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MULTI-OBJECTIVE OPTIMIZATION OF TWO-STAGE HELICAL GEAR TRAIN

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ABSTRACT

Engineering design is an iterative process that requires to be followed with all feasible design solutions in order to arrive at desired objective. Proper design of gear train has a significant place in power transmission applications. Traditional methods used in its design do not have ability in automating the process. Thus, an attempt to automate preliminary design of gear train has been accomplished in the paper. In this paper, the volume and load carrying capacity are optimized. Two different methodologies (i) Genetic algorithm (GA), (ii) Fminsearch Solver optimization technique are used to solve the problem. In the first two methods, volume is minimized in the first step and then the load carrying capacities of both shafts are calculated. In this study, the Genetic Algorithm is introduced for the optimum design of gear trains to solve such problems and we propose a genetic algorithm based gear design system**.** This system is applied for the geometrical volume (size) minimization problem of the two-stage gear train and the gear train to show that genetic algorithm is better than the conventional algorithms for solving the problems. Genetic algorithm is used for optimization by using a Matlab programs are used to solve the problem. For the optimization purpose, face width, module, and number of teeth are taken as design variables. Constraints are imposed on bending strength, surface fatigue strength and interference. The results are validated with the experimental results published in the literature and standard parameters of gear train.

Keywords: design optimisation, gear train, helical gears, genetic algorithm, fmincon algorithm, volume, load carrying capacity.

1. INTRODUCTION

Engineering design is an iterative process that is started with a defined problem, refined and then developed a model, finally arrived at a solution. Due to nature of engineering design there could be more than one solution, therefore a search should be conducted in order to find the best solution. As a mechanical design problem, design of gear train is very complex because of multiple and conflicting objectives.

Mechanical design includes an optimization process in which designers always consider certain objectives such as strength, deflection, weight, wear, and corrosion depending on the requirements. The objectives of the design are geometrical volume (size) minimization of 2-stage gear train and load carrying capacity gear train that has very valuable aspects in lightweight, small size and high strength. With regard to these design objects, we determine the number of teeth, module, face width, and helix angle, considering constraints such as strength (durability), interference, contact ratio and other factors based on AGMA standards so that these gear trains can perform the tasks required in design specification.

However, design optimization for a complete mechanical assembly leads to a complicated objective function with a large number of design variables. So it is a better practice to apply optimization techniques for individual components or intermediate assemblies than a complete assembly.

2. OBJECTIVES

To reduce the weight and volume of the gear trains by using Genetic algorithms in Matlab toolbox for the optimization purpose, face width, module, and number of teeth are taken as design variables. To increase the load carrying capacity of the gear trains by using fmin search algorithms (Find a minimum of an unconstrained nonlinear multi variable function. It has problems in solving problems with a large number of objectives.

3. LITERATURE SURVEY

R. C. Sanghvi *et al.* [1] Multi-Objective Optimization of Two-Stage Helical Gear Train using NSGA-II, in this paper, the volume and load carrying capacity are optimized. Three different methodologies (i) Matlab optimization toolbox, (ii) genetic algorithm (GA), and (iii) Multi objective optimization (NSGA-II) technique are used to solve the problem. The mainly affected parameters of gear from the volume point of view are face width, module, and number of teeth of gear. Result comparison table shows that in the first two cases minimization of volume took place while load carrying. Sa'id golabi *et al.* [2] an objective functions and design constraints for the volume/weight of a gearbox has been written. The objective function and constraints can be used for any number of stages for gearbox ratio but in this paper one, two and three-stage gear trains have been considered by using a Matlab program. From the graphs, all the necessary parameters of the gearbox such as number of stages, modules, face width of gears, and shaft diameter can be derived. The optimization is performed using fmincon which is a component of the Matlab optimization toolbox. By comparing the result with previous papers the validation part is done. Padmanabhan *et al.* [3] investigated that in many real-life problems, objectives under consideration conflict with each other, and optimizing a particular solution with respect to a single objective can result in unacceptable results with respect to the other objectives. Multiobjective formulations are

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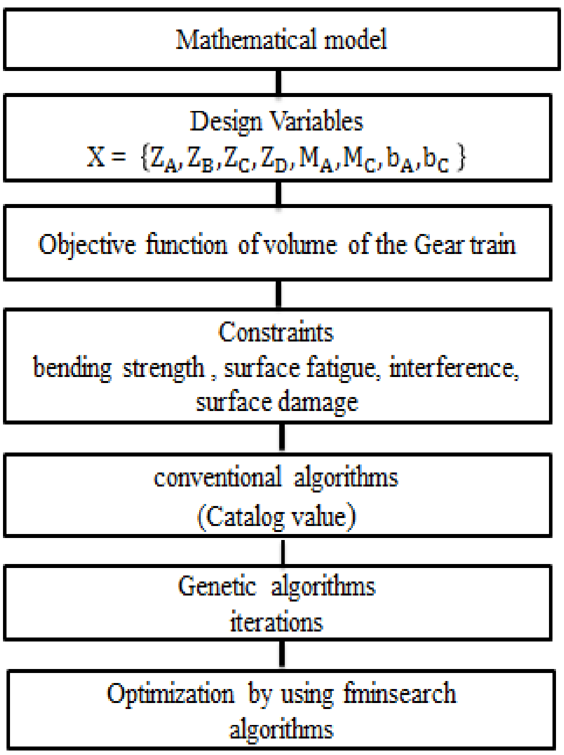
realistic models for many complex engineering optimization problems. Ant Colony Optimization was developed specifically for a worm gear drive problem with multiple objectives. T raja, Senthil kumar *et al.* [4] Optimization of gear parameters by using genetic algorithm, an analysis of the failed gear has been carried out. The fractured gear teeth were subjected to detailed analysis using metallurgical techniques such as Visual Examination, Chemical composition analysis, Micro hardness survey, Tensile strength analysis and Microstructure analysis of the failed gear were carried out in the process to found out various root causes resulting for the failure of the gear. In this study Genetic algorithm is introduced for the optimum Design of gear train to solve such problems and propose a genetic algorithm based gear design system. Huang *et al.*[5] developed interactive physical programming approach of the optimization model of three-stage spur gear reduction unit with minimum volume, maximum surface fatigue life, and maximum load-carrying capacity as design objectives and core hardness, module, face width of gear, tooth numbers of pinion, tooth numbers of gear, and diameter of shaft as design variables. In this modelling, tooth bending fatigue failure, shaft torsional stress, face width, Interference, and tooth number are considered as constraints. The Matlab constrained optimization package is used to solve this nonlinear programming problem.

4. METHODOLOGY



5. FORMULATION OF PROBLEM

The optimization model of two-stage helical gear reduction unit is formulated in this section, with minimum volume and maximum load carrying capacity as design objectives. The schematic illustration of two-stage helical gear reduction unit is shown Figure-1. As it is a case of two-stage gear reduction, the gear ratios between first pair and second pair are chosen in such a way that their values are feasible and their product remains the same as that of required.

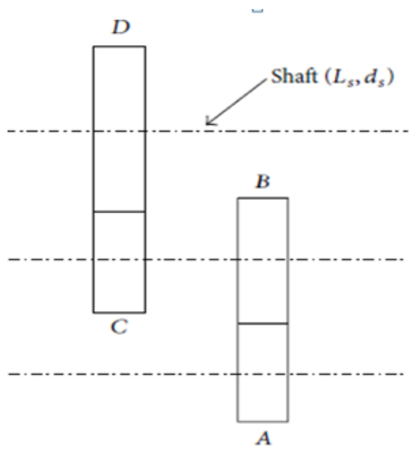


Figure-1. Schematic illustration of two-stage helical gear train.

5.1. Design variables

The mainly affected parameters of gear from the volume point of view are face width, module, and number of teeth of gear. These parameters directly or indirectly affect the objectives widely. So, the design vector$X$ is

$$X = \{Z_A, Z_B, Z_C, Z_D, M_A, M_C, b_A, b_C D_A, D_B, D_C, D_D\}$$

Where z_A, z_B, z_C, and z_D are the number of teeth of gears A, B, C and D, respectively. b_A and b_C are the face widths of gears A and C, respectively; m_{nA} and m_{nC} are the normal modules of gear A, C, respectively. Here it is assumed that all gears are of the same material (say with the same Brinell hardness number) and are of the same helix angle.

Table-1. Coefficients and input values for sample design practice.

Transferred power (kW)	5.5
Input speed (rpm)	1440
Output speed (rpm)	144
Total gear ratios (i)	10
Material (Cementite steel)	16MnCr5
Manufacturing process	Fine work
Usage	Electricity motor
Brinell hardness (N/mm2)	1460
Ultimate tensile strength,	1100(N/mm2)
Available modules (mm)	1, 1.125, 1.25, 1.375, 1.5, 1.75, 2, 2.25, 2.5, 2.75, 3,3.5, 4, 4.5, 5, 5.5

5.2. Objective functions

For the optimization, first the volume of the two-stage helical gear train is minimized. After achieving the

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optimal value of design variables for minimum volume, those values of variables are applied to maximize the load carrying capacity of both of the stages. From both of these stages, the minimum load carrying capacity out of the two is chosen as the maximum capacity for the gear train.

The optimization model of two-stage helical gear trains is derived as follows:

F_1=pi/4[(d_a^2+d_b^2)*b_a+(d_c^2+d_d^2)*b_c+d_1^2*L_1+d_2^2*L_2+d_3^2*L_3]
Module (m) = diameter/Number of teeth
Diameter = module*Number of teeth
F_1=pi/4*[(m_1*z_1+m_1*z_2)^2*b_a+(m_2*z_3+m_2*z_4)^2*b_c+d_1^2*L_1 +d_2^2*L_2+d_3^2*L_3]

The load carrying capacity P is given as

The load carrying capacity (F) for the gear A and B respectively

$$F_A = \frac{2c_s M_{t1}}{d_a} + \frac{21\pi n_1(ce_1 b_a d_a^{1.5}\cos^2\theta + 2d_a^{1.5}M_{t1})\cos\theta}{21\pi d_a^{1.5}n_1 + 60{,}000\sqrt{ce_1}b_a d_a\cos^2\theta + 2M_{t1}}$$

The load carrying capacity (F) for the gear C and D respectively

$$F_C = \frac{2c_s M_{t2}}{d_a} + \frac{21\pi n_2(ce_2 b_c d_c^{1.5}\cos^2\theta + 2d_c^{1.5}M_{t2})\cos\theta}{21\pi d_c^{1.5}n_2 + 60{,}000\sqrt{ce_1 b_c}d_c\cos^2\theta + 2M_{t2}}$$

Where da, db, dc and L_1, L_2, L_3 represent the diameters of Shaft and lengths of shaft 1, 2, 3, respectively. The factorsC_S and C denote service factor and deformation factor, respectively. Mt is the transmitted torque and e_1 and e_2 are sum of error between first meshing teeth and second meshing teeth, respectively. Thus the objectives can be written for minimum volume and maximum load carrying capacity for the shaft.

5.3. Constraints

When the gear tooth is considered as a cantilever beam, the bending strength in working condition should not exceed standard endurance limit, Sn. From Lewis equation, the constraint on bending strength is

$$\frac{F_t p}{by} \leq s_n$$

WhereF_t= tangential force and p diametral pitch, is face width, and is Lewis factor.

However, in this work, the factors affecting bending strength during the production and assembly, such as velocity factor, overload factor, and mounting factor to name a few, are not taken into consideration. So, after adding the effects of these factors, the new constraints on bending strength for both of the gear pairs can be expressed as

$$\frac{F_{ta}P_c}{b_c j_c} k_{vc}k_o(0.93k_{ma}) - s_n^1 c_L c_{Gc} c_s k_r k_t k_{ms} \leq 0$$
$$\frac{F_{tc}P_c}{b_c j_c} k_{vc}k_o(0.93k_{ma}) - s_n^1 c_L c_{Gc} c_s k_r k_t k_{ms} \leq 0$$

Factor Y and a stress concentration factor. K_V, K_o, andK_m denote velocity or dynamic factor, overload factor, and mounting factor, respectively. S_n is standard R. R. Moore endurance limit. C_L, C_G, and C_S denote load factor, gradient factor, and service factor, respectively. k_t, k_r, and k_{ms} denote temperature factor, reliability factor, and mean stress factor, respectively.

Gear teeth are vulnerable to various types of surface damage. As was the case with rolling-element bearings. Gear teeth are subjected to Hertz contact stresses, and the lubrication is often elastohydrodynamic. Excessive loading and lubrication breakdown can cause various combinations of abrasion, pitting, and scoring. It will become evident that gear-tooth surface durability is a more complex matter than the capacity to withstand gear-tooth-bending fatigue. After including all the parameters the surface fatigue Constraint formula

$$c_p\sqrt{\frac{F_{ta}}{b_a d_a I_a} * \frac{\cos\theta}{0.95CR_a}} * k_{va}k_o(0.93k_{ma}) - s_{fc}c_L c_R \leq 0$$

$$dc_p\sqrt{\frac{F_{tc}}{b_c d_c I_c} * \frac{\cos\theta}{0.95CR_c}} * k_{vc}k_o(0.93k_{mc}) - s_{fc}c_L c_R \leq 0$$

Where C_p, C_{Li}, and C_R denote elastic coefficient factor, life factor, and reliability factor, respectively. I_A and I_C are dimensionless constants and C_{RA} and C_{RC} are contact ratios. Sfc represents surface fatigue strength.

While designing the gear, interference is the main factor to consider. Interference usually takes place in the gear. So formulation of the optimization problem must take care of interference. To remove interference, the following constraints should be satisfied

$$r_{aA} - \sqrt{r_{ba}^2} + c_a^2\sin^2\emptyset \leq 0$$

$$r_{ac} - \sqrt{r_{bc}^2} + c_c^2\sin^2\emptyset \leq 0$$

$$\frac{2}{\sin^2\emptyset}\text{-}Z_A \leq 0$$

$$\frac{2}{\sin^2\emptyset}\text{-}Z_B \leq 0$$

$$\frac{2}{\sin^2\emptyset}\text{-}Z_C \leq 0$$

$$\frac{2}{\sin^2\emptyset}\text{-}Z_D \leq 0$$

6. OPTIMIZATION

The optimization of equation required a computer programming. For optimization of equation, all the mathematical equation and constraint parameters is converted into coding language. The coding is validated by Matlab software with different parameters of gear trains of double stage and the optimization is performed using fminsearch.

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Table-2. GA for population size of 90 and 90 generations.

S. No	b_A (mm)	M_A (mm)	Z_A	Z_B	bc (mm)	M_c (mm)	Zc	Z_D	Volume (10^7*mm^3)
1	67	4	18	57	90	3	18	99	2.266
2	64	4	19	60	85	3	18	99	2.188
3	62	4	18	57	86	3	18	99	2.172
4	75	4	18	57	85	3	18	99	2.211
5	66	4	20	63	87	3	18	99	2.232
6	63	4	19	60	86	3	18	99	2.204
7	62	4	18	57	86	3	18	99	2.179
8	65	4	18	57	86	3	18	99	2.247
9	61	4	18	57	86	3	18	99	2.176
10	60	4	18	57	85	3	18	99	2.168

The algorithm does number of iteration to get the optimized minimum value, which implements constraints optimization on nonlinear multivariable problems exhibits generally good performance on a wide range of problems. In case of fminsearch Solver, the iterative procedure starts from an arbitrary population of solutions and gradually the algorithm converges to a population of solutions lying on the Pareto optimal front with higher diversity.

6.1. Genetic algorithm formulation of the problem

In this study a part of the developed software, Gear train optimisation with helical gears will be addressed. In optimising volume of gear trains module, number of teeth and face width are selected as effective design parameters. The module variable m_n is normal module in helical gears and has been defined at interval of 1 to 5 with total of 1, 1.125, 1.25, 1.375, 1.5, 1.75, 2, 2.25, 2.5, 2.75, 3, 3.5, 4, 4.5, 5, 5.5 variables. In design of gear pairs, materials of pinion and gear have accepted same and design process is carried out based on pinion.

The ranges of the problem variables are taken as reference from manufacturer's catalog and these ranges for b_A, m_A, z_A, z_B, b_C, m_C, z_C, and z_D are taken as 60–80, 4–12, 14–20,44–65, 85–105, 3–10, 14–20, and 77–110, respectively.

The GA parameters in the study were chosen as initial population size = 90 number of Generations = 90 crossover probabilities = 0.5 mutation probabilities = 0.01and gear type helical gear is selected and constraints are impose on the genetic algorithms.

There are 15 iterations carried out for the limiting values of two gears namely A and B. The algorithm has to estimate the volumes of shaft and gear for each set of A and B. The diameter limit for gear A and gear B are fixed as 14-20 and 44-65 respectively. The shows the results obtained for volume of first shaft and gear.

Table-3. Iteration value of gears A and B.

D1/D2	44	45.5	47	48.5	50	51.5	53	54.5	56	57.5	59	60.5	62	63.5	65
14	1.339e6	1.339e6	1.340e6	1.340e6	1.340e6	1.341e6	1.341e6	1.342e6	1.342e6	1.342e6	1.343e6	1.343e6	1.344e6	1.344e6	1.344e6
14.41	1.345e6	1.345e6	1.346e6	1.346e6	1.346e6	1.347e6	1.347e6	1.348e6	1.348e6	1.348e6	1.349e6	1.349e6	1.350e6	1.350e6	1.350e6
14.82	1.351e6	1.351e6	1.352e6	1.352e6	1.352e6	1.353e6	1.353e6	1.354e6	1.354e6	1.354e6	1.355e6	1.355e6	1.356e6	1.356e6	1.356e6
15.23	1.357e6	1.357e6	1.358e6	1.358e6	1.358e6	1.359e6	1.359e6	1.360e6	1.3605e6	1.360e6	1.361e6	1.361e6	1.362e6	1.362e6	1.362e6
15.64	1.363e6	1.363e6	1.364e6	1.364e6	1.364e6	1.365e6	1.365e6	1.366e6	1.366e6	1.366e6	1.367e6	1.367e6	1.368e6	1.368e6	1.368e6
16.05	1.369e6	1.369e6	1.370e6	1.370e6	1.370e6	1.371e6	1.371e6	1.371e6	1.372e6	1.372e6	1.373e6	1.373e6	1.374e6	1.375e6	1.374e6
16.46	1.375e6	1.375e6	1.371e6	1.376e6	1.376e6	1.373e6	1.377e6	1.381e6	1.375e6	1.378e6	1.379e6	1.377e6	1.381e6	1.385e6	1.380e6
16.87	1.381e6	1.381e6	1.382e6	1.382e6	1.382e6	1.383e6	1.383e6	1.384e6	1.384e6	1.384e6	1.385e6	1.385e6	1.386e6	1.386e6	1.386e6
17.28	1.387e6	1.387e6	1.388e6	1.388e6	1.388e6	1.389e6	1.389e6	1.390e6	1.390e6	1.390e6	1.391e6	1.391e6	1.392e6	1.392e6	1.392e6
17.69	1.393e6	1.393e6	1.394e6	1.394e6	1.394e6	1.395e6	1.395e6	1.396e6	1.396e6	1.396e6	1.397e6	1.397e6	1.398e6	1.398e6	1.398e6
18.1	1.399e6	1.399e6	1.400e6	1.400e6	1.400e6	1.401e6	1.401e6	1.402e6	1.402e6	1.402e6	1.403e6	1.403e6	1.404e6	1.404e6	1.404e6
18.51	1.405e6	1.405e6	1.406e6	1.406e6	1.406e6	1.407e6	1.407e6	1.408e6	1.408e6	1.408e6	1.409e6	1.409e6	1.410e6	1.410e6	1.410e6
18.92	1.411e6	1.411e6	1.412e6	1.412e6	1.412e6	1.413e6	1.413e6	1.414e6	1.414e6	1.414e6	1.415e6	1.415e6	1.416e6	1.416e6	1.416e6
19.74	1.417e6	1.417e6	1.418e6	1.418e6	1.418e6	1.419e6	1.419e6	1.420e6	1.420e6	1.420e6	1.421e6	1.421e6	1.422e6	1.422e6	1.422e6
20	1.423e6	1.423e6	1.424e6	1.424e6	1.424e6	1.425e6	1.425e6	1.426e6	1.426e6	1.426e6	1.427e6	1.427e6	1.428e6	1.428e6	1.428e6

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Similar kind of iterations are carried out for third (C) and fourth (D) gears, The diameter limit for gear C and gear D is set as 14-20 and 77-110 respectively. The resulting load carrying capacity for different values for second shaft and gears are shown in Table.

Table-4. Iteration value of gears C and D.

D3/D4	77	79.32	81.64	83.96	86.28	88.6	90.92	93.24	95.56	97.88	100.2	102.52	104.84	107.16	110
14	1.367e6	1.368e6	1.368e6	1.368e6	1.369e6	1.369e6	1.370e6	1.370e6	1.370e6	1.371e6	1.371e6	1.372e6	1.372e6	1.372e6	1.373e6
14.43	1.373e6	1.374e6	1.374e6	1.374e6	1.375e6	1.375e6	1.376e6	1.376e6	1.376e6	1.377e6	1.377e6	1.378e6	1.378e6	1.378e6	1.379e6
14.86	1.379e6	1.380e6	1.380e6	1.380e6	1.381e6	1.381e6	1.382e6	1.382e6	1.382e6	1.383e6	1.383e6	1.384e6	1.384e6	1.384e6	1.385e6
15.29	1.385e6	1.386e6	1.386e6	1.386e6	1.387e6	1.387e6	1.388e6	1.388e6	1.388e6	1.389e6	1.389e6	1.390e6	1.390e6	1.390e6	1.391e6
15.72	1.391e6	1.392e6	1.392ee6	1.3929	1.393e6	1.393e6	1.394e6	1.394e6	1.394e6	1.395e6	1.395e6	1.396e6	1.396e6	1.396e6	1.397e6
16.15	1.397e6	1.398e6	1.398e6	1.400e6	1.405e6	1.40e69	1.401e6	1.401e6	1.402e6	1.402e6	1.402e6	1.403e6	1.403e6	1.404e6	1.404e6
16.58	1.404e6	1.405e6	1.405e6	1.406e6	1.406e6	1.406e6	1.407e6	1.407e6	1.408e6	1.408e6	1.408e6	1.409e6	1.409e6	1.410e6	1.410e6
17.01	1.410e6	1.411e6	1.411e6	1.412e6	1.412e6	1.412e6	1.413e6	1.413e6	1.414e6	1.414e6	1.414e6	1.415e6	1.415e6	1.416e6	1.416e6
17.44	1.416e6	1.417e6	1.417e6	1.418e6	1.418e6	1.418e6	1.419e6	1.419e6	1.420e6	1.420e6	1.420e6	1.421e6	1.421e6	1.422e6	1.422e6
17.87	1.422e6	1.423e6	1.423e6	1.424e6	1.424e6	1.424e6	1.425e6	1.425e6	1.426e6	1.426e6	1.426e6	1.427e6	1.427e6	1.428e6	1.428e6
18.3	1.428e6	1.429e6	1.429e6	1.430e6	1.430e6	1.430e6	1.431e6	1.431e6	1.432e6	1.432e6	1.432e6	1.433e6	1.43e67	1.43e61	1.434e6
18.73	1.434e6	1.435e6	1.435e6	1.436e6	1.436e6	1.436e6	1.437e6	1.437e6	1.438e6	1.438e6	1.438e6	1.439e6	1.439e6	1.440e6	1.440e6
19.16	1.440e6	1.441e6	1.441e6	1.442e6	1.442e6	1.442e6	1.443e6	1.443e6	1.444e6	1.444e6	1.444e6	1.445e6	1.445e6	1.446e6	1.446e6
19.59	1.446e6	1.447e6	1.447e6	1.448e6	1.448e6	1.448e6	1.449e6	1.449e6	1.450e6	1.450e6	1.450e6	1.451e6	1.4517e6	1.452e6	1.452e6
20	1.452e6	1.453e6	1.453e6	1.454e6	1.454e6	1.454e6	1.455e6	1.455e6	1.456e6	1.456e6	1.456e6	1.457e6	1.457e6	1.458e6	1.458e6

Table-5. Comparison of results.

Variable and objectives	**Catalog value**	**Genetic algorithm value** (Round off)	**fminsearch solver** (Round off)
Module of gear A (mm)	7	4	4
Face width of gear A (mm)	70	60	62
Number of teeth of gear A	14	18	19
Number of teeth of gear B	44	57	60
Module of gear C (mm)	3.5	3	3
Face width of gear C (mm)	95	85	86
Number of teeth of gear C	14	18	19
Number of teeth of gear D	77	100	100
Volume (mm^3)	2.29×10^7	2.16×10^7	2.15×10^7
Load carrying capacity (N)	3.40×10^4	3.28×10^4	3.42×10^4

7. OPTIMIZATION USING FMINSEARCH SOLVER

In this case, the problem is considered as a multi-objective problem. So, both objectives are treated together. In general, in case of multi objective optimization, the objectives are conflicting. So, a single solution cannot be accepted as the best solution. Since evolutionary algorithms are population based, they are the natural choice for solving this kind of problem. In fminsearch Solver the iterative procedure starts from an arbitrary population of solutions and gradually the algorithm converges to a population of solutions lying on the Pareto optimal front with higher diversity.

There are 15 iterations carried out for the load carrying of two gears namely A and B. The algorithm has to estimate the load of shaft and gear for each set of A and B. The diameter limit for gear A and gear B are fixed as 16-20 and 44-65 respectively. The figure shows the results obtained for load carrying capacity of first shaft and gears are shown in Table.

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Table-6. Iteration value of gears A and B.

D1/D2	44	45.5	47	48.1	50	51.5	53	54.5	56	57.5	59	60.5	62	63.5	65
14	16.0000	16.0038	16.0076	16.0114	16.0152	16.0190	16.0228	16.0266	16.0304	16.0342	16.0380	16.0418	16.0456	16.0494	16.0532
14.43	16.0608	16.0646	16.0684	16.0722	16.0760	16.0798	16.0836	16.0874	16.0912	16.0950	16.0988	16.1026	16.1064	16.1102	16.1140
14.86	16.1216	16.1254	16.1292	16.1330	16.1368	16.1406	16.1444	16.1482	16.1520	16.1558	16.1596	16.1634	16.1672	16.1710	16.1748
15.29	16.1824	16.1862	16.1900	16.1938	16.1976	16.2014	16.2052	16.2090	16.2128	16.2166	16.2204	16.2242	16.2280	16.2318	16.2356
15.72	16.2432	16.2470	16.2508	16.2546	16.2584	16.2622	16.2660	16.2698	16.2736	16.2774	16.2812	16.2850	16.2888	16.2926	16.2964
16.15	16.3040	16.3078	16.3116	16.3154	16.3192	16.3230	16.3268	16.3306	16.3344	16.3382	16.3420	16.3458	16.3496	16.3534	16.3572
16.58	16.3648	16.3686	16.3724	16.3762	16.3800	16.3838	16.3876	16.3914	16.3952	16.3990	16.4028	16.4066	16.4104	16.4142	16.4180
17.01	16.4256	16.4294	16.4332	16.4370	16.4408	16.4446	16.4484	16.4522	16.4560	16.4598	16.4636	16.4674	16.4712	16.4750	16.4788
17.44	16.4864	16.4902	16.4940	16.4978	16.5016	16.5054	16.5092	16.5130	16.5168	16.5206	16.5244	16.5282	16.5320	16.5358	16.5396
17.87	16.5472	16.5510	16.5548	16.5586	16.5624	16.5662	16.5700	16.5738	16.5776	16.5814	16.5852	16.5890	16.5928	16.5966	16.6004
18.3	16.6080	16.6118	16.6156	16.6194	16.6232	16.6270	16.6308	16.6346	16.6384	16.6422	16.6460	16.6498	16.6536	16.6574	16.6612
18.73	16.6688	16.6726	16.6764	16.6802	16.6840	16.6878	16.6916	16.6954	16.6992	16.7030	16.7068	16.7106	16.7144	16.7182	16.7220
19.16	16.7296	16.7334	16.7372	16.7410	16.7448	16.7486	16.7524	16.7562	16.7600	16.7638	16.7676	16.7714	16.7752	16.7790	16.7828
19.56	16.6688	16.6726	16.6764	16.6802	16.6840	16.6878	16.6916	16.6954	16.6992	16.7030	16.7068	16.7106	16.7144	16.7182	16.7220
20	16.7904	16.7942	16.7980	16.8018	16.8056	16.8094	16.8132	16.8170	16.8208	16.8246	16.8284	16.8322	16.8360	16.8398	16.8436

Similar kind of iterations are carried out for third(C) and fourth(D) gears, The diameter limit for gear C and gear D is set as 14-20 and 77-110 respectively. The resulting load carrying capacity for different values for second shaft and gears are shown in Table.

Table-7. Iteration value of gears C and D.

D3/D4	77	79.32	81.64	83.96	86.28	88.6	90.92	93.24	95.56	97.88	100.2	102.2	104.84	107.16	110
14	17.0000	17.0015	17.0030	17.0045	17.0060	17.0075	17.0090	17.0105	17.0120	17.0135	17.0150	17.0165	17.0180	17.0195	17.0210
14.43	17.0240	17.0255	17.0270	17.0285	17.0300	17.0315	17.0330	17.0345	17.0360	17.0375	17.0390	17.0405	17.0420	17.0435	17.0450
14.86	17.0480	17.0495	17.0510	17.0525	17.0540	17.0555	17.0570	17.0585	17.0600	17.0615	17.0630	17.0645	17.0660	17.0675	17.0690
15.29	17.0720	17.0735	17.0750	17.0765	17.0780	17.0795	17.0810	17.0825	17.0840	17.0855	17.0870	17.0885	17.0900	17.0915	17.0930
15.72	17.0960	17.0975	17.0990	17.1005	17.1020	17.1035	17.1050	17.1065	17.1080	17.1095	17.1110	17.1125	17.1140	17.1155	17.1170
16.15	17.1200	17.1215	17.1230	17.1245	17.1260	17.1275	17.1290	17.1305	17.1320	17.1335	17.1350	17.1365	17.1380	17.1395	17.1410
16.58	17.1440	17.1455	17.1470	17.1485	17.1500	17.1515	17.1530	17.1545	17.1560	17.1575	17.1590	17.1605	17.1620	17.1635	17.1650
17.01	17.1680	17.1695	17.1710	17.1725	17.1740	17.1755	17.1770	17.1785	17.1800	17.1815	17.1830	17.1845	17.1860	17.1875	17.1890
17.44	17.1920	17.1935	17.1950	17.1965	17.1980	17.1995	17.2010	17.2025	17.2040	17.2055	17.2070	17.2085	17.2100	17.2115	17.2130
17.87	17.2160	17.2175	17.2190	17.2205	17.2220	17.2235	17.2250	17.2265	17.2280	17.2295	17.2310	17.2325	17.2340	17.2355	17.2370
18.3	17.2400	17.2415	17.2430	17.2445	17.2460	17.2475	17.2490	17.2505	17.2520	17.2535	17.2550	17.2565	17.2580	17.2595	17.2610
18.73	17.2640	17.2655	17.2670	17.2685	17.2700	17.2715	17.2730	17.2745	17.2760	17.2775	17.2790	17.2805	17.2820	17.2835	17.2850
19.16	17.2880	17.2895	17.2910	17.2925	17.2940	17.2955	17.2970	17.2985	17.3000	17.3015	17.3030	17.3045	17.3060	17.3075	17.3090
19.56	17.3120	17.3135	17.3150	17.3165	17.3180	17.3195	17.3210	17.3225	17.3240	17.3255	17.3270	17.3285	17.3300	17.3315	17.3330
20	17.3600	17.3615	17.3630	17.3645	17.3660	17.3675	17.3690	17.3705	17.3720	17.3840	17.3855	17.3870	17.3885	17.3900	17.3901

8. CONCLUSIONS

It is observed that the results remain consistent when the population size is 90and number of generations is 90. So, 10th good results with this population size and number of generations are shown in Table. If we compare the catalog value and genetic algorithm value module, face width and number of teeth are different. It is observed that the right combination of constraint variables and design parameters decrease 5.8% of overall volume with existing gear train design. Module is change from 7 to 4 and number of teeth is changed from 14 to 18 for gear a. for gear b number of teeth is changed from 44 to 57.

Optimization method has been developed for design of multistage gear trains by catalog value compare with fminsearch. It is observed that the right combination of constraint variables and design parameters decrease 6.7% of overall volume with existing gear train design.

Optimization method has been developed for load carrying capacity design of multistage gear trains by catalog value and compare with fminsearch and genetic algorithms. If compare catalog value and Genetic algorithm value load carrying capacity of that the right combination of constraint variables and design parameters decrease 4 % of existing gear train design. If compare catalog value and fminsearch value load carrying capacity of the multistage gear increase 2% of existing gear train design.

REFERENCES

[1] B. S. Tong and D. Walton. 1987. The optimisation of internal gears. International Journal of Machine Tools and Manufacture. 27: 491-504.

[2] T. Yokota, T. Taguchi and M. Gen. 1998. A solution method for optimal weight design problem of the gear using genetic algorithms. Computers and Industrial Engineering. 35: 523-526.

[3] D. F. Thompson, S. Gupta, and A. Shukla. 2000. Trade off analysis in minimum volume design of multi-stage spur gear reduction units. Mechanism and Machine Theory. 35: 609-627.

[4] K. Deb and S. Jain. 2003. Multi-speed gearbox design using multi-objective evolutionary algorithms. Journal of Mechanical Design. 125: 609-619.

[5] H.-Z. Huang, Z.-G. Tian and M. J. Zuo. 2005. Multiobjective optimization of three-stage spur gear reduction units using interactive physical programming. Journal of Mechanical Science. 19: 1080-1086.

[6] S. Padmanabhan, M. Chandrasekaran and V. Srinivasa, 2013. Design optimization of worm Gear drive. International Journal of Mining, Metallurgy and Mechanical Engineering. 1: 57-61.

[7] D. Jhalani and H. Chaudhary. 2012. Optimal design of gearbox for application in knee mounted biomechanical energy harvester. International Journal of Scientific and Engineering Research. 10:1071-1075.

[8] V. Savsani, R.V. Rao, and D. P.Vakharia. 2010. Optimal weight design of a gear train using particle swarm optimization and simulated annealing algorithms. Mechanism and Machine Theory. 45: 531-541.

[9] Sa'id Golabi a, Javad Jafari Fesharaki *et al.* 2014. Gear train optimization based on minimum volume/weight design, Department of Mechanical Engineering; Mechanism and Machine Theory. 73: 197-217.

[10] T Raja, Senthil Kumar, *et al*. 2014. Optimization of gear parameters by using genetic algorithm, International Journal of Mechanical Engineering. Global Science Research Journals. 25: 055-062.

[11] Cevdet Gologlu a, Metin Zeyveli. 2009. A genetic approach to automate preliminary design of gear drives, Faculty of Engineering, Turkey Computers and Industrial Engineering. 57: 1043-1051.

[12] F. Mendi, T. Baskal, K. Boran, F.E. Boran. 2010. Optimization of module, shaft diameter and rolling bearing for spur gear through genetic algorithm. Expert Systems with Applications. 37: 8058-8064.