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Free Vibration, Buckling and Design Optimisation of Composite Pressure Hulls

A.S.BhanuPrasanna[a], K.K.K.SanyasiRaju[b], K.Ramji[c], PSatish[d]

[a]*Faculty member BABA Institute of Technology and Sciences (BABA),Visakhapatnam ,*
[b]*Scientist-F (NSTL,Retd.)Faculty member of LENDI Institute of engineering and technology(LIET),*
[c]*Professor, Department of Mechanical Engineering, Andhra University, Visakhapatnam ,*
[d]*Professor, Faculty member, (LIET), vizainagaram*

Abstract:

Composite materials are being extensively used for underwater applications due to their high specific stiffness and strength and superior corrosion resistance. The structural weight of the composite pressure hulls intended to operate under high operating depths should be minimized for increasing payload, speed and operating range. Apart from minimizing the weight, these structures should resist the specified buckling loads and should not transmit vibrations that are nearer to the frequencies generated inside the structure and hence the weight is to be minimized under minimum buckling pressure specified and also should have natural frequencies of vibration much higher than those that are in the excitation range of equipment mounted in side the structure. An attempt is made in the present study to minimize structural weight of isotropic and composite stiffened shells for under water applications under given buckling pressure and frequency constraints using PSO based algorithm. PSO is being developed recently and it is well documented in literature that PSO is fairly accurate for determining global minimum when compared to other evolutionary algorithms Viz Genetic algorithm, simulated annealing etc. 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, rib height and stacking sequence. The effect of above parameters on the Buckling pressure and Frequency is studied in detail prior to optimizing the stiffened composite shell under buckling pressure and Frequency constraints. Love-Kirchhoff equations and Jone's equations are used for computation of Natural Frequency and buckling pressures of stiffened composite hulls.
Different composite materials Carbon Epoxy, Boron epoxy, Glass Epoxy are considered for design optimization. Carbon epoxies are used for higher operating depths, while Glass epoxies are used for less operational depths. Carbon epoxy is also 100 times more costly than Glass epoxy and hence cost also need to be considered while selecting the above composite materials. The stresses along the fibers and in the direction is perpendicular to the fiber in the different layers of the composite materials namely Carbon epoxy, Boron epoxy and Glass epoxy (90 and 45) under given external pressure are computed. T Sai Hill and T sai – Wu failure theories are applied to the different layers to confirm that all the plies are safe.

*Keywords:*Free vibration, buckling pressure, weight, composite materials, PSO.

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1. Introduction:

In under water applications, space vehicles, and aircrafts and in other defence applications weight becomes important factor. So in these weight sensitive applications importance of light weight materials such as aluminium 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 becomes small. Composite pressure hulls 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. Effect of Design Variables on Buckling Pressure and Frequency

2.1. Effect of Winding angles and stacking sequence:

The Buckling pressure and frequency of a composite shell largely depends on the ratio of Bending to axial stiffness of the total shell structure which varies significantly with variation of Winding angle and Stacking sequence. The fig 1, 2 shows variation of buckling pressure and Frequency with winding angles from 90, 0 to 90, and 90.

Figures 1 and 2 shows relative variation of buckling pressure and frequency with 90, θ (θ varying from 0 to 90) and with only θ (varying from 0 to 90).

It is observed from figures 1 and 2 that the buckling pressure increases linearly (approximately) from (90, 0) degrees to maximum at (90, 45) and there after decrease slightly up to (90, 90) stacking sequence. It would be preferable to use (90, 45) stacking sequence, since the buckling pressure is 14% more than that for the cross ply (90, 0) stacking sequence. This would mean that a stiffened composite shell with (90, 45) stacking sequence can operate at 300 mts more than a stiffened composite shell with cross ply stacking sequence. On the other hand the frequency is found to be maximum at (90, 25) stacking sequenceas against (90, 45) stacking sequence for maximum buckling pressure.

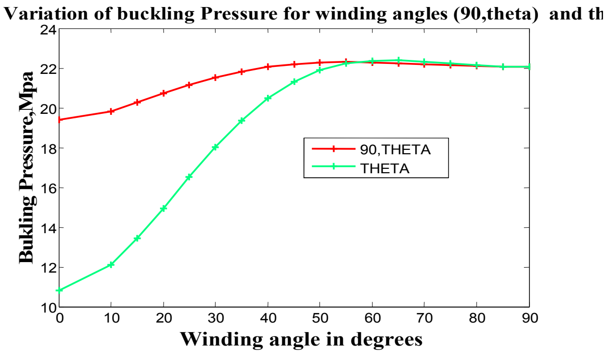

Fig 1. buckling pressure Vs winding angles (90, theta) and theta

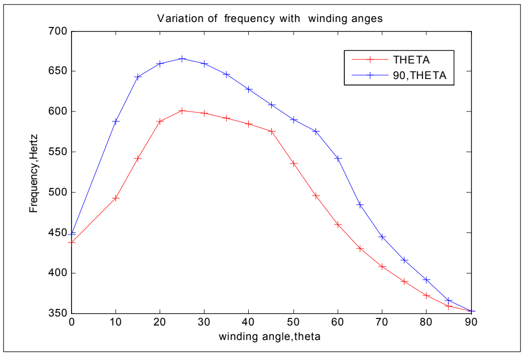

Fig 2 .Frequency Vs winding angles (90, theta) and theta

It is observed that given the choice of all theta and (90, theta) stacking sequence it would be preferable to use (90, theta) stacking sequence combination for better compactness of individual layers. It is also observed that at winding angles greater than 45 the value of the buckling pressure remains same for both 90, theta and theta.

2.2. Effect of shell thickness:

The shell thickness should be chosen to resist the hoop membrane stress, pr/t, where p is the outside external pressure Mpa, r is the mean radius, t is the thickness and generally shell thickness chosen should be able to resist the above membrane stress. Fig 3 and 4 shows the variation of the buckling pressure w.r.t Shell thickness and Frequency w.r.t Shell thickness.