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Effect of Cracks on the Natural Frequency of Cylindrical Shell Structures

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K E Y W O R D S

Cylindrical shell, Vibration, Part-Through Crack, Open crack, Natural frequency.

A B S T R A C T

Shell structures are liable to different kinds of defects and damage like cracking and corrosion which may destroy their structural safety and affect the service life. The cracks' effects are significant considerations in the design of cylindrical shell structures as they influence the vibration characteristics and safety. This present work is an experimental study on the free vibration analysis of a cylindrical shell involving circumferential surface crack. The influence of the ratio of shell's radius to a shell's thickness (R/h)of the shell structure, crack length in the shell, crack depth in the shell, crack location of the shell, and crack orientation in the shell are investigated under a clamped - clamped and simply supported boundary conditions at each end in the shell. Results showed that the minimum impact of the crack is at the angle of crack 75, and the circumferential fissure has more effect than a longitudinal fissure, In addition to this, under SS-SS, C-C the natural frequency will decrease if the fissure is located in the middle of the shell is greater than other locations. but when crack animated across in the ends of the limits the decrease in the natural frequency under C-C only. Results were compared with the literature there was a close agreement.

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1. Introduction

Shell structures have existed in numerous different fields i.e.: mechanical, aeronautical, and civil engineering. A cylindrical shell is one an important kind of shell that has received obtained attention and is used in numerous fields, for example, cooling towers, pipelines, aeronautical, automobile industries, large dams, shell roofs, naval structures, and liquid-retentive constructions. Because of the rising requirements for cylindrical shells and their extensive area of uses, so there is a necessary need for analyzing their dynamic features theoretically. These constructions commonly employ in complex conditions susceptible to various types of loads like (dynamic and fatigue loads) lead to damaging it's by presenting cracks and other flaws deteriorating operational parameters of constructions. Cracks that are on the surface are the most usual flaws in any type of plates and shells, cracks in shell constructions may have an effect on the drop shell's stiffness and strength, which in turn would lower the shell's natural frequencies. Keeping this in mind, the reflection of defects that are pre-formed is an important prodigy when evaluating cylindrical shell in free vibration. The vibration features' analysis for cylinder shells is more difficult than other structures like (pipes, beams, and plates structures). This is due to that the fundamentally the motion's equations for cylinder shells jointly with boundary conditions are more complicated. Conversely, the case of free vibration for cracked shells has been investigated widely in recent decades, to evade undesired accidents which may produce unsteadiness and tearing.

Researchers contributed considerably to the vibration characteristics investigation for shell structures to create analytic relations between the influence of the crack and variant in the dynamic features of the shell as a result of the crack. Wang and Lai [1] introduced the approach to foresee the natural frequencies based on Love's equations of cylinder shells having a finite length without facilitating the motion’s equations for variant boundary conditions. Roytman and Titova, [2] enhanced numerous mathematical Techniques for flexible vibrations of a tubular shell with superficial - closed type fissures. Ip and Tse, [3] created the fissure detecting method in tubular composite material shells built on the natural frequencies, and the styles of the modes at mode shape according to information at certain places. Javidruzi et al. [4] investigated the dynamic behavior of tabular l shells containing different types of fissures fissure subjected to fissure with set supports and lay open to an in-plane (compressive/tensile cyclic edge load). Vaziri and Estekanchi [5] found that the existence of fissures in tabular shells could harshly affect the buckling performance of shell constructions by decreasing their capability for carrying-loads as well as the insertion of buckling locally at the fissure zone. Xin et al. [6] investigated how the performance of free vibration and buckling of a tabular shell is affected by the length of a fissure, orientation, constant rotating speed, and the length diameter ratio. In addition to this the stability features of the fissured shell as well as how the fissure's length. Its orientation, basic speed of rotation, steady load factor, the factor for dynamic load, and the damping ratio were also investigated. Yin and Lam [7] proposed a numerical model for computing natural frequencies for a tubular cylinder shell of finite-length where the fissure is part through the circumferential surface. Moradi and Tavaf [8] investigated with the aid of the quadrature method and Bees algorithm. On how to detect fissures in shell constructions that are tubular cylindrical. Sarker et al. [9] presented a new approach founded on the Ritz procedure for finding impairments in tubular cylindrical structures. Sander’s hypothesis for thin shells coupled with the Ritz's procedure is used for analyzing the dynamic performance of tubular cylindrical shells. K. Moazzeza et al. [10] presented a methodical model to study the performance of free vibration of a long cylindrical tubular shell, involving a changeable oriented surface fissure, in free vibration.

in this research, experimental work to examine the vibration behavior into a cylinder shell involving a circumferential fissure is presented for a given (clamped- clamped and simply supported) boundary conditions controlling the vibrations of cylindrical shells with several parameters of the crack effect. The crack's effect on the natural frequencies and mode shape is analyzed. The experimental work results were verified with the results obtained from the literature and revealed excellent agreement.

2. EXPERIMENTAL WORK

The experimental work presents to calculate the natural frequency of cracked shell structures made from aluminum. The vibration analysis test is carried out under two boundary conditions (Simply supported and Clamped- Clamped) at each end of the shell. The dimensions of the shell are (609.5 mm in length and 242 mm radius). with different thickness (0.5, 0.65, 0.8, 1.2, 2.5 mm) .as shown in Figure 1.

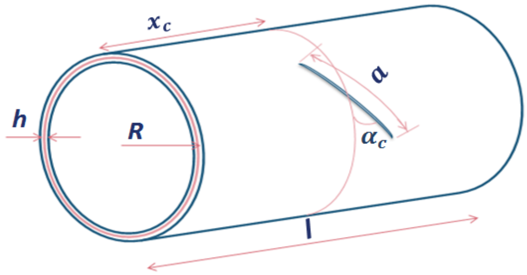

Figure 1: Dimensions of shell Sample with crack.

Where: (R is the shell's radius; l is the shell's length, h is the shell's thickness, a is the length of the crack, α_c is the orientation of the crack, h_c is the depth of the crack, and x_c is the crack location in the shell). The crack in the shell is made by use of (Ferton power tools, that power 135 W and 5000-35000 r.p.m) fixed on the lathe machine as in Figure 2.

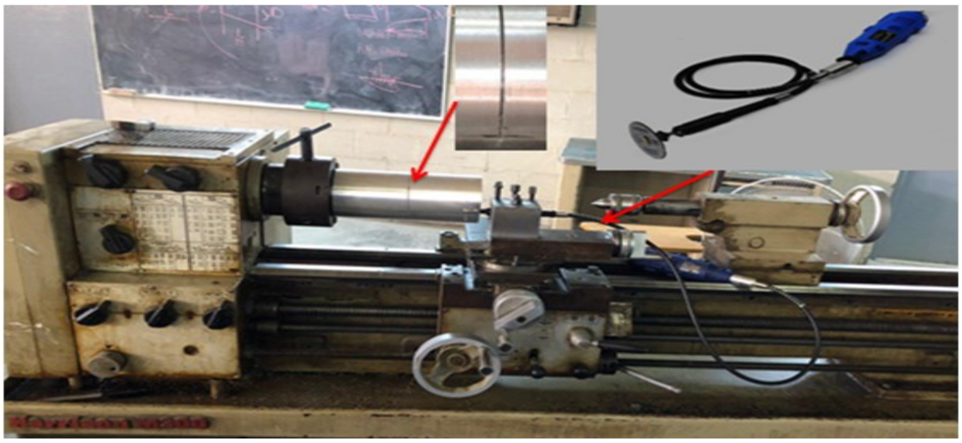

Figure 2: Ferton Power Tools on lathe machine.

Figure 3 shows the cylindrical shell samples used to know the effect of different parameters such as (R/h of the cracked shell, crack length, crack depth, crack location, and crack orientation). Then, the C-C and SS-SS cylindrical shells and other parts and machines were utilized to determine the natural frequency for different parameters of cracked shells. in the vibration structure rig shown in Figures 4, and 5.

The vibration structure consists of the following parts:

i. Structure to support the shell models.
ii. Supported to fixed the shell models.
iii. Impact hammer machine (type 780985-01), the sensitivity of this hammer is 2.27 mV/N. used to stimulate linear structure arrangement since it requires fewer devices than others. its collision forcefulness takes a brief period and can be thought of as pulsation and the tip material was able to be selected to stimulate possibly the low and intermediate natural frequencies.
iv. Accelerometer, (Bruel & Kjaer type 4368) with sensitivity (4.24 µv/m s −1), and it is used to measure the displacement in the shell's transverse direction. The weight of the accelerometer is 30 gm. The accelerometer is mounted in chosen places on the shell and the output signal in millivolts is transmitted to the input channel (charge amplifier).
v. Amplifier (type 2626), it measures the emerging response signal from the accelerometer and gives the produced signal to the digital oscilloscope.
vi. Digital oscilloscope, modal (RIGOL DS1102E), extreme frequency (100 MHz), extreme read of the model per second (25 GS/s).
vii. Then the response signal is saved from the digital storage oscilloscope and convert to the FFT function by used the Sig-view display program to gain the natural frequency of the shell with the different parameters examined. as it is shown in Figure 6.

Figure 3: Cylindrical shell samples

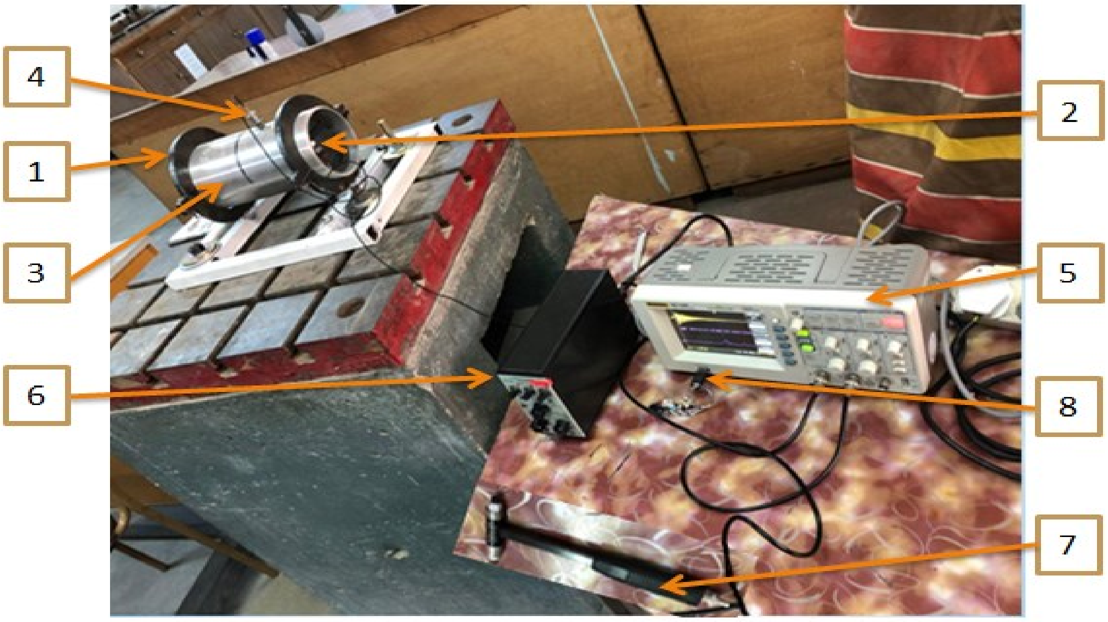

Figure 4: C-C Cylindrical shell vibration test rig.

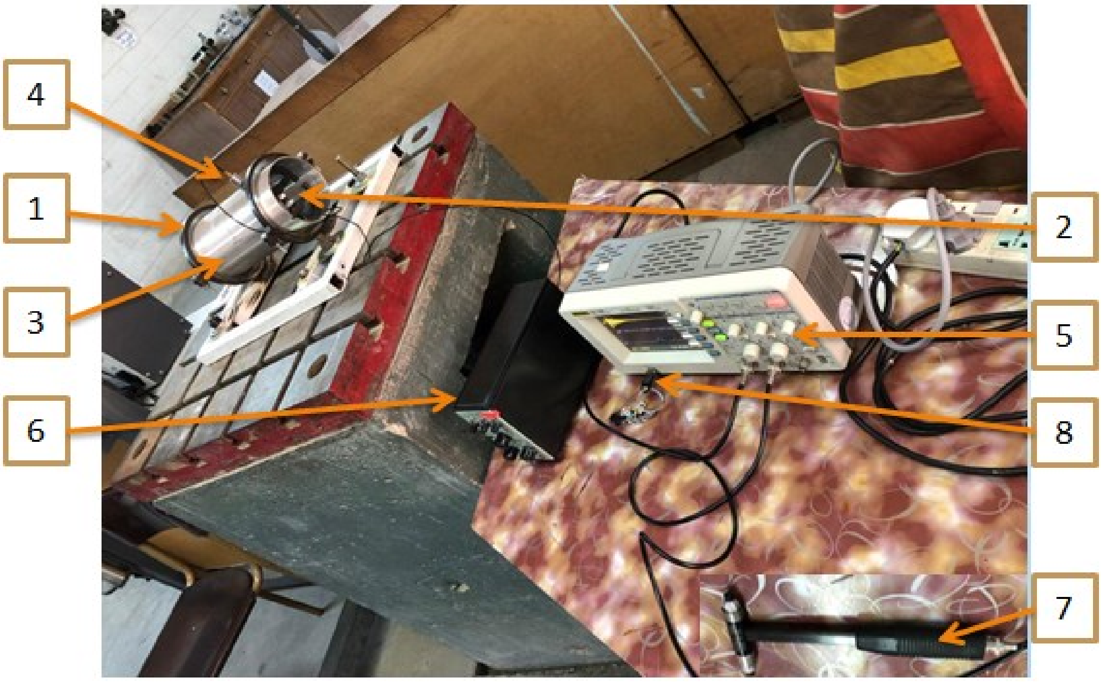

Figure 5: SS-SS Cylindrical shell vibration test rig.

Where: - 1, 2: Boundary conditions, 3: The cylindrical shell, 4: Accelerometer, 5: Digital Oscilloscope, 6: Charge amplifier, 7: Impact hammer, 8: Flash memory.

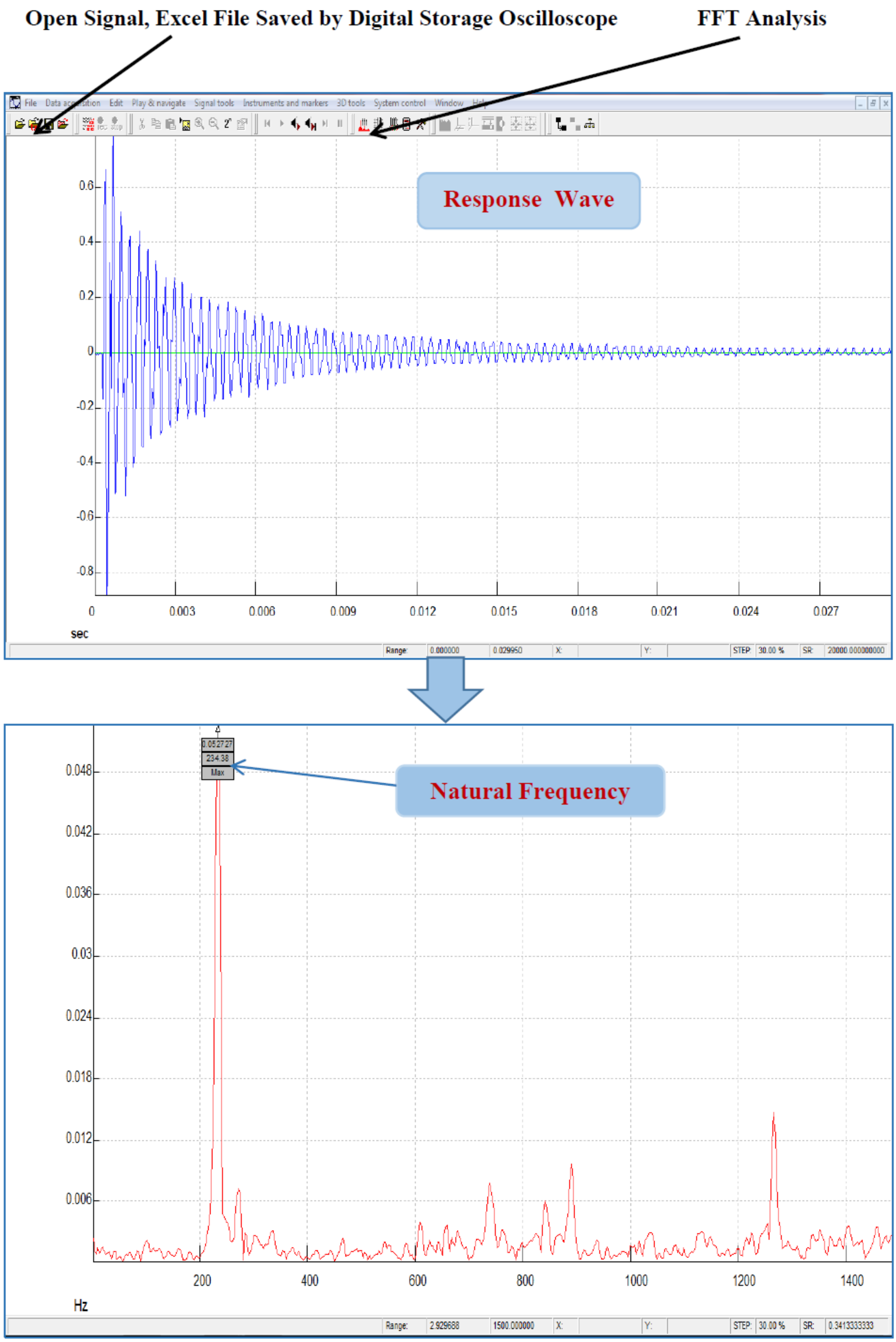

Figure 6: Response wave conversion to FFT function by sig-view program.

3. Results and Discussion

The free vibration analysis is experimentally achieved for the perfect and cylindrical shell involving crack. The Validation of the present work for un-cracked cylinder shells is verified, by the free vibration analysis of a perfect cylindrical shell is performed with (the shell's radius R = 242 mm, shell's length l = 609.5 mm, shell's thickness h = 0.65 mm), aluminum's Young's modulus (E = 68.9 MPa), aluminum's density (ρ = 2700 Kg/m^3) and Poison's ratio (ν = 0.35). The simply supported shell (SS-SS) and clamped- clamped (C-C) boundary conditions are applied to both ends of the shell.

Table I shows that the results (analytical, experimental and numerical) obtained from the literature are united agreement with the present results of the fundamental frequencies.

TABLE I: Comparison of the results obtained from the literature with the present work

Boundary	References	Frequency(Hz)
SS-SS	Experimental (Cook, 1981)[11]	163 and 169
	Analytical (Bolotin 1964)[12]	168.13
	Numerical (Sewall and Naumann, 1968)[13]	166.22
	Numerical (Javidruzi et al., 2004)[5]	166.40
	Numerical (Xin and Wang 2011)[7]	168.73
	Present experimental work	166.41
C-C	Experimental (Cook, 1981)[11]	227
	Numerical (Sewall and Naumann, 1968)[13]	263.44
	Numerical (Javidruzi et al., 2004)[5]	235.91
	Present experimental work	234.38

To study the free vibration characteristics of the cracked cylinder, shell The influences of different parameters like (the ratio of R/h, length crack, orientation crack, crack depth, and location of the crack) on the natural frequencies for several cylindrical shells are examined and discussed as follow:

The effect of thickness of a cylinder shell involves a fissure on vibration characteristics under two kinds of boundary states including (C-C and SS-SS). The results shown in Figure 7 illustrate that the natural frequency of the fissured shell decreases as the thickness of the shell which involving fissure reduces. Also, the frequency lowering of the boundary case (C-C) is more than the boundary case (SS-SS).

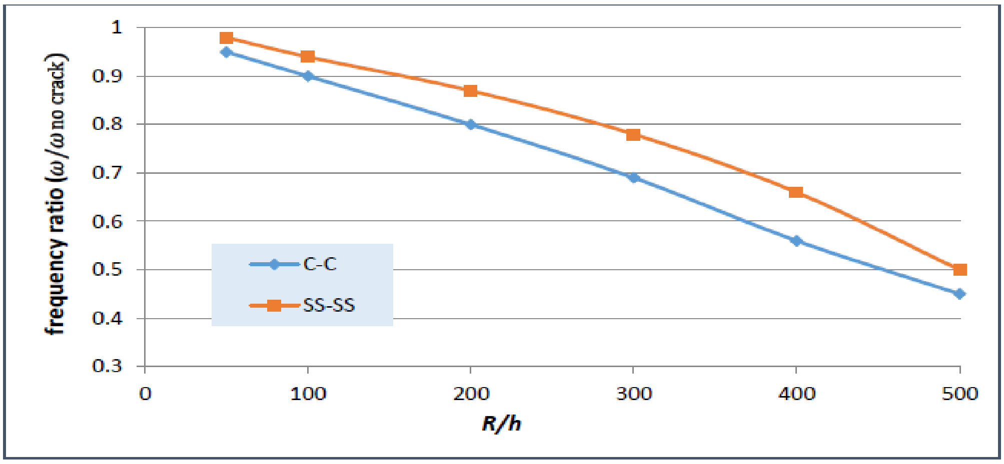

Figure 7: The influence of (R/h) on the change of frequency rate for a cracked shell with open crack, a/2πR = 0.25, Xc/L = 0.5, αc = 0º under two boundary conditions SS-SS and C-C.

Crack length is a significant factor that affects the natural frequency of the cylinder shell which involving a crack as shown in Figure 8. It is also evident that variation of the frequency ratio according to the increase in the fissure length depends on the depth of crack in the shell, and this is causing the lowering in the shell's strength and stiffness.

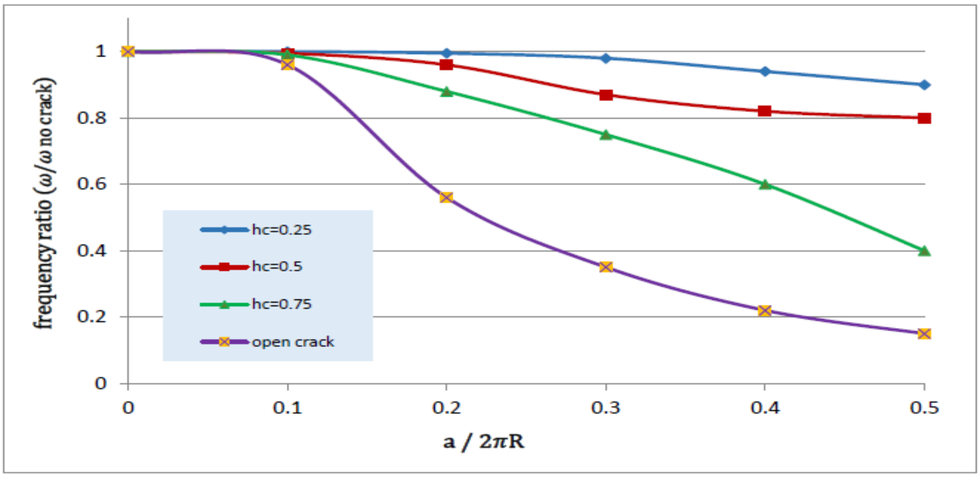

Figure 8: The effects of Normalized crack length (a/2πR) on the change of frequency rate for a cracked shell with Xc/L = 0.5, αc = 0º.

The effect of the orientation of fissure on the frequency of the fissured shell is studied .the results are illustrated in Figure 9. α_c it is the corner lying between the orientation of the flat fissure and the axis of the circumference of the shell. The change of frequency ratio increase obviously as the crack angle increase, until the reaches, 0.8 at 75º then begins to decrease after 75. it will be the shell affected significantly when the crack angle is smaller than 75º. The reason for this is that the transverse component of the oblique fissure is less than it is in the circumferential fissure, this reduces stiffness in the circumferential crack which is the lowest natural frequency of the fissured shell.

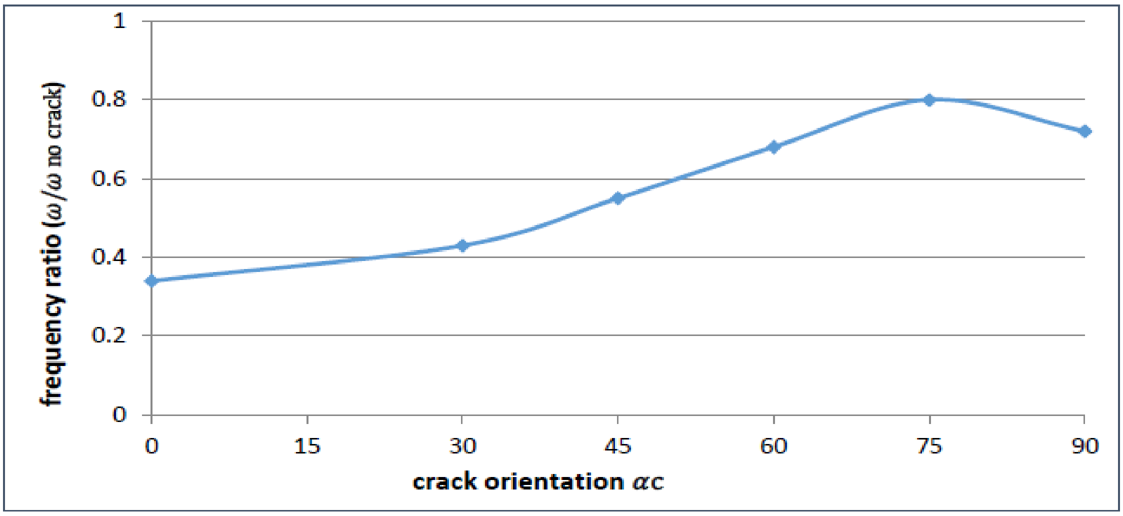

Figure 9: The influence of crack orientation on the change of frequency rate for a cracked shell with open crack, a /2πR = 0.3, X_c /L = 0.5.

the influence of crack location of the cracked shell was studied and results indicated that the lowering in the frequency ratio happened when the crack exists in the center over the longitudinal direction of the shell into the SS-SS and C-C boundary condition. c-c various from the SS-SS boundary condition, by the decreasing in the natural frequency under C-C, which it is larger when the crack is animated across the clamped ends limits as shown in Figures 10 and 11.

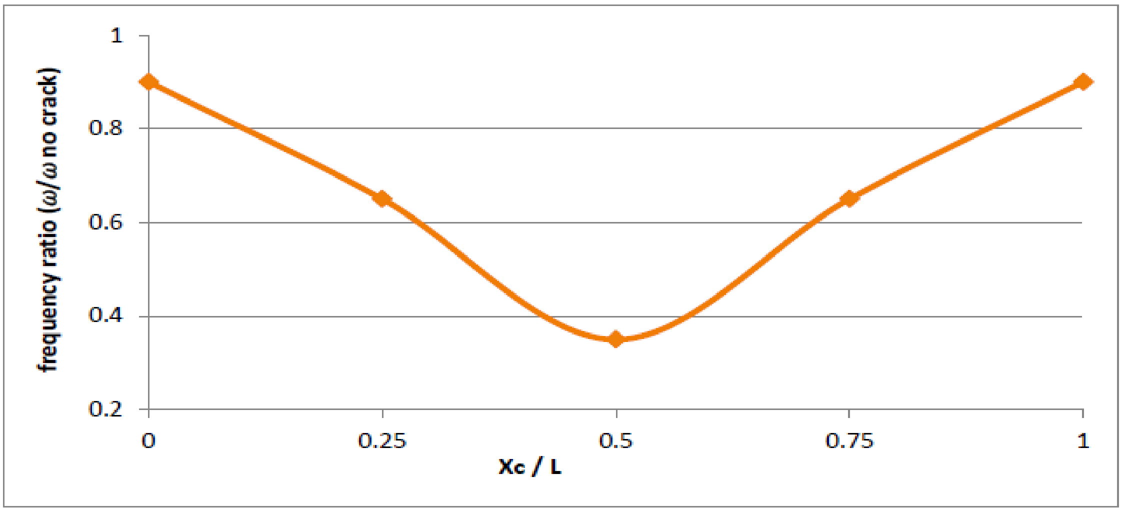

Figure 10: The influence of Normalized crack location on the change of frequency rate for a cracked shell with open crack , a/2πR = 0.3, αc = 0º under SS-SS boundary conditions

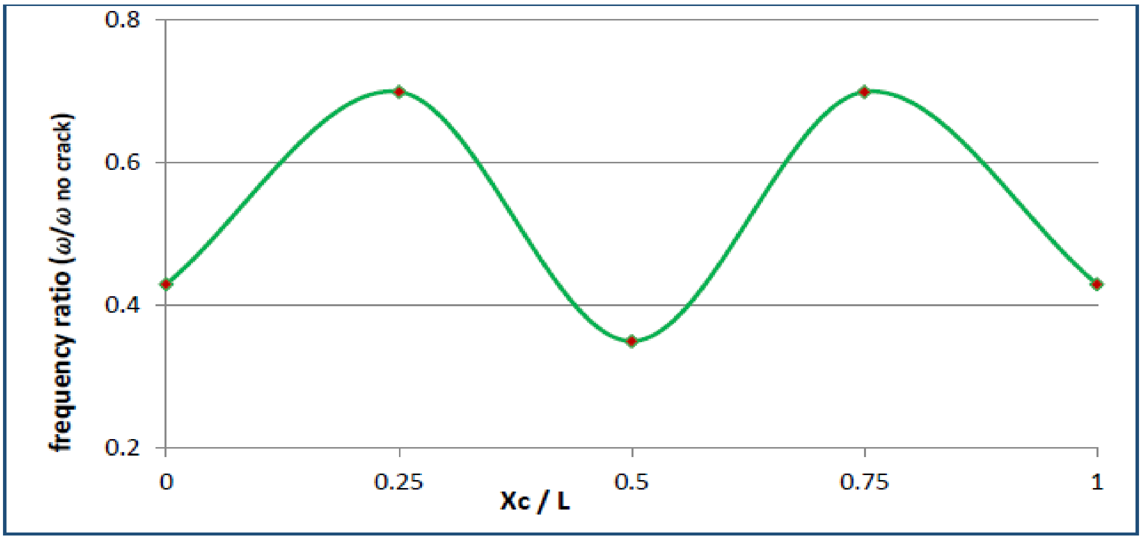

Figure 11: The influence of Normalized crack location on the change of frequency rate for a cracked shell with open crack, a/2πR = 0.3, αc = 0º under C-C boundary conditions.

4. Conclusions

The free vibration analysis experimentally of circular cylinder shell structures having a finite length and which involving a crack was studied. The effect of (R/h), as well as the effect of different parameters of crack such as (crack length, crack depth, the orientation of the crack, and location of the crack), were investigated on the dynamic vibration characteristics of the shell under two representative sets of boundary conditions (SS-SS, and C-C). The results obtained from experimental work for an ideal and cracked cylinder shell were compared with the literature. The verification results were very accurate.

The essential findings able to be summed up as below:

i. For a certain value of L/R, the crack existence reduces the natural frequency of the thin shell by a higher rate than the thick shell.
ii. The natural frequency reduction due to fissuring relies on the boundary state of the tubular shell in which the (C-C) boundary state is extra clear than the (SS-SS) boundary state.
iii. When the fissure length increase, the natural frequency of the tubular shell continues to decrease. This reduction depends on the crack depth and it is more obvious whenever shells were thinner.

iv. The frequency rate increases as the crack angle with the circumference direction of the shell increase until it reached 75º and then decreases frequency ratio when the crack angle greater than 75º this reduction is clearer in thinner shells.
v. The circumferential crack has a greater influence on lowering the frequency than the longitudinal crack of the cylindrical shells.
vi. It is found that the shell's stiffness will decrease as a reaction to an increase in the crack depth and this will lead to a reduction of the natural frequency.
vii. Under a given boundary condition of the shell, the decreasing of the natural frequency in the middle of the length of the shell is higher than in other places.

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