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Optimization of Gear Drive using Genetic Algorithm

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ABSTRACT: An optimal design for an engineering optimization problem involves various decision variables and constraints. In engineering applications, objectives under consideration conflict with each other, and optimizing a meticulous solution with respect to a single objective can result in objectionable results with respect to the other objectives. A practical solution to a multi-objective problem is to examine a set of solutions, each of which satisfies the objectives at a satisfactory level without being conquered by any other solution. In this paper, a new population based evolutionary algorithm used to optimize the gear drive with combined objective function which maximises the power, efficiency and minimises the overall weight, centre distance has been considered. The performance of the proposed algorithms is validated and results are compared.

KEYWORDS: Design Optimization, Genetic Algorithm, Gear Drive and Multi – Objective Optimization.

1 INTRODUCTION

Mechanical engineering design can be defined as the preference of materials and geometry, which satisfies, specified functional requirements of that design. A good design has to reduce the most significant difficult result and to exploit the main significant desirable result. Optimization algorithms are more flexible and ever-increasing in field engineering design problems, rightfully because of the availability and affordability of today's technical world. A population based heuristic algorithm offers well-organized ways of creating and comparing a novel design solution in order to complete an optimal design. Gears, as a class of mechanical mechanism, are used to transmit relative motion between two shafts. The design of gears is critical for smooth functioning of any mechanism, automobile and machinery. Gear drive design starts with the need of optimizing the gear width, module and number of teeth etc., it creates huge challenges to designer.

Hai Huang et al [1] described a goal programming optimization mathematical model in order to improve efficiency of designing point-line meshing gears and also for the bending strength composite stiffness at the point-line meshing gear. Quancai Li et al [2] developed a multi-objective for gear transmission with design variables and choice restrictive constraints. Majid and Esmaile [3] evaluated an engineering optimization problem with continuous design variables with two New

Harmony search heuristic algorithms. Vipin and Chauhan [4] discussed, minimized the surface fatigue life factor and volume of gear box with classical SQP algorithm and other non-traditional NSGA-II with other geometric conditions. Kwon Soon et al [5] developed a genetic algorithm for a gear pump for minimizing the wear rate proportional factor.

Ya Feng Li et al [6], a design of three-stage wind turbine gear box was optimized with genetic algorithm with more optimized result. Savsani et al [7] developed the particle swarm optimization and simulated annealing heuristic algorithms to minimize the weight of a spur gear train. Chong and Lee [8] showed a two-stage gear train and the simple planetary gear train for a minimization volume with genetic algorithm and discussed that genetic algorithm is better than the conventional algorithms. Padmanabhan et al [9] used a Real Coded Genetic Algorithm to optimize the design of helical gear pair with combined objective function to maximize the Power, Efficiency and minimize Weight, Centre distance and proposed algorithm results was compared with LINGO Software. Bozca and Fietkau [10] proposed an empirical model based optimization for an automotive gearbox to reduce rattle noise with geometric design parameters. Parks and Miller [11] described breeding strategies in a multiobjective Genetic Algorithm with parents being selected from the current population. In this work, a population based evolutionary algorithm, Genetic Algorithm (GA) was used to optimize the spur gear drive with combined objective function which maximises the power, efficiency and minimises the overall weight, centre distance has been considered.

2 GEAR DRIVE DESIGN OPTIMIZATION

The Spur gear drive design 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 gear drive design are include: Maximization of Power transmitted (f1), Minimization of Weight (f2), Maximization of Efficiency (f3) and Minimization of Centre distance (f4). Several design constraints should be considered in the design of gear drive like bending stress, compressive stress, module and centre distance etc.

2.1 OBJECTIVE FUNCTIONS FOR SPUR GEAR DRIVE

The equations (1), (2), (3) and (7) represent the maximization of Power, minimization of Weight, maximization of Efficiency and minimization of Centre distance. The efficiency equation (3) has been adopted from Dudley [12].

Maximize, f1 = P (1)

Minimise, f2 =

[[{EMBED Equation.3} {EMBED Equation.3} $d_1^2 \times b \times \rho$] + [{EMBED Equation.3} {EMBED Equation.3} $d_2^2 \times b \times \rho$]] (2)

Maximize, f3 = 100 – PL = η (3)

P_L = {EMBED Equation.3} X {EMBED Equation.3} (4)

H_t = {EMBED Equation.3} X {EMBED Equation.3} - Sin{EMBED Equation.3} (5)

H_s = (i + 1) X {EMBED Equation.3} - Sin{EMBED Equation.3} (6)

Minimise, f_4 = {EMBED Equation.3} = {EMBED Equation.3}[z1+z2] (7)

2.2 DESIGN CONSTRAINTS

The above gear drive objectives should satisfies with the design constraints of allowable bending stress, allowable compressive stress, minimum module and minimum centre distance etc. the below equations (8), (9), (10) and (11) have been adopted from [13].

Bending stress: σ_b = {EMBED Equation.3} X [Mt] ≤ [σ_b] (8)

Compressive stress: σ_c = 0.74 {EMBED Equation.3} {EMBED Equation.3} {EMBED Equation.3} ≤ [σ_c] (9)

Centre distance: a_{min} = (i + 1) {EMBED Equation.3} ≤ a (10)

Module: m_{min} = 1.26 {EMBED Equation.3} {EMBED Equation.3} ≤ m (11)

The gear drive design problem has four different parameters in the objectives considered in this work. i.e., power, weight, efficiency and centre distance. Since all these objectives are on different scales, these factors are to be normalized to the same scale. The normalized objective function is obtained as follows:

COF = {EMBED Equation.3} (12)

Where NW1, NW2, NW3 and NW4 = 0.25.

2.3 A Spur Gear Reducer

In this paper, a spur gear reducer problem is, "Design a spur gear reducer for a turbine running at 500 rpm drive by a 8.5 kW, 2000rpm an engine. The gears are made of carbon steel C45. The material properties of gear drive are tabulated [13] in Table 1.

Table 1. Material Properties of Gear drive

Material	Density (ρ) kg/mm^3	Bending Stress (σ_b) N/mm^2	Compressive Stress (σ_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**

3 Genetic Algorithm

The above stated gear problem was solved by population based algorithm like Genetic Algorithm. The flow code of genetic algorithm is described below:

Generate random population of N chromosomes (Generation)

Evaluate the COF(fitness) of each chromosome x in the population (Evaluation)

Create a new population by repeating following steps until the new population is complete (New population)

Select two parent chromosomes from a population according to their fitness (Selection)

With a crossover probability cross over the parents to form a new offspring (children). (Crossover)

With a mutation probability mutate new offspring at each locus (position in chromosome). (Mutation)

Place new offspring in a new population

Use new generated population for a further run of algorithm

If the end condition is satisfied, stop, and return the best solution in current population.

Or Go to Evaluation step.

4 Result And Discussion

The above algorithm was developed using Microsoft Visual C#, with design parameters (P, m, b and Z1) boundary values as inputs. After iteration of GA for the three different gear materials for the specified spur gear reducer, the optimized results were tabulated in table 2 in compared with existing design. The GA result shows, significantly enhanced values with respect to power and weight reduction for the spur gear drive.

Table 2. Comparasion of gear drive optimized results by GA

Parameters / Material	Existing Trail Design System	GA
Power (P) kW	**8.5**	**8.62**
Module (m) mm	**4.00**	**3.69**
Gear Thickness (b) mm	**40.00**	**34.36**
No. of teeth on pinion (Z1)	**25**	**25**
Centre Distance (a) mm	**250.00**	**230.625**
Gear Weight (kg)	**41.92**	**30.65**
Efficiency (%)	**98.91**	**98.91**

The above Table 2, 1.6% increases in power and 26.88% of weight reduction for the existing C45 material with respect to GA results. From the results, GA shows a significant improvement in its optimal design values to its objectives.

5 CONCLUSION

The majority of an engineering design involves extensive calculations and a number of non linear, non-differentiable and multi variables objective functions. It is extremely impracticable to solve by mechanical optimal techniques. Evolutionary algorithm like GA can be powerfully applied for best solutions in an engineering design. Genetic algorithm shows the substantial decrease in weight of gear drive with above gear materials, which is directly proportional to cost of the gear drive. The amount of material consumed is reduced due to reduction in weight of the gear drive and also its shows considerable increase in power with respect to all materials in compare with conventional design. As a future work, this algorithm can be used evaluated the range of engineering design application like multispeed gear box, epicyclic gear train and springs etc.

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