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VIBRODIAGNOSTICS OF FATIGUE CRACKS IN CYLINDER SHELLS

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ABSTRACT

The experimental-theoretical method of vibrodiagnostics of "breathing" cracks in cylinder shells is offered. By "breathing" crack, we understand the following. In the first of the semicycles of oscillations fibers with the crack are compressed, the crack is closed and the crack's influence is neglected. In the second semicycle of oscillations the fibers with the crack are stretched the crack is open and the shell's thickness being under stretching is decreased by crack's depth. The offered method is based on registration of a modification of frequency of a signal. The method is convenient for units of constructions, in which it is possible to rather easily excite oscillations bringing the material of shell in a state of tension - squeezing. The analytic model of oscillations of a cylinder shell with a "breathing" crack is constructed. The shape of oscillations is picked depending on an aspect of a crack, its orientation and location on the shell. The diagnostic function permitting approximately to define depth of a crack depending on its location and parameters a shell is constructed.

KEYWORDS

Vibrodiagnostics, Fatigue Crack, Cylinder Shell, Oscillations, Diagnostic Function.

INTRODUCTION

The units of modern constructions, for example aerospace constructions, work in rather heavy duties. As a result, during the oscillations there may be observed fractures that are preceded by formation of cracks caused by vibrations of details.

The restricted number of researches is devoted to problems of calculation of a stressedly-deformed state and diagnostics of cracks in elements construction[1 - 3]. In this connection the problems of diagnostics of cracks in shells remain actual.

The researches are developed in directions of practical application (aerospace engineering, atomic engineering, construction of pipelines, sea drilling platforms, shipbuilding, etc). The problem of finding the reliable criteria of damage estimation is of particular interest.

The paper [4] represents the set of indicators of damages (diagnostic functions), which can be used for diagnostics of cracks in units of machine-building constructions, with the definition of their advantages and disadvantages. In the paper more than one hundred papers devoted to this subject are surveyed. The following basic types of indicators are considered : 1. Natural frequencies, 2. The modal forms, 3. Damping, 4. Resonant frequencies, 5. Amplitudes of oscillations, 6.

Transitional or superharmonic indicators, 7. Forced oscillations, 8. Phase curves. The method of natural frequencies is regarded the most acceptable for measuring with a rather high level of accuracy.

The damages of such a type were presumably the cause of catastrophes of the first jet passenger planes and atomic submarines. The cracks were a corollary of low-cycle fatigue. During each take-off (immersion) at considerable height (depth) a fuselage of the plane or hull of a submarine were essentially deformed in comparison with a state on ground (sea level). The complexity of diagnostics of such cracks is caused by that in a unloaded state the cracks it are not discovered, and "are uncovered" only at take-off (immersion) on considerable height (depth).

In the present paper the experimental-theoretical method of vibration diagnostics of "breathing" cracks of cylinder shells is offered.

BODY OF PAPER

The solution of the problem of free oscillations of the circular cylinder shells without the crack is the function [5]:

$$w = C_{m,n} \sin \frac{xm\pi}{l} \cos n\varphi \cos \omega t. \tag{1}$$

Here m - number of half-waves in the longitudinal direction, n - number of waves in the transverse direction, the axis x is directed along the symmetry axis of the median surface of shell, l - length of the shell, t - time of the oscillations. The model of shell is presented on Figure 1.

The parameters of oscillations of such shell can be found with the help of the energy method. It is supposed, that the system is conservative and that is $K + \Pi = const$, where K and Π - kinetic and potential energy of oscillations of shell respectively. In the process of oscillations the shell transits some positions, at one of which $K = K_{\max}$, $\Pi = 0$, and at the second - $K = 0$, $\Pi = \Pi_{\max}$. Then $K_{\max} = \Pi_{\max}$. Using last equality we shall find the frequency of oscillations of the cylinder shell without the crack.

By reviewing oscillations of shell we count, that $m = 1$, $n = 0$ in a case, when it has a circular transversal crack at $l/2$, whose depth is much less than half of width of shell (Figure 2), and $m = 1$, $n = 2$, when it has a longitudinal crack (Figure 3).

By reviewing oscillations of a cylinder shell with other configuration of the crack it is necessary to select other form of oscillations, more convenient, for example tortional form of oscillations for the crack, which is located at angle on the surface of shell.

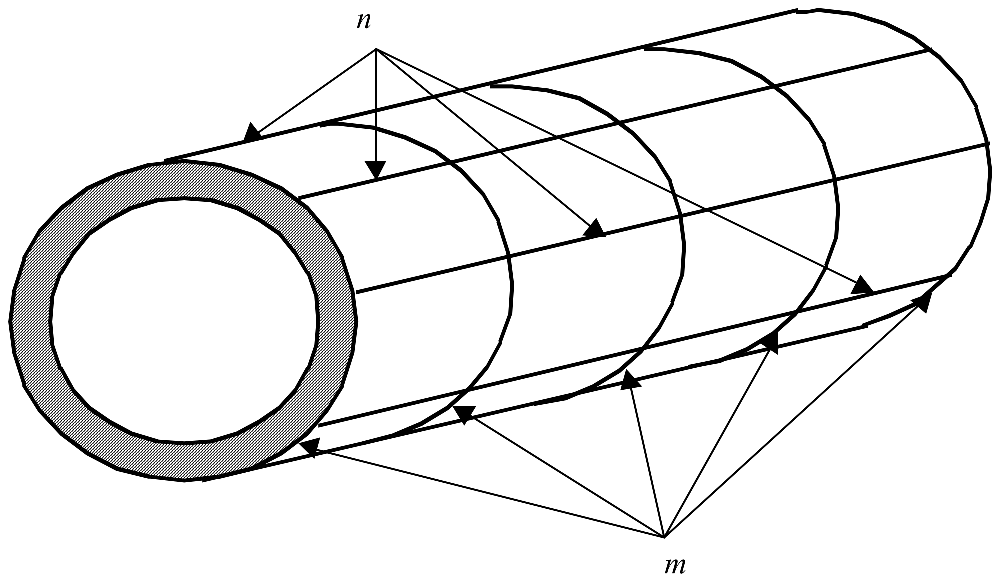

Figure 1: The modes of vibration of shell

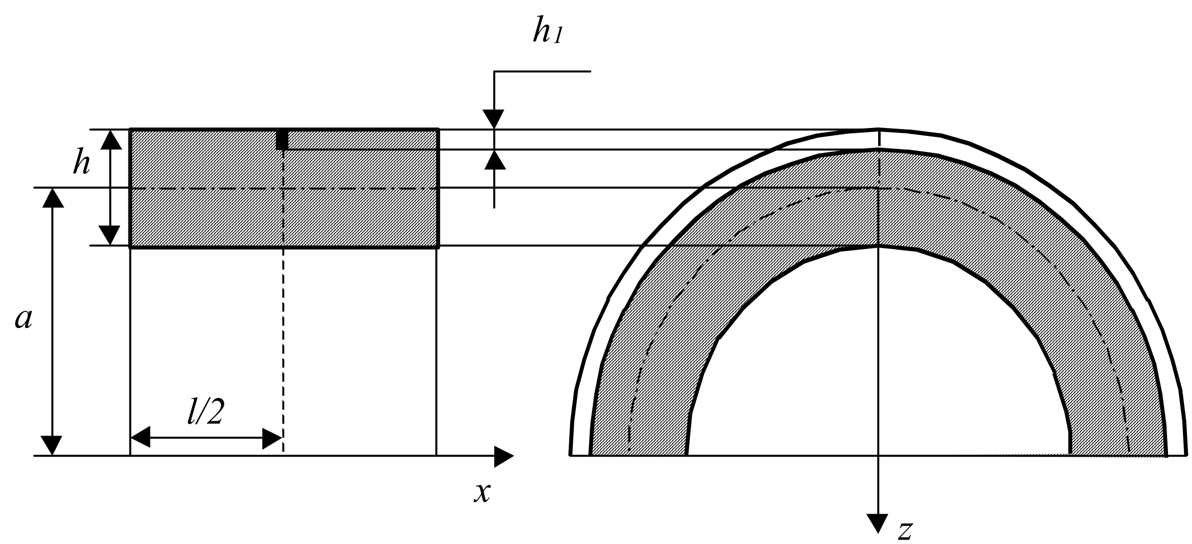

Figure 2: The shell with transversal crack

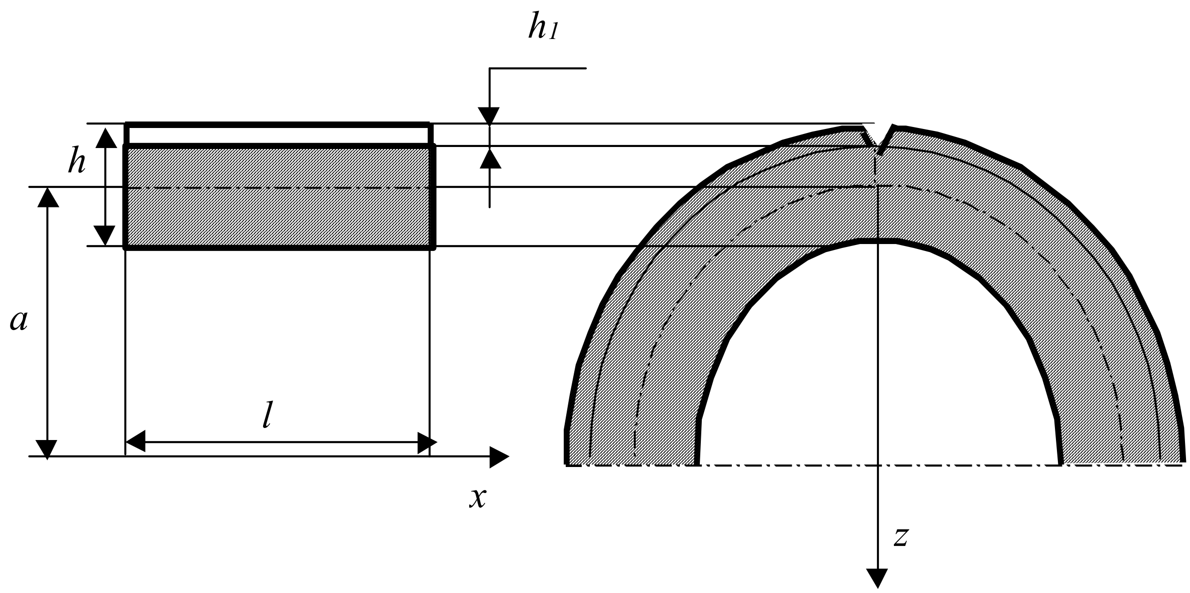

Figure 2: The shell with longitudinal crack

The oscillations of the shell start at the moment when the load acting on the shell is removed. The crack is closed and does not influence the process of oscillation. Further shell reaches a neutral position, the crack opens up to the maximum value, starts to close and the shell transits neutral and achieves an initial position.

It is supposed, that two frequencies will appear in period of oscillations cycle T: ω_0, corresponding to the closed crack, and ω_1, corresponding to the open crack. The period of oscillations is written as follows [2, 5]:

$$T = \frac{\pi}{\omega_0} + \frac{\pi}{\omega_1} = \frac{\pi(\omega_1 + \omega_0)}{\omega_1 \omega_0}. \tag{2}$$

The oscillations will transit with the averaged frequency $\overline{\omega} = \frac{2\pi}{T} = \frac{2\omega_1\omega_0}{\omega_1 + \omega_0}$. In this case w is possible to be written as follows:

$$w = \begin{cases} A_0 \sin\frac{\pi x}{l}\cos\omega_0 t, \qquad 0 \le t \le \frac{\pi}{2\omega_0}, \text{the crack is closed,} \\ A_1 \sin\frac{\pi x}{l}\cos\omega_1\left(t + \frac{\pi}{2\omega_1} - \frac{\pi}{2\omega_0}\right), \frac{\pi}{2\omega_0} < t \le \frac{\pi}{2\omega_0} + \frac{\pi}{\omega_1}, \text{ the crack is opened,} \\ A_0 \sin\frac{\pi x}{l}\cos\left(t + \frac{\pi}{\omega_0} - \frac{\pi}{\omega_1}\right), \frac{\pi}{2\omega_0} + \frac{\pi}{\omega_1} < t \le T, \text{the crack is closed,} \end{cases} \tag{3}$$

where A_0 - amplitude of oscillations of shell on the semicycle with the closed crack, A_1 - on the semicycle with the closed crack.

With the help of the energy method we can find the frequency ω_1. For this purpose it is necessary to remove the material of shell, in which the elastic energy of deformation is absent. Using the energy method we can find amplitude A_1 and A_0.

As analytical indicators of cracks it is possible to consider the following diagnostic functions: ω_0/ω_1 and A_1/A_0.

The graphs of the ratios of frequencies and amplitudes of oscillations depending on relative depth of the crack are showed on Figure 4.

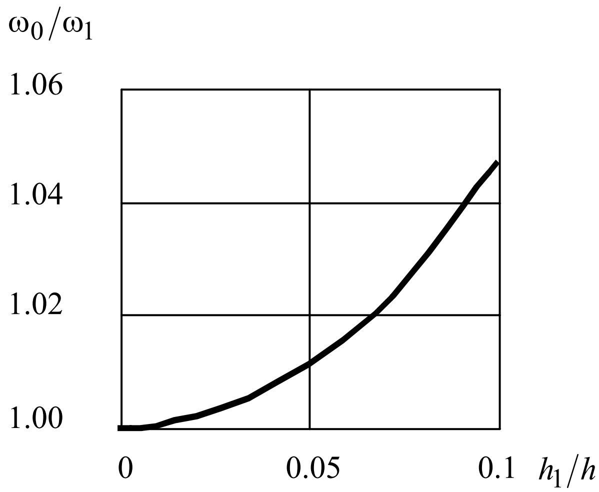

Figure 4: The graphs of the ratios of frequencies and amplitudes of oscillations depending on relative depth of the transversal crack

The function (3) in a Fourier series is decomposed:

$$w(x,t) = \frac{a_0}{2} + \sum_{k=1}^{n} (a_k \cos k\overline{\omega}t + b_k \sin k\overline{\omega}t), \tag{4}$$

In this case indicator of the crack can be diagnostic function, which characterizes the ratio of amplitude k-harmonic, which is exhibited at presence of the crack, to amplitude of the first harmonic:

$$d_k = \frac{\sqrt{a_k^2 + b_k^2}}{\sqrt{a_1^2 + b_1^2}} = \left| \frac{a_k}{a_1} \right| \tag{5}$$

The graphs of functions (5) for transversal cracks are shown in the Figure 5.

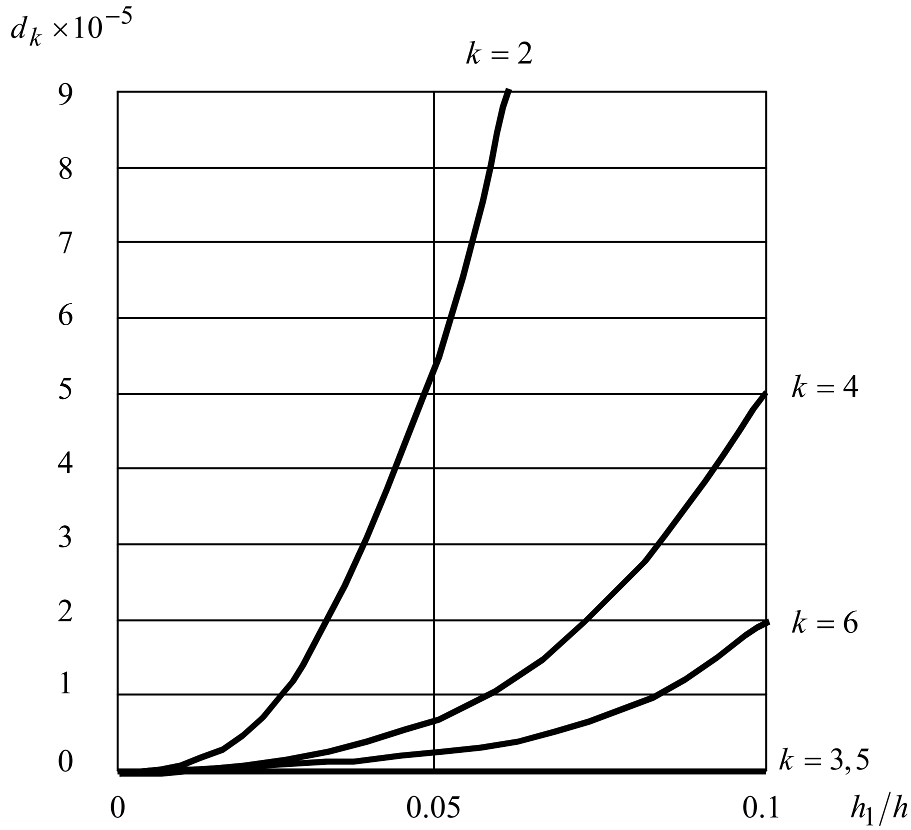

Figure 5: The graphs of functions (5) for transversal crack

REFERENCES

1. Bovsunovsky, A.P. and Matveev, V.V. (2000) *Journal of Sound and Vibration* 235(3), pp. 415-434.
2. Roytman, A.B., Pylov, A.A. and Aleksandrova, N.B. (1999) *Strength of Materials* 31, pp. 23-34.
3. Boltezar, M. , Strangar, B. and Kunelj, A. (1998) *Journal of Sound and Vibration* 211(5), pp. 729-734.
4. Krawczuk, M. and Ostachowicz, W. (1996) *Journal of Theoretical and Applied Mechanics* 34, pp. 307-326.
5. Roytman, A.B., Shamrovsky, A.D. and Titova, O.A. (2000) *Proceedings of the International Conference "Mechanika-2000"*, Kaunas, Litvenia.