Experimental Investigation of Al -Thin Shells Subjected to Random Vibrations

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Abstract: Experiments were conducted to obtain the modal damping ratios of two hollow cylinders of different thicknesses of Aluminum. An electro dynamic exciter with slip table is used to excite the hollow cylinders. The hollow cylinder (unit under test) is fastened to the exciter. The exciter is placed in the horizontal direction and connected to the slip table. A control accelerometer is placed at the bottom of the cylinder and a measured accelerometer is placed at the top of the cylinder. A control acceleration spectrum is applied at the base of the cylinder to obtain the response power spectrum at the tip. Charge type accelerometers (B&K 4383) are used to measure the acceleration responses along with the signal conditioners (B&K 2635). A lid is fasted to the cylinder to avoid the spilling of the water on the slip table. Tests are performed at different water levels in each cylinder. From each test, half power method is used to estimate the modal damping ratios.

Keywords: Thin shells, Random vibrations, Damping.

I. INTRODUCTION

Vibrations are inherently present in all aspects of everyday life. Examples of industries where knowledge in the area of vibrations is deemed important include the transport, construction, aerospace, naval, manufacturing, military and music industries to name a few. These applications all contain mechanical systems, which can be viewed upon as comprising of distributed elements with characteristics of mass, stiffness and damping. A vibrating response in these systems occurs when an external or internal force excites the system. Such a force is generally either periodic or random in nature. Periodic loadings are most often a result of mass imbalances in machinery such as motors and propellers or cyclic impacts from reciprocating compressors and punching machines. The system responses from such harmonic forceings are generally steady state motion whilst the response from a single random excitation is expected to be a decaying oscillation. In all cases where the structure is surrounded by a fluid, it is possible for noise generation to occur due to the fluctuating pressure disturbance that arises from vibrating motion.

The specific area of vibrations in thin cylindrical shells is applicable to understanding and controlling the dynamic behaviour of aircraft fuselages, submarine hulls, ship hulls, satellite launches, pipelines and pressure vessels where vibrations and the associated noise are considered an issue. Excitations caused by the operation of propellers, motors and other machinery in these applications can generate potentially damaging fatigue stresses, component misalignment, increased wear, energy loss, passenger stress and discomfort from both noise and vibration and finally sonar detectable acoustic signatures in submarines. In order to reduce these undesired effects it is necessary to have a knowledge base of the dynamic behaviour of cylindrical systems and of strategies that can be employed to attenuate the vibration levels.

Each cylindrical system, like all other mechanical systems, has a series of natural vibration frequencies and mode shapes determined by the system geometry, size, material properties and boundary conditions. It is important to note that structural discontinuities such as shell stiffeners, bulkheads, junctions, changes in diameter and end closures and other complicating factors such as fluid loading and fluid dynamic effects should be considered if a more realistic cylindrical shell vibration analysis is desired. Studies have shown that these factors can play a significant part in determining the free response of the system.

Once the free response characteristics of a system have been understood, active and passive control methods can be implemented to reduce the undesired effects of vibration. Passive control involves modifying the mass, stiffness and damper properties to more effectively absorb radiated energy resulting from system disturbances. Active control involves the use of feedback and feed forward control loops to detect the unwanted disturbance and apply a secondary force to minimize the resulting structural response.

The generalized expression for static and dynamic analysis of complicated machines or structures is generally of the form

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[M][\ddot{u}] +[C][\dot{u}] +[K][u] = \{F(t)\}

Where [M] is the global mass matrix, [C] is the damping matrix and [K] is the global stiffness matrix. \{F(t)\} is a given forcing function vector in time, [u] is the resultant displacement vector, [\dot{u}] and [\ddot{u}] are velocity and acceleration respectively.

Depending upon the nature of the coefficients [M], [C],[K] the problems are classified as static dynamic, linear or non-linear.

When [C] = 0,[M] = 0 [K] and \{F(t)\} are constants, the result is a static linear problem.

When [C] and [M]are absent, and [K] is a function of [u] and \{F(t)\} a constant the result is a non-linear static problem.

If \{F(t)\} and [C] are absent , and [M] and [K] are constants, one gets an eigenvalue problem.

If [M], [C] and [K] are constants and \{F(t)\} is a periodic forcing function, the result is a multi-degree of freedom steady state vibration problem.

If [M],[C] and [K] are constants and \{F(t)\} is a transient function of time, the result is a transient vibration problem.

II. LITERATURE REVIEW


Geometrically nonlinear shell theories

Donnell (1934) established the nonlinear theory of circular cylindrical shells under the simplifying shallow-shell hypothesis. Due to its relative simplicity and practical accuracy, this theory has been widely used. The most frequently used form of Donnell’s nonlinear shallow shell theory (also referred as Donnell-Mushtari-Vlasov theory) introduces a stress function in order to combine the three equations of equilibrium involving the shell displacements in the radial, circumferential and axial directions into two equations involving only the radial displacement \(w\) and the stress function \(F\).

The fundamental investigation on the stability of circular cylindrical shells is due to Von Karman and Tsien (1941), who analyzed the static stability (buckling) and the postcritical behavior of axially loaded shells. In this study, it was clarified that discrepancies between forecasts of linear models and experimental results were due to the intrinsic simplifications of linear models; indeed, linear analyses are not able to predict the actual buckling phenomenon observed in experiments; conversely, nonlinear analyses show that the bifurcation path is strongly subcritical, therefore, safe design information can be obtained with a nonlinear analyses only. After this important contribution, many other studies have been published on static and dynamic stability of shells.

Mushtari and Galimov (1957) presented nonlinear theories for moderate and large deformations of thin elastic shells in their book. In the book of Vorovich (1999) the nonlinear theory of shallow shells is also discussed.

Sanders (1963) and Koiter (1966) developed a more refined nonlinear theory of shells, expressed in tensorial form; the same equations were obtained by them around the same period, leading to the designation of these equations as the Sanders-Koiter equations. Later, this theory has been reformulated in lines-of-curvature coordinates, i.e. in a form that can be more suitable for applications; see Budiansky (1968). According to the Sanders-Koiter theory, all three displacements are used in the equations of motion.

Changes in curvature and torsion are linear according to both the Donnell and the Sanders-Koiter nonlinear theories (Yamaki 1984). The Sanders-Koiter theory gives accurate results for vibration amplitudes significantly larger than the shell thickness for thin shells.

Free and forced (radial harmonic excitation) vibrations of shells

The first study on vibrations of circular cylindrical shells is attributed to Reissner (1955), who isolated a single half-wave (lobe) of the vibration mode and analyzed it for simply supported shells; this analysis is therefore only suitable for circular panels. By using Donnell’s nonlinear shallow-shell theory for thin-walled shells, Reissner found that the nonlinearity could be either of the hardening or softening type, depending on the geometry of the lobe. Almost at the same time, Grigolyuk (1955) studied large-amplitude free vibrations of circular cylindrical panels simply supported at all four edges. He used the same shell theory as Reissner (1955) and a two-mode expansion for the flexural displacement involving the first and third longitudinal modes. He also developed a single mode approach. Results show a hardening type nonlinearity. Chu (1961) continued with Reissner’s work, extending the analysis to closed cylindrical shells. He found that nonlinearity in this case always leads to hardening type characteristics, which, in some cases, can become quite strong.

Cummings (1964) confirmed Reissner’s analysis for circular cylindrical panels simply supported at the four edges; he also investigated the transient response to impulsive and step functions, as well as dynamic buckling. Nowinski (1963) confirmed Chu’s results for closed circular shells. He used a single-degree-of-freedom expansion for the radial displacement using the linear mode excited, corrected by a uniform displacement that was introduced to satisfy the continuity of the circumferential displacement. All of the above expansions for the description of shell deformation, except for Grigolyuk’s, employed a single mode based on the linear analysis of shell vibrations.
Evensen (1963) proved that Nowinski’s analysis was not accurate, because it did not maintain a zero transverse deflection at the ends of the shell. Furthermore, Evensen found that Reissner’s and Chu’s theories did not satisfy the continuity of in-plane circumferential displacement for closed circular shells. Evensen (1963) noted in his experiments that the nonlinearity of closed shells is of the softening type and weak, as also observed by Olson (1965). Indeed, Olson (1965) observed a slight nonlinearity of the softening type in the experimental response of a thin seamless shell made of copper; the measured change in resonance frequency was only about 0.75 %, for a vibration amplitude equal to 2.5 times the shell thickness. The shell ends were attached to a ring; this arrangement for the boundary conditions gave some kind of constraint to the axial displacement and rotation. Kaña et al. (1966; see also Kaña 1966) also found experimentally a weak softening type response for a simply supported thin circular cylindrical shell.

Chen and Babcock (1975) used the perturbation method to solve the nonlinear equations obtained by Donnell’s nonlinear shallow-shell theory, without selecting a particular deflection solution. They solved the classical simply supported case and studied the driven mode response, the companion mode participation, and the appearance of a travelling wave. A damped response to an external excitation was found. The solution involved a sophisticated mode expansion, including boundary layer terms in order to satisfy the boundary conditions. They also presented experimental results in good agreement with their theory, showing a softening nonlinearity. Regions with amplitude-modulated response were also experimentally detected.

Raju and Rao (1976) employed the Sanders-Koiter theory and used the finite element method to study free vibrations of shells of revolution. They found hardening-type results for a closed circular cylindrical shell, in contradiction with all experiments available. Their paper was discussed by Evensen (1977), Prathap (1978a, b), and then again by Evensen (1978a, b). In particular, Evensen (1977) commented that the authors ignored the physics of the problem: i.e., that thin shells bend more readily than they stretch.

Gonçalves and Batista (1988) conducted an interesting study on fluid-filled, complete circular cylindrical shells. A mode expansion that can be considered a simple generalisation of Evensen’s (1967) was introduced by Varadan et al. (1989), along with Donnell’s nonlinear shallow-shell theory, in their brief note on shell vibrations. This expansion is the same as that used by Watawala and Nash (1983); as previously observed, it is not moment-free at the ends of the shell. The results were compared with those obtained by using the mode expansion proposed by Dowell and Ventres (1968) and Atluri (1972). Varadan et al. (1989) showed that the expansion of Dowell and Ventres and Atluri gives hardening-type results, as previously discussed; the results obtained with the expansion of Watawala and Nash correctly display a softening type nonlinearity.

Chiba (1993a) studied experimentally large-amplitude vibrations of two cantilevered circular cylindrical shells made of polyester sheet. He found that almost all responses display a softening nonlinearity. He observed that for modes with the same axial wave number, the weakest degree of softening nonlinearity can be attributed to the mode having the minimum natural frequency. He also found that shorter shells have a larger softening nonlinearity than longer ones. Travelling wave modes were also observed.

Koval’chuk and Lakiza (1995) investigated experimentally forced vibrations of large amplitude in fiberglass shells of revolution. The boundary conditions at the shell bottom simulated a clamped end, while the top end was free (cantilevered shell). One of the tested shells was circular cylindrical. A weak softening nonlinearity was found, excluding the beam-bending mode for which a hardening nonlinearity was measured. Detailed responses for three different excitation levels were obtained for the mode with four circumferential waves (second mode of the shell). Travelling wave response was observed around resonance, as well as the expected weak softening type nonlinearity.

Ganapathi and Varadan (1996) used the finite element method to study large-amplitude vibrations of doubly-curved composite shells. Numerical results were given for isotropic circular cylindrical shells. They showed the effect of including the axisymmetric contraction mode with the asymmetric linear modes, confirming the effectiveness of the mode expansions used by many authors, as discussed in the foregoing. Only free vibrations were investigated in the paper, using Novozhilov’s theory of shells. A four-node finite element was developed with five degrees of freedom for each node. Ganapathi and Varadan also pointed out problems in the finite element analysis of closed shells that are not present in open shells. The same approach was used to study.

Amabili et al. (1998) investigated the nonlinear free and forced vibrations of a simply supported, complete circular cylindrical shell, empty or fluid-filled. Donnell’s nonlinear shallowshell theory was used. The boundary conditions on the radial displacement and the continuity of circumferential displacement were exactly satisfied, while the axial constraint was satisfied on the average. Galerkin projection was used and the mode shape was expanded by using three degrees of freedom; specifically, two asymmetric modes (driven and companion modes), plus an axisymmetric term involving the first and third axisymmetric modes (reduced to a single term by an artificial constraint), were employed. The time dependence of each term of the expansion was general. Different tangential constraints were imposed at the shell ends. An inviscid fluid was considered. Solution was obtained both numerically and by the method of normal forms. Numerical results were obtained for both free and forced vibrations of empty and water-filled shells. Some additions to this paper were given by Amabili et al.
(1999a). Results showed a softening type nonlinearity and travelling-wave response close to resonance. Numerical results are in quantitative agreement with those of Evensen (1967), Olson (1965), Chen and Babcock (1975) and Gonçalves and Batista (1988). In a series of four papers, Amabili, Pellicano and Paidoussis (1999b, c, 2000a, b) studied the nonlinear stability and nonlinear forced vibrations of a simply supported cylindrical shell with and without flow by using Donnell’s nonlinear shallow-shell theory. The Amabili et al. (1999c, 2000a) papers deal with large-amplitude vibrations of empty and fluid-filled circular shells, also investigated by Amabili et al. (1998), but use an improved model for the solution expansion. In Amabili et al. (1999c) three independent axisymmetric modes with an odd number of longitudinal half-waves were added to the driven and companion modes. Therefore, the model can be considered to be an extension of the three-degree-of-freedom one developed by Amabili et al. (1998), in which the artificial kinematic constraint between the first and third axisymmetric modes, previously used to reduce the number of degrees of freedom, was removed. Results showed that the first and third axisymmetric modes are fundamental for predicting accurately the trend of nonlinearity and that the fifth axisymmetric mode only gives a small contribution.

Driven modes with one and two longitudinal half-waves were numerically computed. Periodic solutions were obtained by a continuation technique based on the collocation method. Amabili et al. (2000a) added, to the expansion of the radial displacement of the shell, modes with twice the number of circumferential waves vis-à-vis the driven mode and up to three longitudinal half-waves, in order to check the convergence of the solution with different expansions. Results for empty and water-filled shells were compared, showing that the contained dense fluid largely enhances the weak softening type nonlinearity of empty shells; a similar conclusion was previously obtained by Gonçalves and Batista (1988). Experiments on a water-filled circular cylindrical shell were also performed and successfully compared to the theoretical results, validating the model developed. Experiments showed a reduction of the resonance frequency by about 2% for a vibration amplitude equal to the shell thickness. These experiments are described in detail in Amabili, Garziera and Negri (2002), where additional experimental details and results are given. It is important to note that, in this series of papers (Amabili et al. 1999b, c; 2000a, b), the continuity of the circumferential displacements and the boundary conditions for the radial deflection were exactly satisfied.

Imperfect shells

Jansen (1992) studied large-amplitude vibrations of simply supported, laminated, complete circular cylindrical shells with imperfections. He used Donnell’s nonlinear shallowshell theory and the same mode expansion as Watawala and Nash (1983); the boundary conditions at the shell ends were not fully satisfied. The results showed a softening-type nonlinearity becoming hardening only for very large amplitude of vibrations (generally larger than ten times the shell thickness). Imperfections having the same shape as the asymmetric mode analyzed gave a less pronounced softening behaviour, changing to hardening for smaller amplitudes. Moreover, the linear frequency of the imperfect shell may be considerably lower than the frequency of the perfect shell. In a subsequent study Jansen (2002) developed his model further by using a four-degree-of-freedom expansion. However, numerical results are presented only for a perfect shell. In a third paper by the same author (Jansen 2001), results for composite shells with axisymmetric and asymmetric imperfections are given.

Chia (1987a, b) studied nonlinear free vibrations and postbuckling of symmetrically and asymmetrically laminated circular cylindrical panels with imperfections and different boundary conditions. Donnell’s nonlinear shallow-shell theory was used. A single-mode analysis was carried out, and the results showed a hardening nonlinearity. In a subsequent study Chia (1988b) also investigated doubly-curved panels with rectangular base by using a similar shell theory, and a single-mode expansion in all the numerical calculations, for both vibration shape and initial imperfection. However, in this study, numerical results for circular cylindrical panels and doubly curved shallow shells generally show a softening nonlinearity, which becomes hardening only for very large vibrations, as expected. The equations of motion are obtained by Galerkin’s method and are studied by using the harmonic balance method. Only the backbone curves are given. Iu and Chia (1988a) studied antisymmetrically laminated cross-ply circular cylindrical panels by using the Timoshenko-Mindlin kinematic hypothesis, which is an extension of Donnell’s nonlinear shallow-shell theory. Effects of transverse shear deformation, rotary inertia and geometrical imperfections were included in the analysis. The solution was obtained by the harmonic balance method after Galerkin projection. Fu and Chia (1989) extended this analysis to include a multi-mode approach.

Amabili (2003c) included geometric imperfections in the model previously developed by Pellicano et al. (2002) and performed in depth experimental investigations on large-amplitude vibrations of an empty and water-filled, simply supported circular cylindrical shell subject to harmonic excitations. The effect of geometric imperfections on natural frequencies was investigated. In particular, it was found that: (i) axisymmetric imperfections do not split the double natural frequencies associated with each couple of asymmetric modes; outward (with respect with the center of curvature) axisymmetric imperfections increase natural frequencies; small inward (with respect with the center of curvature) axisymmetric imperfections decrease natural frequencies; (ii)
Ovalisation has a small effect on natural frequencies of modes with several circumferential waves and it does not split the double natural frequencies; (iii) imperfections of the same shape as the resonant mode decrease both frequencies, but much more the frequency of the mode with the same angular orientation; (iv) imperfections with the twice the number of circumferential waves of the resonant mode decrease the frequency of the mode with the same angular orientation and increase the frequency of the other mode; they have a larger effect on natural frequencies than imperfections of the same shape as the resonant mode. The split of the double natural frequencies, which is present in almost all real shells due to manufacturing imperfections, changes the traveling wave response. Good agreement between theoretical and experimental results was obtained. All the modes investigated show a softening type nonlinearity, which is much more accentuated for the water-filled shell, except in a case displaying internal resonance (one-to-one) among modes with different number of circumferential waves. Travelling wave and amplitude-modulated responses were observed in the experiments.

Results for imperfect shells obtained by Donnell’s nonlinear shell theory retaining inplane-inertia and Sanders-Koiter nonlinear shell theory are given by Amabili (2003a).

**Shells Subjected to Seismic excitation**

Vijayarachavan and Evan-Iwanowski (1967) analyzed, both analytically and experimentally, the parametric instabilities of a circular shell under seismic excitation. The cylinder position was vertical and the base was axially excited by using a shaker. In this problem, the in-plane inertia is variable along the shell axis and, when the base is harmonically excited, it gives rise to a parametric excitation. Instability regions were found analytically and compared with experimental results.

Bondarenko and Galaka (1977) investigated the parametric instabilities of a composite shell under base seismic motion and free top end. They identified principal instability regions of several modes and also secondary regions; they observed that, the transition from stable to unstable regions is accompanied by a “bang” that can lead the shell to the collapse.

Bondarenko and Topalov (1982) studied experimentally the dynamic instability and nonlinear oscillations of shells; the frequency response was hardening in the region of the main parametric resonance for circumferential wave number $n=2$ and softening for $n > 2$.

Trotsenko and Trotsenko (2004), studied vibrations of circular cylindrical shells, with attached rigid bodies, by means of a mixed expansion based on trigonometric functions and Legendre polynomials; they considered only linear vibrations.

Pellicano (2005) presented experimental results about violent vibration phenomena appearing in a shell with base harmonic excitation and carrying a rigid mass on the top. When the first axisymmetric mode is in resonance conditions the top mass undergoes to large amplitude of vibration and a huge out of plane shell vibration is detected (more than 2000g), with a relatively low base excitation (about 10g).

Pellicano and Avramov (2007) published a paper concerning the nonlinear dynamics of a shell with base excitation and a top disk. The work was mainly theoretical, i.e. only some experimental results concerning the linear dynamics were presented; the shell was modelled using the nonlinear Sanders–Koiter theory and a reduced order model was used; the analysis was mainly focused on the principal parametric resonance due to high frequency excitations. A similar analysis was presented also in Avramov and Pellicano (2006).

Pellicano (2007) developed a new method, based on the nonlinear Sanders–Koiter theory, suitable for handling complex boundary conditions of circular cylindrical shells and large amplitude of vibrations. The method was based on a mixed expansions considering orthogonal polynomials and harmonic functions. Among the others, the method showed good accuracy also in the case of a shell connected with a rigid body; this method is the starting point for the model developed in the present research.

Mallon et al. (2008) studied isotropic circular cylindrical shells under harmonic base excitation; they used the Donnell’s nonlinear shallow shell theory; a multimode expansion, suitable for analyzing the nonlinear resonance and dynamic instability of a specific mode, was used; they presented comparisons between the semianalytical procedure and a FEM model in the case of linear vibrations or buckling. Using the nonlinear semi-analytical model they found beating and chaotic responses, severe out of plane vibration and sensitivity to imperfections.

Kubenko and Koval’chuk (2009) published an experimental work focused on shells made of composite materials; they pointed out the inadequateness of the linear viscous damping models. Axial loads (base excitation, and free top end of the shell) and combined loads were considered. The analysis of the principal parametric instability was carried out (probably with sub harmonic response, but no information are give about). Dynamic instability regions were determined experimentally: a disagreement between previous theoretical models (narrower region) and experiments (wider) was found, the conjecture made by such scientists was that the disagreement was due to shells geometric imperfections. Such paper summarizes some of experimental results published on a previous book (Kubenko et al., 1984).

Mallon et al. (2010) studied circular cylindrical shells made of orthotropic material, the Donnell’s nonlinear shallow shell theory was used with a multimode expansion for discretization (PDE to ODE). They presented also experimental results. The theoretical
model considered also the shaker-shell interaction (it is to note that one of the first works concerning the interaction between an electromechanical shaker and a mechanical system is due to Krasnopolskaya (1976)). Mallon et al. (2010) investigated the imperfections sensitivity and found a reduction of the instability threshold. No good quantitative match between theory and experiments was found: saturation phenomena, beating and chaos were found numerically. However, this can be considered a seminal work due to the intuition that some complex phenomena can be due to the shaker shell interaction.

In Pellicano (2011), experiments are carried out on a circular cylindrical shell, made of a polymeric material (P.E.T.) and clamped at the base by gluing its bottom to a rigid support. The axis of the cylinder is vertical and a rigid disk is connected to the shell top end. In Pellicano (2007) this problem was fully analyzed from a linear point of view. Here nonlinear phenomena are investigated by exciting the shell using a shaking table and a sine excitation. Shaking the shell from the bottom induces a vertical motion of the top disk that causes axial loads due to inertia forces. Such axial loads generally give rise to axial-symmetric deformations; however, in some conditions it is observed experimentally that a violent resonant phenomenon takes place, with a strong energy transfer from low to high frequencies and huge amplitude of vibration. Moreover, an interesting saturation phenomenon is observed: the response of the top disk was completely flat as the excitation frequency was changed around the first axisymmetric mode resonance.

Raydin Salahifar (2010) analysed cylindrical shells based on the variational form of Hamilton’s principle, the field equations and boundary conditions are formulated for circular cylindrical thin shells under general in-phase and out-of-phase harmonic loads. The resulting field equations are solved in a closed form for general loading and boundary conditions. Through Fourier decomposition of the body forces in the longitudinal direction, a technique for developing the particular solution for general harmonic loading was developed. Through four examples, the results based on the current formulation are shown to be in consistent agreement with those based on established shell models in Abaqus.

Liu and Xing (2012) presented an exact procedure and closed-form solutions with analytically determined coefficients for free vibrations of thin orthotropic circular cylindrical shells with classical boundary conditions. The Donnell–Mushtari thin shell theory and the separation of variables method are employed in the derivation. The proposed method has been verified through comparing its results against results available in literature and of the highly accurate semi-analytical differential quadrature finite element method (S-DQFEM) developed by the authors. The characteristics of the eigenvalues are also examined. It may be known that the Donnell–Mushtari shell theory is the simplest thin shell theory and its results for the lowest frequencies of a closed cylinder may not be as accurate.

Sun and Chu (2012) has been successfully applied the Fourier expansion method to analyze the vibration of a thin rotating cylindrical shell. Validation of this method has been checked by comparisons with previous results in the literature. The method presented makes it possible to derive an analytical solution for a thin rotating cylinder with classical boundary conditions of any type. And, the frequencies of travelling wave can be obtained easily from corresponding frequency determinants. The order of frequency determinant may vary from one to eight depending on the boundary conditions to be satisfied, while the frequency determinant by previous studies [13, 26] is always eight-by-eight. One can easily obtain the frequency determinant of a thin rotating cylindrical shell with any given boundary conditions by deleting corresponding rows and columns from frequency determinant of a thin rotating cylindrical shell with “AD-S-S” boundary, and thus complexity of reconstructing frequency determinants for various boundary conditions is avoided.

The literature shows that, in the past, several methods were developed for investigating: i) nonlinear vibration and stability; ii) the role of imperfections; iii) fluid structure interaction. However, there are few experimental studies about dynamic instabilities and the comparisons between theory and experiments are not yet satisfactory.

Problem formulation and description

In the present work an experimental investigation of aluminum circular cylindrical shell of two different thicknesses (h= 2 mm and 3mm) with outer diameter of 100mm and length of 300mm were considered. The shaker shell interaction. However, there are few experimental studies about dynamic instabilities and the comparisons between theory and experiments are not yet satisfactory. The shell is fixed at one end to a vibration testing slip table with bolt and nut using a fixture. The shell is subjected to random base excitations with and without fluid. Two accelerometers were fixed to the shell one at fixed end another at its free end. Its response at free end is recorded.

Shell With geometry
Specifications of the Shaker Table:

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<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Armature Diameter, m</td>
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<tr>
<td>Rated Force, kgf</td>
<td>10000 Peak, Sine</td>
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<td></td>
<td>10000 rms, Random</td>
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<tr>
<td>Frequency range, Hz</td>
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<tr>
<td>Maximum acceleration, g</td>
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<tr>
<td>Armature resonance, Hz</td>
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<td>Velocity, m/s</td>
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<tr>
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<tr>
<td>Pay load capacity, kg</td>
<td>800 direct</td>
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<tr>
<td></td>
<td>1400 with load support platform</td>
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**RESULTS:**

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<td>Amplitude, g/g</td>
<td>Damping ratio, %</td>
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<td>22.0251</td>
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<tr>
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MATERIAL

<table>
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<th>thickness</th>
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<td>Frequency Hz</td>
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<td>Damping ratio %</td>
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IV. CONCLUSIONS

It is observed that as water column is increased the frequency is decreased for 2mm shell.

The frequencies are less for 2mm shell compared to 3mm shell. The amplitude is decreased as water column is increased to 60mm from empty and then it is increased as further water column is increased.

REFERENCES:


