Optimization of mechanical design problems using advanced optimization technique

Jigar L. Patel, Parthiv B. Rana, D. I. Lalwani

Mechanical Engineering Department, SVNIT, Surat, Gujarat-395007.
Corresponding author: *jigu.mech1515@gmail.com*

Abstract. In design of mechanical elements, designers usually consider certain objectives that are related with cost, time, quality and reliability of product depending on the requirements. In this paper, parametric optimization of spring design problem and pressure vessel design problem has been carried out using Amended Differential Evolution Algorithm (ADEA). ADEA is modified DE that can handle constraint and complex problems effectively. In spring design problem, parameters are optimized to reduce volume of compress ion and in pressure vessel design problem, parameters are optimized to reduce total cost. The results obtained using ADEA are compared with the results reported by other researchers. The comparison of results shows that ADEA provides better results for both spring and pressure vessel design problems.

1. Introduction

For the competitive market, industries always look for solutions that reduces cost of a component without compromising quality and time to manufacture a component. One of the ways to reduce the cost of a component is improvement in design. Optimization of design problems consists of certain objective function, viable solution and optimization technique. The viable solutions are the set of all designs that are distinguished by all feasible values of the design parameters. Optimization methods search for the optimum design from all available viable solutions.

Asoptimization of mechanical assembly leads to a complex objective function with many design parameters, individual components or intermediate assemblies are optimized in practice. Appropriateselection of design parameters is necessary to reduce cost, improve productivity and quality, increase reliability, etc. For the complex real life problems, Evolutionary Optimization Techniques are preferred than Conventional Optimization Techniques (COTs) (Savsani and Savsani, 2014).

In this work, ADEA is used to optimize two design problems, namely, spring design that has three design parameters (two continuous and one integer) and eight constraints and pressure vessel design that has four design parameters and four constraints

2. Amende d differential evolution algorithm

Unconstraint problem can be solved by using DE algorithm. Rana and Lalwani (2017) made some modifications to improve the performance of Differential Evolution (DE) and added constrained handling technique to solve real life complex problems. The modified DE algorithm is named as ADEA. They made following modifications in DE (Rana and Lalwani, 2017):

1) Initialization of random population
2) Selection of scale factor (*F*) and crossover rate (*CR*) based on rank (*R*)
3) Selection of mutant vector
4) Condition for crossover vector.
5) Constraint handling technique

The detailed description of all modifications is available in Rana and Lalwani (2017).

3. Formulation of design problems

Two design problems viz., spring design problem and pressure vessel design problem are discussed below with objective function and constraints.

3.1. Spring design problem

Spring design problem involves integer and continuous design variables. The spring design problem, investigated by He et al., (2004), is taken to optimize design parameters. In this problem, material used for spring is music wire spring steel ASTM A228 and three design parameters, such as, the wire diameter (d), the mean coil diameter(D) and number of active coils (N) are optimized to minimize the volume of compression spring.

The problem with objective function and constraints is given below (He et al., 2004).

Minimize, $f(X) = \frac{\pi^2 x_2 x_1^2 (x_3+2)}{4}$

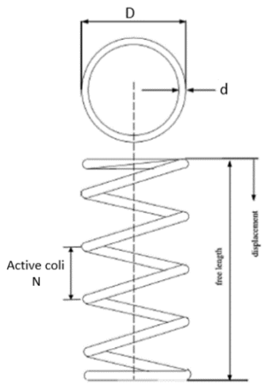

Figure 1: Spring design (He et al., 2004)

Subject to constraints:

$g_1(X) = \frac{8 C_f F_{max} x_2}{\pi x_1^3} - S \leq 0,\ g_2(X) = l_f - l_{max} \leq 0$

$g_3(X) = d_{min} - x_1 \leq 0,\ g_4(X) = x_2 - D_{max} \leq 0$

$g_5(X) = 3.0 - \frac{x_2}{x_1} \leq 0,\ g_6(X) = \sigma_p - \sigma_{pm} \leq 0$

$g_7(X) = \sigma_p + \frac{(F_{ma} - F_p)}{K} + 1.05(x_3 + 2)x_1 - l_f \leq 0$ and $g_8(X) = \sigma_w - \frac{(F_{ma} - F_p)}{K} \leq 0$

where,

$C_f = \frac{4(\frac{x_2}{x_1} - 1)}{4(\frac{x_2}{x_1} - 4)} + \frac{0.615 x_1}{x_2},\ K = \frac{G x_1^4}{8 x_3 x_2^3},\ \sigma_p = \frac{F_p}{K},\ l_f = \frac{F_{max}}{K} + 1.05(x_3 + 2)x_1$

Table 1 Design parameters and its ranges

Design parameters	**Range**
x_1	0.2-1
x_2	0.6-3
x_3	1.0 -70
Other parameters	
The maximum load (F_{max})	1000 lb.
The maximum free length l_{max}	14 in.
The minimum wire diameter d_{min}	0.2 in.
The allowable maximum shear stress (S)	$189000 .0\ psi$
The maximum outside diameter of the spring (D_{max})	3 in
The preload compression force (F_p)	$300\ lp$
The allowable maximum deflection under preload (σ_{pm})	$6\ in$
The deflection from preload to maximum load positon (σ_w)	$1.25\ in$
Shear modulus (G)	$11.5 \times 10^6\ psi$

3.2. Pressure vessel design problem

The pressure vessel design problem (Fig. 3) was investigated by He et al., (2004). In this problem, the material used for pressure vessel is carbon steel ASME SA 203 grade B andthe design parameters such as, the shell thickness (T_s), the thickness of the head $(T$)and the inner radius R are optimized to minimize the total cost.

The problem with objective function and constraints is given below (He et al., 2004).

Minimize, $X = 0.6224x_1x_3x_4 + 1.7781x_2x_3^2 + 3.1661x_1^2x_4 + 19.84x_1^2x_3$

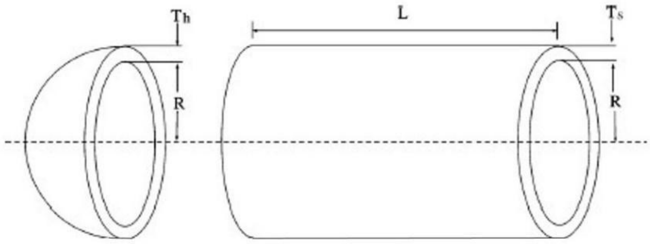

Figure 2 Pressure vessel design (He et al., 2004)

Subject to constraints:

$g_1 \quad = 0.0193x_3 - x_1 \leq 0,$ $g_2\, X = 0.00954x_3 - x_2 \leq 0,$

$g_3\ X = 1296000 - \pi x_3\ \ ^2x_4\ \ \frac{4}{3}\pi\ _3{}^2 \leq 0$and $g_4\ X = x_4\ \ - 240 \leq 0$

Table 2 Design parameters and its ranges

Design parameters	Range
x_1	0.0625-6.1875
x_2	0.0625-6.1875
x_3	10-200
x_4	10-200

4. Results and discussion

The above two problems are solved using ADEA with following parameters:
Population size (PS) = 25, number of iteration (G) = 1000, number of runs = 5, control parameters i.e., $F\ (0.5-0.8)$ and $CR\ (0.85-0.95)$. The results are reported by writing the program in MATLAB®.

4.1. Spring design problem

The spring design problem was optimized by many researchers, such as He et al. (2004), Sandgren (1990), Deb and Goyal (1997) and Lampinen and zelinka(1999) using different optimization techniques. Comparison of results obtained using ADEA with other researchers' work is shown in Table 3.

Table 3 Comparison of results obtained using ADEA with other researchers' work for spring design

Design Variables	ADEA	PSO He et al. (2004)	NLPA Sandgren (1990)	GA Deb (1997)	DE Lampinen (1999)
x1	0.29162	0.283	0.283	0.283	0.283
x2	1.38421	1.22304101	1.180701	1.226	1.22304101
x3	7	9	10	9	9
Constraints					
g1	-1.2584	-1008.8114	-54309	-713.51	-1008.8114
g2	-9.4584	-8.9456	-8.8187	-8.933	-8.9456
g3	-0.09162	-0.083	-0.08298	-0.083	-0.083
g4	-1.6158	-1.777	-1.8193	-1.491	-1.777
g5	-1.7466	-1.3217	-1.1723	-1.337	-1.3217
g6	-5.4643	-5.4643	-5.4643	-5.461	-5.4643
g7	0	0	0	0	0
g8	-4.2997E-5	0	0	-0.009	0
Objecti ve Function					
fx	2.6141	2.65856	2.7995	2.665	2.65856

* NLPA-Nonlinear programming algorithm, * PSO- Particle Swarm Optimization, *GA-Genetic Algorithm,
* DE-Differential Evolution

The comparison of results shows that ADEA gives the f(x) value as 2.6141 that is superiorto results reported by other researchers. ADEA provides 1.67% enhancement in the results compared with best value reported by Heet. al.(2004).

4.2. Pressure vessel design problem

The pressure vessel design problem was optimized by many researchers, such as Rao (2011), He et al., (2004), CoelloCoello (2001) and Deb (1997) using different optimization techniques. Comparison of results obtained using ADEA with other researchers' work is shown in Table 4.

Table 4 Comparison of results obtained using ADEA with other researchers' work for pressure vessel design

Design Variables	ADEA	TLBO Rao (2011)	PSO He et al. (2004)	GA Coello (2001)	GA Deb (1997)
x1	0.778168641	NA	0.8125	0.8125	0.9345
x2	0.384649163	NA	0.4375	0.4375	0.5
x3	40.31961872	NA	42.0984456	40.097398	48.329
x4	200	NA	176.6365	176.654047	112.679
Constraints					
g1	0	NA	0	-0.00002	-0.00475
g2	-5.55E-17	NA	-0.03588083	-0.035891	-0.038941
g3	0	NA	0	-27.886075	-3652.87684
g4	-40	NA	-63.36340416	-63.345953	-127.321

Objecti ve Function					
fx	5885.872354	6059.7143	6059.7143	6059.946341	6410.3811

*NA-Not Available, *TLBO-Teaching Learning Based Optimization, *GA-Genetic Algorithm

The comparison of results shows that ADEA gives the objective function f(x) value as 5885.872354 that is superiorto the results reported by other researchers. ADEA provides 2.87 %enhancement in the results compared with the best value reported by Rao (2011).

5. Conclusions

Optimization of spring design and pressure vessel design problems have been carried out using ADEA and the results obtained using ADEA are compared with the results reported by other researchers. The comparison of results shows that ADEA provides better results than the results reported by other researchers. In spring design problem, ADEA gives improvement of 1.67 % over PSO, in pressure vessel design problem, ADEA gives improvement of 2.87 % over TLBO.

References

[1] Coello Coello, C. A. and Mezura Montes, E., 2001. Use of dominance-based tournament selection to handle constraints in genetic algorithms. In: Intelligent Engineering Systems through Artificial Neural Networks (ANNIE'2001), Vol. 11, *ASME Press, St. Louis, Missouri, pp. 177–182.*

[2] Deb, K., 1997. Geneas: a robust optimal design technique for mechanical component design. In: *Evolutionary Algorithms in Engineering Applications,* Ed. D. Dasgupta and Z. Michalewicz, Springer-Verlag, pp. 497–514.

[3] He et al., 2004. An improved particle swarm optimizer for mechanical design optimization problems. *Engineering Optimization* 2004; 36(5):585–605.

[4] Lampinen, J. and Zelinka, I., 1999. Mixed integer-discrete-continuous optimization by differential evolution. In: *Proceedings of the 5th International Conference on Soft Computing*, pp. 71–76.

[5] Rana Parthiv B. and Lalwani D. I., 2017. Optimization of turning process using Amanded Differential Evolution Algorithm. *Engineering Science and Technology, an International Journal* 20: (2017) 1285-1301.

[6] Rao et al., 2011. Teaching learning based optimization: A novel method for constrained mechanical design optimization problems. *Computer-Aided Design* 43:303-315 (2011).

[7] Sandgren, E., 1990. Nonlinear integer and discrete programming in mechanical designoptimization. *Journal of Mechanical Design*, 112, 223–229.

[8] Savsani Poonam, R. Jhalab L., Savsani Vimal, 2014. Effect of hybridizing Biogeography- based Optimization (BBO) technique with Artificial Immune Algorithm (AIA) and Ant Colony Optimization (ACO*). Applied Soft Computing*: 21. 542–553.