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EXPERIMENTAL INVESTIGATION OF THE SENSITIVITY OF A ROTATING SHELL TO THE POSITION OF ITS AXIS

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It is established that the vibrations of a rotating shell excite the vibrations of the whole system consisting of a cylindrical shell, an electric motor, and a reducer on a common elastic base. It is shown that the vibrational accelerations excited by two different methods approach each other when the angle of the shell axis changes

Keywords: cylindrical shell, added masses, vibration, rotation of shell, axis inclination, natural frequencies, resonant frequencies

Experimental studies into the dynamic behavior of thin shells of revolution are elucidated is a great many publications, which are reviewed in, e.g., [2, 4, 8]. It follows from these reviews that the vibrations of rotating shells with added masses have been poorly investigated. In this connection, there is a need for further research into the vibrations of cylindrical shells.

Here we discuss the results from an experimental investigation of the effect of point added masses on the natural frequencies of a rotating shell depending on the angle of its axis during resonant vibrations excited with an electrodynamic vibrator.

1. The test subject is a fiberglass cylindrical shell of radius $R = 16$ cm, length $L = 90$ cm, and thickness $h = 0.8$ mm with three equal weights M_1, M_2, and M_3, 0.34 kg each. The weights, each having the form of a cylinder with a length of 10.5 cm and a diameter of 23 mm, are evenly spaced along the circumference of the shell at a distance of 3 cm from the upper end. First, the natural frequencies of the shell were determined by the resonance method. Then the shell was inserted by the lower end into circular slots in steel disks filled with Wood metal melt, the upper end remaining free. The disk was fixed to a massive base.

To examine the effect of the weights on the minimum natural frequency of the shell–weights system, we used the technique described in [5–7]. Vibrations were excited with a vibrator. Its mobile coil, 5.32 g in mass, was attached at the midsection of the shell and oriented in the plane passing through the axes of the shell, one of the weights, and the coil. The natural frequencies of the shell were determined from measured amplitudes A_1 and accelerations a_1 of its free end. The accelerations were measured with a D14 transducer and a vibration meter. The natural frequency f_{ex} as a function of the number of circumferential modes n is shown in Fig. 1. Table 1 collects experimental minimum natural frequencies f_{min} for $n = 3$ and $m = 1$ (n is the number of circumferential waves, and m is the number of meridional half-waves). The vibration modes at distances $0.5L$, $0.75L$, and L from the lower end of the shell were determined by measuring amplitudes at thirty evenly spaced points along the circumference with a noncontact transducer by the method outlined in [5–7]. In addition, vibration modes were observed visually.

Figure 2*a*, *b*, *c* shows vibration modes in the sections L, $0.75L$, and $0.5L$, respectively. The arrow indicates the point of application of the exciting force, and the open circles show the weights (the force is applied in the mid-section of the shell).

An analysis of the results reveals that the attached weights increase the number of half-waves along the circumference (see Fig. 2*c*).

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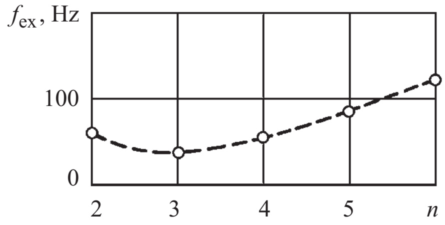
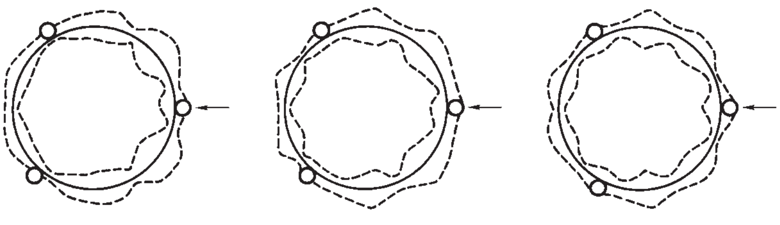


Fig. 1



a *b* *c*

Fig. 2

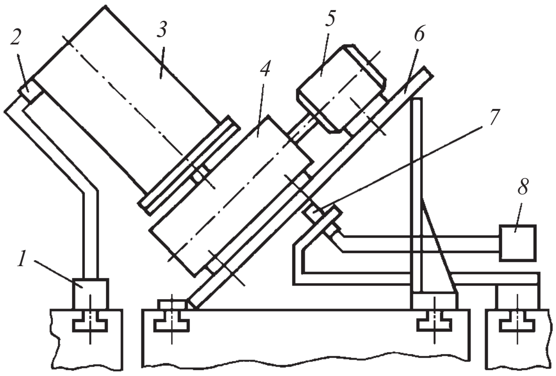


Fig. 3

In this case, nine half-waves are excited at the minimum natural frequency of the shell–weights system (one local half-wave is generated by each weight, and one wave is between weights). In the sections $0.75L$ and L, the added point masses of the weights are almost at the nodes.

The position of the rotation axis of the shell was varied on a specially designed setup (Fig. 3).

Shell *3* is rotated by electric motor *5* (1.1 kW; 2,850 rpm) and reversible worm reduction gear *4*, which are fixed to stainless steel 101×33×0.45 cm plate *6*. The disk with the shell is fixed to the rotating part of the setup. The shell rotates counter-clockwise when viewed from above.

The setup makes it possible to rotate the shell with a speed of 0.5 rps and to vary the angle between the shell axis and the vertical from 0 to 45°. The amplitude A_2 of the upper end of the shell was measured visually, with a ruler. The acceleration a_2 was measured with transducer *2* (attached at the mount point of one of the weights) and vibration meter *1* of a VÉDS-10A electrodynamic shaker.

The resonant frequencies of the rotating shell have been calculated from the measured amplitudes A_2 and accelerations a_2 by the following formula [3, formula 10.42]:

$$f_r = \frac{1}{2\pi}\sqrt{\frac{a_2}{A_2}}\,.$$

The experimental and theoretical results are summarized in Table 1.

The resonant frequencies f_{r1} of the plate with a shell with and without weights have also been calculated from the measured amplitudes and accelerations by the above formula. The accelerations of the plate were measured with transducer *2* fixed at the midsection of the plate (not shown in Fig. 1). The amplitudes of the plate were measured with noncontact eddy-current transducer *7* and electronic unit *8*. The resonant frequency of the plate turned out to be equal to 53.6 Hz, which is greatly different from f_r.

An analysis of the table reveals that the weights and the position of the rotation axis affect the vibrational accelerations. The three weights attached at the upper end make it stiffer, which follows from the substantial increase in the experimental minimum natural frequencies.

TABLE 1

Shell	γ, deg	f_{ex}^{min}, Hz	f_r, Hz	$2A_1$, μm	a_1, m/sec^2	$2A_2$, μm	a_2, m/sec^2
without weights	0	39	22.5	1000	52	800	8
with weights	0	47	21.4	250	3.5	1000	9
without weights	45	39	30.8	1000	80	800	15
with weights	45	47	18.8	550	3.7	1000	7

Since, according to the results, the resonant frequencies are in some cases close to the minimum natural frequencies of the shell measured experimentally, some of the vibration modes excited during rotation are close to the modes corresponding to these minimum natural frequencies.

When the shell with three weights rotates about the axis inclined at an angle of 45°, the vibrational accelerations excited by two different methods are close. The accelerations of the shell with (without) weights increase (decrease) compared with those excited by the vibrator.

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