Research of Optimization Model for Sliding Bearing based on Artificial Bee Colony Algorithm

Da-en HuangFu, Zhipeng Wei

College of Information Engineering, Kaifeng University
Kaifeng, Henan, China

***Abstract*—As power consumption is a key problem which is directly related to the performance, efficiency and energy saving of the whole unit, it is the main target of the bearings' optimization design by reducing the power consumption, improving the static stability and dynamic stability of bearings, improving its life and reducing the manufacturing cost at present. In this paper, we adopt the Artificial Bee Colony Algorithm to analyze and design sliding bearing by optimizing its parameters. Finally, an example is given to show its effectiveness and feasibility.**

Keywords-Artificial Bee Colony Algorithm; parameters; sliding bearing

I. INTRODUCTION

As power consumption is a key problem which is directly related to the performance, efficiency and energy saving of the whole unit, it is the main target of the bearings' optimization design by reducing the power consumption, improving the static stability and dynamic stability of bearings, improving its life and reducing the manufacturing cost at present.

There are mainly two kinds of optimization algorithms now. One kind is the traditional optimization algorithm, and the other is intelligent optimization algorithm. It mainly includes classical differentiation, nonlinear programming and dynamic programming, etc. for the traditional optimization algorithms. Because the global optimization ability of the traditional optimization algorithm is not strong, it's unable to solve a series of large scale and complex issues in the modern engineering field.

Due to the complexity between the design parameters of the bearings' design plan and stability, economy, it leads to many complex nonlinear optimization problems with multiple decision variables. While the traditional method is often acquired by the designer's experience. So people urgently need a new kind of algorithm that is suitable for the large scale and complex problems. Intelligent optimization algorithms emerge that they are built on the mechanism of natural phenomenons and have the intelligent characteristics and the ability of large scale parallel computing. Intelligent optimization algorithms mainly include genetic algorithms, artificial design network algorithm and the colony algorithm etc.. All of them have an unique optimal mechanism and great ability of realizing the global optimization. Therefore they have become a powerful tool to solve complex engineering optimization problems at present in literature [1]. Bee Colony Algorithm is a kind of free-algorithm based on swarm's self-organization model in the nature and swarm intelligence. D. Karaboga successfully used the bee colony algorithm on the problem of function's numerical optimization in 2005[2] and put forward a systematic ABC algorithm (Artificial Bee Colony Algorithm), which is simple and has a strong robustness. In 2006, D. Karaboga applied ABC to numerical optimization problem with constraints and achieved a good effect in literature [3]. Li Rui Ming made a successful optimization for batch scheduling issues that the size of workpiece has a difference by using artificial bee colony algorithm in 2009[4]. In 2009, Hu Zhong Hua and Zhao Min put ABC algorithm successfully apply to the path planning problem in literature [5].

In this paper, we adopt the Artificial Bee Colony Algorithm to analyze and design sliding bearing by optimizing its parameters.

II. A ELEMENTS OF OPTIMIZATION DESIGN FOR MATHEMATICAL MODEL

A. *The Design Variables*

The design variables are also known as decision variables which has an effect on mathematical model based on its optimization criterion. All the design parameters are usually used by $X=[X_1, X_2, X_3,..., X_n]$ for the objective function, where X is the transport matrix form of N-dimensional column vector.

B. *The Objective Function*

In the process of optimization design, the pursuit design goals(performance index) can be expressed by the function form of design variables.

The objective function is established for the design variables, which is used to measure the bad extent of pursuit index. The process of optimization haunted design is to find optimal design variables to make the objective function reach the optimal value, or to find the the minimum or maximum of target function.

C. The Constraint Conditions

The design variables cannot choose values arbitrarily. What should abide in the process of the structural design is called the conditions with constraints for the design variables.

D. The Establishment of the Optimization Mathematical Model

After selecting the design variables, giving the objective function and constraint conditions, an optimization mathematical model can be constructed. The general form of the mathematical model is that

$$\begin{cases} \min f(x) & x = [x_1, x_2, ..., x_n]^T \\ s.t & g(x) \le 0 \quad i = 1,2,...,m \\ x \in R^n & \end{cases} \tag{1}$$

Therefore, the optimization design should follow the above format to make a description for the engineering design mathematical problem, in order to adapt to the need of adopting the method of optimization design. It's called a mathematical model by optimal designing.

III. ARTIFICIAL BEE COLONY ALGORITHM

Artificial Bee Colony algorithm is a kind of optimization method based on the honey bee swarm intelligence behavior. ABC belongs to the PSO (Particle Swarm Optimization), which are methods inspired by the collective intelligence of populations, Interactive agency or group can solve the following problems of collective rule.

In particular, ABC algorithm mimic the foraging behavior of bees to prove that these intelligent insects have the ability to select the finest food by several parameters, such as quality, quantity, grade, and distance of the source.First, the bees are randomly explore an area surrounding the hive area, then communicated the data of food sources in a dancing area(communication hall of the hive) to other bees. With the continuous repetition and exploring different areas, bees can converge to the best food sources, minimizing the nectar distance and maximizing the nectar quantity and quality.From the point of view of mechanical optimization,food sources are investigated based on a function value of the algorithm. The following interpretation logic, to find the optimal solution from the target space.

Bees in the colony are divided into three types, and each type plays a specific role: employees, onlookers and scouts. The onlookers are those bees area waiting for the information of food origin in the dancing area, the employees are foraging bees, when the food source is depleted, they need to find new sources of food, so they are called scouts.

In nature, the scouts are initially dispatched to search for new food sources in a seemingly random order. However, once the discovery of new sources of food, the scouts will return to the hive, and share their information to the bees located in the dance area, then become employed and access to new sources of food, once the source of the food comes from their memory that will never be forgotten. When the nectar is exhausted the workers choose a new food source in the neighborhood of the source of the visual information is based on the bee In each process, the worker's dance is proportional to the amount of nectar that has just visited the region.

In the ABC, the food source location represents the possible solution (minimal function) and is also associated with the vector of the variable values determined. The amount of nectar represents the fitness (associated to the solution quality). The algorithm mimics the bees' natural behavior in the choice of new food sources. For comparison, the choice is not based on visual information (which is not provided), but the random selection.

Each solution's position is a vector $x(k)$, $k = 1,2,...,l$ which has l number of food source. After initialized the random choice of food sources, the probabilistically of food sources which subjected to repeated cycles and choose the new positions as follows:

$$prob(k) = \frac{fit(k)}{\sum_{k=1}^{l} fit(k)} \tag{2}$$

In the formula, $prob$ is the probability, fit is the fitness value.

The formula can produce a new food source from the old solutions set is shown as follow:

$$v(k,i) = x(k,i) + v(k,i)(x(k,i) - x(ii,i)) \tag{3}$$

In the formula, v is the new candidate solution. ii is the employed bees index and is randomly chosen yet must be differ to $i.v$ (between [-1 1]). $v(k,i)$ is the new candidate food source and updated using all the optimization parameters in the formula (3). If the food source is abandoned due to inappropriate, the scout can use the following formula to find a new one.

$$x_i^j = x_{\min}^j + rand[0,1](x_{\max}^j - x_{\min}^j) \tag{4}$$

The algorithm of the tool is:

Initialize the population of solutions $x(k)$ for $k = 1:l$

Evaluate the population

$cycle = 1$

repeat

Produce new solutions $v(k,i)$ for the employed bees by using (3) and evaluate them

Apply the greedy selection process for the employed bees

Calculate the probability values $prob$ for the solution $x(k)$ by (2)

Produce the new solutions v(k,i) for the onlookers from the solutions $x(k)$ selected depending on $probi$ and evaluate them

Apply the greedy selection process for the onlookers

Determine the abandoned solution for the scout, if exists, and replace it with a new randomly produced solution $x(k)$ by (4)

Memorize the best solution achieved so far

$cycle = cycle + 1$

until $cycle = mcn$

From the above, it is clear that there are three control parameters can affect the algorithm search. The first one is, the source of food is equal to the number of employed and onlooker bees (the ratio is fixed to the Karaboga algorithm [6-8]of the first version, but can be changed). The second argument is that a bee can access the same source of food restriction. After reaching this limit, the source is abandoned. The last one is the maximum number of cycles.

IV. RESULTS OF THE OPTIMIZATION

Taking diesel engine as the research case. The design point is that the speed of the maximum torque point is 2500 RPM (246 arc / second), the torque is 326 nm, the power is 85 kilowatts and the role of the bearing on the force is 1750N.The material of the shaft is steel; the material of the sleeve is bronze alloy; the inlet channel is a round hole in the upper bearing housing. Which can bear 140000 pa pressure. The lubricant is 15W40 with $\mu_0 = 0.02$ Pas and $\beta = 0.0381$ /K. Using Von-Mises criteria and the maximum calculate the minimum diameter was $D_{\min}$, added to 30%. $D_{\max}$ is 34.2 mm. So we can get the minimum is 26.3 mm (appendix A). The diameter ratio minimum length is 0.3; the maximum is 0.9. The minimum clearance is $C_{\max}$ =15 μm and the maximum is $C_{\max}$ =30 μm. The force is applied to the center of the bearing. so L_f =0. Select this restriction has completed as follows:

1.To get the minimum film thickness, we use the formula 4 to calculate it. Where the values are all relative to the roughness of the bearing, and they are related to the diameter directly by the manufacturing relationships. The 3 μm which is absolute has been chosen according to the work of Allmaier et al[9].

2.Temperature rise. Although 20 ° C is a common decision of choosing the author to limit this problem. In addition, 10 ° C limit is used through comparing two main reference for the result (Hirani et al. [9] and Ghorbanian [10]). Moreover, to choose the 10 ° C, instead of 20 ° C , because it is a lot of lubricant, no additives, rapid degradation, due to the temperature rise of the reference specifically explain if higher than 10 ° C[11].

3.The Maximum pressure. 28 MPa chose a great restrictions to impose the pressure, because the future trend of the hydrodynamic journal bearing is using polymeric materials to replace metals. And the author's intention is to prove the theory to come ture more simple, so as to adapt to the choice of the material. The minimum supply is 4 mm in diameter, while the largest is the 9 mm. Inlet temperature is 25 ° C. The location of the hole can be any suitable housing by Angle direction - between 65 ° and 65 °.

TABLE I. TABLE 1 RESULTS OF THE OPTIMIZATION COMPARED WITH DIFFERENT TECHNIQUES

Type	Weights		Decision Variables			Performance			
Symbol	w_p	w_Q	D	C	λ	P_f		Q	
Unit	[-]	[-]	[m]	[μm]	[-]	[W]	[%]	[m^3/s]	[%]
Reference Design	-	-	0.0300	23	0.55	41.7		2.20E-06	
Ghorbanian	-	-	0.0263	20	0.34	25.1	-39.84	1.02E-06	-53.5
Hirani	-	-	0.0300	24	0.88	53.0	26.99	3.15E-06	43.5
Optimal design (GA)	0.5	0.5	0.0263	20	0.72	35.3	-15.42	1.28E-06	-41.7
Optimal design (ABC)	0.5	0.5	0.0263	20	0.72	35.3	-15.42	1.28E-06	-41.7
Optimal design	0.45	0.45	0.0263	17	0.69	36.0	-13.74	1.45E-06	-34.0

Type	Performance					
Symbol	ΔT	$P_{\max}$	$h_{\min}$	w_{cr}	Q	ε
Unit	[K]	[MPa]	[μm]	[rad/s]	[l/h]	[-]
Reference Design	9.0	15.8	4.4	4627	7.90	0.81
Ghorbanian	13.1	44.2	1.8	13984	3.68	0.91
Hirani	6.7	8.7	7.6	2157	11.34	0.68
Optimal design (GA)	8.7	14.7	4.5	3825	4.61	0.78
Optimal design (ABC)	8.7	14.7	4.5	3825	4.61	0.78
Optimal design	9.0	4.4	15.4	3346	5.22	0.74

The results of the optimization process are shown in table 1. Here, the result list different design techniques. Ghorbanian technology to generate design saves 39.8% of power consumption and more than 50% of the mass flow rate. On the other hand, the combination of decision variables to generate a minimum film thickness of bearing (including 1.8 m, 44 MPa maximum pressure and maximum temperature of 13.1 ° C. Although the calculation precision is in the performance of the Ann in [10], the optimization goal is too restrictive to complete the HJB analysis. The second method is using a Hirani [9]. Here the dominance of the target generates a bearing on the punishment, and saves the temperature rise.

The results of the work listed are in the third and the fourth row in table 1. Both the skills are for finding the minimum objective function for the same solution. Power consumption was reduced by 15.4%, while the mass flow rate was reduced 41.7% of the reference design. For the temperature rise, the maximum stress and minimum film thickness both have strict restrictions.

The optimal diameter of multidimensional objective function depends on the study on the edge of space. It means that it has the border of the global minimum in the same space. If it can increase the study space, then another minimum global will be found. Confirmed the fact that this theory, where only one can consider multiple objective decision variable and fuzzy constraints associated with stochastic control problems of the dynamic programming optimization to solve the problem. Ideally, if the diameter can be set to zero, and it does not exist, the friction and the possibility of mass flow rate and an unrealistic goal will be reduced to the minimum. Starting from this point, it need to calculate the space for the research of the border.

In figure 1, the graphs illustrates which is the role of the weights in the optimization. For each combination of weights the optimization has been carried out. The author noted that when the search is unbalanced more the 0.2 (e.g. w_p=0.2 and w_Q =0.8), the two main performances cannot be decreased simultaneously. And one of them have to be augmented to reduce the other.

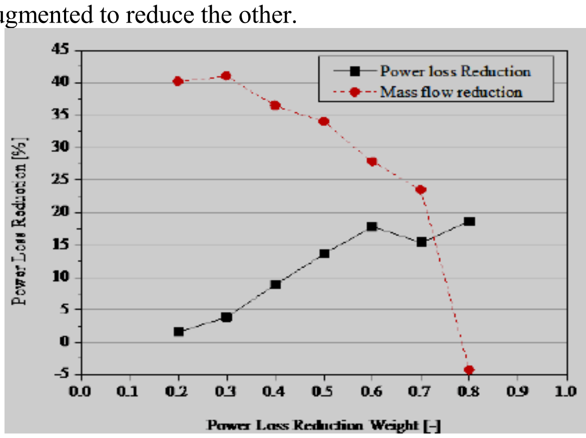

Figure 1. Figure 1. TheFigure Shows the Percentage of Power Loss and Mass Flow Reduction Varying the Weight for Power Loss Reduction.

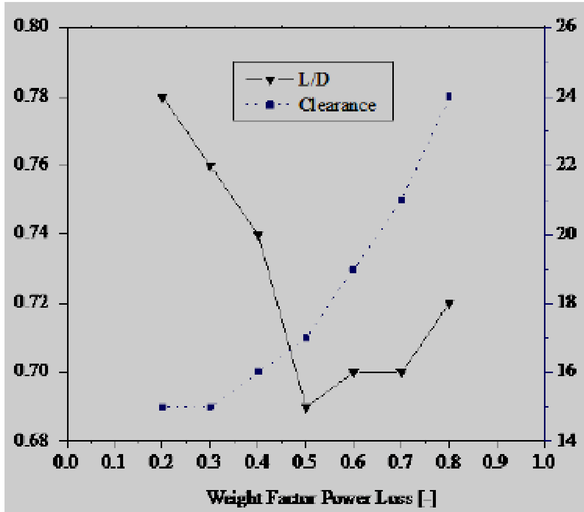

Figure 2. Figure 2. The Figure Shows the Values of Clearance and L/D Ratio Obtained With Different Values of The Weight Reduction Factor for Power Loss.

Figure 2 illustrates how the clearance and λ are modified when there is an attempt to reduce the power loss. To reduce the friction shear stress the clearance is increased and the length is decreased, this augment the mass flow and demonstrate the quality of this scientific research in explaining exactly what happens in terms of physics inside the slider.

In figure 3 and figure 4 two main performance of the HJB are plotted when the dynamic viscosity is increased for different value of the power loss weight (w_p). The figures clearly shoe then when higher is the coefficient higher is the save of power loss and is the opposite for the mass flow (the algorithm is working, the weights are unbalancing the objective function as requested). Most important is what is presented in figure 5 and figure 6. These figures represent one of the most important outcomes of this work, and they are called optimization maps.

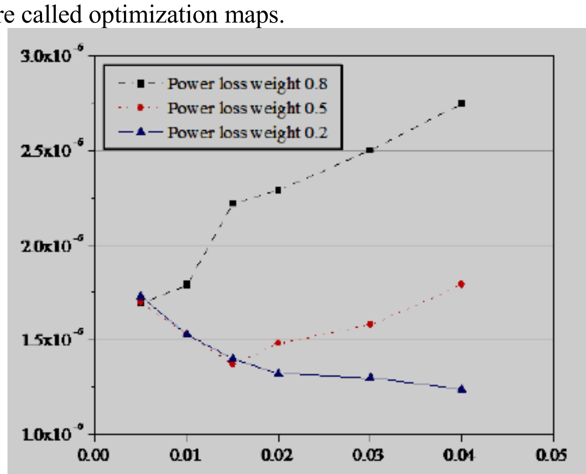

Figure 3. Figure 3. In This Figure Mass Flow Has Been Plotted When Dynamic Viscosity And the Weights Are Simultaneously Changed.

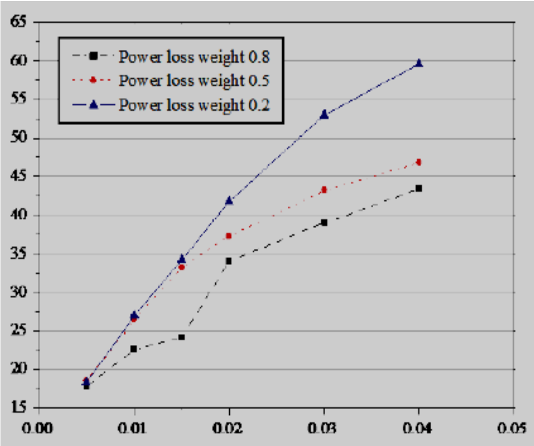

Figure 4. In This Figure Power Loss Has Been Plotted When Dynamic Viscosity And the Weights Are Simultaneously Changed.

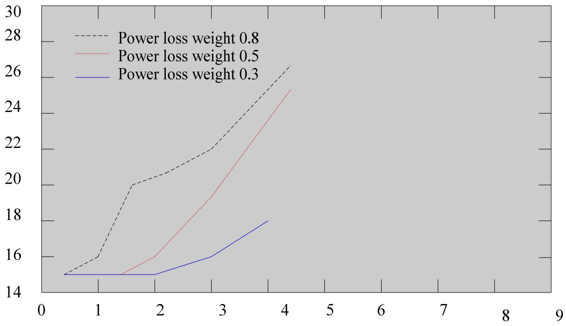

Figure 5. Optimization Map For Clearance

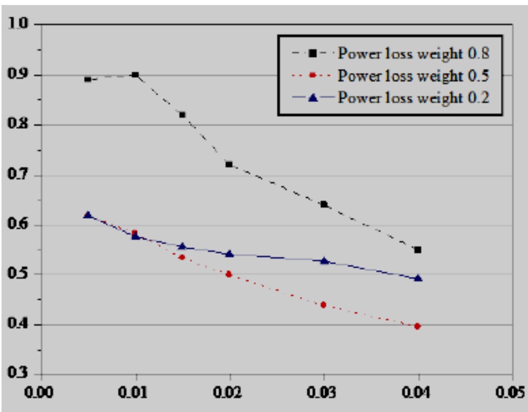

Figure 6. Optimization Map For L/D Ratio

According to the results of figure 5 increase the clearance reduce the power loss. Figure 6 suggests that more the dynamic viscosity is high and more the load capacity is increased hence, a shorter bearing is needed.

Figure 5 and figure 6 constitute an optimization map, each point is the results of an optimization cycle carried out with different viscosities. Each designer according to the lubricant, can chose clearance and length to diameter ratio for his specific problem. In this way the author wants to connect a theoretical work to practice of daily design.

Future developments of this work can be the creation of maps for different forces, speeds and specific values of dynamic viscosities corresponding to commercial lubricant values.

REFERENCES

[1] Chen Lun Jun, Luo Yan Ke, Chen Hai Hong. "Mechanical optimization design based on genetic algorithm". Bejing:China Machine Press,vol. 3, 2005.

[2] KARABOGA D. "An Idea Based On Honey Bee Swarm for Numerical Optimization". Turkey: Erciyes University, 2005.

[3] BASTURK B, KARABOGA D. Artificial Bee Colony(ABC) Optimization Algorithm for Solving Constranined Optimization Problems.

[4] Li Rui Ming, Cheng Ba Yi. "Optimization for batch scheduling issues that the size of workpiece has a difference by using artificial bee colony algorithm". Journal of Sichuan University,vol.46,No.3,pp. 657-662, 2009.

[5] Hu Zhong Hua, Zhao Min. "The path planning for robot based on ABC",vol.39,No.4,pp.94-96,2009.

[6] A. Singh, An Artificial Bee Colony Algorithm for the Leaf Constrained Minimum Spanning Tree Problem. Appl. Soft Comp,vol, 9,pp.625-631, 2009.

[7] B. Basturk, D. Karaboga. "An Artificia Bee Colony (ABC) Algorithm for Numeric Function Optimization". Proceedings of the IEEE Swarm Intelligence Symposium,pp. 12-14, May 2006, Indianapolis, USA.

[8] D. Karaboga. "An idea Based on the Honey Bee Swarm for Numerical Optimization", Technical Report TR06, Erciyes University, Engineering Faculty, Computer Engineering Dept. 2006.

[9] H. Hirani. "Multiobjective Optimization of a Journal bearing using the Pareto optimal Concept". Proceedings of the institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, pp.218-323, 2004.

[10] J. Ghorbanian, M. Ahmadi, R. Soltani. "Design Predictive Tool and Optimization of Journal Bearing Using Neural Network and Multiobjective Genetic Algorithm". Scientia Iranica,vol. 18,No.5,pp.1095-1105, 2011.

[11] G. Mascolo, R. Rausa, G. Bagnuolo. "Thermal Degradation of Synthetic Lubricants Under Oxidative Pyrolytic Conditions", J. Anal. Appl. Pyrolysis, vol.75,pp.167-173, 2006.