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COST MINIMIZATION OF WELDED BEAM DESIGN PROBLEM USING PSO, SA, PS, GODLIKE, CUCKOO, FF, FP, ALO, GSA and MVO

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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 cost of designing welded beam to obtain global optimum solutions. The cost, number of iterations and the total elapsed time to complete the problems are all compared using these ten non-traditional optimization methods.

KEYWORDS: Welded Beam Design, Pattern Search, Simulate Annealing, Pattern Search, GODLIKE, Cuckoo Search, Firefly Algorithm, Flower Pollination, Ant Lion Optimizer, Gravitational Search Algorithm, Multi-Verse Optimizer

INTRODUCTION

Welding can be defined as a process of joining metallic parts by heating to a suitable temperature with or without the application of pressure. Welding is an economical and efficient method for obtaining a permanent joint of metallic parts. There are two distinct applications of welded joints.

- A welded joint can be used as a substitute for a riveted joint
- A welded structure can be used as an alternative method for casting or forging.

Welding process are broadly classified with the following two groups

- Welding process that use heat alone to join the two parts
- Welding process that use a combination of heat and pressure to join the two parts. (Bhandari.V.B)

The welding process that uses heat alone is called fusion welding process. In this method the parts to be joined are held in position and molten metal is supplied to the joint. The molten metal can come either from the parts themselves called Parent metal or external filler metal is supplied to the joint. The joining surface of two parts becomes plastic or even molten under the action of heat. When the joint solidifies, the two parts fuse into a single unit.

A beam is a member subjected to loads applied transverse to the long dimension, causing the member to bend. Beams are frequently classified on the basis of supports or reactions. A beam supported by pins, rollers or smooth surfaces at the ends is called simple beam. A beam support will develop a reaction normal to the beam but will not produce a moment at the reactions. If either or both ends of a beam projects beyond the supporters, it is called simple beam with overhang.

Description

A beam A is to be welded to a rigid member B. The welded beam is to consist of 1010 steel and is to support a force P of 6000 lb. The dimensions of the beam are to be selected so that the system cost is minimized. A schematic of the system is shown in the figure 1.

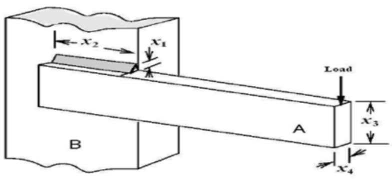


Figure 1: Welded Beam

The diagram illustrates a rigid member (A) welded onto a beam. A load is applied to the end of the member. The beam is to be optimized for minimum cost by varying the weld and member dimensions $X = (h, l, t, b) = (x_1, x_2, x_3, x_4)$.

This includes limits of the shear stress, bending stress, buckling load and end deflection. The variables x_1 and x_2 are integer multiples of 0.0625 inch, but for this application are assumed continuous. (Amie Mesari, 2012) (Hong-Shaung Li, Siu-Hui Au, 2010)

PARAMETERS:

(Welded Beam Design Optimization)

Young's Modulus (psi)

$$E = 30 \times 10^6 \ psi$$

Shearing modulus for the beam material (psi)

$$G = 12 \times 10^6 \ psi$$

Overhang length of the member (inch)

$$L = 14 \ in$$

Design stress of the weld (psi)

$$\tau_{\max} = 13600 \ psi$$

Design normal stress for the beam material (psi)

$$\sigma_{\max} = 30000 \ psi$$

Maximum deflection (inch)

$$\delta_{max} = 0.25\, in$$

Load (lb)

$$P = 6000\ lb$$

COST FUNCTION:

(Welded Beam Design Optimization)

The performance index appropriate to this design is the cost of a weld assembly. The major cost components of such an assembly are (1) set up labour cost, (2) welding labour cost, and (3) material cost:

$$f(X) = C_0 + C_1 + C_2$$

where $f(X)$ = cost function

C_0 = set up cost

C_1 = welding labor cost

C_2 = material cost

Setup Cost C_0

The company has chosen to make this component a weldment, because of the existence of a welding assembly line. Furthermore, assume that fixtures for setup and holding of the bar during welding are readily available. The cost C_0 can therefore be ignored in this particular total-cost model.

Welding Labour Cost C_1

Assume that the welding will be done by machine at a total cost of $10/hr (including operating and maintenance expense). Furthermore, suppose that the machine can lay down a cubic inch of weld in 6 min. The labour cost is then

$$C_1 = \left(10\ \frac{\$}{hr}\right)\left(\frac{1}{60}\ \frac{hr}{\min}\right)\left(6\frac{\min}{in^3}\right)V_w = 1\left(\frac{\$}{in^3}\right)V_w$$

Where V_w = weld volume, in^3.

Material Cost C_2**:**

$$C_2 = C_3 V_w + C_4 V_B$$

where C_3 = cost per volume per weld material, $\$/in^3$ = (0.37)(0.283)

C_4 = cost per volume of bar stock, \$/in^3 = (0.17)(0.283)

V_B = volume of bar A, in^3.

From the geometry,

$$V_w = 2\left(\frac{1}{2}h^2 l\right) = h^2 l$$

Volume of the weld material (inch^3)

$$V_{weld} = x_1^2 x_2$$

And

$$V_B = t\,b\,(L + l) \;,$$

Volume of bar (inch^3)

$$V_{bar} = x_3 x_4 (L + x_2)$$

Therefore the cost function become

$$f(X) = h^2 l + C_3 h^2 l + C_4 t b (L + l)$$

Or, in terms of the x variables,

$$f(X) = (1 + C_3) x_1^2 x_2 + C_4 x_3 x_4 (14.0 + x_2)$$

$$f(X) = 1.10471 x_1^2 x_2 + 0.04811 x_3 x_4 (14.0 + x_2)$$

ENGINEERINGRELATIONSHIP: (Hasancebi.O, 2012)

To complete the model, it is necessary to define the important stress states.

Weld stress

$$\tau(X) = \sqrt{\tau_1^2 + 2\tau_1\tau_2 \cos\theta + \tau_2^2} \qquad \text{Where} \qquad \cos\theta = \frac{x_2}{2R}$$

Weld stress has two components τ_1 and τ_2, where τ_1 the primary stress acting over the weld throat area and τ_2 is a secondary torsional stress.

Primary stress acting over the weld throat

$$\tau_1 = \frac{P}{\sqrt{2}\, x_1 x_2} = \frac{6000}{\sqrt{2}\, x_1 x_2}$$

Secondary torsion stress

$$\tau_2 = \frac{MR}{J}$$

Moment of P about centre of gravity of weld setup

$$M = P\left(L + \frac{x_2}{2}\right) = 84000 + 3000\ x_2$$

$$R = \sqrt{\frac{x_2^2}{4} + \left(\frac{x_1 + x_3}{2}\right)^2}$$

Polar moment of inertia of weld

$$J = 2\left\{\sqrt{2}\ x_1 x_2 \left[\frac{x_2^2}{12} + \left(\frac{x_1 + x_3}{2}\right)^2\right]\right\}$$

Bar bending stress: The maximum bending stress can be shown to be equal to

$$\sigma(X) = \frac{6PL}{x_4 x_3^2} = \frac{504000}{x_4 x_3^2}$$

Bar deflection. To calculate the deflection, assume the bar to be a cantilever of length

$$\delta(X) = \frac{4PL^3}{E x_3^3 x_4} = \frac{2.1952}{x_3^3 x_4}$$

The buckling load is approximated by

$$P_c(X) = \frac{4.013E\sqrt{\frac{x_3^2 x_4^6}{36}}}{L^2}\left(1 - \frac{x_3}{2L}\sqrt{\frac{E}{4G}}\right) = 64746.022(1 - 0.028234\, x_3) x_3 x_4^3$$

CONSTRAINT:

The shear stress at the beam support location cannot exceed the maximum allowable for the material

$$\tau(X) \le \tau_{\max}$$

$$\tau(X) \le 13600$$

The normal bending stress at the beam support location cannot exceed the maximum yield strength for the material

$$\sigma(X) \le \sigma_{\max}$$

$$\frac{504000}{x_4 x_3^2} \le 30000$$

$$16.8 \le x_4 x_3^2$$

The weld thickness is less than the material thickness

$$x_1 \le x_4$$

$$c_3 x_1^2 + c_4 x_3 x_4 (L + x_2) \le 5.0$$

$$0.10471 x_1^2 x_2 + 0.04811 x_3 x_4 (14.0 + x_2) \le 5.0$$

The defined minimum must be less than the weld thickness

$$0.125 \le x_1$$

The deflection cannot exceed the maximum deflection

$$\delta(X) \le \delta_{\max}$$

$$\frac{2.1952}{x_3^3 x_4} \le 0.25$$

$$8.7808 \le x_3^3 x_4$$

The applied load is less than the buckling load

$$P \le P_c(X)$$

$$6000 \le 64746.022(1 - 0.028234 x_3) x_3 x_4^3$$

$$0.0926697859 \le (1 - 0.028234 x_3) x_3 x_4^3$$

Size constraints

$x_1 \geq 0.1$

$x_2 \geq 0.1$

$x_3 \leq 10$

$x_4 \leq 2$

Hence the minimum cost and optimized dimensions are

Solution = optimization minimize (f(X), cons, bounds)

MATHEMATICAL FORMULATION (Janga Reddy.M, D.Nagesh Kumar, 2007) (Ali Riza Yildiz, 2008)

The mathematical formulation of the objective function $f(X)$ which is the total fabrication cost mainly comprised of the set-up, welding labour and material cost is as follows

The objective is to minimize the cost of the welded beam design problem.

Minimize $$f(X) = 1.10471 x_1^2 x_2 + 0.04811 x_3 x_4 (14.0 + x_2)$$

Subject to

$$\tau(X) \leq \tau_{max}$$

$$\sigma(X) \leq \sigma_{max}$$

$$x_1 \leq x_4$$

$$0.10471 x_1^2 x_2 + 0.04811 x_3 x_4 (14.0 + x_2) \leq 5.0$$

$$0.125 \leq x_1$$

$$\delta(X) \leq \delta_{max}$$

$$P \leq P_c(X)$$

Where

$$\tau(X) = \sqrt{\tau_1^2 + 2\tau_1\tau_2\left(\frac{x_2}{2R}\right) + \tau_2^2}$$

$$\tau_1 = \frac{P}{\sqrt{2}\, x_1 x_2}$$

$$\tau_2 = \frac{MR}{J}$$

$$M = P\left(L + \frac{x_2}{2}\right)$$

$$R = \sqrt{\frac{x_2^2}{4} + \left(\frac{x_1 + x_3}{2}\right)^2}$$

$$J = 2\left\{\sqrt{2}\ x_1 x_2\left[\frac{x_2^2}{12} + \left(\frac{x_1 + x_3}{2}\right)^2\right]\right\}$$

$$\sigma(X) = \frac{6PL}{x_4 x_3^2}$$

$$\delta(X) = \frac{4PL^3}{E x_3^3 x_4}$$

$$P_c(X) = \frac{4.013E\sqrt{\frac{x_3^2 x_4^6}{36}}}{L^2}\left(1 - \frac{x^3}{2L}\sqrt{\frac{E}{4G}}\right)$$

Size constraints

$$0.1 \le x_1 \le 2$$

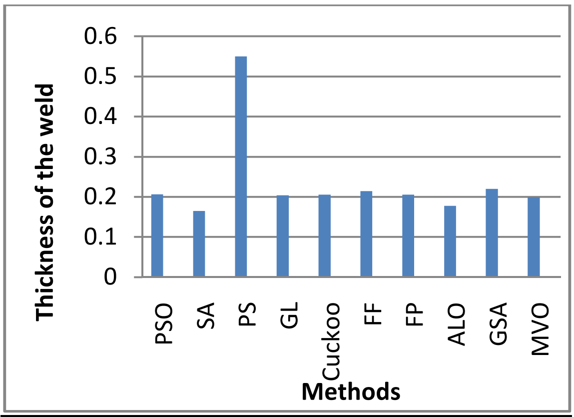
$$0.1 \le x_2 \le 10$$

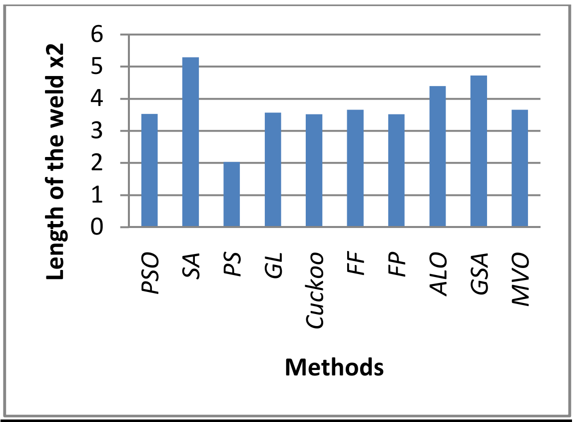
$$0.1 \le x_3 \le 10$$

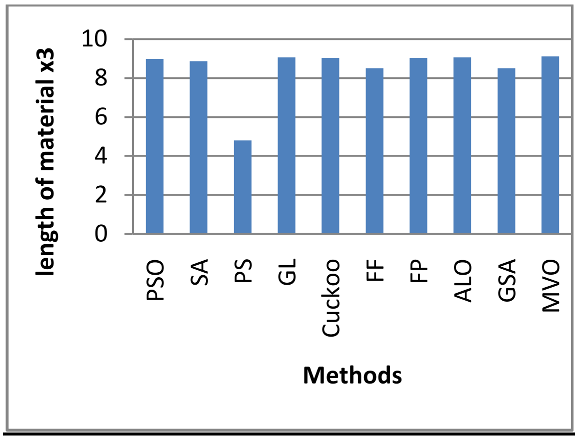
$$0.1 \le x_4 \le 2$$

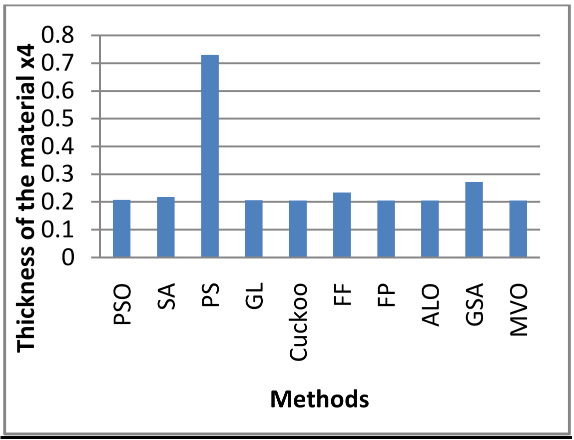
COMPARATIVE RESULTS

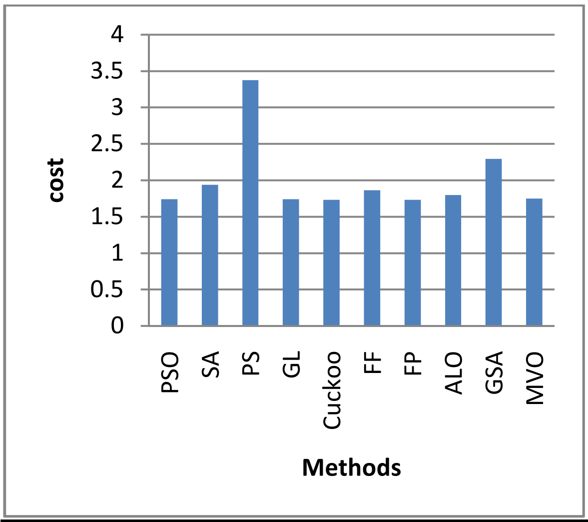
Trial No	PSO	SA	PS	GL	Cuckoo	FF	FP	ALO	GSA	MVO
Thickness of the weld X_1	0.206412	0.165306	0.55	0.204164	0.20573	0.214698	0.205729	0.177859	0.219556	0.199033
Length of the weld x_2	3.528353	5.294754	2.028512	3.565391	3.519497	3.655292	3.519502	4.393466	4.728342	3.652944
Length of the material x_3	8.988437	8.872164	4.798717	9.05924	9.036624	8.507188	9.036628	9.065462	8.50097	9.114448
Thickness of the material x_4	0.208052	0.217625	0.729557	0.206216	0.20573	0.234477	0.20573	0.20559	0.271548	0.205478
Cost	**1.742326**	1.939196	3.37756	1.7428	1.731527	1.864164	1.731528	1.796793	2.295076	1.749834
Iteration	178	4666	**5**	66573	100000	20000	2000	1000	1000	1000
Time	**1.235504**	4.38926	0.746971	8.338414	12.45931	8.083191	7.041082	59.04323	23.97281	8.962193

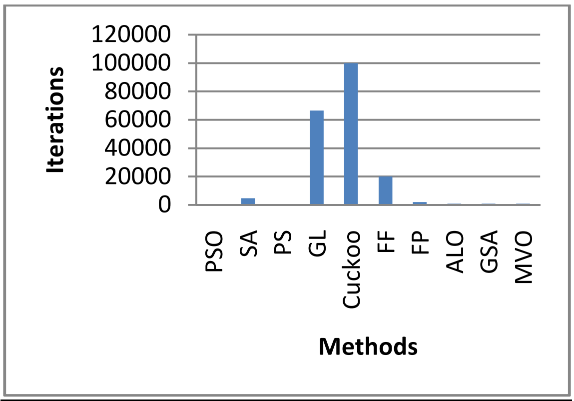


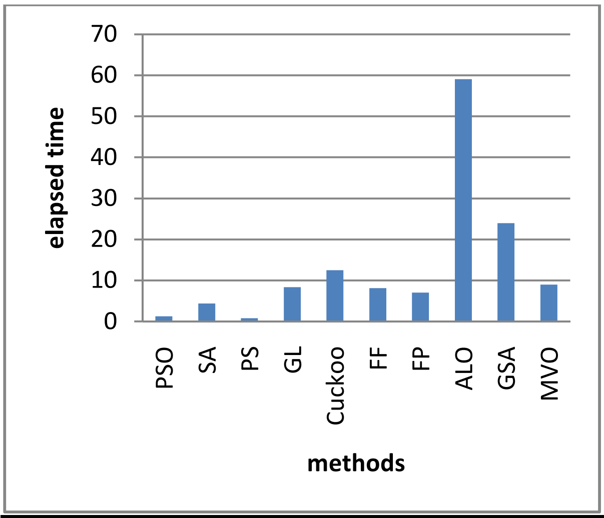



length of material x3
10
8
6
4
2
0
PSO
SA
PS
GL
Cuckoo
FF
FP
ALO
GSA
MVO
Methods


Thickness of the material x4
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
PSO
SA
PS
GL
Cuckoo
FF
FP
ALO
GSA
MVO
Methods


cost
4
3.5
3
2.5
2
1.5
1
0.5
0
PSO
SA
PS
GL
Cuckoo
FF
FP
ALO
GSA
MVO
Methods





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) And an average of all trials are taken as a final value of the parameter by the solver. The solvers are compared with three different criteria.

1. Consistency:

The cost is consistent in pattern search (3.37756)

2. Minimum run time:

For minimum run time of the problem we have PS (0.746971 seconds), PSO (1.235504 seconds).

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 5 and 178 respectively.

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 cost becomes maximum whereas the cost in PSO is 1.7423. Therefore the particle swarm optimization has the minimum cost with time 1.23 seconds and 178 iteration. So the appropriate algorithm for welded beam design is suggested as Particle Swarm Optimization.

CONCLUSIONS

In the present study the PSO algorithm is proposed as a simple and efficient optimization technique for handling welded beam 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 welded beam design optimization. Performance evaluation of the PSO algorithm through welded beam 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 welded beam design optimization problem, it can be easily employed for solving other types of optimization problems as well.

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APPENDIES

Tables having the option set and stopping criteria for the optimization methods

Methods	PSO	SA	PS	GL	CUCKOO	FF	FP	ALO	GSA	MVO
Option set	Max.Generation =200 Max.Time Limit=∞ Average change in fitness value=10^{-6} Function Tolerance:10^{-6} Cognitive Attraction=0.5 Population Size=40 Social Attraction=1.25	Initial Temperature:100 Annealing Function: Fast Annealing Reannealing Interval :100 Time limit:∞ Max.Function Evaluation:3000*No.of variables. Max.Iteration:∞ Function Tolerance:10^{-6} Objective Limit:10^{-6}	Poll Method:GPS positive basis 2N Initial Mesh Size:1 Expansion Function:2 Contraction Factor:0.5 Mesh Tolerence:10^{-6} Max.Function Evaluation:2000*No.of variables. Max.Iteration:100*No.of variables. Max.Time Limit:∞ Function Tolerance:10^{-6}	Max.Fun Evaluations = 10^{-5} Max.Iterations=20 Min.Iterations=2 Total Iterations= 15 Functions Tolerance= 10^{-4}	Max.Fun. Evaluations =10^{-5} Max.Iterations=20 Functions Tolerance= 10^{-6} Max.Time Limit=∞	Max.Fun. Evaluations =10^{-5} Max.Iterations=20 Functions Tolerance= 10^{-6} Max.Time Limit=∞	Max.Fun Evaluations =10^{-5} Max.Iterations=20 Functions Tolerance= 10^{-6} Max.Time Limit=∞	Max.Fun Evaluations=10^{-5} Max.Iterations =20 Functions Tolerance=10^{-6} Max.Time Limit=∞	Max.Fun Evaluations =10^{-5} Max.Iterations=20 Functions Tolerance= 10^{-6} Max.Time Limit=∞	Max.Fun Evaluations=10^{-5} Max.Iterations=20 Functions Tolerance= 10^{-6} Max.Time Limit=∞
Stopping criteria	Max.Generation =200 Max.Time Limit=∞ Average change in fitness value=10^{-6} Function Tolerance:10^{-6}	Max.Time reached The average change in value of the objective function is < 10^{-6} max.iterations are reached if the number of functions evaluations reached. If the best objective function value is less than or equal to the value of objective limit.	Mesh Tolerance:10^{-6} Max.Iteration: 100*No.of variables. Evaluation:2000*No.of variables Max.Time Limit:∞ Function Tolerance:10^{-6}	Max.Fun Evaluations = 10^{-5} Max.Iterations=20 Min.Iterations=2 Total Iterations= 15 Functions Tolerance= 10^{-4}	Max.Fun Evaluations =10^{-6} Max.number of Iterations= 100000 Functions Tolerance= 10^{-6} Max.Time Limit=∞	Max.Fun Evaluations =10^{-6} Max.number of Iterations= 100000 Functions Tolerance= 10^{-6} Max.Time Limit=∞	Max.Fun Evaluations =10^{-6} Max.number of Iterations= 100000 Functions Tolerance= 10^{-6} Max.Time Limit=∞	Max.Fun Evaluations= 10^{-6} Max.number of Iterations= 100000 Functions Tolerance=10^{-6} Max.Time Limit=∞	Max.Fun Evaluations =10^{-6} Max.number of Iterations= 100000 Functions Tolerance= 10^{-6} Max.Time Limit=∞	Max.Fun Evaluations=10^{-6} Max.number of Iterations= 100000 Functions Tolerance= 10^{-6} Max.Time Limit=∞