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Review Article

OPTIMIZATION APPROACH FOR DESIGN OF SPUR GEAR BASED ON GENETIC ALGORITHM

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ABSTRACT

The problem of designing spur gear with minimum mass and smaller size without violating the constraints plays a major role in today's industrial world since the most commonly encountered mechanical power transmission require low weight. This paper presents a genetic approach to reduce the weight and thickness of the gear, also increases the power transmitting capacity and effectiveness using genetic algorithm (GA). It can be observed that the proposed optimal design with GA has the potential to yield considerably better solutions than the traditional heuristics. At the same time, the GA offers a better understanding of the trade-offs between various constraints.

Keywords: Optimal design, Genetic algorithm, Spur gear.

INTRODUCTION

In most of the machine tools and applications, power transmission becomes an essential criterion. Designing a mechanical power transmission unit is a very complex task. The complexity arises due to two opposing demands created from design and application, i.e., the size of the gear should be decided based on the safety by the designer and the application required the gears with smaller size. Furthermore, it is known that designing of a reducer is an iterative process in which it is necessary to make some tentative choices to determine the optimal size. Moreover, for solving such complex real design problem, conventional optimization techniques are very difficult to consider, taken into account a large number of design variables and the complexity which are highly non-linear nature. For the past decades, evolutionary algorithms such as GA are getting increasing attention to solve the complex mechanical power transmission design problems among the scientific and engineering community. At the same time, the simple trial and error type methods which are used to tackle this design problem are used more rarely.

In this research, four different parameters such as thickness, weight, power transmitting capacity, and number of teeth were considered for the optimization. In turn, these parameters reduce the weight and size of the gear along with the center distance. Furthermore, it improves the efficiency of the power transmission. Thereby, the size of the gear along with the assembly gets reduced, and on the other hand, the effectiveness of the power transmission also increased.

The various works done in the field of gear design optimization have been explained in Section 2. In Section 3, this formulation in detail. Section 4 contains an effective example of optimal design followed by a discussion and a comparison between an optimal design with GAs and traditional design (when we used a common trial and cut error procedure). Eventually, some suggestions regarding the possible extensions of the results of this study are presented.

LITERATURE SURVEY

Madhusudan and Vijayasimha [11] presented a computer program to design a required type of gear under a specified set of working conditions. A new computer-aided method for automated gearbox design was described in Lin and Shea [10]. An interactive physical programming was developed in Huang *et al.* [8] to optimize a three-stage spur gear reduction unit. An expert system for designing and manufacturing a gearbox is described by Aberšek *et al.* [1]. Li and Symmons [9] carried out a study for minimizing the center distance of a helical gear using American Gear Manufacturers Association procedures. An optimal weight design problem of a gear with an improved GA is presented in Yokota *et al.* [17]. A non-dominated sorting genetic algorithm (GA)-II was used in Deb and Jain [3] to solve a multiobjective optimization of a multispeed gearbox. Thompson *et al.* [15] presented a generalized optimal design of two-stage and three-stage spur gear reduction units in a formulation with multiple objectives. The benefits of the particle swarm searches in resolving different engineering designs are shown in Ray and Saini [12]. Two advanced optimization algorithms known as particle swarm optimization and simulated annealing are used in Savsani *et al.* [14] for minimizing the weight of a spur gear train. The results of the proposed algorithms were compared with the results obtained in Yokota *et al.* [17]. In Gologlu and Zeyveli [5], GA was applied to minimize the volume of a two-stage helical gear train. A complete automated optimal design of a two-stage helical gear reducer using a two-phase evolutionary algorithm is presented in Tudose *et al.* [16]. The motivation behind the work described in this paper is that evolutionary computing technology has now reached the level where it is computationally feasible to consider an automated optimal design. The studies referenced above have been instrumented to highlight the importance of using modern global optimization techniques in mechanical power transmission design (as opposite to conventional, trail, and error type methods), even when considering certain subproblems.

Thus, from the above literature, it becomes clear that the researchers were not concentrated on the above defined four parameters for optimization using GA.

SPUR GEAR

Gears are the friction wheels used to transmit the power between the shafts. These gears have the teeth's which will mate with each other, and thereby, it transmits the power. The gear wheel in which the power is given is called as the driven gear and the gear wheel, which rotated by the driven gear is called the driven wheel. The size of the gear pair decides speed and the amount of power to be transmitted. The gears can use to reduce or increase the speed, power, torque, etc.

Gears are classified based on the shape, nature, and application it is used. Some of the commonly used gears are spur gear, helical gear, herringbone gear, bevel gear, worm gear, rack, and many more. Spur gears are by far the most common type of gear and with the exceptions of the "cog," the type of gear that has been around the longest. Spur gears have teeth that run perpendicular to the face of the gear. Hence, the spur gear is taken in this research to optimize.

GA

The GA is the most well-known and best of all evolution-based search algorithms [2]. The basic concepts of GA were developed by Holland [7] described the biological processes of evolutionary systems. The main objective of GA is that the better offspring will survive and the worst offspring will die in the population. After many generations, most of the offspring will be better, as that offspring is reproduced from the best parents. The individual offspring called genetic chromosome represents a solution for a problem and each element called as genes represents the parameters to be optimized. The various stages of the GA are explained in the solution methodology section.

SOLUTION METHODOLOGY

As the spur gear design is a complex task, it was solved in six different stages. They are explained in the following sections. The entire framework is explained in Fig. 1.

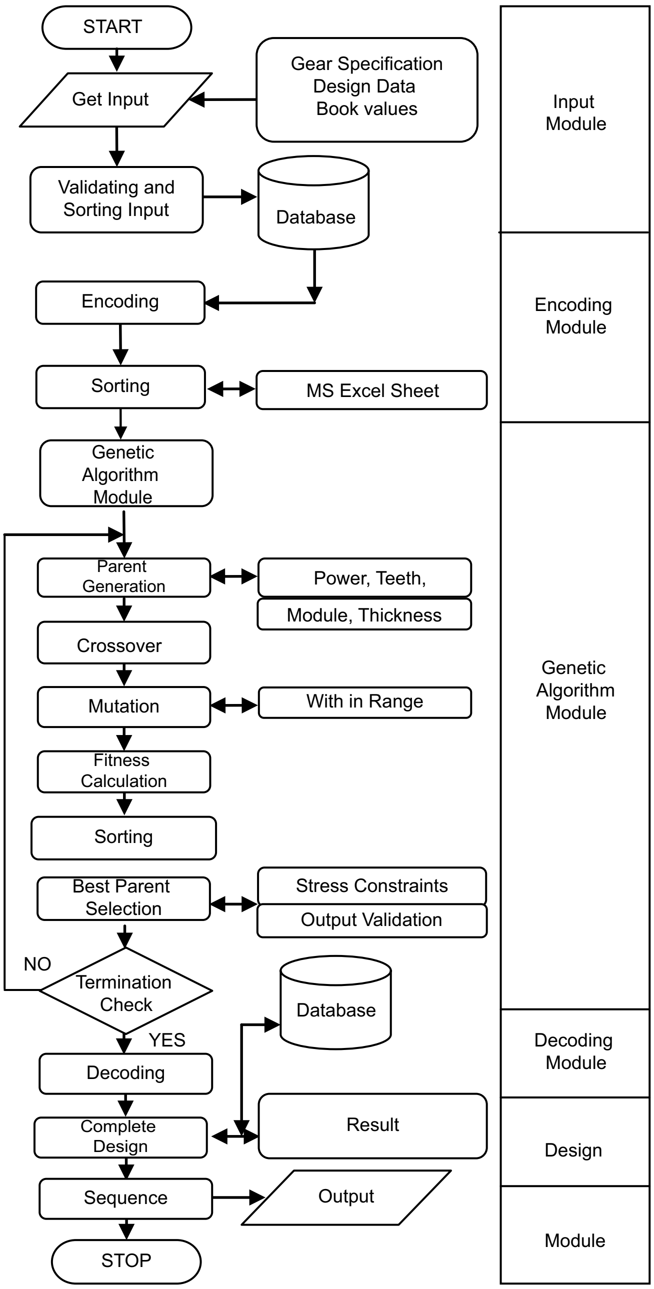

Fig. 1: Framework of the project

User input stage

The input module is used to interact with the user for getting the required data such as speed, gear ratio, and load to be transmitted. These user-defined constraints are classified as primary constraint and secondary constraints. The primary constraints are also called as stress constraint which checks the feasible of the gear. The secondary constraints are also called as functional constraints which make ease in manufacturing and assembly. The functional constraints considered are standardization of module, load bearing constraint, weight constraint, etc. In addition to these data, the user has to enter the standard PSG design data book values. These data need to be encoded in genetic chromosomal format and given as input to the GA module.

Encoding stage

Encoding module is the process of converting the user understandable data format into a genetic acceptable format such as binary codes/ decimal codes/alphabets/ASCII codes for further processing. In this work, decimal encoding has been implemented; the four parameter values were given directly as input. The computational complexities were reduced by represented by its parameter numbers instead of its specifications. This encoded data will be given as input to the GA module.

GA module

GA has been employed in this research to optimize the solution to the bin packing problem. The first stage in the GA module is the initial population generation.

Initial parent generation

In this stage, "n" number of parents with "m" numbers of strings was generated randomly. In this work, population size was set to 100 with four strings in a parent and this was generated using a randomize function. A sample set of five parents was generated using the random function which is given in Fig. 2. Each parent has the decimal number ranges in a specific order.

The number denotes the power, module, the number of teeth, and the thickness. The generated parents have been allowed for the crossover operation to inherit the best properties from the parents.

Crossover

The second stage in GA is the crossover or reproduction between the parents in the population. Crossover is the process of interchanging a certain set of strings at random between two parents to generate two child having properties of both the parents. Crossover parents and crossover site are selected randomly. In general, most of the researchers set the crossover probability as 80% to avoid the inheritance of the worst properties from the parents. Fig. 3 explains crossovers with a sample set of parents represented as "parent I," and "parent II." Randomly generated crossover sites are shown in Fig. 3.

Mutation

The fitness function value of the obtained offspring can stagnate around the optimal point and fail to produce better bin packing pattern. This stagnation could be resolved by applying the mutation operator. Mutation is the operation of swapping an individual string from a parent by selecting the position of string randomly. Fig. 4 explains the mutation overloading with a sample parent.

Parent 1/1	30.417, 20.22, 18, 4.734,
Parent 2/1	30.061, 36.12, 18, 4.833,
Parent 3/1	30.073, 44.23, 22, 7.744,
Parent 4/1	31.273, 30.53, 24, 6.286,
Parent 5/1	31.299, 46.36, 16, 5.071,

Fig. 2: Five set of randomly generated parents

In general, most of the researchers set the mutation probability between 1 and 10% because higher mutation rate deviates the convergence from the right path.Thus, in every generation, child's chromosomes with the best and worst properties will be generated. Chromosomes with better properties will be allowed for the next generation and the better chromosome can be identified based on the fitness function value.

Fitness function

The fitness function is also called as the objective function, which is used to select the best parent from the generated population. The developed fitness function F (x) is given in equation.

Objective functions

1. Maximization of power transmitted by the gear pair.

$$f_1 = P \text{ where, } P^{(L)} \leq P \leq P^{(U}$$

2. Minimization of the weight of the gear pair.

$$f_2 = [[\frac{\pi}{4} \times d_1^2 \times b \times \rho] + [\frac{\pi}{4} \times d_2^2 \times b \times \rho]]$$

3. Maximization of efficiency of the gear pair

$$f_3 = 100 - P_L$$

4. Minimization of center distance between the pinion and gear. Eqn. (4.7) represents this objective function.

$$f_4 = \frac{(d_1 + d_2)}{2}$$

Theoretically, expected value for the fitness function is one, which represents optimal design. In general, for the multiobjective and multiconstrained problems, achieving one will be a difficult task. Thus, a set of conditions are required to identify the best sequence and the conditions are normally called termination conditions.

parent No.	Initial Parent (Pow, Thick, Teeth, Mod)	Crossover Parent	Crossover Site	Crossover Offspring
Parent 1 /1	30.417, 20.22, 18, 4.734,	1	2	30.417,36.12,18,4.833,
Parent 2 /1	30.061, 36.12, 18, 4.833,	1		30.061,20.22,18,4.734,
Parent 3 /1	30.073, 44.23, 22, 7.744,	2	2	30.073,30.53,24,6.286,
Parent 4 /1	31.273, 30.53, 24, 6.286,	2		31.273,44.23,22,7.744,
Parent 5 /1	31.299, 46.36, 16, 5.071,	3	2	31.299,42.16,20,6.671,
Parent 6 /1	30.001, 42.16, 20, 6.671,	3		30.001,46.36,16,5.071,
Parent 7 /1	31.201, 26.46, 16, 5.213,	4	2	31.201,44.66,18,5.226,
Parent 8 /1	30.174, 44.66, 18, 5.226,	4		30.174,26.46,16,5.213,
Parent 9 /1	30.476, 32.66, 22, 7.426,	5	3	30.476,32.66,22,5.691,
Parent 10 /1	30.097, 36.43, 22, 5.691,	5		30.097,36.43,22,7.426,

Fig. 3: Crossover

Crossover Offspring	Mutation Parent	Mutation Site	Mutant
30.417,36.12,18,4.833,			30.417,36.12,18,4.833,
30.061,20.22,18,4.734,			30.061,20.22,18,4.734,
30.073,30.53,24,6.286,			30.073,30.53,24,6.286,
31.273,44.23,22,7.744,			31.273,44.23,22,7.744,
31.299,42.16,20,6.671,	5	1	31.273,42.16,20,6.671,
30.001,46.36,16,5.071,			30.001,46.36,16,5.071,
31.201,44.66,18,5.226,			31.201,44.66,18,5.226,
30.174,26.46,16,5.213,			30.174,26.46,16,5.213,
30.476,32.66,22,5.691,			30.476,32.66,22,5.691,
30.097,36.43,22,7.426,			30.097,36.43,22,7.426,

Fig. 4: Mutation operations

Termination conditions

A set of termination conditions given below is used to identify the optimal solution in this research work is as follows:

1. Minimum criterion condition: The obtained fitness value should be greater than the threshold value. In this work, the threshold value was set to 0.99.
2. Generation condition: Maximum number of generations should be reached; in this work, maximum number of generation is set to 100 generations.
3. Stagnation condition: Successive iterations no longer produce better results.

The above three conditions will be checked at each stage of the population generation and the generation terminates on satisfying any one condition. Then, the parent with the best fitness value should be considered as the best parent. This obtained that genetic chromosome has been decoded to user understandable format.

Decoding module

Decoding is the reverse of encoding process. Decoding process converts genetic chromosomal output into user understandable format. Once the genetic chromosome is decoded to design data; then, the complete gear specification has to be calculated in the output module.

Output module

The output module utilized the decoded data and generated the values to calculate the gear specification.

CONCLUSION

In this paper, GA has been used to solve a complex spur gear design problem with multiobjective optimization. The objective is to identify the optimal design parameters which minimize the total size and weight of the gear. Optimal design solutions obtained were compared to the traditional design (i.e. a trial and cut error procedure) and found that the GA solution has been satisfactory. In both cases, the objective function was subjected to a set of stress constraints. The design variables considered in the optimization are number of teeth, power, module, and thickness of teeth. The results obtained using GA show significant improvement over the results obtained by traditional design. The proposed GA could be easily modified to suit multiobjective design optimization of multistage gear units. Furthermore, in the same vein, other objective functions could be considered that manufacturing cost is a simply potential example.

REFERENCES

1. Aberšek B, Flasker J, Balic J. Expert system for designing and manufacturing of a gear box. Expert Syst Appl 1996;11:397-405.
2. Bentley P. An introduction to evolutionary design by computers. In: Evolutionary Design by Computers. San Francisco: Morgan Kaufmann; 1999.
3. Deb K, Jain S. Multi-speed gearbox design using multi-objective evolutionary algorithms. ASME J Mech Des 2003;125:609-19.
4. DeutschesInstitutFürNormungEV.Din3990,Tragfähigkeitsberechnung von Stirnrädern Teil 3. Berlin: Deutsches Institut Für Normung EV; 1987.
5. Gologlu C, Zeyveli M. A genetic approach to automate preliminary design of gear drives. Comput Ind Eng 2009;57:1043-51.
6. Grote K, Antonsson EK. Springer Handbook of Mechanical Engineering. Heidelberg: Springer; 2009.
7. Holland JH. Adaptation in Natural and Artificial Systems. Ann Arbor: The University of Michigan Press; 1975.
8. Huang HZ, Tian ZG, Zuo M. Multiobjective optimization of three-stage spur gear reduction units using interactive physical programming. J Mech Sci Technol 2005;19:1080.
9. Li X, Symmons GR. Optimal design of involute profile helical gears. Mech Mach Theory 1996;31:717-28.

10. Lin Y, Shea K. A Method and Software Tool for Automated Gearbox Synthesis. San Diego, California, USA: Proceedings of the ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference; 2009. p. 1-11.
11. Madhusudan G, Vijayasimha CR. Approach to spur gear design. Comput Aided Des 1987;19:555-9.
12. Ray T, Saini P. Engineering design optimization using a swarm with an intelligent information sharing among individuals. Eng Optim 2001;33:735-48.
13. Renner G, Ekárt A. Genetic algorithms in computer aided design. Comput Aided Des 2003;35:709-26.
14. Savsani V, Rao RV, Vakharia DP. Optimal weight design of a gear train using particle swarm optimization and simulated annealing algorithms. Mech Mach Theory 2010;45:531-41.
15. Thompson DF, Gupta S, Shukla A. Tradeoff analysis in minimum volume design of multi-stage spur gear reduction units. Mech Mach Theory 2000;35:609-27.
16. Tudose L, Buiga O, Stefanache C, Sobester A. Automated optimal design of a two-stage helical gear reducer. Struct Multidiscip Optim 2010;42:429-35.
17. Yokota T, Taguchi T, Gen M. A solution method for optimal weight design problem of the gear using genetic algorithms. Comput Ind Eng 1998;35:523-6.