IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e- ISSN: 2278-1684, p-ISSN : 2320–334X
PP 06-10
www.iosrjournals.org

A Novel Evolutionary Algorithm for Engineering Design Optimization

S.Padmanabhan[1], M.Chandrasekaran[2], J.Jeswin Arputhabalan[3] and B.Balaji[4]
[1](Research Scholar, Faculty of Mechanical Engineering, Sathyabama University, Chennai, India)
[2](Professor, Faculty of Mechanical Engineering, Vels University, Chennai, India)
[3,4](Assistant Professor, Faculty of Mechanical Engineering, Sathyabama University, Chennai, India)

ABSTRACT : *The In 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 a gear drive is considered as an application and novelty of the evolutionary algorithm evaluated through this gear drive. Gearbox is an universally used mechanical element 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. Gearbox design can be defined as the selection of material and geometry, which satisfies individual and implied efficient requirements. In this paper, a two stage spur gear box is considered with maximization of power and efficiency, minimization of weight and centre distance as objective functions with design stresses as constraints. The above problem is optimized with a new population based evolutionary algorithm and results are compared with existing design.*

Keywords - *Artificial Immune System, Design Optimization, Evolutionary Algorithm, Gearbox design.*

1. 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 Algorithms 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, a generic population-based metaheuristic optimization algorithm. A new Evolutionary algorithm named Modified Artificial Immune System (MAIS) algorithm is proposed by the inspiration of Juan Carlos et al [1] , who introduces a cloning operator and for the maturation stage of the clones, two simple and fast mutation operators are used in a nominal convergence that works at the side of a reinitialization method to preserve the variety.

Jean-Luc [2] evaluated with the integrated optimization of mechanisms with genetic algorithms and the possible use of neural networks for complex mechanisms or processes. Lian et al [3], this paper reviews about progress in design optimization using evolutionary algorithms to solve real-world aero dynamic problems includes design of turbo pump, compressor, and micro-air vehicles. Majid and Khorram [4] have described about two New Harmony search meta-heuristic algorithms for engineering optimization problems with continuous design variables. Chaoli Sun et al [5] have developed a modified particle swarm optimization with feasibility-based rules for mixed-variable optimization problems. Deb and Jain [6] has proposed a Non-Sorted Genetic Algorithm II for optimizing multi speed gear box which consider multi objectives such as maximizing the power and minimizing the total volume of the gear. Padmanabhan et al [11] proposed modified Artificial Immune System algorithm for a helical gear design with multi objectives. In this paper, a two stage gear box problem was used to evaluate the above algorithm where gear box weight is reduced and increase in the output power.A gearbox is a mechanical device utilized to increase the output torque or change the speed of a motor and its application are in the field of power plant, automotive, aerospace industries, machine tools etc.

2. DESIGN OPTIMIZATION

A two stage gear box problem was adopted to explain the engineering design optimization by a new evolutionary algorithm, Modified Artificial Immune System in this paper. "The input shaft rotates at 1440 rpm receives 10kW power through coupling. The speed of the output shaft should be approximately 180 rpm [9]". For space limitation and standardization reasons a double stage gearbox with equal ratios was adopted.

2.1 Objectives

The gearbox problem consists of determining the design variable such as module, gear thickness and number of teeth in order to optimize the design. A number of objective functions by which optimality of gearbox design are includes: Maximization of Power transmitted and Efficiency and Minimization of Weight, Center distance. Design constraints are considered in the design of gearboxes are bending stress, crushing stress etc. The various assumptions involved in the work are described below;

- All the gears in the gearbox are spur gears.
- The thicknesses of the gears are same in a gear-pair.
- In a gear-pair, wheel is assigned the larger number of teeth between the mating gears.

Equations (1), (2), (3) and (7) represent the above said objective functions,

$$\text{Maximize, } f_1 = P, \text{ Where } P^{(L)} \leq P \leq P^{(U)} \tag{1}$$

$$\text{Minimize, } \quad f_2 = \frac{\pi}{4}\sum_{i=1}^{3} m^2 (Z_{pi}{}^2 + Z_{wi}{}^2) b_i \quad \text{for } i = 1, 2,. \tag{2}$$

$$\text{Maximize, } \quad f_3 = 100 - P_L \tag{3}$$

$$P_L = \frac{50f}{\cos\Phi} \times \frac{(H_s^2 + H_t^2)}{(H_s + H_t)} \tag{4}$$

$$\text{Where, } \quad f = 0.08, \; \Phi = 20^o$$

$$H_t = \frac{(i+1)}{i} \times \sqrt{\left(\left[\frac{r_0}{r}\right]^2 - \cos^2\Phi\right)} - \sin\Phi \tag{5}$$

$$H_s = (i+1) \times \sqrt{\left(\left[\frac{R_0}{R}\right]^2 - \cos^2\Phi\right)} - \sin\Phi \tag{6}$$

$$\text{Minimize, } f_4 = \frac{m}{2}(Z_1 + Z_2) \tag{7}$$

The power loss 'P_L' is calculated for each gear pairs from Dudley [10].

2.2 Constraints

There are two gear-pairs, or G = 8 [9]. There also exist a number of constraints associated with this problem. By considering fixed number of teeth Z_i varying thickness values b_i and power delivered P, each gear must satisfy two constraints mentioned by eqn. (8) and (9) were adopted from [6].

$$\text{Bending stress: } \quad \frac{97500\,PK_C K_d (r_i + 1)}{w_i\, a_i\, b_i\, m\, r_i\, y_i \cos\Phi} \leq [\sigma_{bi}]_{al} \tag{8}$$

$$\text{Crushing stress: } \quad \frac{0.59(r_i + 1)}{r_i a_i} \sqrt{\frac{97500 PK_C K_d (r_i + 1)E}{w_i b_i \sin 2\Phi}} \leq [\sigma_{ci}]_{al} \tag{9}$$

The transmission ratio is defined as the ratio of the number of teeth Z_{wi} in wheel to the number of teeth Z_{pi} in pinion and it is expressed by eqn. (12).

$$r_i = \frac{Z_{wi}}{Z_{pi}} \qquad (10)$$

The center distance for the corresponding gear-pair is found by eqn. (13).

$$a_i = \frac{m(Z_{wi} + Z_{pi})}{2} \qquad (11)$$

Since multiple-criteria are on different scales, to reflect their actual contribution to the multiple-criterion objective function their values have to be normalized to the same scale. Hence the combined objective function was adopted as,

$$COF = \left[\left(\frac{power}{max.power} \times NW_1 \right) + \left(\frac{min.weight}{weight} \times NW_2 \right) + \left(\frac{efficiency}{max.efficiency} \times NW_3 \right) + \left(\frac{min.cent.dist}{cent.dist} \times NW_4 \right) \right] \qquad (12)$$

3. MODIFIED ARTIFICIAL IMMUNE SYSTEM

By adapting the new mutation operators, the flow of Modified Artificial Immune System as followed:

a. Generate randomly a population of "N" size with design variables (P,m,b and Z_1). In the initial generation, these variables are copied directly to the working population and nominal convergence is controlled by the number of generation.

b. Find the Objective Function (COF) for those variables and continued for sorting and ranking.

c. Use selection based on ranking. The variables with the highest affinity will be the best individual. Affinity is an inverse of COF.

d. Perform the cloning of the antibodies using equation (13) was adopted from Juan Carlos Herrera et al. [1].

$$Nc = \sum(n - (i - 1)) \qquad (13)$$

Where, N_C is the number of clones to be generated for each variable, n is the total number of variable in the population and i is the current variables starting from the variables with the highest affinity.

e. All the clones in the set of clones which are the copies of variables with good affinity degrees undergo a mutation process. Here two phased mutation process carried out using the equation (14), Juan Carlos Herrera et al. [1].

$$x' = x + \frac{(\alpha * range * generation)}{Nc} \quad \text{and} \quad x' = x + \frac{(\alpha * range)}{(Nc * geneartion)} \qquad (14)$$

Where, x' is mutated variable, α is a random number between (0,1), range is variables between upper and lower limit and generation is current generation cycle.

f. After the first mutation operator, In the case of having a better solution in mutated string, then the clone is replace with the new one, else the second operator is used.

g. In the second mutation method, if there is no improvement in the mutated string, then the original solution remains with no change.

h. A model of receptor editing mechanism of the immune system was used, i.e., a proportion of the worst solution eliminated (normally by 10%) and new ones are generated in placed after predefined iterations.

i. Again find the objective function for the clones and sort it, rank it mutate it then extract first best 10 solutions from the list for the further design process and visualization.

Many researchers have shown more interests on non-traditional optimization techniques such as Genetic Algorithm, Simulated Annealing and Artificial Immune System etc and applied the same in various engineering fields [7, 8]. Here, an effort to be made with a new Artificial Immune System Algorithm for the optimum design of two stage gear box with C-45.

4. RESULTS AND DISCUSSION

To determine optimum values for all the decision variables such as the teeth number, thickness, module and power so as to increase the power output and efficiency and reduce the volume and center distance of gear box. Number of equality and inequality constraints should be satisfied to obtain desired design solution. The above problem was solved by assuming the gear as C-45. The Material Properties of Gear is as tabulated in Table 1.

Table 1. Material Properties of Gear

Material	Density (ρ) kg/mm^3	Bending Stress ($\square_b$) N/mm^2	Compressive Stress ($\square_c$) N/mm^2	Young's Modulus (E) N/mm^2
C-45	7.85 x 10^{-6}	140	500	2.1 x 10^5

Table 2. Optimum results by MAIS

Design Tool	No. of Teeth		Gear Thickness (mm)	Module (mm)	Power (kW)	Weight (kg)	Eff. (%)	Center Dist. (mm)
Existing design	Z_1=18	Z_2=51	b_1=60	6	10	77.91	98.44	207
	Z_3=18	Z_4=51	b_3=60	6				207
MAIS (C-45)	Z_1=18	Z_2=51	b_1=52.5	5.5	10.2	57.27	98.44	189.75
	Z_3=18	Z_4=51	b_3=52.5					189.75

The Table 2 shows, 2 % increase in power and 26.5% of weight reduction for the existing C45 material with respect to MAIS results. From the results, MAIS shows a significant improvement in its optimal design values to its objectives in compared with conventional design.

5. CONCLUSION

Design plays a vital role in all aspects of manufacturing. Obtaining a best design value is not practical by mechanical optimal methods due to presence of complex calculations, presence of nonlinear, non different, and multi variables objective function. Hence evolutionary algorithms like Modified Artificial Immune System come in to play. By using MAIS algorithm the optimum solution is obtained for a two stage gear box problem in this paper. Evolutionary algorithm shows that when the weight of the gear is reduced the cost of the material reduces. As weight is minimized production cost will be reduced. Industries like manufacturing, production, automotive can take advantage of this algorithm and can produce gears at a sensible cost. MAIS can be evaluated by optimizing various design applications like piping, pressure vessels, heat exchangers etc. As a result in future best solutions can be obtained for more complicated problems conclusion section must be included and should indicate clearly the advantages, limitations, and possible applications of the paper. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

REFERENCES

[1] Juan Carlos Herrera-Lozada, Hiram Calvo, and Hind Taud, "A Micro Artificial Immune System", Polibits no.43 México ene./jun. 2011.
[2] Jean-Luc Marcelin (2010), "Integrated Optimization of Mechanisms with Genetic Algorithms", Engineering, 2, 2010, 438-444.
[3] Lian, Yongsheng; Oyama, Akira; Liou, Meng-Sing, "Progress in design optimization using evolutionary algorithms for aerodynamic problems", Progress in Aerospace Sciences, 5-6, 2010, 199–223.

[4] Majid Jaberipour, Esmaile Khorram , "Two improved harmony search algorithms for solving engineering optimization problems", Commun Nonlinear Sci Numer Simulat 15 ,2010, 3316–3331.
[5] Chaoli Sun, Jianchao Zeng, Jeng-Shyang Pan, "A modified particle swarm optimization with Feasibility-based rules for mixed-variable Optimization problems", International Journal of Innovation Computing, Information and Control , 7(6) ,2011, 3081- 3096
[6] Deb. K, Jain, S, "Multi-Speed Gearbox Design Using Multi-Objective Evolutionary Algorithms", Journal of Mechanical design, 125, 2003, 609-619.
[7] Asokan P, Saravanan R., Vijayakumar K,"Machining parameters Optimization for Turning Cylindrical stock into a continuous Finished Profile using Genetic Algorithm and Stimulated Annealing. International Journal of Advanced Manufacturing Technology, 21, 2003, 1-9.
[8] Chandrasekaran, M., Asokan, P., Kumanan, S., Balamurugan, T. and Nickolas, S., 'Solving job shop scheduling problems using artificial immune system', The International Journal of Advanced Manufacturing Technology, 31(5–6), 2006, pp.580–593.
[9] V. B. Bhandari, Design Of Machine Elements, Tata McGraw-Hill Education 3rd Edition, 2010, pp 686.
[10] Dudley.D.W, "Handbook of Practical Gear Design", McGraw –Hill Book Co: New York, 1994.
[11] Padmanabhan.S, M.Chandrasekaran, P.Asokan and V. Srinivasa Raman, Optimal Solution for Gear Drive Design Using Population Based Algorithm, Intl Journal of Review of Mechanical Engineering, 5 , 2013, 802-806

Nomenclature

H_s	*: Specific sliding velocity at start of approach action*
Ht	*: Specific sliding velocity at end of recess action.*
P	*: Power transmitted in kW*
R_0	*: Addendum circle radius of Gear in mm*
r_0	*: Addendum circle radius of pinion in mm*
R	*: Pitch circle radius of Gear in mm*
r	*: Pitch circle radius of pinion in mm*
K_c	*: Stress concentration factor, 1.5*
K_d	*: Dynamic load factor,1.1*
r_i	*: Transmission ratio*
W_i	*: Speed of the wheel in rpm*
a_i	*: Centre distance for the corresponding gear-pair in cm*
b_i	*:Thickness of the gear-pair in cm*
y_i	*:Form factor*
Z_{pi}, Z_{wi}	*: Number of teeth in pinion, gear*
d_1,d_2	*: Pitch circle diameter of pinion, Gear in mm*
m	*: Module in cm*
i	*: Gear (or) transmission ratio*
ρ	*: Density of the material in kg/mm^3*
E	*: Young's modulus in N/mm^2*
NW	*:Normalized Weight , 0.25*
η	*: Percentage Efficiency*
P_L	*: Percentage of power loss*
f	*: Average coefficient of friction, 0.08*
Φ	*: Pressure angle in degrees, 20°*