International Journal of Mechanical Engineering and Technology (IJMET)
Volume 9, Issue 8, August 2018, pp. 339–349, Article ID: IJMET_09_08_036
Available online at http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=9&IType=8
ISSN Print: 0976-6340 and ISSN Online: 0976-6359

DESIGN OPTIMIZATION OF WEIGHT OF SPEED REDUCER PROBLEM THROUGH MATLAB AND SIMULATION USING ANSYS

S. ElizabethAmudhini Stephen
Associate Professor, Department of Mathematics Karunya University, Coimbatore

Christu Nesam David. D
Scholar, Karunya University

GirishDalvi
Assistant professor, F.C.R.I.T, Vashi

ABSTRACT

The objective functions used in Engineering Optimization are complex in nature with many variables and constraints. Conventional optimization tools sometimes fail to give global optima point. Very popular methods like Genetic Algorithm, Pattern Search, Simulated Annealing, and Gradient Search are useful methods to find global optima related to engineering problems. This paper attempts to use new non-traditional optimization algorithms which are used to find the minimum weight of designing a speed reducer to obtain global optimum solutions. The weight, number of iterations and the total elapsed time to complete the problems are all compared using these ten non-traditional optimization methods.

Keywords: Pattern search , Simulate annealing, Pattern search, GODLIKE, Cuckoo search, Firefly algorithm, Flower pollination, Ant lion optimizer, Gravitational search algorithm, Multi-verse optimizer

Cite this Article: S. Elizabeth Amudhini Stephen, Christu Nesam David. D and GirishDalvi, Design Optimization of Weight of Speed Reducer problem through MatLab and Simulation using ANSYS, International Journal of Mechanical Engineering and Technology, 9(8), 2018, pp. 339–349.
http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=9&IType=8

1. INTRODUCTION

The toothed are used as independent units to reduce or increase the speed and they are enclosed in rigid closed housings. The housings provide support for the shafts, hold lubricants inside, protect the gears from dust and moisture and give necessary cooling surface to dissipate the heat generated. When the unit is used as a speed reducing device, it is called speed reducer. Speed reducers are widely used for reduction of speed in turbine generator set, from motor to machine tools, in rolling mills from engine to road wheels in automobiles etc.

Nomenclature

b - Face width of gear

m - Teeth module

z - Number of pining teeth

l_1 - Length of shaft 1 between bearing

l_2 - Length of shaft 2 between bearing

d_1 - Diameter of shaft 1

d_2 - Diameter of shaft 2

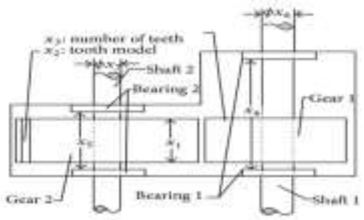

Figure 1 Schematic of the speed reducer to be designed **Figure 2** Speed reducer

2.1. FORMULATION OF PROBLEM

The design of the speed reducer is considered with the face width (b) , module of teeth (m), number of teeth on pining (z), length of shaft 1 between bearings (l_1) , length of the shaft 2 between bearings (l_2), diameter of the shaft 1 (d_1), diameter of shaft 2 (d_2) respectively. The constraints include limitations on the bending stress of gear teeth, surface stress, transverse deflections of shaft 1 and 2 due to transmitted force, and stresses in shafts 1 and 2. The objective is to minimize the total weight of the speed reducer. The weight of the speed reducer includes both the weight of the gears as well as the weight of the shafts.

2.2. CONSTANTS: (Golinski's Speed Reducer)

		C_1	0.7854
		C_2	3.3333
		C_3	14.9334
		C_4	43.0934
		C_5	1.508
		C_6	7.4777
		C_7	27
		C_8	397.5
		C_9	1.93
		C_{10}	745
		C_{11}	$16.9*10^6$
		C_{12}	0.1

		C_{13}	1100
		C_{14}	$157.5*10^6$
		C_{15}	850
		C_{16}	40
		C_{17}	5
		C_{18}	12
		C_{19}	1.5
		C_{20}	1.9
		C_{21}	1.1

2.3. DESIGN VARIABLES (Leticia C.Cagnina and Susana C. Esquivel, 2008)

The seven design variables of the problem are as follows

b - Face width of gear (x_1)

m - Teeth module (x_2)

z - Number of pining teeth (x_3)

l_1 - Length of shaft 1 between bearing (x_4)

l_2 - Length of shaft 2 between bearing (x_5)

d_1 - Diameter of shaft 1 (x_6)

d_2 - Diameter of shaft 2 (x_7)

Optimization problem is defined as (Parashar.S., 2004) (AL-Oraby et.al.H., 2014)

Minimise $F(\text{Gear box weight})$ Subject to

g_1 $(\text{bending stress of gear tooth}) \le 0.0$

g_2 $(\text{contact stress of gear tooth}) \le 0.0$

$g_{3,}, g_4$ $(\text{transverse deflection of shafts } 1,2) \le 0.0$ $g_{5,}, g_6$ $(\text{stresses in shafts } 1,2) \le 0.0$

$g_{7-}\, g_9$ $(\text{dimensional restrictions})$

g_{10}, g_{11} $(\text{dimension requirements on the shafts})$

2.4. CONSTRAINTS

Upper bound on the bending stress of the gear tooth (Constraint 1)

$$\frac{C_7}{b m^2 z} \le 1 \qquad \frac{27}{b m^2 z} \le 1$$

1

Upper bound on the contact stress of the gear tooth (Constraint 2)

$$\frac{C_8}{b m^2 z^2} \le 1 \quad \frac{397.5}{b m^2 z^2} \le 1 \qquad (2)$$

Upper bounds on the transverse deflection of shaft 1
(Constraint 3)

$$\frac{C_9\, l_1^3}{m\, z\, d_1^4} \le 1 \quad \frac{1.93\, l_1^3}{m\, z\, d_1^4} \le 1 \qquad (3)$$

Upper bounds on the transverse deflection of shaft 2 (Constraint 4)

$$\frac{C_9\, l_2^3}{m\, z\, d_2^4} \le 1 \quad \frac{1.93\, l_2^3}{m\, z\, d_2^4} \le 1 \qquad (4)$$

Constraint on stress in the gear shaft 1 (Constraint 5)

$$\frac{\sqrt{\left(\frac{745\ l_1}{m\ z}\right)^2 + 16.9 \times 10^6}}{0.1\ d_1^3} \le 1100 \qquad (5)$$

Constraint on stress in the gear shaft 2 (Constraint 6)

$$\frac{\sqrt{\left(\frac{745\ l_1}{m\ z}\right)^2 + 157.5 \times 10^6}}{0.1\ d_1^3} \le 850 \qquad (6)$$

Dimensional restrictions based on space and experience (Constraints: 7 – 9)

$$\frac{m\ z}{C_{16}} \le 1 \quad \frac{m\ z}{40} \le 1 \qquad (7)$$

$$\frac{C_{17}\ m}{b} \le 1 \quad \frac{5\ m}{b} \le 1 \qquad (8)$$

$$\frac{b}{C_{18}\ m} \le 1 \quad \frac{b}{12\ m} \le 1 \qquad (9)$$

Design requirements on the shafts based on experience (Constraints - 10, 11)

$$C_{19}\ d_1 + C_{20} \le l_1 \quad 1.5\ d_1 + 1.9 \le l_1 \qquad (10)$$

$$C_{21}\ d_2 + C_{20} \le l_2 \quad 1.1\ d_2 + 1.9 \le l_2 \qquad (11)$$

2.5. Variables bounds

The upper bounds and lower bounds of design variables are

$$2.6 \le b \le 3.6 \,;\ 0.7 \le m \le 0.8 \,;\ 17 \le z \le 28 \,;\ 7.3 \le l_1 \le 8.3 \,;\ 7.3 \le l_2 \le 8.3 \,;$$
$$2.9 \le d_1 \le 3.9 \,;\ 5.0 \le d_2 \le 5.5$$

	b - Face width of gear x1		**m - Teeth module x2**		**z - Number of pining teeth x3**		**L1 - Length of shaft 1 between bearings x4**		**L2 - Length of shaft 2 between bearings**		**D1 - Diameter of shaft 1 x6**		**D2 - Diameter of shaft 2 x7**	
	Cm	mm	cm	mm	cm	mm	cm	mm	cm	mm	cm	mm	cm	mm
Upper Bound	3.6	36	0.8	8	28	280	8.3	83	8.3	83	3.9	39	5.5	55
Lower Bound	2.6	26	0.9	9	17	170	7.3	73	7.3	73	2.9	29	5	50
Optimum	3.500101	35	0.700008	7	17.00002	170	7.51772	75.1772	7.783269	77.8326	3.35084	33.5084	5.28679	52.8679

2.6. Mathematical formulation: (Afondo C.C.Lemonge,Helio I.C.barbosa Carlos C.H.Borges, Francilene B.S.Silva, 2010)

$$F(b,m,z,l_1,l_2,d_1,d_2) = C_1\, b\, m^2\left(C_2 z^2 + C_3 z - C_4\right) - C_5\left(d_1^2 + d_2^2\right) + C_6\left(d_1^3 + d_2^3\right) + C_1\left(l_1 d_1^2 + l_2 d_2^2\right)$$

$$F(objective) = C_1\, x_1 x_2^2\left(C_2 x_3^2 + C_3\, x_3 - C_4\right) - C_5\left(x_6^2 + x_7^2\right) + C_6\left(x_6^3 + x_7^3\right) + C_1\left(x_4 x_6^2 + x_5 x_7^2\right)$$

$$F(objective) = 0.7854\, x_1 x_2^2\left(3.3333 x_3^2 + 14.9334 x_3 - 43.0934\right) - 1.508\left(x_6^2 + x_7^2\right) + 7.4777\left(x_6^3 + x_7^3\right) + 0.7854\left(x_4 x_6^2 + x_5 x_7^2\right)$$

Mathematical formulation:(Afondo C.C.Lemonge,Helio I.C.barbosa Carlos C.H.Borges, Francilene B.S.Silva, 2010)

The mathematical formulation of the objective function $f(X)$ is to minimize the weight of the speed reducer subject to the constraints of the gear teeth, surface stress, transverse deflections of the shafts and stresses in the shaft. The objective is to minimize the weight of the speed reducer design problem. The problem is:

Minimize:

$$f(X) = 0.7854\, x_1 x_2^2\left(3.3333 x_3^2 + 14.9334 x_3 - 43.0934\right) - 1.508\left(x_6^2 + x_7^2\right) + 7.4777\left(x_6^3 + x_7^3\right) + 0.7854\left(x_4 x_6^2 + x_5 x_7^2\right)$$

subject to

$$\frac{27}{x_1 x_2^2 x_3} \le 1$$

$$\frac{397.5}{x_1 x_2^2 x_3^2} \leq 1$$

$$\frac{1.93\, x_4^3}{x_2\, x_3\, x_6^4} \leq 1$$

$$\frac{1.93\, x_5^3}{x_2 x_3 x_7^4} \leq 1$$

$$\frac{1}{110\, x_6^3} \sqrt{\left(\frac{745.0 x_4}{x_2\, x_3}\right)^2 + 16.9 \times 10^6} \leq 1$$

$$\frac{1}{85\, x_7^3} \sqrt{\left(\frac{745.0 x_5}{x_2\, x_3}\right)^2 + 157.5 \times 10^6} \leq 1$$

$$\frac{x_2\, x_3}{40} \leq 1$$

$$\frac{x_2\, x_3}{40} \leq 1$$

$$\frac{5\ x_2}{x_1} \leq 1$$

$$\frac{x_1}{12\ x_2} \leq 1$$

$$\frac{1.5 x_6 + 1.9}{x_4} \leq 1$$

$$\frac{1.1 x_7 + 1.9}{x_5} \leq 1$$

Explicit bounds on design variable

$2.6 \leq x_1 \leq 3.6$; $0.7 \leq x_2 \leq 0.8$; $17 \leq x_3 \leq 28$; $7.3 \leq x_4 \leq 8.3$; $7.3 \leq x_5 \leq 8.3$;
$2.9 \leq x_6 \leq 3.9$; $5.0 \leq x_7 \leq 5.5$

3. COMPARATIVE RESULTS

The ten methods are run 20 trails and the average is taken and the results were compared.

Face width of gear (x_1)

Teeth module (x_2)

Number of pining teeth (x_3)

Length of shaft 1 between bearings (x_4)

Length of shaft 2 between bearings (x_5)

Diameter of shaft 1 (x_6)

Diameter of shaft 2 (x_7)

Comparative Results

Trial	**PSO**	**SA**	**PS**	**GL**	**Cuckoo**	**FF**	**FP**	**ALO**	**GSA**	**MVO**
X_1	3.500101	3.500291	3.5	3.508781	3.500017	3.50001	3.500004	3.5	3.559327	3.521317
X_2	0.700008	0.7	0.7	0.700511	0.7	0.7	0.7	0.7	0.706531	0.7
X_3	17.00002	17.38547	18.17172	17.01117	17	17	17	17	19.44552	17
X_4	7.51772	7.839092	7.3	7.712554	7.3	7.794979	7.300051	7.698099	7.904567	7.530287
X_5	7.783269	7.975486	7.715146	7.933927	7.715927	8.024645	7.715378	7.917097	8.024617	8.017789
X_6	3.350842	3.357579	3.349371	3.355449	3.350315	3.355642	3.350218	3.350991	3.566817	3.454274
X_7	5.286797	5.286776	5.286492	5.290331	5.286692	5.286774	5.286657	5.286724	5.350509	5.287023
Weight	3145.922	3223.153	3350.404	3162.799	3142.226	3154.947	3142.159	3150.358	3799.345	3191.186
Time	0.817205	30.84923	0.879797	10.39364	15.78775	8.008205	6.479024	62.66622	14.56511	6.759705
Iteration	200	20760	3	67106	100000	20000	2000	1000	1000	1000

4. RESULTS AND DISCUSSION

With the two extreme values of the parameters the optimization is carried out with different solvers. As they are stochastic type the results may vary from trial to trial. So the problem is made to run for 20 trials. (Elbeltagi.E., Tarek Hegazy.I., Grierson D., 2005)Andan average of all trials is taken as a final value of the parameter by the solver. The solvers are compared with three different criteria.

4.1. Consistency

The weight is consistent in Pattern Search (3350.404)

4.2. Minimum run time

For minimum run time of the problem we have PS (0.879797 seconds), PSO (0.817205 seconds).

4.3. Minimum Evaluation

This Criterion will determine the effectiveness of the algorithm. From the table we see that the PS and PSO algorithm have minimum evaluation of 3 and 200 respectively.

4.4. The Simplicity of Algorithm

Of all the algorithms, Pattern Search algorithm is the most simplest followed by Particle Swarm Optimization.

Thus it is seen that the PS solver satisfies all the criteria. Even though the pattern search satisfies all the above criteria, the weight becomes maximum whereas the weight in PSO is 3145.922. Therefore the particle swarm optimization has the minimum weight with time 0.817205 seconds and 200 iteration so the appropriate algorithm for speed reducer design is suggested as Particle Swarm Optimization. It is apparent from the results that PSO algorithm is able to provide promising solutions with less objective function evaluations. This desirable characteristic of PSO algorithm would be more significant in one engineering problems which entail higher computational effort.

5. SIMULATION FOR VALIDATING OPTIMIZED RESULTS

Minimizing the mass of the speed reducer (gear) design is tested practically using simulation. Simulation was carried out using Ansys software. The gear is designed in Autodesk inventor 2017 using gear design module. Then the file is converted into IGS format and imported into Ansys.

5.1. Speed Reducer Design Optimization

Stress constrain is the practical constrain that is checked against simulation. The constrains are tested for each geometry namely lower bound geometry, upper bound geometry and optimum geometry from particle swarm optimization algorithm by simulation as it gives the most optimum mass.

Following Constrains applied in all three cases

Contact constraint: no separation between both gears

Frictionless support is given to both gears at the inner surfaces of hole

A moment of 50N.m is given to smaller gear. While applying moment both surfaces are selected (front and back)

Results are obtained for Von mises stress

Bodies	2
Active Bodies	2
Nodes	292081
Elements	63864
Mesh Metric	None

Constants

Density	7850 kg m^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	434 J kg^-1 C^-1
Thermal Conductivity	60.5 W m^-1 C^-1
Resistivity	1.7e-007 ohm m

Colour

Red	**Green**	**Blue**
132	139	179

5.1.1. Results of Lower bound geometry

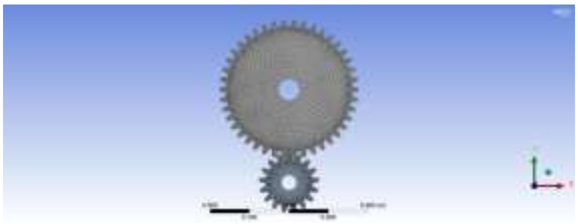

Figure 3 Mesh generation of the gear (lower bound)

The mesh is generated for lower bound geometry. The meshed model for lower bound geometry is shown in Figure.5.23 from the figure it is evident that the mesh flow is progressive without any discontinuity.

Figure 4 Stress developed in the gear (lower Bound)

Table Equivalent Stress

Time [s]	Minimum [Pa]	Maximum [Pa]
1.	0.53458	1.5267e+007

The stress developed in the gear for the lower bound geometry is shown in Figure.5.24. Stress developed in the gear is 1.5267*10^7 psi.

5.1.2. Results of Upper bound geometry

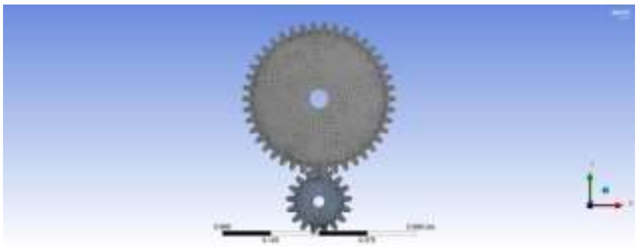

Figure 5 Mesh generation of the gear(upper bound)

The mesh is generated for upper bound geometry. The meshed model for upper bound geometry is shown in Figure.5.25 From the figure it is evident that the mesh flow is progressive without any discontinuity.

Figure 6 Stress developed in the gear(upper Bound)

Table Equivalent Stress

Time [s]	Minimum [Pa]	Maximum [Pa]
1.	0.48253	1.9402e+007

The stress developed in the gear for the upper bound geometry is shown in Figure.5.26. Stress developed in the gear is $1.9402*10^7$ psi

5.1.3. Results of Optimum geometry

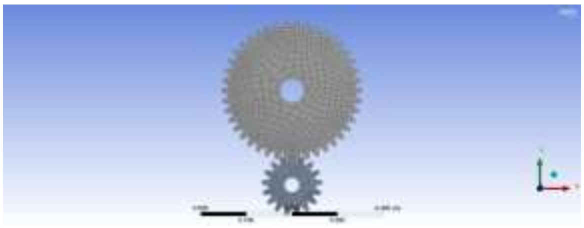

Figure 7 Mesh generation of the gear(optimum)

The mesh is generated for optimum geometry. The meshed model for optimum geometry is shown in Figure.5.27. From the figure it is evident that the mesh flow is progressive without any discontinuity

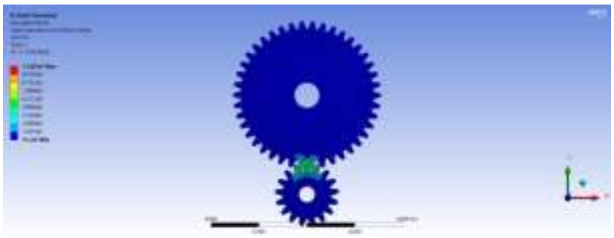

Figure 8 Stress developed in the gear(optimum)

Table Equivalent Stress

Time [s]	Minimum [Pa]	Maximum [Pa]
1.	11.223	1.1227e+007

The stress developed in the gear for the optimum geometry is shown in Figure.5.28. Stress developed in the gear is $1.1227*10^7$ psi.

5.2. Conclusion from simulation

From the above three geometry we can observe that the optimum result derived from non-traditional optimization algorithm (Particle Swarm Optimization) is validated using simulations. The stress developed in the gear is minimum for optimum geometry which is derived from Particle swarm optimization. So for speed reducer design problem we can use Particle Swarm Design solver will give practical relevant result.

6. CONCLUSION

We have formulated the Speed reducer design problem with two shafts. The objective is to minimize the total weight of the speed reducer. The weight of the speed reducer includes both the weight of the gears as well as the weight of the shafts.

We have used MATLAB to solve the Speed Reducer design problem. Ten non-traditional optimization methods were used to solve the weight model of the Speed Reducer and concluded that the Particle Swarm Optimization method gives the minimum weight even though the Pattern Search gives minimum evaluation.

To validate the results, simulation of the design was carried out using ANSYS software package. Stresses developed between both shafts were calculated for lower bound geometry, upper bound geometry and optimal boundary. The stress developed in the gear for the lower bound geometry is $1.5267*10^7$ psi. The stress developed in the gear for the upper bound geometry is $1.9402*10^7$ psi. The stress developed in the gear for the optimum geometry is the $1.1227*10^7$ psi which is minimum.

From the above we can observe that the optimum result derived from the non- traditional optimization algorithm Particle Swarm Optimization is validated using simulation. Hence we can use Particle Swarm Optimization for a design related problem to get a practically relevant result and one of the best in time of computation and similarity of the algorithm.

In the present study the PSO algorithm is proposed as a simple and efficient optimization technique for handling speed reducer design problem. PSO algorithm is a population based technique which follows a stochastic iterative procedure to locate the optimum or a reasonably near- optimum solution for the speed reducer design optimization. Performance evaluation of the PSO algorithm through speed reducer design optimization reveals the efficiency of this technique in solving practical optimization problems. Although in the present study the PSO algorithm is utilized only for solving speed reducer design optimization problem, it can be easily employed for solving other types of optimization problems as well.

REFERNCES

[1] Afondo C.C.Lemonge,Helio I.C.barbosa Carlos C.H.Borges, Francilene B.S.Silva. (2010). Constrained Optimization Problems in Mechanical Engineering Design using a Real-Coded Steady-State Genetic Algorithm. Mechanical Computation, 29, 9287-9303.

[2] AL-Oraby et.al.H. (2014, January). Journal of Global Research in Mathematical Archives. 2(1), 1-10.

[3] Elbeltagi.E., Tarek Hegazy.I., Grierson D. (2005). Comparision among Five Evolutionary-based Optimization Algorithms. Advanced Engineering Informatica, 19, 43-53.

[4] Golinski's Speed Reducer. (n.d.). httmp://www.eng.buffalo,edu/Research/MODEL/mdo.test.orig/class2prob/descry.htm.

[5] Leticia C.Cagnina and Susana C. Esquivel. (2008). So lving Engineering Problems with the Simple Constrained Particle Swarm Optimizer. Informtica 32, 319-326.

[6] Parashar.S. (2004). Decision Support Tool for Multidisciplinary Design Optimization using Multi-Domain Decomposition. Master of Science Thesis, 29-34.

[7] A. A. Bamfo-Asante, Isaac Nkrumah, Mark Paal and K. Singh, Effect of Deposition and Annealing Temperatures on Optical Band Gap of Sno2 Thin Films Deposited on Glass Substrate by Chemical Vapour Deposition (Cvd) Method

[8] Youssef Nagem Amhamad and Jyoti Shrivastava, Application of Modified (PSO) and Simulated Annealing Algorithm (SAA) In Economic Load Dispatch Problem of Thermal Generating Unit. International Journal of Electrical Engineering & Technology, 7(2), 2016, pp. 69–78.

[9] V. Radhakrishna, C. Srinivas and Dr. C. V. GuruRao, High Performance Pattern Search Algorithm Using Three Sliding Windows, International Journal of Computer Engineering and Technology (IJCET), Volume 3, Issue 2, July- September (2012), pp. 543-552.