Journal of Material Science and Mechanical Engineering (JMSME)
Print ISSN: 2393-9095; Online ISSN: 2393-9109; Volume 2, Number 5; April-June, 2015 pp. 434-437

http://www.krishisanskriti.org/jmsme.html

Engineering Design Optimization of Stiffened Composite Shells under External Hydrostatic Pressure

A.S. Bhanu Prasanna[1], K.K.K. Sanyasi Raju[2] and K. Ramji[3]

[1]LENDI Institute of Engineering and Technology (LIET)
[2]Scientist-F (NSTL, Retd.) Faculty member, LIET
[3]Department of Mechanical Engineering, Andhra University, Visakhapatnam
E-mail: [1]bhanu.3549@gmail.com, [2]rajukurada2012@gmail.com, [3]ramjidme@yahoo.co.in

Abstract—*A Swarm intelligence based design optimization of stiffened Composite cylindrical shells under buckling pressure and frequency constraints for under water applications is considered in the present study. Swarm intelligence is based on the collective intelligence of birds by means of indirect communication (P.S.O Algorithm). Buckling pressure and free vibration natural frequency of a stiffened composite shell depends on various parameters viz. rib thickness, rib spacing, rib width, shell thickness, winding angles in each layer and stacking sequence. The effect of above parameters on the buckling pressure and frequency prior to optimizing the stiffened composite shell is discussed in detail. Love-Kirchhoff equations and Jone's equations are used for computation of Natural Frequency and buckling pressures of stiffened composite shells. It is observed that for Carbon epoxy composite cylindrical shell the mass of the shell has increased when frequency is added as a constraint. The increase in mass is due to increase in number of ribs, which has caused the bending stiffness to increase thus satisfying the frequency constraint of minimum 520 Hz. It is also observed that the objective function has not converged when the iterations are 100 and the converged value was obtained only after 200 iterations indicating that it is always preferable to increase the number of iterations till reasonable limit of convergence is attained especially when the search space is large and when the number of design variables and constraints are more. It is observed from present study that for a Carbon epoxy shell when the number of particles increased from 50 to 500 the global minimum is obtained for few number of iterations indicating requirement of large number of particles in the initial population especially when the design space is large and the objective function is constrained.*

1. INTRODUCTION

The use of fibrous composite materials has advanced extensively not only in aerospace industry but also in automobile, civil, Naval and other fields of engineering. The long fiber composites are typically used in the form of prepegs or by wet layup process followed by filament including allowing designs to control or tailor the mechanical properties by considering fiber orientation angles, stacking sequence and individual layer thickness. These materials are used for submersible and underwater weapon structures/weapon platforms allowing low weight to displacement ratio and long endurance with limited energy and maximum payload carrying capability. Submarine explosive housings, Autonomous Underwater Vehicles are currently being developed by IFREMER (French Research Institute for exploitation of sea).

1.1 Particle Swarm Optimization:

Particle Swarm Optimization as a method of Optimization was developed by Eberhart and James in 1995. They had simulated the bird flock to generate the population in two-dimensional space. Each particle in the flock keeps track of its position, velocity, individual best position and global best position. If particles current position is better than the individual best position then the individual best position is replaced by current position. Similarly if the particles current position is better than the global best position then the global best position is replaced by current position.

Design of cylindrical shell for minimization of mass

In under water applications, space vehicles, and aircrafts and in other defensive applications weight becomes important factor. So in these weight sensitive applications importance of light weight materials such as aluminum alloy, Titanium alloy and composite materials have become significant. Though the metals have given excellent service for the construction of shells in hydro space applications, the requirements for service at greater depths has created considerable difficulties with metal owing to problems of weight. A point is reached where the shell becomes so thick that all buoyancy is lost and the pay load is reducing to zero. Composite pressure vessels designed for moderate to extreme depths, require minimization of structural weight for increasing performance, speed and operating range and hence more interest is being shown for the weight minimization of composite structures.

2. MASS MINIMIZATION OF OBJECTIVE FUNCTION FOR THE STIFFENED COMPOSITE CYLINDRICAL SHELL UNDER BUCKLING PRESSURE AND FREQUENCY CONSTRAINTS:

A carbon epoxy composite shell is considered for mass minimization under buckling pressure constraint of minimum 12.5 Mpa and also under combined constraints of buckling pressure and frequency constraints, minimum 12.5 Mpa and minimum 520 Hz respectively. Relevant material properties and geometry properties and lower and upper bounds of design variables namely, shell thickness, rib spacing, rib widths are given as under:

Material properties		Geometry	
Material	Carbon epoxy	Overall Length	1000 mm
Young's Modulus1	181 Gpa	Mean Radius	250 mm
Young's Modulus2	10.340 Gpa	Rib height	20 mm
Poisson's Ratio	0.28		
Density	1.6 gm/c.c		
Design variables are			
	upper bound	Lower bound	
Shell thickness, (t)mm	2	10	
Rib spacing, (er) mm	80	120	
Rib width, (br) mm	10	30	
No of layers	16		
Angle	[90 45 90 45 90 45 90 45 45 90 45 90 45 90 45 90]		

Layer thickness = shell thickness /number of layers;

Objective function: Minimization of total mass of the stiffened shell, W

W= W1 + W2

W1 = Weight of the cylindrical shell portion

W2 = weight of total number of ribs

Constraints

1. General instability buckling pressure > 12.5MP
2. Frequency > 520 Hz

The objective function Vs Number of iterations and corresponding optimal values are given at Figures 1, 2 and 3 and tables 1 and 2. To ensure that the shell should fail in buckling mode only and not by failure by stresses in the composite layers exceeding corresponding strengths , the stresses along the fiber across the fiber and also the shear stress are computed by **classical laminate** theory and are given at table3.

3.1.1 Carbon epoxy shell under buckling pressure constraint:

Graph for Variation of Objective function under buckling pressure constraint , Mass in Kgs

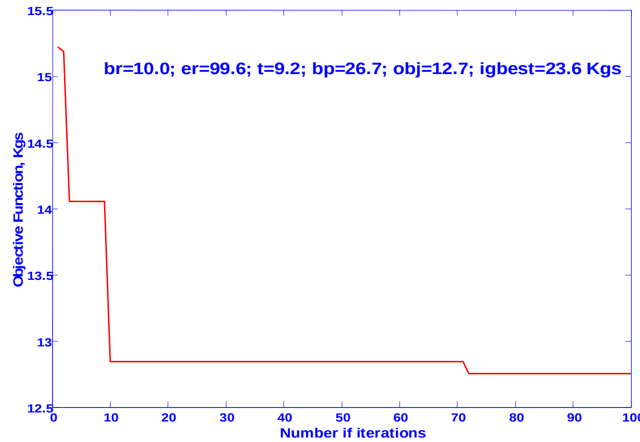

Fig. 1

Table 1

Material Name	**Carbon epoxy**
Iterations	100
No of particles	40
Rib Width, br, mm	10.09
Rib Spacing, er, mm	99.6
Thickness, t, mm	4.9
Objective value, kgs	12.7
Overall Buckling pressure,Mpa	26.7

Objective and Constraint values for Carbon epoxy shell under buckling Pressure constraint

3.1.2 Carbon epoxy shell under buckling pressure constraint, Frequency constraints

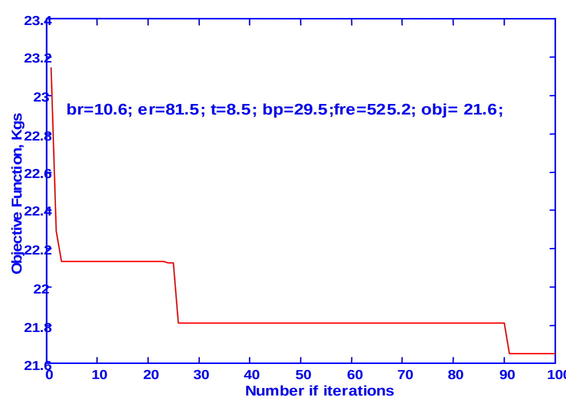

Fig. 2

Objective function values for 40 particles 100 iterations

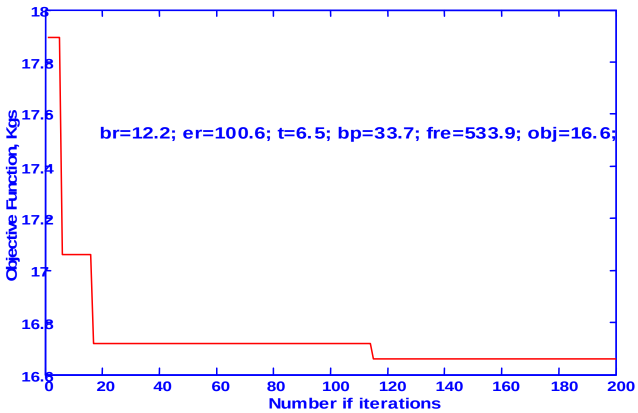

Fig. 3

Objective function values for 40 particles 200 iterations

Table 2

Material Name	Carbon epoxy	
Iterations	100	200
No of particles	40	40
Rib Width, br, mm	10.6	12.2
Rib Spacing, er, mm	81.5	100.6
Thickness, t, mm	8.5	6.5
Objective value, kgs	21.6	16.6
Overall Buckling pressure,Mpa	29.5	33.7
Frequency, Hz	525.2	533.9

Objective and Constraint values for Carbon epoxy shell under buckling pressure and frequency constraint

It is observed from the above figures 1 to 3 that the mass of the shell has increased by 5 Kgs approx when frequency is added in addition to buckling pressure constraint. The decrease in mass is due to reduction in number of ribs from 12 to 10. Further it is also observed that the converged objective function is obtained after 200 iterations (mass has decreased from 21.6 to 16.6 Kgs for 100 and 200 iterations respectively) indicating that it is always preferable to increase the number of iterations till reasonable limit of convergence is attained especially when the search space is large and when the number of design variables and constraints are more.

3.1.3 Stress in carbon Epoxy shell at 12.5 Mpa external pressures

Table 3

Material Name	Carbon/Epoxy	
Pressure, Mpa	12.5	
Angle	90	45
Nx, N/m	_ 1562500	_ 1562500
Ny, N/m	_ 3125000	_ 3125000
SigL, Mpa	-1100 (-1500)	-164 (-1500)
SigT, Mpa	-35 (-246)	-74 (-246)
TouLT, Mpa	-44 (-68)	-30 (-68)

Stress values for Carbon/Epoxy

(Values in brackets indicate corresponding longitudinal compressive strength, Transverse compressive strength and Shear strength values)

It is observed that all the stresses are below their corresponding strength values and the Tsai Hill and Tsai Wu factor are found to be less than one indicating safe design with respect to stresses in both 90 and 45 degree layers.

3.2 Effect of Variation of Objective Function with initial population for carbon epoxy composite shell under buckling pressure and frequency constraint:

The global best position in the PSO algorithm is computed initially with a population normally equal to the population being used subsequently for further iterations. The smaller the distance between the initial global best position and global optimum, the faster the solution for global optimum is reached as there is no need to search the total search space of each variable. Three initial populations of 50, 150, 500 particles are considered to study the effect of g best on objective function and the same is shown in fig. 4.

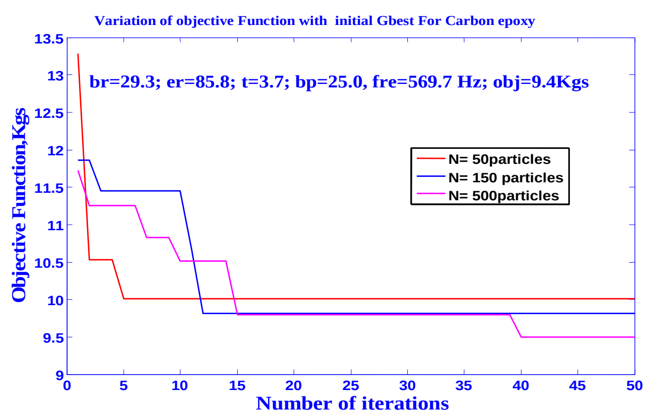

Fig. 4

Output:

F_{OPT} (weight) = 9.4 kgs Rib Width = 29.3mm
Buckling pressure= 25.0 Mpa Rib Spacing = 85.8 mm
Frequency = 569.7 Hz Thickness = 3.7 mm

It is observed from the Fig. 4, that the global optimum is 9.4 kgs for maximum population of 500 particles while it is 10.2

and 9.9 kgs for 50 and 150 particles indicating need for large number of iterations to be carried out when smaller numbers of particles are used for initial population. Hence it is preferable to use large number of particles for initial gbest position computation for faster computation of global minimum when the design space is large and the objective function is considered rather than resorting larger number of iterations with smaller number of initial number of particles for initial gbest position.

3. CONCLUSIONS

A Swarm intelligence based design optimization of stiffened Composite cylindrical shells for Naval applications is considered. Following observations are made

- It is observed from the Carbon epoxy composite cylindrical shell that the mass of the shell has increased when frequency is added as a constraint. The increase in mass is due to increase in rib width from 10.09 mm to 12.2 mm nand increase in shell thickness from 4.9 to 6.5 mm , which has caused the bending stiffness to increase thus satisfying the frequency constraint of minimum 520 Hz.

It is observed that the global optimum is 9.4 kgs for maximum population of 500 particles while it is 10.2 and 9.9 kgs for 50 and 150 particles indicating need for large number of iterations to be carried out when smaller numbers of particles are used for initial population. Hence it is preferable to use large number of particles for initial gbest position computation for faster computation of global minimum when the design space is large and the objective function is constrained rather than resorting to larger number of iterations with smaller number of initial number of particles for initial gbest position.

- The Particle Swarm optimization algorithm proved to be an efficient algorithm for optimization problem as observed in present study.

REFERENCES

[1] Bin Jiao, Zhigang, Xingsheng Gu, “A dynamic inertia weight particle swarm optimization algorithm”, a journal in chaos, solitons and Fractals, 2006.

[2] Yan Wang, Xiao-Yue Feng, Yan-Xin Huang, Dong-Bing Pu, Wen-Gang Zhou, Yan- Chun Liang, Chun-Guang Zhou, “A novel quantum swarm evolutionary algorithm and its applications”, A journal in Neurocomputing 70 (2007) 633-640.

[3] Rania Hassan, Babak Cohanim, Olivier de Weck, “ A comparison of Particle swarm optimization and the Genetic algorithm”.

[4] Chunming Yang and Dan Simon, A New particle swarm optimization technique”, c.yang@csuohio.edu.

[5] X.H. Shi,Y.C. Liang, H.P. Lee, C.Lu, L.M. Wang, “An improved GA and a novel PSO-GA-based hybrid algorithm”, A journal in information processing letters, 93 (2005) 255-261.

[6] Ben Niu, Yunlong Zhu, Xiaoxian He, Henry Wu, “A multi-swarm cooperative Particle swarm optimizer-(MCPSO)”, A journal in Applied mathematics and computation,2006.

[7] K.Jarmai, J.A. Snyman, J. Farkas, “Minimum cost design of a welded orthogonally stiffened cylindrical shell”, A journal in Computers and Structures 84 (2006) 787- 797.

[8] Ying Dong, Jiafu Tang, Baodong Xu and Dingwel Wang, “An application of swarm ptimization to nonlinear programming”, An International journal in Computers and mathematics with applications 49 (2005) 1655-1668.

[9] S.Suresh, P.B. Sujit, A.K.Rao, “Particle swarm optimization approach for multi- objective composite box-beam design”, A journal in Composite structures 81(2007) 598-605.

[10] F.Van den Bergh, A.P. Engelbrecht, “ A study of particle swarm optimization . particle trajectories”, An International journal in Information sciences 176 (2006) 937-971.

[11] GUO Chuang-xin, HU Jia-sheng, YE Bin, CAO YI-jia, “Swarm intelligence for mixed-variable design optimization”, A journal of Zhejiang University SCIENCE ISSN 1009-3095 accessed in November 2003.

[12] Kai sedlaczek and peter Eberhard, “ Constrained particle swarm optimization of mechanical systems”, 6th World congresses of structural and multidisciplinary optimization Rio de Janeiro, 30 may-03 june 2005.

[13] Andres Perez-Uribe, “ collective and swarm intelligence in natural and artificial systems” http://www.geocities.com/fastiland/Teaching/acs/swarm.html.

[14] GUO Chuang-xin, HU Jia-sheng, YE Bin , CAO Yi-jia “Swarm intelligence for mixed variable optimization”, accessed in November 2003.

[15] P.S.Shelokar, P.Siarry, V.JayaRaman, B.D.Kulakarni, “PSO and ACO Hybridized for improved continuous optimization”, A Journal in Applied mathematics and computation, 2006.

[16] CAPT Harry A.Jackson, “ Fundamentals of Submarine Design”, SNAME Transactions, Vol . 100,1992.

[17] James J Gorman, Lisa L. Louie, “ Submersible Pressure Hull Design Parameters”, SNAME Trasactions, Vol 99, 1991.

[18] V.Carvelli, N. Panzeri, C.. Poggi , “Buckling strength of GFRP under-water vehicles”, A Journal in Composites: part B 32 (2001) 89-101.

[19] Thomas G.Perry, Craig D.Douglas, James J.Gorman, “ Analytical design procedures for Buckling-Dominated Graphite/Epoxy pressure hulls”,

[20] S. Patnaik and G.V.Sankaran, vibration of initially stressed stiffened circular cylindrical and panels. Journal of Sound and Vibration (1973) 31(3), 369 – 382.

[21] Lixuebin and Chen Yaju free vibration of an orthtropic circular cylindrical shell under external hydrostatic pressure. Journal of Ship Research, Vol.46, No.3, step 2002, PP.201 – 207.

[22] M.EI-Mously, fundamental natural frequencies of thin cylindrical shells: A comparative study. Journal of Sound and Vibration 264 (2003) 1167-1186.

[23] M.EI-Mously, Timoshenko – beam – on pasternak foundation analogy for cylindrical shells. Journal of Sound and Vibration 261 (2003) 635-652.

[24] B.A.J.Mustafa and R. Ali, prediction of natural frequency of vibration of stiffened cylindrical shells and orthogonally stiffened curved panels. Journal of Sound and Vibration.

[25] P.B. Goncalves and R.C.Batista, frequency response of cylindrical shells partially submerged or filled with liquid. Journal of Sound and Vibration (1987) 113 (1), 59-70.