k,i}|)$" indicates the tendency of the solution to move away from worst solution. The value of $X'_{j,k,i}$ is only accepted if it give better function value. All the accepted function values at the end of iteration are taken as the input to the next iteration.

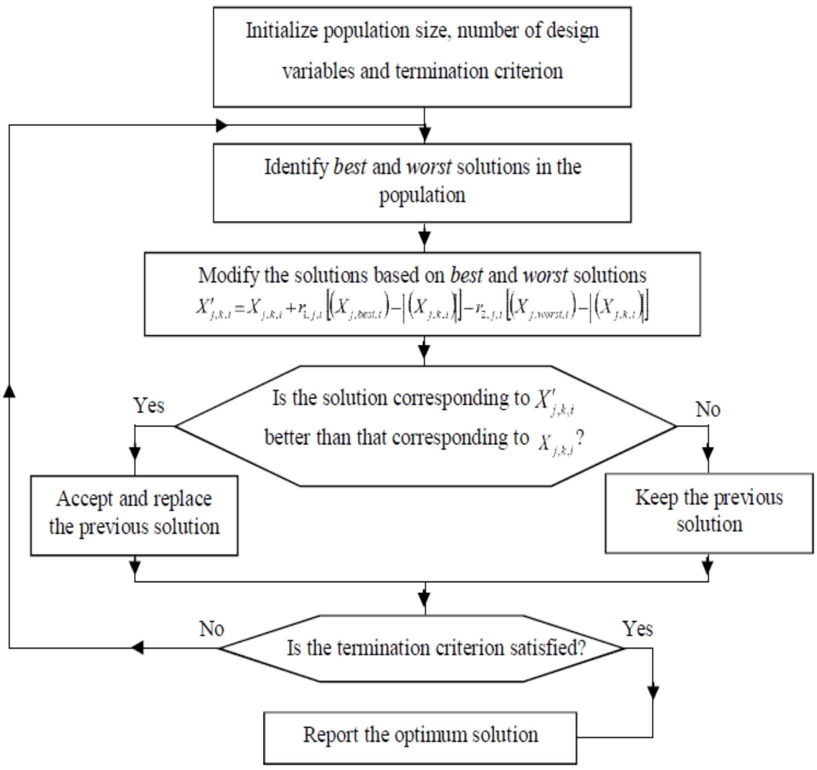


**Fig. 1 Flow chart of Jaya algorithm**

## IV DESIGN OPTIMIZATION OF BALL BEARING

On the basis of operating requirements, different objective functions for rolling element bearings may be proposed, the most important of these being the requirement of the longest fatigue. Thus, the basic requirement for a ball bearing is the long fatigue life. In normal operating conditions of ball bearings, the main reason of failure is contact stress. The most frequent failure of bearing is due to surface fatigue or flaking phenomenon. Flaking is a phenomenon of removable of scaly surface particles from the bearing material which is due to surface fatigue that occurs between the rolling elements and the inner and outer rings. Fatigue life of bearing is defined as the number of revolutions after which flanking or any cracks initiates due to repeated stresses. Fatigue life of bearing is the most important factor in bearing design. Therefore, the bearings are designed for maximum fatigue life as an objective. The fatigue life of bearing under a radial load can be expressed as

$$L_{10} = \left(\frac{C_d}{F_e}\right)^a (10^6) \text{ rev.} \qquad (2)$$

where, $L_{10}$ is the fatigue life in revolutions with 90% reliability, $C_d$ is the dynamic load capacity of bearing, $F_e$ is the dynamic equivalent load, and n is the load life exponent, which is taken as 3 for point contact or ball bearing. It can be seen from eq. (2) that the fatigue life of bearing is directly proportional to the dynamic load capacity of bearing. Hence, the dynamic load capacity is taken as objective function for maximization in this case study. Micro- geometry of ball bearing and formation of optimization problems are described below.

### 4.1. Micro- geometry of radial bearings

Ball bearing is a type of rolling contact bearing, in which rollers are in the form of small spherical balls. It can take both radial and axial loads. Fig. 2 shows micro-geometry of a ball bearing in which various geometrical parameters are indicated.

### 4.2. Objective function

In this present case study, the basic dynamic capacity is taken as objective for maximization and expression of basic dynamic capacity for ball bearing is given as:

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

with

$$f_c = 37.91 \left\{1 + \left[1.04 \left(\frac{1-\gamma}{1+\gamma}\right)^{1.72} \left(\frac{f_i(2f_o-1)}{f_o(2f_i-1)}\right)^{0.41}\right]^{10/3}\right\}^{-0.3} * \left[\frac{\gamma^{0.3}(1-\gamma)^{1.39}}{(1+\gamma)^{1/3}}\right]\left[\frac{2f_i}{2f_i-1}\right]^{0.41} \qquad (4)$$

and

$$\gamma = (D_b \cos\alpha / D_m) \qquad (5)$$

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where, $\gamma$ is a dependent parameter, $\alpha$ is the free contact angle of bearing and it depends on type of bearings. In present of deep groove ball bearing $\alpha$ is equal to zero.

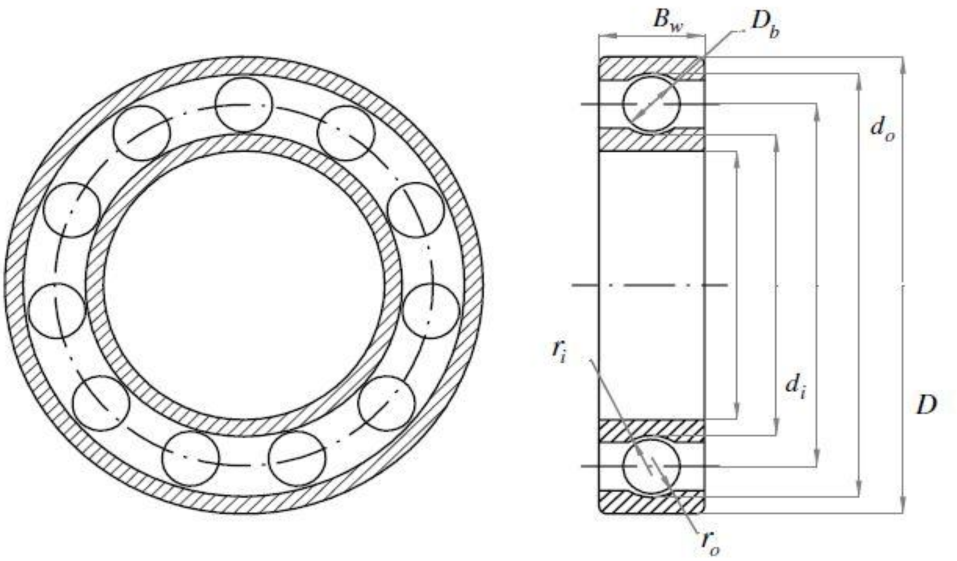


**Fig. 2. Micro-geometries of a typical ball bearing.**

The present optimization problem is a single objective multi constraint optimization problem and the maximization of dynamic load capacity of radial ball bearing is the main objective.

$$\max[\, f(X) \,] = \max[\, C_d \,] \tag{6}$$

where $f(X)$ represent the objective function, which is to be maximized and $X$ is the design variable vector.

### 4.3. Design variable vector

Referring to eq. (3) and eq. (4), the ball bearing design parameter vector has been chosen as

$$\{X\} = [\, D_b \,, D_m \,, Z, f_o, f_i, \,]^T$$

where, $D_b$, $D_m$, $Z$, $f_o$, $f_i$, are the parameters defining the internal geometry of ball bearing (see Fig. 2), $D_b$ is the diameter of the ball in mm, $D_m$ is the bearing pitch diameter in mm, $Z$ is the numbers of balls, $f_o$ (= $r_o/D_b$ ) is the curvature radius coefficient of the outer raceway groove, $f_i$ (= $r_i/D_b$ ) is the curvature radius coefficient of the inner raceway groove; $r_o$ and $r_i$ are the outer and the inner raceway groove curvature radius, respectively. There are three more parameters are used in constraints to give bearing a feasible design space. The value of these parameters has taken constant in this problem. $K_{Dmin}$ is the minimum roller diameter limiter = 0.5, $K_{Dmax}$ is the maximum roller diameter limiter = 0.8, $\varepsilon$ is the Parameter for outer ring strength consideration = 0.1, and $e$ is parameter for mobility condition = 0.1.

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### 4.4. Constraints

Designing of radial ball bearing involved various constraints proposed by researchers (Indraneel Chakraborty , Vinay Kumar , Shivashankar B. Nair & Rajiv Tiwari). These constraints are obtained based on the bearing internal geometries, manufacturing consideration, running consideration and contact stresses. Various constraints have been complied in Table 1 and small description about them given below.

**TABLE 1 Constraint defining the range of geometric design variables of spherical roller bearings**

| S.N. | Constraint no. | Constraint parameter ranges and constraint conditions for design variables. |
|---|---|---|
| 1. | Constraint 1 | $2(Z-1)\sin^{-1}(D_b/D_m) \le \varphi_o$ <br> $g_1(X) = \frac{\varphi_o}{2\sin^{-1}(D_b/D_m)} - Z + 1 \ge 0$ |
| 2. | Constraint 2 | $K_{D_{min}} \frac{D-d}{2} \le D_b \le K_{D_{max}} \frac{D-d}{2}$ <br> $g_2(X) = 2D_b - K_{D_{min}}(D-d) \ge 0$ |
| 3. | Constraint 3 | $g_3(X) = K_{D_{max}}(D-d) - 2D_b \ge 0$ |
| 4. | Constraint 4 | $g_4(X) = D_m - (0.5-e)(D+d) \ge 0$; where $e = 0.1$ |
| 5. | Constraint 5 | $g_5(X) = (0.5+e)(D+d) - D_m \ge 0$ |
| 6. | Constraint 6 | $g_6(X) = 0.5(D - D_m - D_b) - \varepsilon D_b \ge 0$; where $\varepsilon = 0.1$ |
| 7. | Constraint 7 | $g_7(X) = 0.52 \ge f_i \ge 0.515$ ; and |
| 8. | Constraint 8 | $g_8(X) = 0.53 \ge f_0 \ge 0.515$ |

Constraint 1 is used to find out the number and diameter of balls, for convenience of bearing assembly, first constraint must be satisfied. $\varphi_o$ (= 4.7124 radians) is the maximum tolerable assembly angle which depends upon the bearing geometry. Constraints 2 and 3 are used to choose the bounds of diameter of ball. Constraints 4 and 5 are defined for running mobility of bearings. Bearing pitch diameter of bearing should fall in a certain range. Constraint 6 is defined to take care of thickness of bearing ring at the outer raceway, so that bearing ring not distorted under process of manufacturing and mounting. Constraint 7 and 8 defined to take care of groove curvature radii of raceways to provide relief in contact stress. The coefficient of groove curvature radii of the inner and outer raceways of ball bearing should not be less than $0.515D_b$.

### 4.5. Results

Jaya algorithm is used for obtaining optimum values of design variables of various sizes of ball bearings. These bearings are selected from bearing standards belonging to various dimensional series, which is available commercially. Table 2 enlists the ranges of design variables used in design optimization of a first bearing. The

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ranges of various design parameters are obtained using various constraints. Computations were conducted using MATLAB09 and it is executed in dual core – 2.00GHz (3 Gb RAM) computer.

**TABLE 2 Bounds of design variables for ball bearing (*D = 30; d = 10* )**

| Design variables | Lower bound | Upper bound |
|---|---|---|
| $D_b$ | 3 | 9 |
| $D_m$ | 18 | 24 |
| $Z$ | 4 | 50 |
| $f_i$ | 0.515 | 0.52 |
| $f_o$ | 0.515 | 0.53 |

Optimization of ball bearing was carried out through Jaya algorithm using the bounds of variables with a population size of 300 and number of generation of 10000. In order to verify effectiveness of newly proposed Jaya algorithm, it is applied to various ball bearings, listed in Table 3. And the results obtained are compared with previously proposed algorithms. The algorithm is run several times and the results obtained are found consistently better than the results of previously proposed. Table 3 shows the various optimized design variables of ball bearing obtained through Jaya algorithm and comparison of dynamic capacity obtained using Jaya algorithm with Genetic algorithm obtained by past researchers. The results obtained using Jaya algorithm is found better than other algorithm.

**TABLE 3 Optimum design of radial ball bearing using Jaya algorithm and comparison with other algorithms.**

| *D* | *d* | $D_b$ (mm) | $D_m$ (mm) | *Z* | $f_i$ | $f_o$ | $C_d$ *(GA) (N)* | $C_d$ *(Jaya) (N)* | *increment %* |
|---|---|---|---|---|---|---|---|---|---|
| 30 | 10 | 7.85 | 20.586 | 7 | 0.515 | 0.515 | 7306.6 | 8312.722 | 13.77 |
| 35 | 15 | 8.00 | 25.400 | 8 | 0.515 | 0.515 | 9553.7 | 10631.9672 | 11.28 |
| 47 | 20 | 10.80 | 34.040 | 8 | 0.515 | 0.515 | 16213.4 | 18117.3040 | 11.74 |
| 62 | 30 | 12.80 | 46.640 | 9 | 0.515 | 0.515 | 25785.0 | 28158.0334 | 9.20 |
| 80 | 40 | 16.00 | 60.800 | 10 | 0.515 | 0.515 | 38979.1 | 43609.0014 | 11.87 |
| 90 | 50 | 16.00 | 70.800 | 11 | 0.515 | 0.515 | 45161.4 | 49073.2518 | 8.66 |
| 110 | 60 | 20.00 | 86 | 11 | 0.515 | 0.515 | 64542.3 | 71822.0417 | 11.28 |
| 125 | 70 | 22.00 | 98.60 | 11 | 0.515 | 0.515 | 81701.2 | 87885.5382 | 7.57 |
| 140 | 80 | 24.00 | 111.20 | 12 | 0.515 | 0.515 | 95915.9 | 105237.88 | 9.71 |
| 160 | 90 | 28.00 | 126.40 | 12 | 0.515 | 0.515 | 121401.9 | 131190.78 | 8.06 |

Convergence study is carried out by plotting graphs between design variables and number of generations. Convergence graph of dynamic capacity of ball bearing shows fast increment in its value, Dynamic capacity

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attends convergence at 44th generation with a value of 8312.722 N and become constant for rest of generations. Fig. 4 to Fig.6 shows variation of basic design variable with number of population. The value of ball diameter initially increases to 7.699mm at 12th generation, after that its value once decrease and again increases to 7.862mm at 993th generation and remain constant for rest generation. The pitch diameter of ball bearing attends convergence value of 20.59mm at 1014th generation and remains constant. Similarly, the number of balls also attends fast convergence value of 7 at 241th generation and remains constant for rest generations.

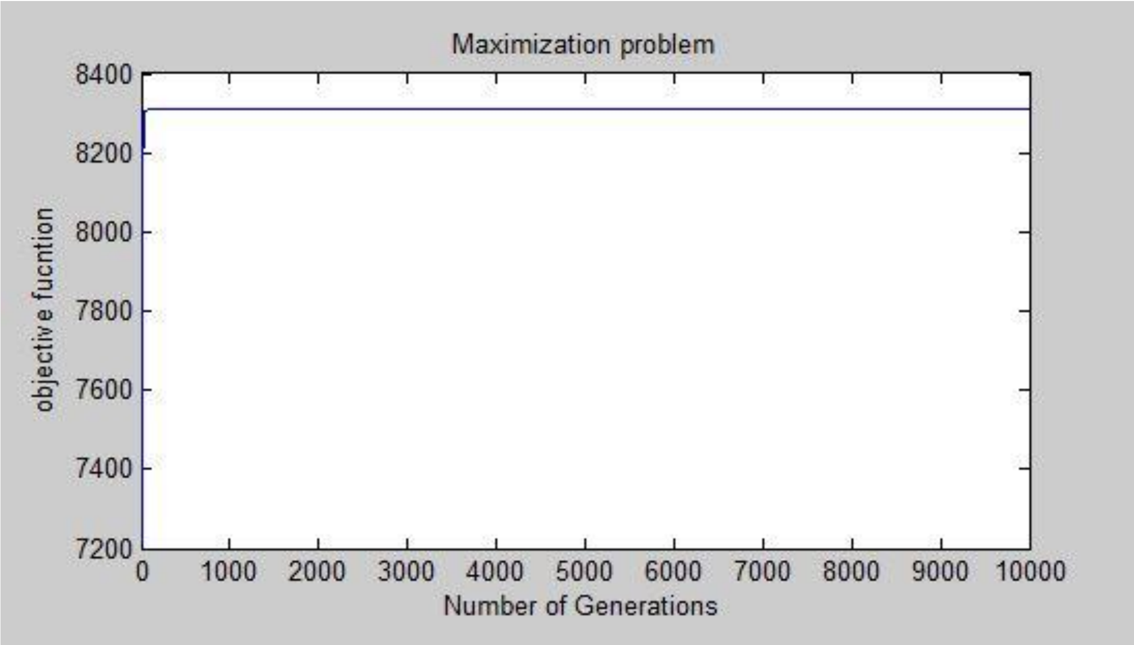


**Fig. 3 shows the variation of dynamic capacity with no. of generation for radial ball bearing 6200 series.**

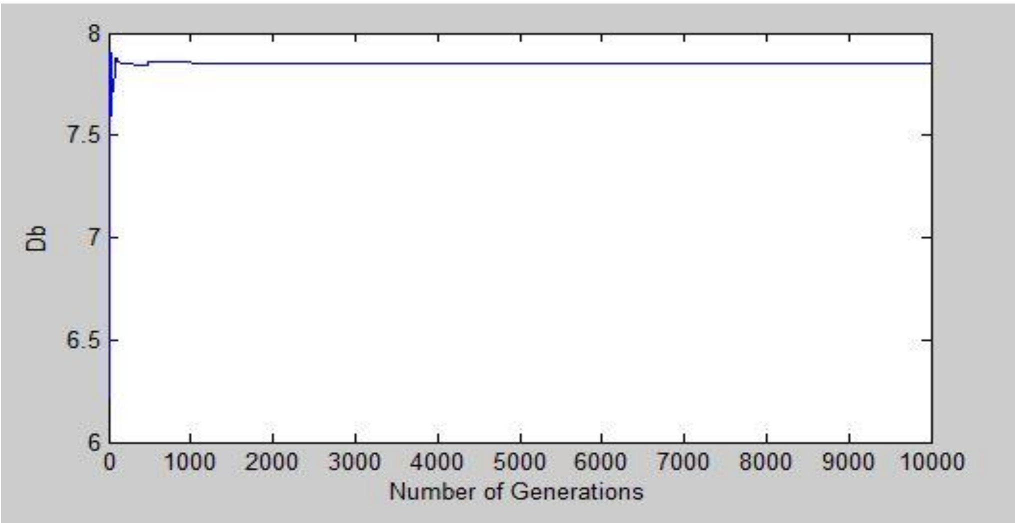


**Fig. 4 Variation of ball diameter versus number of generations for a radial ball bearing.**

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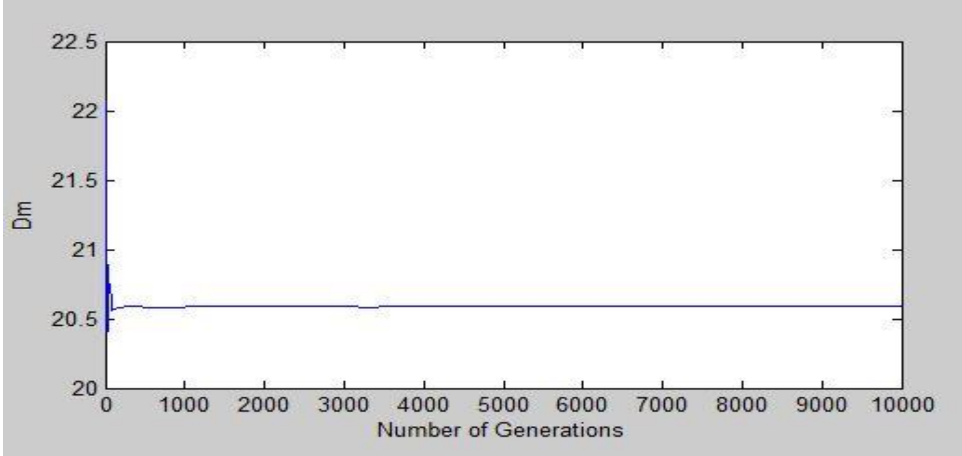


**Fig. 5 Variation of the pitch diameter versus number of generations**

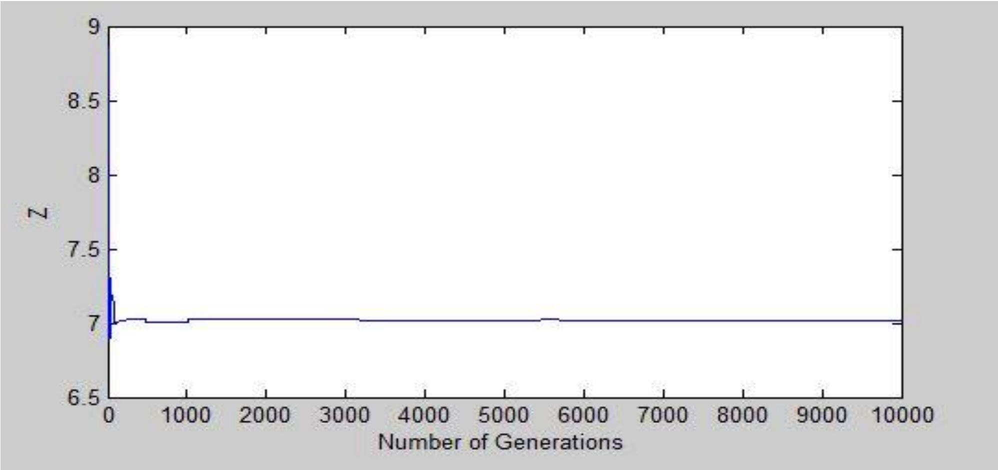


**Fig. 6 Variation of no. of balls versus no. of generations for a radial ball bearing.**

## V CONCLUSION

Selection of the optimal values of different design variables is of chief importance for designing of any kind of bearings. Design optimization has to yield maximize dynamic capacity while considering various design parameter and constraints. In the present paper, Jaya algorithm has used successfully for obtaining optimized design of ball bearing, which is taken from literature. This case study is a single objective problem and subjected to various non-linear constraints. The main aim is to increase fatigue life of the bearing. The design of ball bearings of various sizes was optimized using Jaya algorithm and their results compared with genetic algorithm, which obtained by previous researchers. The results obtained using Jaya algorithm is better than genetic algorithm and also fulfilling all necessary constraints. Convergence studies are also carried out and it shows very fast convergence towards than other algorithm. The analysis of the optimized design parameters and variables indicates that $D_r$, $D_m$, $l_e$, $Z$ are the key design variables. Further case studies could be carried out on

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other types of bearings. Some more realistic constraints can be introduced for getting more precious result. Heat generation could be taken as objective along with dynamic capacity incorporated for multi objective bearing design problems.

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