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**ORIGINAL ARTICLE**

# DAMAGE DETECTION OF SURFACE IN COMPOSITE SHELLS USING MODE SHAPE CURVATURE (MSC) METHOD

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**ABSTRACT:** Importance of having the ability to monitor structural health and detect damage in the fastest possible time is one of the main concerns of engineers, particularly in the fields of mechanical and aerospace. This importance is due to damage in a structure during work can be very severe and sometimes irreparable damages to be followed. One of the methods in this field is the mode shape curvature method. The purpose of this study is located sensitivity methods based on the mode and susceptibility to different intensities of damage in a composite cylindrical shell. The results indicate that this method will capable to recognize 0.08% and over of damage in the total area of the sample.
**KEYWORDS:** Modal analysis, Mode shape curvature method, Composite cylindrical shell.

## INTRODUCTION

Cylindrical Shells have many uses in engineering structures such as pipelines, pressure vessels, rocket bodies, etc. The structures during working life are applied the external forces such as pressure, axial force and dynamic forces. Load conditions in case study with cracks and small imperfections in the layer structures shall be spread over them and suffer serious and complete destruction of the structure. So, one of the essential principles of structural health monitoring, is detecting imperfections before spread in structures. The first attempt to locate defects in composite structures with using natural frequencies is attributed to the Cowley (Cawley and Adams, 1979). Their method is based on the assumption that the comparison frequency modes in pairs, representing the position of the damage. He used both graphite - epoxy and honeycomb plates in research and several types of imperfections, such as holes, cutting saws, local heating and impact successfully locate and assess the extent of the damage. In this research was made the comparison between the measured and predicted frequency of the mode. Cornwell et al (Cornwell *et al.,* 1999), have improved methods of modal strain energy ratio for detections such as one-dimensional beam structures for two-dimensional plate. The results obtained from this method could show the location of imperfection in plate that damage modeled in it with a 10% reduction of stiffness. Hu *et al.,* (2006) examined a method to detect cracks in the surface of a composite plate. Their samples were composite plates layup $[90]_{16}$, $[0]_{16}$ that made of carbon epoxy. They established the damage of crack with laser cutting machine on the surface of their samples and were extracted both experimental and finite element method to analyze the modes the structure. They used mode shapes that are obtained strain energy by DQM method (Schuiz, 1997).

Finally, they could identify the location of the imperfects in the original structure with used strain energy of structure in safe and damage states. Location of defects is most in shell of structural or mechanical joints such as welding and places with high stress concentration. According to results of research in America's military research center, 85% of defects in composite structures are because of lamination that these imperfections are not visible with the eye and only detectable with vibration test (Hu *et al.,* 2006). In this paper, tried to assess its sensitivity to the amount of imperfections with based on mode shapes. Thus a typical cylindrical shell made of composite glass - epoxy that prepared with filament winding and did modal test from healthy structure and then bore surface of the composite shell. Surface of hole increased in the later steps of testing. The results of the evaluation and validation tests of healthy sample were compared with the results of Abaqus software.

## METHOD OF RESEARCH

The method of mode shape curvature (MSC) that the absolute difference between the maximum curvature of the damage modes and normal modes are shown is as follows:

$$\Delta\psi''_{ij} = \left|\psi''^{*}_{ij} - \psi''_{ij}\right| \quad (1)$$

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If more than one mode shape is used, the imperfect index is calculated as follows:

$$MSC_i = \sum_j \Delta\psi''_{ij} \qquad (2)$$

Composite materials are used in a circular cylindrical shell of glass fiber with epoxy resin. The mechanical properties of these materials are given in Table (1). Geometric finite element model of the shell with its geometric dimensions is shown in Figure (1) and Table (2). In this geometry, the coordinate X,θ and Z refer to axial, environmental and radial coordinate directions respectively. The composite shell has done $[+45/-45]_2$ layup and 70% volume of fibers fraction.

**Table 1:** Mechanical properties of used in composite cylindrical shell

| Properties | Glass | Epoxy | Glass/Epoxy |
|---|---|---|---|
| $E_1$ (Gpa) | 51.7 | 2.744 | 37.02 |
| $E_2 = E_3$ (Gpa) | 9.4 | 2.744 | 6.5 |
| $G_{12} = G_{13}$ (Gpa) | 3.02 | 1.148 | 2.58 |
| $G_{23}$ (Gpa) | - | 1.148 | 2.5 |
| $\upsilon_{12} = \upsilon_{13}$ | 0.22 | 0.35 | 0.26 |
| $\upsilon_{23}$ | - | 0.35 | 0.3 |
| ρ (kg/m3) | 2615 | 1200 | 2190.5 |
| Thickness(mm) | - | - | 0.73 |

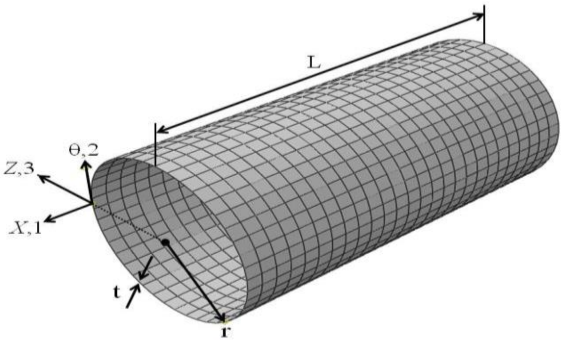


**Figure 1:** Finite element model of composite cylindrical shell

**Table 2:** Geometric dimensions of the composite cylindrical shell

| Length (mm) | Radius (mm) | Thickness (mm) | L/r | r/t |
|---|---|---|---|---|
| 395 | 105 | 2.92 | 3.8 | 36 |

Before done the experimental tests to validate the process of testing, finite element analysis of composite cylindrical shell made with Abaqus software. The number of elements on convergence of mesh selected that consider the error less than 0.5%. Nodes in each element have 3 degrees of movement and 3 degrees of rotation. To create an imperfect in the cylindrical shell used the drilling method. After the modal testing procedures and obtained data structures from without imperfection sample, somewhere near the middle of the cylinder at a distance of 35 mm from the center of it (between nodes No. 39,40,51,52) was drilled hole diameter of 4 mm. This hole is equivalent to 0.02% of the total area of sample. In the next steps of testing on the first sample were created 6 and 8 mm diameter defects in the same location and case studies have been done on the imperfections. It is an area of 0.043% and 0.077% of the total area of the sample respectively. For done modal analysis was selected MRIT method and using a hammer for excitation signal. Free - free boundary conditions were studied to do modal tests on cylindrical shells. In general, 84 points was chosen on structure as the excitation. The number of points in the radial direction is 12 and in the longitudinal direction are 7 numbers. These points have been selected based on the structural behavior of various tests. Figure (2), is shown two-dimensional map grid of sample along with the location of accelerometer and create imperfect zone.

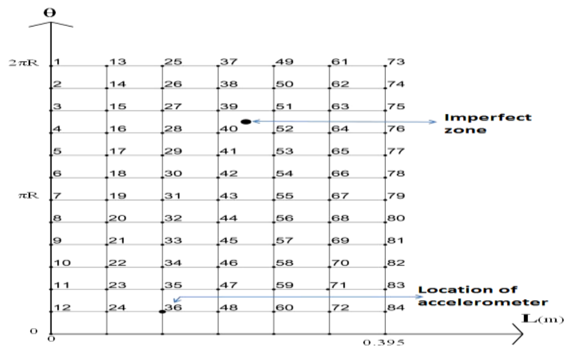


**Figure 2:** Two dimensional mapped grid of cylindrical sample

After analyzing the results of the FRF curve fitting algorithm and application by polynomial functions of order 30 and in the range of 0 to 500 Hz, The modal characteristics of cylindrical composite structure was obtained before and after the imperfections table (3).

**Table 3:** Natural frequencies of cylindrical sample

| Mode | cylindrical sample | | | | | |
|---|---|---|---|---|---|---|
| | before imperfection | | | after imperfection | | |
| | EMA (HZ) | FEM (HZ) | Δ% | D=4 (mm) | D=6 (mm) | D=8 (mm) |
| 1 | 77.44 | 79.38 | 2.5 | 77.46 | 77.5 | 77.52 |
| 2 | 94.73 | 97.17 | 2.9 | 94.53 | 94.77 | 94.99 |
| 3 | 217.99 | 224.15 | 2.8 | 218.13 | 218.3 | 218.22 |
| 4 | 239.93 | 247.86 | 3.2 | 240.22 | 240.36 | 240.86 |
| 5 | 415.36 | 428.45 | 3.1 | 415.62 | 415.77 | 415.81 |
| 6 | 436.74 | 453.58 | 3.7 | 436.98 | 437.12 | 437.52 |

In this section obtained the results of modal testing in cylindrical shell and have been located imperfections with method that were described in this study. So, to avoid errors caused by data of mode shape structures the used of the first, third and fifth modes of the structure. The results of this investigation is given in Figures (3) to (5).

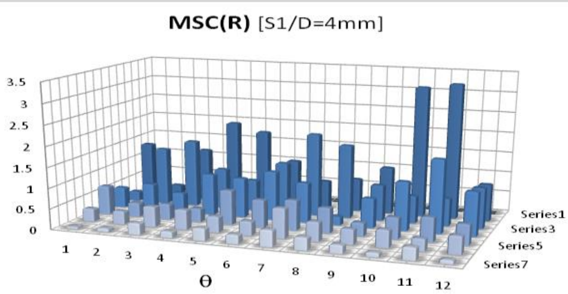


**Figure 3:** The result of defect in first step with mode curvature shape.

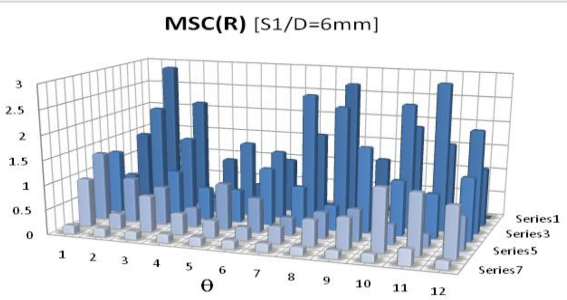


**Figure 4:** The result of defect in second step with mode curvature shape.

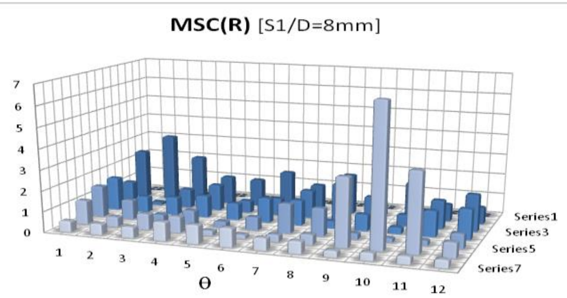


**Figure 5:** The result of defect in third step with mode curvature shape.

## CONCLUSIONS

Based on results with use the method of mode shape curvature only in the third step of damage that more than 0.08% of the total area of the structural will be able to identify and this research illustrates the precision of the method and limits that can use of it. This method cannot distinguish the imperfections in first and second steps that have 0.02% and 0.04% of the total area of composite cylindrical shell.

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