APPLICATION OF GENETIC ALGORITHM TO OPTIMIZE WORM GEAR DESIGN FOR MINIMUM CENTRE DISTANCE

Hiren V. Patel, Maniya K. D.

Abstract— A gear transmission problem is one of the most complex optimization problems because of relationship between different variables. A gear design require the designer to compromise many design variables; i.e. continuous, discrete & integer variables in order to determine best performance of gear set. Numbers of conventional methods are available for solving different types of optimization problems. But due to their complexity and convergence problem these methods are not able to give optimal solution. Therefore researchers are now going to use evolutionary techniques. Genetic Algorithm is one of such technique. A non-conventional algorithm namely Genetic Algorithm is presented for optimization of worm gear mechanism with respect to specified set of constraints. The Genetic Algorithm is an efficient search method which is inspired from Darw in's concept of selection process to explore a given search space.

Keywords — Worm Gear Optimization, Genetic Algorithm

1 INTRODUCTION

Worm and worm wheel drive are widely used for non-parallel, non-intersecting, right angled gear drive system. Due to its large reduction ratio, it's used for low to medium speed reducer in many engineering application. The worm gear design optimization is very complex in nature since the consideration of multiple objective and number of design variables. Therefore more consistent and efficient optimization technique will be considered to obtain better result. In this paper, a problem consists of minimizing of a centre distance of worm gear; it is taken as the objective function under various design constraints. Moreover, increasing demand for compact, efficient, and reliable gears forces the designer to use optimal design methodology.

Till now, many numerical optimization techniques have been developed and used to optimize engineering problems. Solving engineering problem can be complex and time consuming as it has very large number of design variables and constraints. If the optimization problem involves the objective function and constraints that are not stated as explicit functions of the design variables or which are too complicated to manipulate, it is hard to solve by classical optimization methods. Therefore, some optimization methods such as Genetic Algorithm (GA) have been developed to solve complex optimization problems recently [1].

Yokata et al (1998) evaluated minimum weight of a spur gear train using genetic algorithm [2]. Kalyanmoy and Jain (2003) motivated many researchers in gear optimization, have proposed a non-sorted Genetic Algorithm II for optimizing multi speed gear box which consider multi objective such as maximizing power and minimizing the total volume of gear [3]. Maniya and Vakhariya (2004) carried out minimum center distance of worm gear as their objective function and used penalty function method to solve it [4]. Mendi et al (2010) optimized volume of gear box. The gear volume obtained by GA was 1.47% lower than the gear volume obtained by analytical method [5]. Yaman et al applied GA to optimize worm gear design for minimum power loss [6].

- *Hiren V. Patel is currently pursuing master degree in mechanical engineering in C.K.Pithawalla College of Engineering and Technology, India, PH-08905765066. E-mail: hiren43patel@gmail.com*
- *Maniya K.D. is currently Assistant Professor in mechanical engineering department in C.K.Pithawalla College of Engineering and Technology, India,*

2 OBJECTIVES

Minimum centre distance is taken as the objective function for worm gear under given power transmission and gear ratio.

Also it is subjected to following constraints,

g(1) = Velocity ratio is constant.
g(2) = Bending stress ≤ Permissible bending stress.
g(3) = Check for Hertzain stress, Compressive stress ≤ Permissible compressive stress.
g(4) = Check for heat dissipation (Calculated power ≥ Given power).
g(5) = Wear load ≥ Dynamic load.
g(6) = Minimum number of teeth.
g(7) = Checking the deflection worm gear for rigidity (Deflection ≤ 0.01module).

Here objective function and constraints are converted in to design variables.

3 PROBLEM STATEMENT FOR WORM GEAR OPTIMIZATION

3.1 Design Problem

A worm gear drive to transmit 10 kW at a worm speed of 1440 rpm transmission ratio is 24.

3.2 Objective Function

Minimize the centre distance

$$a = \left\{1 + \frac{d_2/m}{q}\right\}\left[\left[\left\{\frac{0.477}{\frac{d_2/m}{q}[\sigma_c]}\right\}^2 E[M_t]\right]\right]^{1/3} \quad (1)$$

3.3 Design Constraints

Subjected to constraints,

$$g_1 = i = 24 \tag{2}$$

$$g_2 = [\sigma_b] \geq \frac{6.08\times10^6 \times P_{kw}}{mbyN_2 d_2}\left(\frac{k_s}{k_v}\right) \tag{3}$$

$$g_3 = \sigma_c = \left(\frac{d_2/m+q}{q\times a}\right)^{1.5}\left\{\frac{0.477q}{d_2/m}\right\}\sqrt{E[M_t]} \leq [\sigma_c] \tag{4}$$

$$g_4 = \frac{0.02899a^{1.7}}{i+5} \geq P_{kw} \tag{5}$$

$$g_5 = d_2 bk_w \geq \left(\frac{6+V_2}{6}\right)\frac{2M_t}{d_2} \tag{6}$$

$$g_6 = \frac{d_2}{m}\left(\frac{1}{i}+1\right) - 40 \geq 0 \tag{7}$$

$$g_7 = \delta = \frac{\left[(11m+0.06d_2)\right]^3\sqrt{(F_t\tan\gamma)^2+(F_t\tan\alpha)^2}}{48E\dfrac{\pi[qm-2.4m]^2}{64}} \leq [0.01m] \tag{8}$$

$$g_8 = m > 0 \tag{9}$$

$$g_9 = d_2 > 0 \tag{10}$$

4 Simplified Objective Function

The objective function and design constraints are converted in the form of axial module (m) and diameter of worm wheel (d2) with various input parameters as shown in Table: 1.

TABLE 1

INPUT PARAMETERS

Parameters	Values for Worm Gear drive
Power Transmitted (P_{Kw})	10
Transmission Ratio (i)	24
Input Speed (N_1)	1440
Normal Pressure Angle of worm wheel (ϕ_n)	20^0
Worm material	C-45
Worm wheel material	Bronze(sand)
Initially value of form factor (q)	11

Minimize $f(x) = 65.09\ (11+d_2/m)\ (m/d_2)^{0.666}$ (11)

Subjected to,

$$g_1(X) = \frac{d_2}{m} - 48 = 0 \tag{12}$$

$$g_2(X) = \frac{164165.04}{m^2 d_2}(6+0.1508m) - 78 \leq 0 \tag{13}$$

$$g_3(X) = 6081.62\frac{m}{d_2} - 159 \leq 0 \tag{14}$$

$$g_4(X) = 32501.46 - (d_2+11m)^{1.7} \leq 0 \tag{15}$$

$$g_5(X) = 16289.11(6+0.1508m) - 8.25m^2 d_2 \leq 0 \tag{16}$$

$$g_6(X) = 40 - 1.041\frac{d_2}{m} \leq 0 \tag{17}$$

$$g_7(X) = \frac{3.14(11m+0.06d_2)^3}{5400.45 d_2 m^4} - 0.01m \leq 0 \tag{18}$$

$$g_8 = m > 0 \tag{19}$$

$$g_9 = d_2 > 0 \tag{20}$$

5 Genetic Algorithm

Genetic algorithms are based on the strategy of model development based on genetic evolution mechanisms based on Darwinian Theory for selection process to explore a given search space.

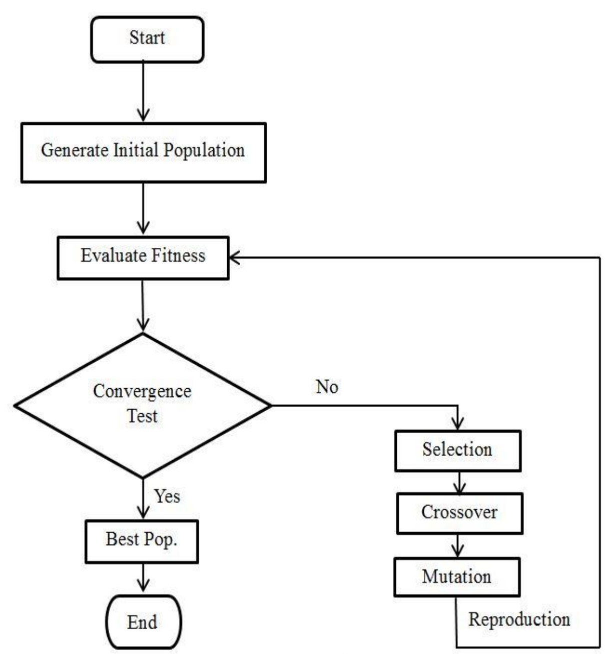

Fig. 1 Flowchart of GA

The algorithm is provided with a set of possible solutions (represented by chromosomes) termed a population. Solutions from one population are taken and used to form a new population. This is motivated by a hope that the new population will perform better than its predecessors. Solutions chosen to form new solutions (offsprings) are selected based on their fitness – the more suitable they are, the better their chances of being reproduced. This process of selection is repeated till some predetermined condition based on, for instance, the number of populations or improvement of the best solution, is satisfied [7]. Procedure for solving the discrete optimization problem mentioned using GA is illustrated in Figure 1.

5.1 Genetic Operators

The genetic algorithm requires the design variables of the optimization problem to be coded. Binary coding, as a finite length strings, is generally used although other coding schemes have been used. These strings are represented as chromosomes. Every design variable has its specified range $X_L < X < X_U$. The continues design variable can be represented as ε. The number of the digits in the binary strings, l, is estimated from the Eq. (21) [8].

$$2^l \geq \left(\frac{X_U - X_L}{\varepsilon} \right) + 1 \tag{21}$$

Where, X_L and X_U are the upper and lower bound for design variables, respectively. The design variables are coded into the binary digit {0,1}. The physical value of the design variables can be computed from the Eq. (22).

$$\left(\frac{X_U - X_L}{(2^l - 1)} \right) d + X_L \tag{22}$$

In order to find out population size, Eq. (14) is suggested. l represented the chromosome length in the Eq. (23).

$$Population\ Size = 1.65 * 2^{0.21*l} \tag{23}$$

Selection is the first genetic operator. Fitness function is evaluated for each individual in the population and at least two individuals with low fitness function are selected to form next generation. Crossover is the second genetic operator that allows producing offspring by recombining the chromosomes of two individuals (Table 3). Mutation is the third genetic operator allowing creating a new individual by changing 0 to 1 or changing 1 to 0. Each bit of each individual is possible subject to mutation.

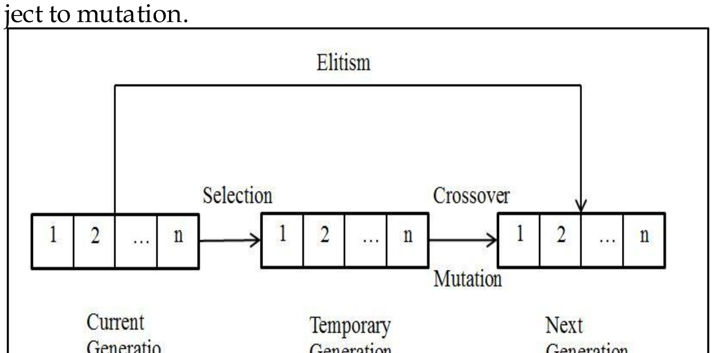

Fig. 2 Genetic Algorithm Operators

TABLE 2
Design Variables

Design Variables			
Symbol	Specification	Interval	Precision
d_2	Diameter of Worm wheel (mm)	$200 \leq d_2 \leq 600$	1
m	Module (mm)	$4 \leq m \leq 9$	0.1

TABLE 3
Crossover For Binary Represented Design Variables

Crossover	
Parent 1	110010**00** **00000100**
Parent 2	11101011 00101010
offspring 1	1100101100101010
offspring 2	111010**0000000100**

TABLE 4
Mutation

Mutation	
Individual gene before mutation	11001011**0**0101010
New individual gene after mutation	11001011**1**0101010

6. Results and Discussion

MATLAB program is developed to solve above problem using optimization methods which discussed in the above topics and following results are carried out.

On the center distance according that variable center distance is changed so it is necessary to find out pairs of module and diameter which satisfy all constraints and according to that worm gear design has been done.

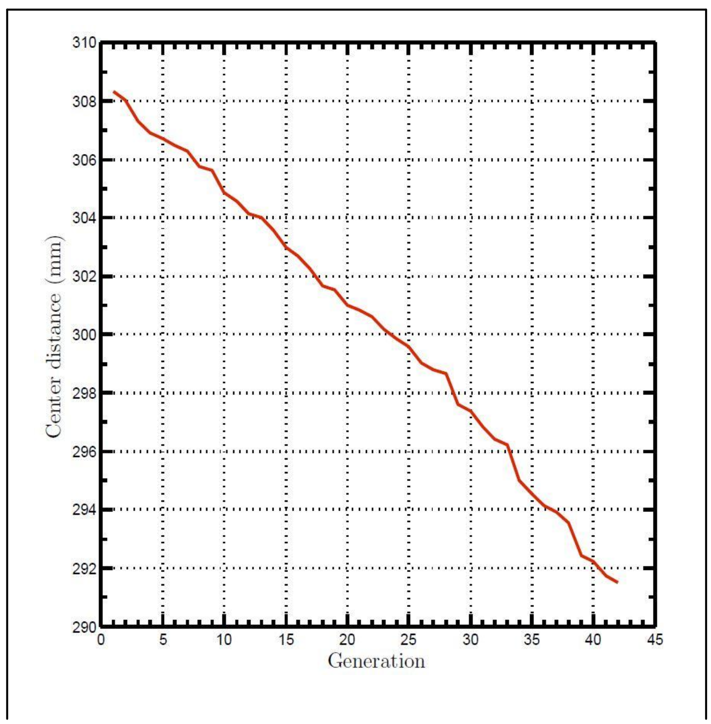

Fig. 3 Generation v/s Center Distance

The comparison values of design variables, constraints and objective function are done which is obtained using penalty function method by Maniya and Vakhariya [4].

TABLE 5
Results Comparision

Parameters	Penalty Function Method	Genetic Algorithm	% change
Face Width (mm)	58	74	27.58
Pitch circle diameter of worm (mm)	77	99	28.57
Pitch circle diameter of worm wheel (mm)	336	432	-22.22
Centre distance b/w worm and worm wheel(mm)	296	291	-1.68
Deflection of worm (mm)	0.000661	0.000399	-39.63
Bending stress (N/mm^2)	70.35	34.51	-50.94
Compressive stress (N/mm^2)	126.70	126.70	0.00

7. Conclusion

In this study the attempt has been made to optimize the worm and worm wheel with multiple objectives such as minimizes centre distance, deflection of worm, bending stress. There is 1.68% reduction in centre distance, 50.94% reduction in bending stress and 39.63% reduction in deflection of worm have been observed compared to penalty function method.

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Nomenclature

Symbol	Particular	unit
a	Center distance	mm
m	Module	mm
d_1	Diameter of worm	mm
d_2	Diameter of worm gear	mm
b	Face width	mm
L	Length of worm	mm
Z_1	No. of starts on worm	
Z_2	No. of teeth on worm wheel	
i	Gear ratio	
q	Diameter factor	
N_1	Speed of worm	rpm
N_2	Speed of worm wheel	rpm
V_s	Sliding velocity	m/s
V_1	Pitch line velocity of worm	m/s
V_2	Pitch line velocity of worm wheel	m/s
α	Pressure angle	degree
γ	Lead angle	degree
P_{kw}	Power transmitted	Kw
M_t	Normal torque transmitted by worm wheel	N-mm
$[M_t]$	Design torque transmitted by worm wheel	N-mm
$[\sigma_c]$	Design surface stress	N/mm^2
$[\sigma_b]$	Design bending stress	N/mm^2
E	Equivalent young’s modulus	N/mm^2
F_t	Tangential load	N
F_r	Radial load	N
F_a	Axial load	N
F_d	Dynamic load	N
F_w	Wear load	N
K	Load concentration factor	
k_d	Dynamic load factor	
k_s	Service factor	
k_v	Velocity factor	
k_w	Wear load stress factor	
y	Lewis form factor	