SPUR GEAR OPTIMIZATION BY USING GENETIC ALGORITHM

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ABSTRACT

This paper involves about the optimization of spur gear set for its center distance, weight and tooth deflections are taken as an objective functions and the decision variable such as module, face width and number of teeth on pinion, and subjected to constraints namely, bending stress, contact stress. Since it is multi-objective function with constraints is very difficult to optimize using conventional optimization techniques, used non-traditional optimization technique called Genetic algorithm.

Non-traditional algorithms are very difficult to solve manually. Solutions for the non-traditional methods can be obtained by computerizing algorithms using "C" language. The results are calculated by using "C" language for three materials namely Cast Iron, C-45 and Alloy steel (15Ni2 Cr1).

Keywords: Optimization, Spur gear, Genetic Algorithm

1.0 INTRODUCTION

Gears are used in most types of machinery and vehicles for the transmission of power. The design of gears is highly complicated involving the satisfaction of many constraints such as strength, pitting resistance, bending stress, scoring wear, and interference in involute gears etc. The concentration is focused on spur gear sets which are used to transmit motion between parallel shafts because of the reason that out of the various methods of power transmission, the toothed gear transmission stands unique due to its high efficiency, reliable service, transmit large power, compact layout and simple operation.

Gear design is an art as well as an engineering science. Designer based on his design principles and the knowledge about the gear, lays out a gear for a particular application. The community of engineers now knows that applying engineering principles alone cannot suggest a good design. It is, in many cases that the designer's expertise suggests good design. The problem with the conventional design procedure is that it gives out a single solution and the manufacturing is carried out on that basis.

Optimization is the act of obtaining the best result under the given circumstances. Design optimization of spur gear sets at reduces the size, weight, tooth deflection and increase the life span of the gear. The optimization methodology adopted in this work is an artificial genetics approach proposed by Goldberg based on natural genetics. Genetic algorithms efficiently exploit useful information contained in a population of solutions to generate new solutions with better performance. Figure 1 shows the spur gear

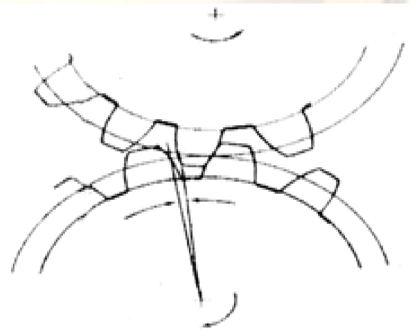

Fig:1

1.1 GENETIC ALGORITHM

Genetic Engineering is a growing field that is being utilized in a variety of areas. People are interested in this field because of the ability to make the next generations are easier and faster algorithms and are being used in multidisciplinary design methods for optimal design.

Genetic algorithms (GA's) are adaptive search optimization algorithms based on mechanics of natural selection and natural genetics. GA's operated on the survival of the fittest. Genetic Algorithms, a class of evolutionary algorithms are non-deterministic stochastic search methods that utilize the theories of evolution and natural selection to solve a problem within a complex solution space. GA's maintain a population of structures that evolve according to rules of selection and other operations that are referred to as "search operators" such as recombination and mutation. Each individual in the population receives a measure of its fitness in the environment. Reproduction focuses attention on high fitness individuals, thus exploiting the available fitness information. Recombination and mutation perturb those individuals providing general heuristics for exploration.

Genetic Algorithms begin with a population of randomly generated string that represents the problem and there possible solutions. Thereafter, each of these strings is evaluated to find its fitness. If a satisfactory solution based on the acceptability or search stoppage criterion exists search is stopped. If not, the initial population is subjected to genetic evolution to procreate the next generation of candidate solutions. The genetic process of procreation uses the population as the input. The members of the population are "processed by the four main GA operators – reproduction, crossover, mutation and inversion to create the progenies for the next generation of candidate-solutions. The progenies are then evaluated and tested for termination.

Gears are used in most types of machinery and vehicles for the transmission of power. The design of gears is highly complicated involving the satisfaction of many constraints such as strength, pitting resistance, bending stress, interference in involute gears and so on. Because of the reason that out of the various methods of power transmission, the toothed gear transmission stands unique due to its high efficiency, reliable service, simple operation, transmit exact velocity ratios, and transmit large powers in a compact layout. The main concentration is focused on spur gear set, that are used to transmit motion from one shat to another shaft whose axis are parallel to each other.

2.0 DESIGN OPTIMIZATION

The objectives of spur gear design here are

Minimize center distance
Minimize weight of the meshing gear set
Minimize tooth deflection

2.1 Centre Distance

The user of gears or products which contain gears often demands smaller gear sets. In general, the most desirable gear set is the smallest one that will perform the required job. Smaller gears are easier to make, run more smoothly due to small inertial loads and pitch line velocities and also less expensive. Smaller gears would require less material to make and less space to operate it. The following is the equation govern the center distance of gear set

Center distance $a = 0.5\, m\, (T_1+T_2)$

Where a is the center distance in mm
m is the module in mm
T_1 is the number of teeth on pinion
T_2 is the number of teeth on gear

2.2 Gear Weight

User of the gear sets expects a gear set, which is normally less in weight so that vibration can be reduced and quite in running. Weight reduction of gears improves performance of non-stationery systems. Weight reduction saves the material, which leads to cost reduction and easy assembling. The following is the equation governing the weight of the gear set

$$\text{Weight } W = \frac{\pi}{4} m^2\, b\, (T_1^2\, \rho_1 + T_2^2\, \rho_2)\, g$$

Where b is the face width in mm
ρ_1, ρ_2 be the density of pinion and gear material and
g acceleration due to gravity = 9.81 m/ Sec^2

2.3 Gear Tooth Deflection:

Although tooth deflection has much to do with gear failure, it is often not considered during the design. But, for any considerable good design work, tooth deflection must be evaluated with high consideration and should be kept minimum. Tooth deflection can produce more complex load misdistribution and also has significant effect on gear failure. The equation that governs the tooth deflection is

$$\text{Deflection}(\delta)=\frac{15.12\ HP\ P_d}{(h_1-h_2)\,T_1\,T_2\,b\,E}\left\{\left(\frac{h_1}{h_2}-3\right)\left(\frac{h_1}{h_2}-1\right)+2\log\left(\frac{h_1}{h_2}\right)\right\}$$

Where $h_1 = 2\ m\ (0.7854 - \tan\psi)$

$h_2 = 2\ m\ (1.25 \tan\psi + 0.7854)$

HP is the power in kW

P_d is the diametral pitch

E is the Young's Modulus N/ mm^2

The deflection of the loaded gear tooth is the resultant of so complex stress patterns that elementary treatment as cantilever gives misleading results (10). The subject was investigated experimentally by Dr. Harry Walker. The deflection of geometrically similar teeth within the elastic limit is directly proportional to the applied load per inch of the face width and is independent of the pitch. Further, for different tooth forms, the deflection for a given loading does not follow the l/d^3 relationship for an elementary cantilever in bending, where l is the length and d is the depth, but was found experimentally, for tooth-forms of full-depth proportions to be proportional to l/d.

3.0 CONSTRAINTS

The constraints represent some functional relationship among design variables and other design parameters satisfying some physical phenomenon and certain resource limitations. The above objective functions are subjected to the following constraints.

3.1 Bending Stress

Failure in bending is generally catastrophic; hence appropriate care in the designing process is prudent and appropriate. To avoid tooth breakage, the bending stress should be limited to the maximum allowable bending stress of the material

Bending Stress σ_b= i+1/ a m b y $[M_t] < [\sigma_b]$, material bending stress

Where i is the velocity ratio in mm

a is the center distance in mm

m is the module in mm

b is the face width in mm

y is the form factor

$[M_t]$ is the torque in N-mm

$[\sigma_b]$ is the allowable bending stress in N/ mm^2

3.2 Contact Stress

The contact stress calculated should be kept smaller than the allowable contact stress of the material

Contact Stress, $\sigma_c = 0.74\,\frac{i+1}{a}\sqrt{\frac{i+1}{i\,b}\,[EM_t]} \leq [\sigma_c]$, material surface stress

4.0 FORMULATION OF THE PROBLEM

Design Variables: $x=\begin{Bmatrix} m \\ b \\ T \end{Bmatrix}$

Objective Function $F(x) = f(x_1) + f(x_2) + f(x_3)$

Constraints $g_1(x) < \sigma_{b\ Design}$

$g_2(x) < \sigma_{C\ Design}$

Variables: m=module

b= face width

T=No. of teeth on pinion

Objective:
$f(x_1)$ = Minimizing the center distance of the gear set
$f(x_2)$ = Minimizing the weight of the gear set
$f(x_3)$= Minimizing the tooth deflections of gear set
Constraints: g_1 (x) =Bending stress
g_2(x) =contact stress

5.0 CONVENTIONAL CALCULATION RESULTS

Considering the problem as optimization of spur gear set with decision variables such as module, face width and number of teeth on pinion, minimizing the center distance, weight and a tooth deflection of gears are taken as an objective function and are subjected to constraints such as bending stress and contact stress. With this data, solved the problem in traditional method

Input Data

Power P = 8 KW
Velocity ratio i = 3.2
Speed of pinion N_p = 720 rpm

Material	Cast Iron	C-45	Alloy Steel
Module(mm)	3	3	3
Face Width (mm)	10	10	10
No. of teeth on pinion	18	18	18
Centre Distance (mm)	114	114	114
Gear Weight (N)	19.94	19.99	19.81
Deflection	0.000032	0.0000524	0.0000524

Table 1: Conventional Calculations for three materials

6.0 GENETIC ALGORITHEM RESULTS

Considering the problem as optimization of spur gear set with decision variables such as module, face width and number of teeth on pinion, minimizing the center distance, weight and a tooth deflection of gears are taken as an objective function and are subjected to constraints such as bending stress and contact stress. With this data, solved the problem in non-traditional method (Genetic algorithm). Genetic algorithms solutions are solved by using software TURBO C.

Input Data

Power P = 8 KW
Velocity ratio i = 3.2
Speed of pinion N_p = 720 rpm

Material	Cast Iron	C-45	Alloy Steel
No. of Generations	150	150	150
At Generation	123	144	150
Module(mm)	3.000000	3.000003	3.000027
Face Width (mm)	10.001736	10.001953	10.002194
No. of teeth on pinion	18.000000	18.000000	18.000000
Centre Distance(mm)	113.400028	113.402069	113.401680
Gear Weight (N)	18.184130	19.748686	19.572247
Deflection	0.0000152	0.0000152	0.0000152
Best Fitness	44.559204	45.073822	45.015465
Average Fitness	58.452965	58.960320	45.015465

Table 2: Genetic Algorithm Results for Three Materials

7.0 GRAPHS

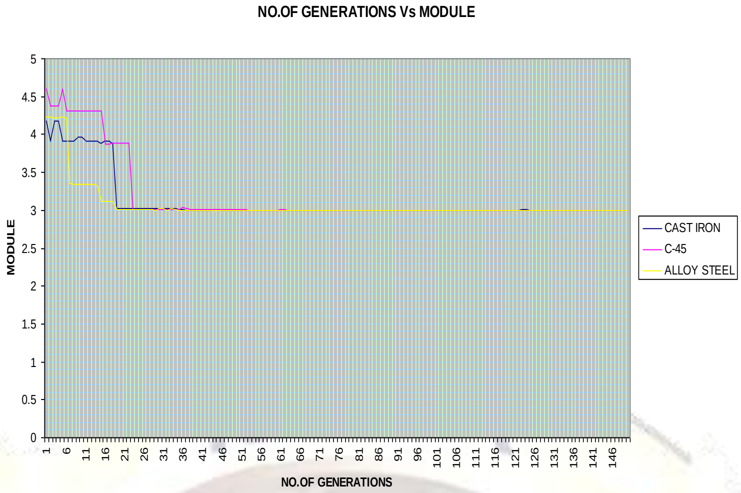

Fig.2: No.of generations Vs module

From the above graph the optimal solution lies at 41st generation and module is equal to 3.

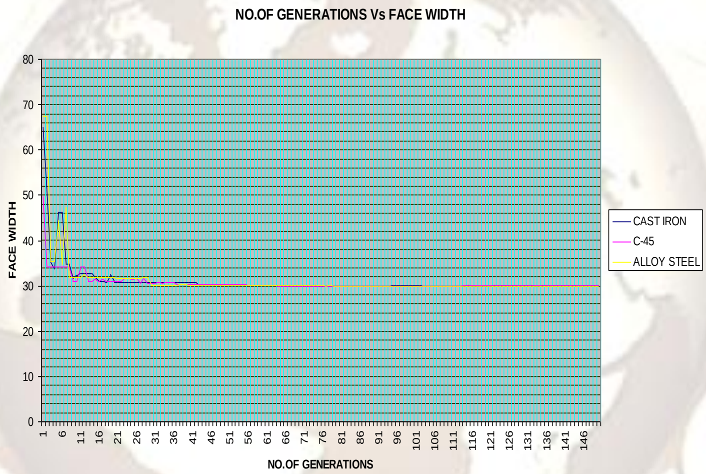

Fig.3: No. of generations Vs face width

The above graph show at 46 generation is giving the optimum value and its gives the straight line in the graph.

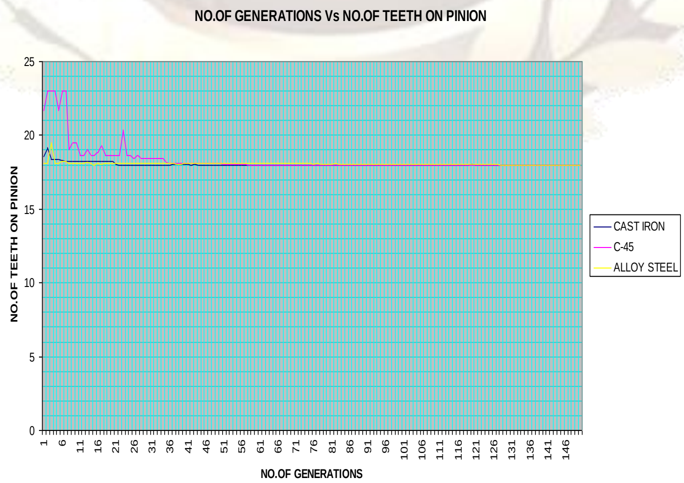

Fig.4: No. of generations Vs No. of teeth on pinion

The above graph show at 39 generation is giving the optimum value and its gives the straight line in the graph.

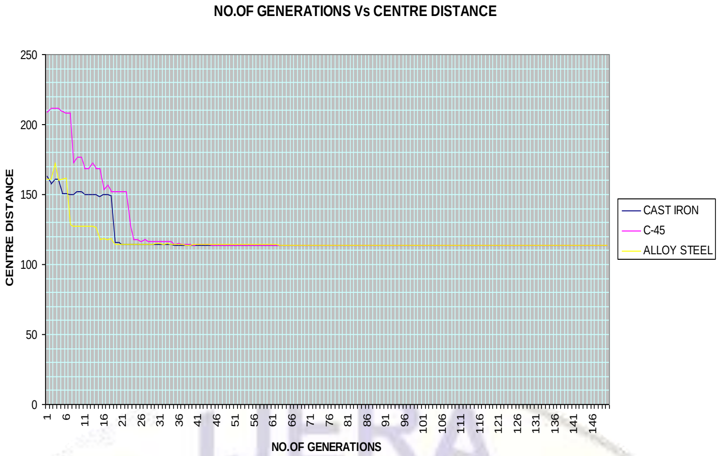

Fig.5: No. of generations Vs centre distance

The above graph show at 36 generation is giving the optimum value and its gives the straight line in the graph.

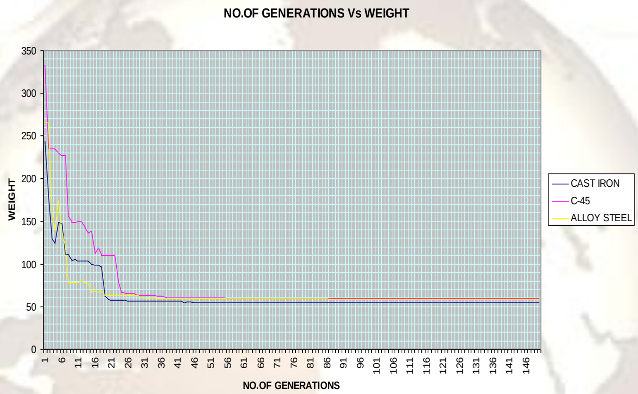

Fig.6: No.of generations Vs weight

The above graph show at 46 generation is giving the optimum value and its gives the straight line in the graph.

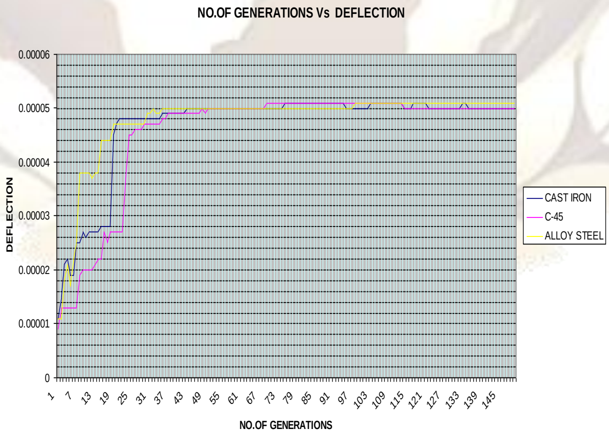

Fig.7: No. of generations Vs deflection

The above graph show at 48 generation is giving the optimum value and its gives the straight line in the graph.

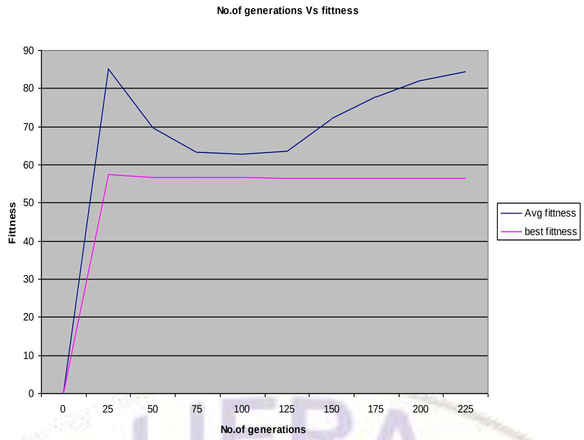

Fig.8: Number of generations Vs Fitness---Cast iron

The above graph show at 100 generation is giving the optimum value and its gives the straight line in the graph.

Fig.9: Number of generations Vs Fitness---Cast iron

The above graph show at 39 generation is giving the optimum value and its gives the straight line in the graph.

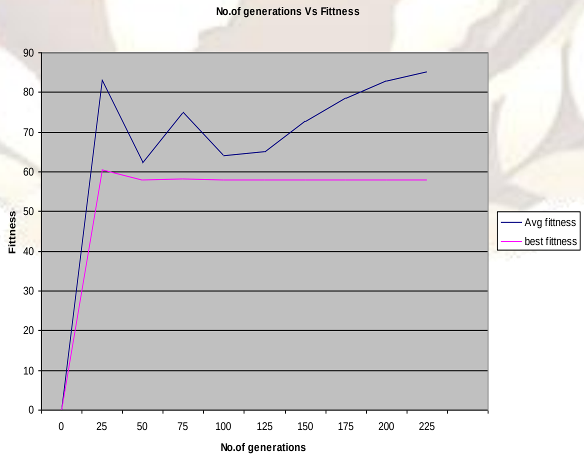

Fig.10: Number of generations Vs Fitness ---Alloy steel

The above graph show at 65 generation is giving the optimum value and its gives the straight line in the graph.

8.0 CONCLUSION

The design variables for spur gear set are module, face width and number of teeth on the pinion, minimizing the center distance, weight and tooth deflection of gears are taken as an objective function and subjected to constraints such as bending stress and contact stress.

From the above study, the following inferences are drawn as follows:

The proposed algorithm is able to find the optimal solution.

i) Since GA is random function search and optimization technique, the chance of getting global optimum is more.
ii) This algorithm does not require gradient information of the objective function, which makes it very attractive.
iii) The results of proposed algorithm have been compared to those of the traditional techniques, such as, graphical technique, geometric programming, etc for solving the same problem and proposed traditional techniques.

Most of the mechanical design involves exhaustive calculations and a number of multi variables multi modal, non linear and non-differentiable functions. It is highly impossible to apply technical optimal techniques in these cases. Non-traditional method like genetic algorithm can be efficiently applied for best results in the above problem.

The performance of designed gear set using genetic algorithm is evaluated and compared. Traditional method gives one or two optimal solutions but non-traditional methods give more number of solution out of which the best solution is selected by fitness value.

Variables	Conventional Calculations	GA Results
Module(mm)	3	3.000000
Face Width (mm)	10	10.001736
No. of teeth on pinion	18	18.000000
Centre Distance(mm)	114	113.400028
Gear Weight(N)	19.94	18.184130
Deflection	0.000032	0.000015

Table3: Comparison between Conventional Calculations & Genetic Algorithm Results for C-45 material.

The above table shows the comparison between the conventional and the genetic algorithm calculations for the C-45 material.

From results and graphs it is concluded that the gear parameters obtained from genetic algorithm gives more optimal than the traditional gear design approach.

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