iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 2 **Issue:** II **Month of publication:** February 2014

DOI:

INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE AND ENGINEERING TECHNOLOGY (IJRASET)

Design Formulation and Optimum Load Carrying Capacity of Hydrodynamic Journal Bearing By using Genetic Algorithm

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***Abstract*— The ever increasing demand of lower initial costs for bearing, to withstand competition, has prompted engineers to apply optimization methods in bearing design. The optimization scheme that optimizes load carrying capacity with respect to clearance along with minimization of power loss, temperature rise, geometry of grooves, film thickness, film pressure, eccentricity, journal surface velocity etc. i.e., parameters which governs the performance of the bearing. The load carrying capacity with respect to clearance relation derived from Reynolds equation. The optimization is carried out by Genetic Algorithm (GA) tool in MATLAB software. The study is motivated by bearing design available in literature though very limited works seems to be available in the area of optimum design of bearing. In this paper it is planned to concentrate upon the design parameter and design formulation of hydrodynamic short journal bearing and thus optimization using GA tool. This tool is based on GA which is derived from Darwin Theory of Evolution wherein natural selection and heredity governs the whole performance.**

***Keywords*— Genetic Algorithm, Load Carrying Capacity, Radial clearance, surface velocity, MATLAB Software.**

I. INTRODUCTION

Journal bearings are considered to be sliding bearings as opposed to rolling bearings such as ball bearings. Despite this categorization, a shaft spinning within a journal bearing is actually separated from the journal bearing's metal facing by an extremely thin film of continuously supplied motor oil that prohibits metal to metal contact. As such, the journal bearing allows the crankshaft to normally be contacted only by oil, which explains the long life of engines that get regular oil changes normal attitude position in a lower quadrant of the bearing. [1]

The normal attitude angle will depend upon the shaft rotation direction with a clockwise rotation having an attitude angle in the lower left quadrant. External influences, such as hydraulic volute pressures in pumps or generator electrical load can produce additional relocating forces on the shaft attitude angle and centerline position.[2]

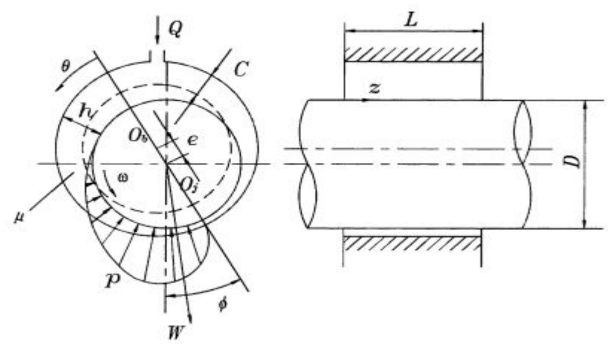

Fig.1. A Short Journal bearing

Many methodologies are available in literature to design the journal bearing such as

1. Raimondi and Boyd method.
2. Cameron method.
3. ESDU charts.
4. Reason and Narang method.

However each above design method has its own way of deciding the clearance or minimum oil film thickness. Since the load carrying capacity (LCC) is directly proportional to inverse of square of clearance the larger clearance would decrease the load carrying capacity and lesser would result in metal to metal

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ISSN: 2321-9653

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contact. Hence, the decision of clearance becomes crucial. An attempt will be made here to optimize the clearance by satisfying the required performance of the bearing from load carrying capacity, temperature rise etc. points of view.

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II. Design Optimization Method: Genetic Algorithm

Genetic algorithms were formally introduced in the United States in the 1970s by John Holland at University of Michigan. The continuing price/performance improvements of computational systems have made them attractive for some types of optimization. In particular, genetic algorithms work very well on mixed (continuous and discrete), combinatorial problems. They are less susceptible to getting 'stuck' at local optima than gradient search methods. But they tend to be computationally expensive. To use a genetic algorithm, it is must to represent a solution to a problem as a genome (or chromosome). The genetic algorithm then creates a population of solutions and applies genetic operators such as mutation and crossover to evolve the solutions in order to find the best one(s).[4]

The three most important aspects of using genetic algorithms are: (1) definition of the objective function, (2) definition and implementation of the genetic representation, and (3) definition and implementation of the genetic operators. Once these three have been defined, the generic genetic algorithm works fairly well. Beyond that many different variations can be tried to improve performance, find multiple optima (species - if they exist), or parallelize the algorithms.

Genetic algorithms are search methods that employ processes found in natural biological evolution. These algorithms search or operate on a given population of potential solutions to find those that approach some specification or criteria. To do this, the algorithm applies the principle of survival of the fittest to find better and better approximations. At each generation, a new set of approximations is created by the process of selecting individual potential solutions (individuals) according to their level of fitness in the problem domain and breeding them together using operators borrowed from natural genetics. This process leads to the evolution of populations of individuals that are better suited to their environment than the individuals that they were created from, just as in natural adaptation.

Standard genetic algorithms are implemented where the initial population of individuals is generated at random. At every evolutionary step, also known as generation, the individuals in the current population are decoded and evaluated according to a fitness function set for a given problem. The expected number of times an individual is chosen is approximately proportional to its relative performance in the population. Crossover is performed between two selected individuals by exchanging part of their genomes to form new individuals. The mutation operator is introduced to prevent premature convergence.

Every member of a population has a certain fitness value associated with it, which represents the degree of correctness of that particular solution or the quality of solution it represents. The initial population of strings is randomly chosen. The GA using genetic operators, to finally arrive at a quality solution to the given problem manipulates the strings. GAs converge rapidly to quality solutions. Although they do not guarantee convergence to the single best solution to the problem, the processing leverage associated with GAs make them efficient search techniques. The main advantage of a GA is that it is able to manipulate numerous strings simultaneously by parallel processing, where each string represents a different solution to a given problem. Thus, the possibility of the GA getting caught in local minima is greatly reduced because the whole space of possible solutions can be simultaneously searched. Basic Component of GA are following:

1. Chromosome: A set of genes. Chromosome contains the solution in form of genes.
2. Gene: A part of chromosome. A gene contains a part of solution. It determines the solution. E.g. 16743 is a chromosome and 1, 6, 7, 4 and 3 are its genes.
3. Individual: Same as chromosome.
4. Population: No of individuals present with same length of chromosome.
5. Fitness: Fitness is the value assigned to an individual. It is based on how far or close a individual is from the solution. Greater the fitness value better the solution it contains.
6. Fitness function: Fitness function is a function which assigns fitness value to the individual. It is problem specific.
7. Selection: Selecting individuals for creating the next generation.
8. Recombination (or crossover): Genes from parents form in some way the whole new chromosome.
9. Mutation: Changing a random gene in an individual.

III. Formulation

For formulation of optimization problem for load carrying capacity (LCC) of a short journal bearing following assumptions are considered.[10]

1. The load condition on bearing is steady state with radial load fixed in magnitude and direction.
2. The lubricant is supplied to the bearing at atmospheric pressure.[11]
3. The viscosity of the oil is constant and corresponds to the average temperature of the oil flowing and form the bearing.
4. The entire heat generated in the bearing is carried away by the oil i.e. heat is carried away through convection only.
5. The co-efficient of friction is taken as Petroff's co-efficient of friction.
6. The diameter of journal (D) and Ra value of bearing surfaces are known.

A. Objective Function

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Reynolds's equations for short journal bearing,[12]

$$\frac{\partial}{\partial x}\left(h^3\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial z}\left(h^3\frac{\partial p}{\partial z}\right)=6U\mu\frac{dh}{dx} \qquad \text{….. (a)}$$

For short bearing $\frac{\partial p}{\partial x} \ll \frac{\partial p}{\partial z}$ this means that first term of Reynolds equation can be neglected with respect to second term and becomes

$$\frac{\partial}{\partial z}\left(h^3\frac{\partial p}{\partial z}\right)=6U\mu\frac{dh}{dx} \qquad \text{….. (b)}$$

Now usually h is not a function of y, only of x, so that the L.H.S. is $h^3\frac{\partial^2 p}{\partial x^2}$. The equation can be rearranged

$$\frac{\partial^2 p}{\partial z^2}=6U\mu\frac{dh/dx}{h^3} \qquad \text{…..(c)}$$

By making mathematical procedure we get below equation for pressure,

$$p=\frac{3\,\mu\,U\,\epsilon\,\sin\theta}{r\,c^2\,(1+\epsilon\,\cos\theta)^3}\left[\frac{l^2}{4}-z^2\right] \qquad \text{...... (d)}$$

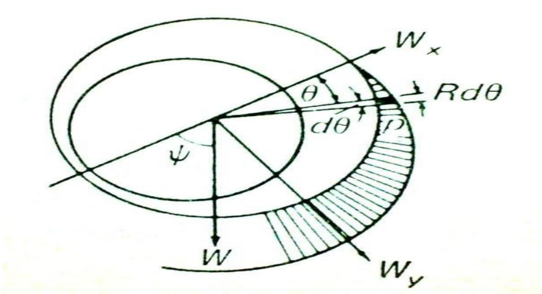

Fig.2 Components of load in a journal bearing [13]

Force in direction of p = p r dθ dz Component of force along N-direction = p r dθ dz cosθ Component of force along T-direction = p r dθ dz sinθ

We get two component of load as below,

$$W_T=\frac{\pi\,\mu\,U\,\epsilon\,l^3}{4\,c^2}\cdot\frac{1}{(1-\epsilon^2)^{3/2}} \qquad \text{…. (e)}$$

$$W_N=\frac{-\mu\,U\,\epsilon^2\,l^3}{c^2\,(1-\epsilon^2)^2} \qquad \text{…. (f)}$$

So total load is given as below,

$$W=\sqrt{W_N{}^2+W_T{}^2}$$

$$W=\frac{\pi\,\mu\,U\,l^3}{4\,c^2}\cdot\frac{\epsilon}{(1-\epsilon^2)^2}\sqrt{\left(\frac{16}{\pi^2}-1\right)\epsilon^2+1} \qquad \text{….. (g)}$$

Equation (g) gives the load carrying capacity of short hydrodynamic journal bearing. Usually the value of ϵ varies between 0 and 1. However, the extreme most value of ϵ on both extremes are not used for design purpose because of concentricity and metal to metal contact. Hence common useful range of ϵ is 0.5-0.7. Considering ϵ = 0.6 the equation (g) gives ,5

$$W=1.27263\frac{U\,\mu\,l^3}{c^2} \qquad \text{…... (h)}$$

Equation (h) contains four variables and solution will be complex to achieve. Therefore it is desired to convert four variables problem into three variables problem. In Turbine and crankcase bearings usually SAE 20 oil is used for which the maximum temperature is 150° C. Correspondingly if the inlet temperature is 50° C the temperature rise will be 100°C.

T_{eff} = T_{inlet} + 0.8 Δt = 50 + 0.8*100 = 130° C ……(j)

According to T_{eff} of 130° C, from ASTM chart the viscosity of SAE 20 oil is [8]

2.8×10^{-3} N-s/m^2, this leads to

$$W=3.56336\times10^{-3}\frac{U\,l^3}{c^2} \qquad \text{….. (k)}$$

This is required objective function in three variables.

B. Formulation of Constraints

According to above discussion is carried out the constraint can be enlisted as follows.

- $0.25 \le L/D \le 0.75$
- $1000 \le U \le 7000$
- $\Delta t \le 100°$ C
- For different λ= L/D ratios, the corresponding Sommerfeld variable can be found as below using chart [20] for minimum film thickness variable [4]
- $0.25 \le S \le 0.47$
- $c \ge 50\ R_a$

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C Optimization problem in Standard format

Sr.No..	L/D	U	L	Rc	w
1	0.7064	4623	0.20346	0.0015	105,020
2	0.6969	4795	0.20084	0.00116	102,843
3	0.7217	4705	0.22290	0.00135	102,295
4	0.5880	4935	0.22476	0.00145	94,849
5	0.6918	4584	0.21865	0.00135	93,008
6	0.6469	4943	0.22252	0.00145	92,772
7	0.7029	4981	0.20504	0.00132	88,090
8	0.5713	4892	0.18616	0.00113	87,813
9	0.5661	4626	0.21204	0.001137	83,756
10	0.7487	4848	0.19938	0.00133	77,081

From above the optimization problem in standard format can be stated as belows.

The design Vector

X = {U, L, c} which maximizes,

$f_1(x) = W = 3.56336 \times 10^{-3} \frac{UL^3}{c^2}$ [6] …..(I)

Inequality constraint for the maximization of the given function is

Subjected to behavioral constraints (in normalized form)

- $g_1(x) = \Delta t - 100° C \leq 0$ [9]
- $g_2(x) = 0.25 - S \leq 0$
- $g_3(x) = S - 0.47 \leq 0$
- $g_4(x) = 1000 - U \leq 0$
- $g_5(x) = U - 15000 \leq 0$

And geometric constraints (in normalized form)

- $g_6(x) = 0.25 - L/D \leq 0$
- $g_7(x) = L/D - 0.75 \leq 0$
- $g_8(x) = 50 R_a - c \leq 0$
- $g_9(x) = L \geq 0$
- $g_{10}(x) = D \geq 0$
- $g_{11}(x) = S \geq 0$

IV. RESULTS

A. Based on the results of the optimal parameters, Input parameters for optimum design[3]

- Minimum radial clearance C_{min}=10 μm
- Maximum radial clearance C_{max}=150 μm
- Minimum length to diameter ratio λ_{min}=0.25
- Maximum length to diameter ratio λ_{max}=0.75
- Lubricant viscosity $\eta = 2.8*10^{-3}$ Pa·s
- Pressure acting on bearing $P = 2*10^6$ N/M^2
- Sommerfeld No. S_{min} = 0.25 to 0.47
- Allowable film temperature rise T_{eff} = 130°C
- Minimum Journal rotational speed U_{min} =1000 m/s
- Minimum Journal rotational speed U_{max} =7000 m/s

Table 1: Optimized Functional Values

Where,
L/D=length to diameter ratio λ
U= Surface Speed of Journal (m/s)
L= Bearing length (m)
Rc=Radial Clearance (m)
W=Load carrying capacity (N)

With the use of MATLAB the fitness function *f*(1) for the genetic algorithm is calculated with the inequality constraints and the bound limit for the four variables 1) surface speed of the journal U, m/s 2) length of journal L, m 3)length to diameter ratio λ, 4)Radial clearance c, m. The optimized results of the fitness function are shown in to the Table No.1.And result No.1 is optimum value for maximize the load carrying capacity with other four variable.

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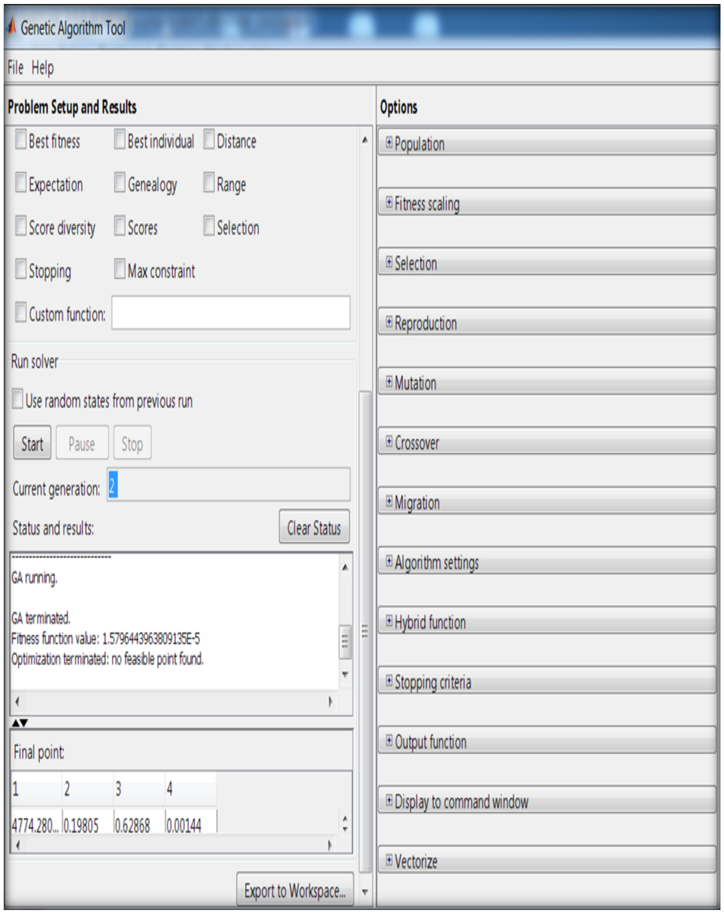

Fig. No. 3 Genetic Algorithm Tool

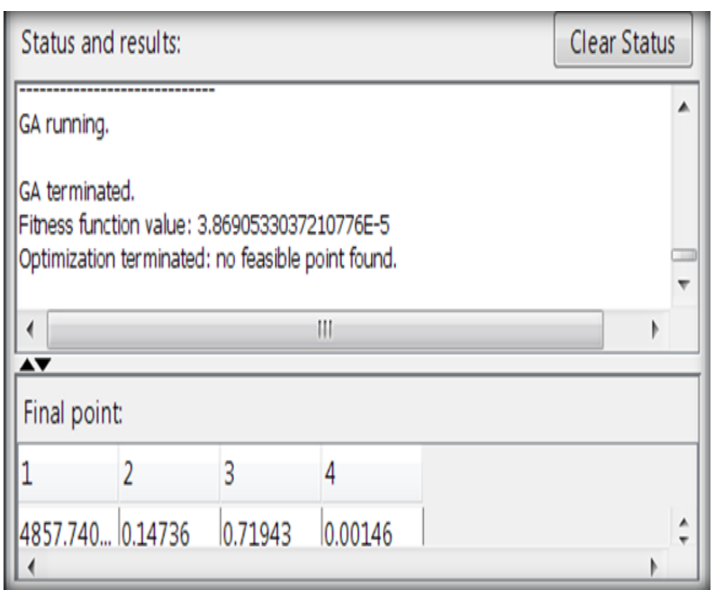

Fig. No.4 Sample Result

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B. Surface plot for the fitness function

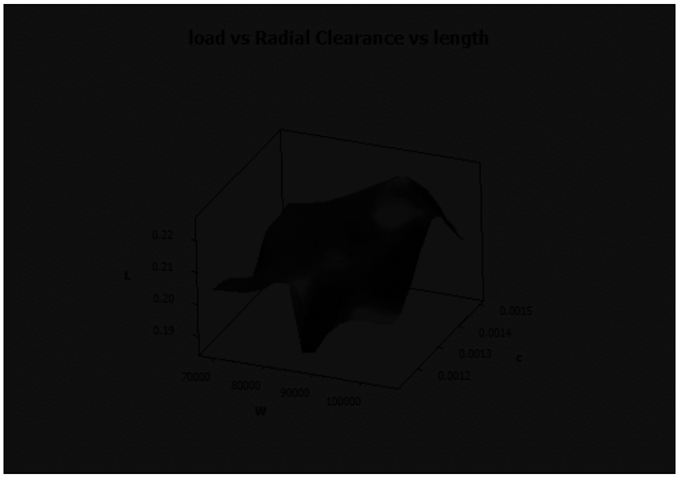

Fig.6 Graph on load carrying capacity Vs length & radial clearance

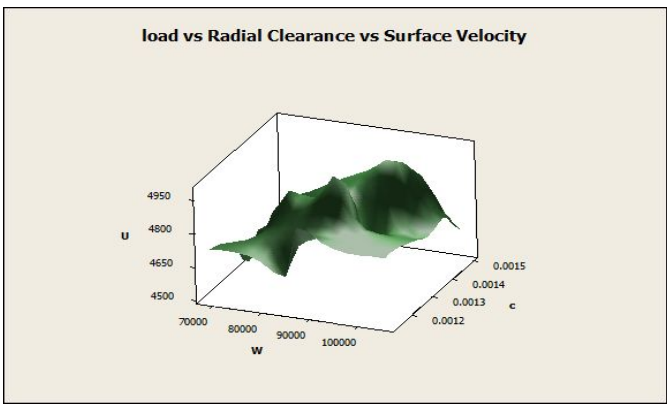

Fig.7 Graph on load carrying capacity Vs surface velocity & radial clearance

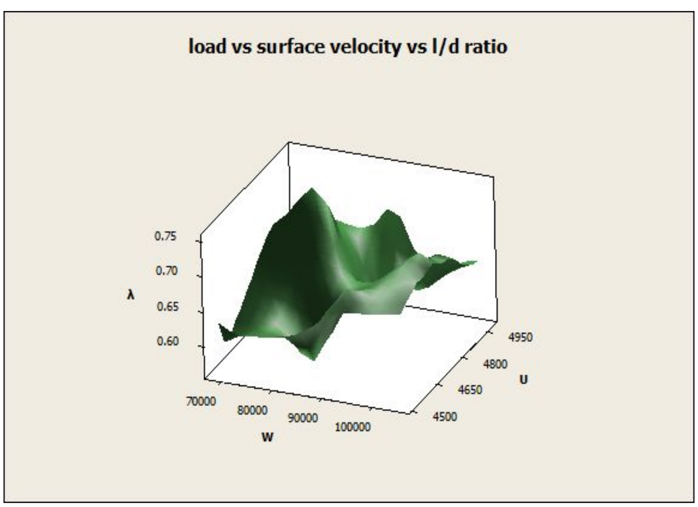

Fig.8 Graph on load carrying capacity Vs surface velocity & l/d ratio

C. Scatter plot for the fitness function

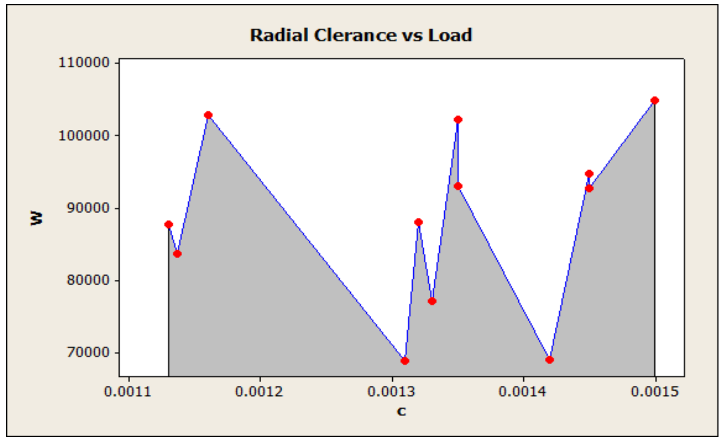

Fig.9 Graph on Radial clearance Vs. load carrying capacity

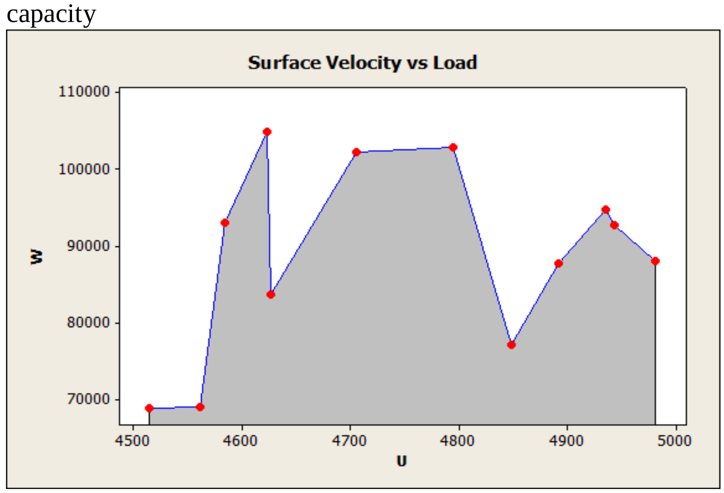

Fig.10 Graph on Surface Speed of Journal Vs. load carrying capacity

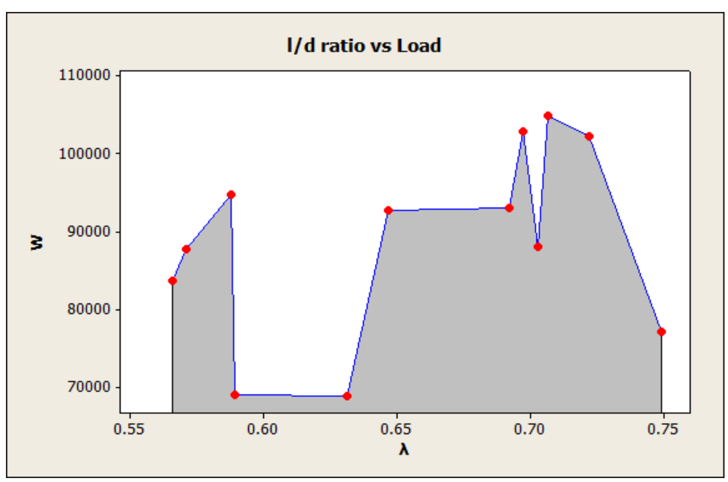

Fig.11 Graph on Surface Speed of Journal Vs. Length to Diameter Ratio

V. CONCLUSION

A genetic algorithm has been used for the optimum design of load carrying capacity of Bearing. Some examples of optimum design that Maximize the Load carrying capacity under constraints are presented. The numerical results are given in graphical forms of the four variables 1) surface speed of the journal U, m/s 2) length of journal L, m 3)length to diameter ratio λ, 4)Radial clearance c, m.

A. Formulation

1. Formulation of single objective function is done for the maximization of load carrying capacity (w) using 1) surface speed of the journal U, m/s 2) length of journal L, m 3)length to diameter ratio λ, 4)Radial clearance c, m.

B. Genetic Algorithm

1. The genetic algorithm only uses the function value and doesn't need derivatives calculated analytically or numerically.

2. The scatter plot drawn with the data formed by genetic algorithm, maximization of load carrying capacity (w) with four variable using 1) surface speed of the journal U, m/s 2) length of journal L, m 3)length to diameter ratio λ, 4)Radial clearance c, m.

3. The surface plots give the relationship of Load Carrying capacity (w) to the four parameter and it concludes that the Load Carrying capacity (w) is proportional to 1) surface speed of the journal U, m/s 2) length of journal L, m 3)length to diameter ratio λ, 4)Radial clearance c, m.

4. Genetic algorithm gives the different solution each time so that more generations need to be created for better and correct solution.

So from above discussion and results the short journal bearing finds lots of applications in industries such as spindle supports in lathe machines, crankshaft journal bearing, and connecting rod bearings, rotor turbine bearings and The performance of the bearing depends greatly on the design and optimization, which not only gives compact size of bearing but also enhances the performance with cost effectiveness.

ACKNOWLEDGMENT

I would like to express my gratitude to the many people who have assisted me during the course of this research. The support extended by the C.U.Shah University and college authorities is highly appreciated and acknowledged with due respect

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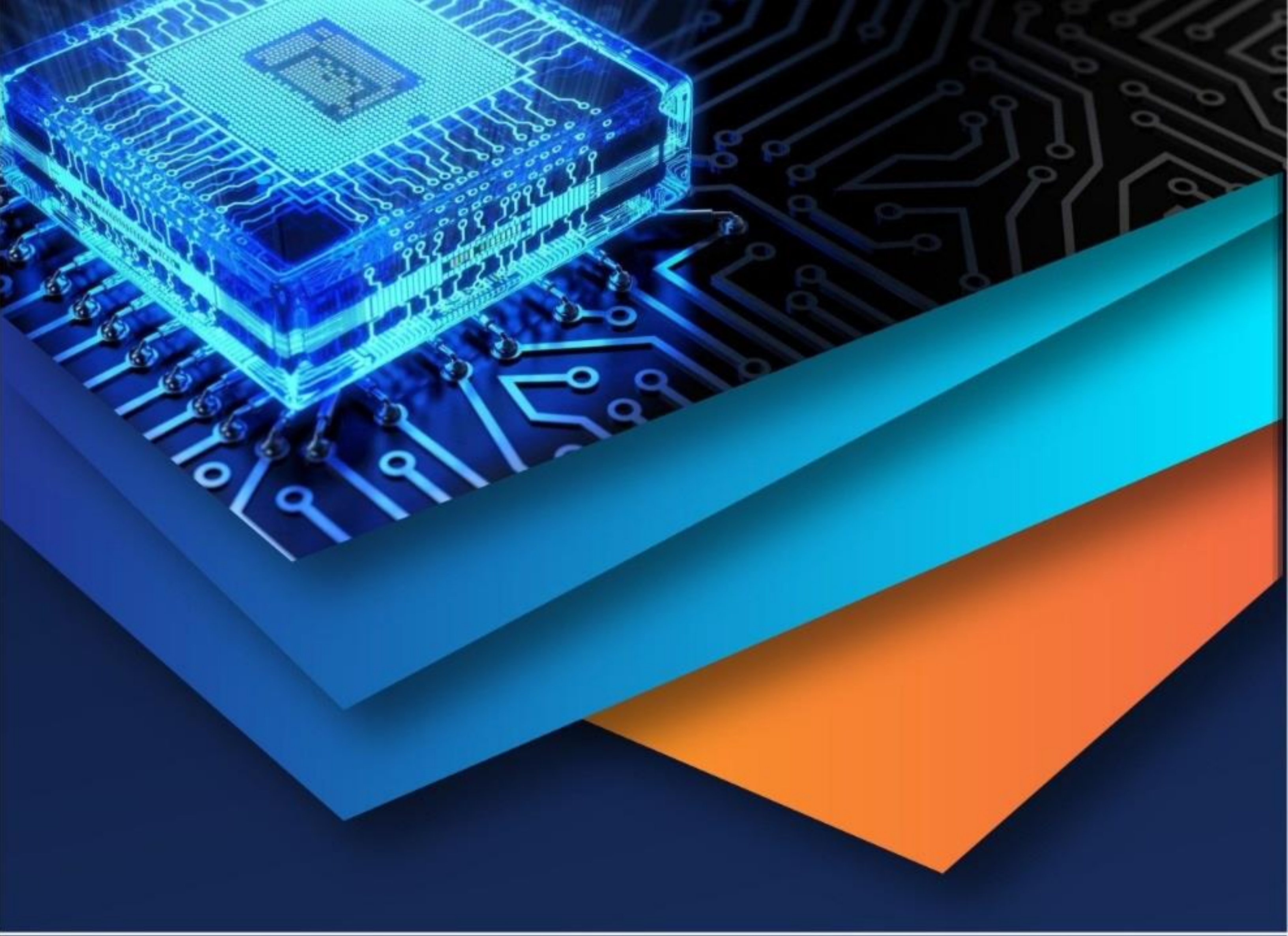

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