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# EXPERIMENTAL STUDY OF FORCED OSCILLATIONS AFFINITY-SHAPED REINFORCED THIN-WALLED CYLINDER MODEL

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***Summary***. *In this paper, the experimental study of forced oscillations affinity-shaped model that strengthened since mid-stringers and frames. For the experimental investigations of forced transverse vibrations horizontally oriented cylindrical shell using a modification of previously proposed methods.*
***Key words:*** *reinforced cylindrical shell, forced oscillations, stringers, frames.*

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**Formulation of the problem.** Thin-walled shell structures have found wide practical application in many areas of the economy. Thus, the silos that are used in agriculture to store grain in constructive point is enhanced cylindrical shells. In the aerospace industry, in particular in rocketry, thin-walled reinforced cylinders are a basic structural element for the manufacture of fairings and shells of launch vehicles. Such elements protect the internal components of launch vehicles and satellites when they are launched into orbit. Reinforcement of thin cylindrical shells approx. carried out by installing inside the longitudinal rods – stringers and transverse rings – frames. Under normal operating conditions, reinforced shells receive aerodynamic loads from the surrounding gas environment and engines. In addition, during transportation to the launch pad on the membrane has a complex variety loads, a feature which is determined by the type of vehicle. Thus, when transported by air, the shells can perform both free and forced oscillations due to the inhomogeneity of the air in flight, as well as the operation of aircraft engines, vertical accelerations (overloads).

**Analysis of known research results.** Basic aspects of the calculation and design of the main elements of launch vehicles are given in [1]. Theoretical studies on the dynamics of shell elements of rocket carriers and reinforced shell elements are covered in [2–4]. Results of linear accelerations measured at sea transporting launch vehicle «Zenit 3SL-» given in work [5]. Statistical processing of the maximum values of the measured accelerations on the supports of the installation during 29 missions «Zenith-3SL» was carried out. It is shown that the accelerations are polyharmonic in nature with variable frequencies and amplitudes, and the main contribution to the dynamic load of the launch vehicle is made by the low-frequency weft of the launch platform. An overview of experimental research methods is given in [6–8]. Thus, in [6] the influence of reinforcing ribs and attached solids on the amplitude-frequency characteristics of shell structures was investigated by the method of holographic interferometry. An analytical method for determining the oscillatory characteristics of cylindrical shells reinforced with transverse rings is presented in [10]. In [11] a damping device for reducing the frequency of oscillations of long shells during transportation, developed using alloys with shape memory, is presented.

The results of these works are generalized and reflect the basic approaches in experimental studies of oscillations of reinforced cylindrical shells. Thus, in particular, the results of linear accelerations measured during sea transportation of the launch vehicle are presented. Due to the specifics of transportation of reinforced shells by aircraft, the assessment of frequencies and shapes of forced oscillations and, accordingly, their strength and durability is carried out in each case, which reflects the relevance of experimental study of forced oscillations of affine-like model of reinforced cylindrical shell.

**The aim of this work** is to experimentally study the basic regularities of the influence of the frequency of external loading on the amplitude-frequency characteristics of the forced oscillations of the model of the reinforced cylindrical shell.

**Problem statement.** Using the improved method previously developed by the authors [10], the frequencies and amplitudes of forced oscillations of the model of a reinforced cylinder placed on two supports under the action of an external cyclic load at a constant displacement amplitude are determined experimentally.

**Experimental installation.** The experimental model was developed on the basis of the first stage of the launch vehicle, the length of which is 6300 mm, and the diameter is 1800 mm, the wall thickness is 1.5 mm. The dimensions of the affine-like model (Fig. 1), based on the scale factor and geometric parameters of the testing machine, the following: the cylinder cavity length L= 1500 mm, diameter D= 400mm. Thickness of a wall of a model reinforced cylinder similar to the actual design and is t = 1,5 mm. Longitudinal reinforcing elements of the model – stringers, made in the form of an equilateral angle measuring 10x10x1.5 mm. Stringers were placed maintaining the same relationship between the areas of reinforced and free areas of the model and the actual object. Transverse reinforcing rings, made in the form of overlays 1.5 mm thick and 100 mm wide and located at both ends of the affine-like model, mimicking the connecting frames.

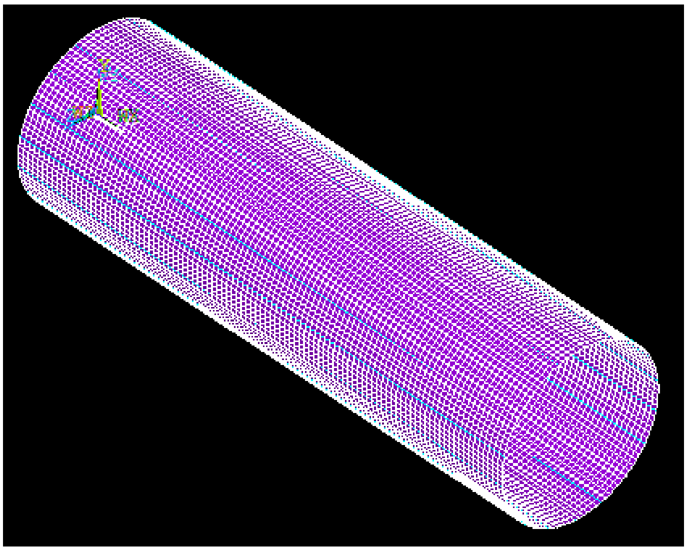

**Figure 1**. Finite – elemental affine-like model of the reinforced shell

Material for the manufacture of the model of the shell and reinforcing elements (stringers and frames) – aluminum alloy D16 AT, which has the following mechanical characteristics: Young's modulus $E = 7.2 \times 10^5$ MPa; rate Poisson $\nu = 0,3$; $\rho = 2.7 \cdot 10^4$ N/m$^3$.

The experiment was performed on the basis of the test machine STM-100.

Spatial truss in a prescribed affinity-shaped reinforced cylinder model (Fig. 2) and attached the necessary readers' amplitude and vibration speed mounted on the platform and connected to the rod testing machine. To reduce inertial forces and displacements, the truss was made of aluminum angle 10x10x1 mm.

**Figure 2.** General view of the experimental installation for the study of the load of thin-walled cylindrical shells during transportation

To simulate the hinge fixation, the edges of the experimental model of the reinforced cylinder are fixed by a special clamping elastic device.

The scheme of fastening of the shell model, the location of readers and the scheme of information processing is shown in Fig. 3.

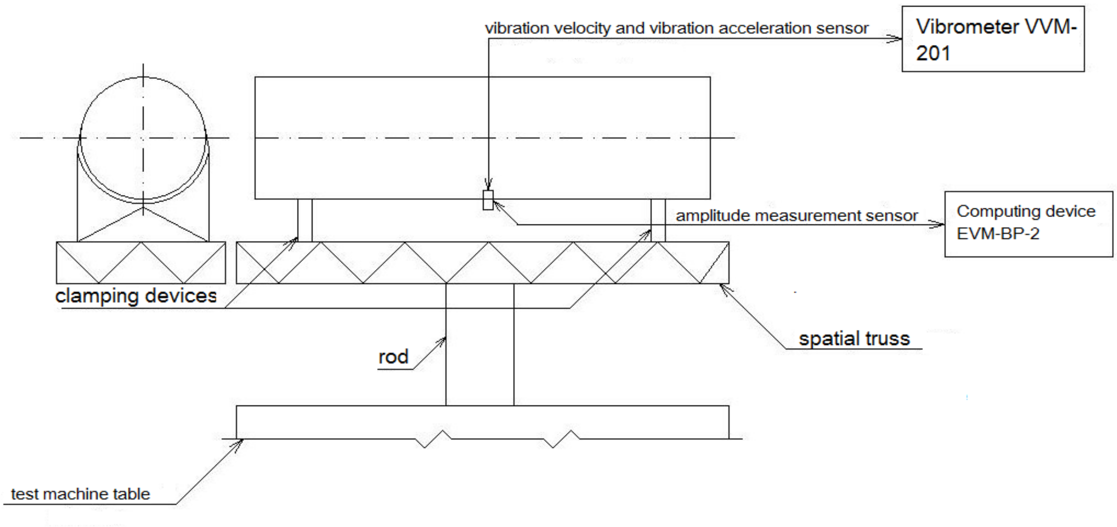


**Figure 3.** Scheme of model mounting, recording of load parameters and deformations on the CTM-100 test machine

To measure the parameters of oscillations (vibration acceleration and vibration speed) used vibrometer VVM-201 (Fig. 4) – a device with digital display is designed to take readings in a wide range of frequencies from 0,2 to 4000 Hz from operating equipment, machines and other objects in laboratory and production conditions in various industries.

The VVM-201 vibrometer is completed with the DN-3-M1 piezoelectric vibroconverter. Technical characteristics of the vibrometer are given in table.1.


a) b)

**Figure 4.** Vibrometer VVM-201: a) – general view; b) – vibration velocity measurement sensor

**Table 1**

Technical characteristics of the VVM-201 vibrometer

| | |
|---|---|
| Measuring range of root mean square values: | |
| - Vibration acceleration (in the frequency range 0, 2 ... 4000 Hz), $m/s^2$ | 0.1 ... 1000 |
| - Vibration speed (in the frequency range 0, 2 ... 2800 Hz) mm/s | 0.5. ..1000 |
| The main relative measurement errors, %: | |
| - Vibration acceleration in the frequency range, Hz | 0, 2 ... 10, 10 ... 1000, 1000 ... 4000 |
| - Respectively in % | (+/-) 15, (+/-) 10, (+/-) 15 |
| - Vibration velocities in the frequency ranges, Hz | 0, 2 ... 10, 10 ... 1000, 1000 ... 2800 |
| - Respectively in % | (+/-) 15, (+/-) 10, (+/-) 15 |
| The device is powered by chemicals current sources (A332-12 el.), rated voltage, V | 8.3 |
| Consumer power, mVA | 180 |
| Operating temperature range, ºC | 10… + 50 |
| Mass of the vibrometer, kg | 1.7 |

To measure the amplitude used a EVM-BP 2 (Fig. 5) electric balancing vibrometer designed to measure the magnitude and phase of unbalance of the rotating parts of engines and machines during their balancing on the stands in the shop and laboratory conditions. The principle of operation of the vibrometer is to convert mechanical vibrations of the object under study into proportional electrical signals. In this case, the energy developed by the sensor is sufficient to deflect the arrow of the microammeter to the end of the scale.


a) b)

**Figure 5.** Computing device EVM-BP-2: a) – general view;
b) – sensor for measuring the amplitude of forced oscillations

Technical characteristics of the vibrometer EVM-BP-2 are given in table 2.

**Table**

Technical characteristics of the EVM-BP-2 vibrometer

| | |
|---|---|
| Final values of the amplitude of the vibration displacement measurement ranges | 100 μm; 300 μm; 500 μm |
| Vibration strength of the induction vibration measuring transducer in the operating frequency range | not more than 150 m / s $^{2}$ |
| Vibration displacement measurement error | not more than 10%. |
| Error in determining the angular position of the imbalance | not more than 5 ° |
| Converter characteristics: | |
| - resonant frequency | not more than 8 ± 1 Hz; |
| - conversion factor at a frequency of 40 Hz | not more than 180; |
| - relative coefficient of transverse transformation | not more than 5%. |

With the help of this experimental complex, the following parameters can be controlled: forces (F), rod displacements (S) and deformation (E), which allows to realize hard and soft load with asymmetry of the load cycle from R = -1… + 1 and by choosing one of the three forms of the cycle: sinusoidal, linear or rectangular.

It is also possible to scale the control parameter in the ranges: 1: 1; 2: 1; 5: 1 and registration of measured values F, S, E.

**Research results**. As a result of the experiment, the values of frequencies (Fig. 6) and amplitude (Fig. 7) of forced oscillations of the reinforced cylinder model from the action of external force of F = 0.15 kN and at constant amplitude movement of the rod S = 1 mm were obtained. The frequency of application of effort varied from 10 to 20 Hz. It was found that the forced frequency of the amplified cylinder is in the range from 0.5 to 1.5 Hz. The amplitude value is 0.3 mm at a frequency of 1.5 Hz and 0.8 mm at 0.5 Hz.

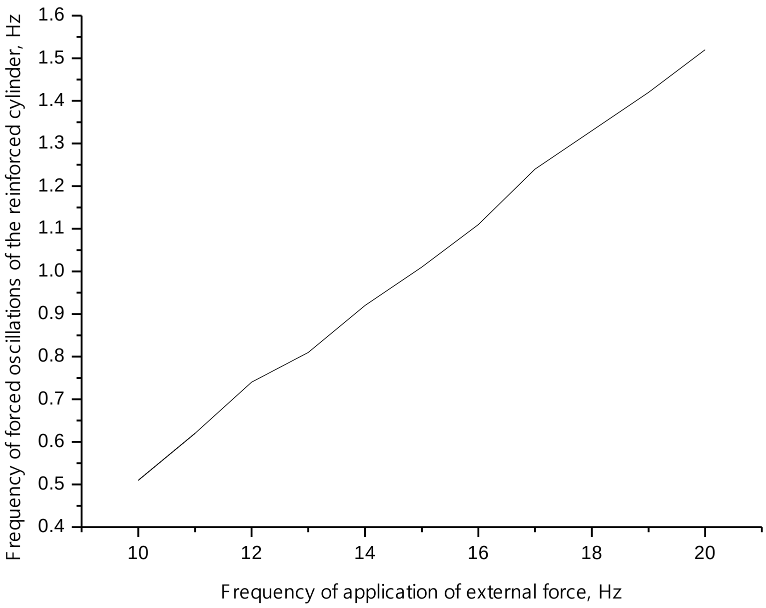


**Figure 6.** Dependence of the frequency of forced oscillations on the frequency of application of external force

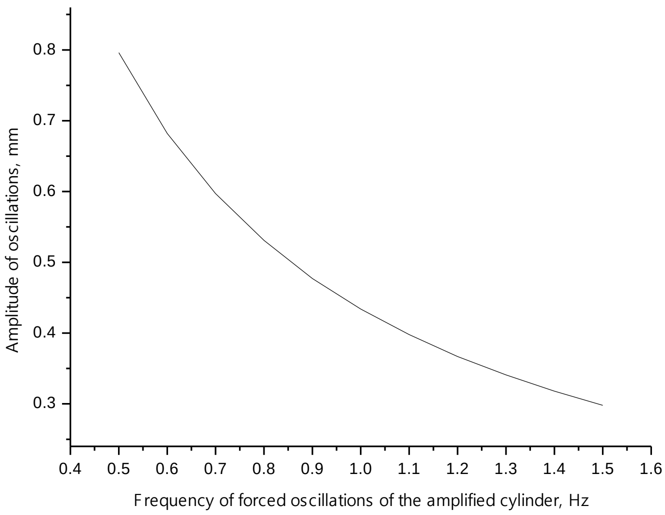


**Figure 7.** The magnitude of the amplitude depending on the frequency of forced oscillations of the amplified cylinder model

## Conclusions

1. Forced transverse oscillations of a horizontally oriented model of a reinforced cylindrical shell placed on two supports under the action of a cyclic load at a constant amplitude of movement of the platform were investigated experimentally

2. It is found that with increasing the frequency of the applied load from 10 to 20 Hz, the frequency of forced oscillations of the reinforced cylindrical shell increases in direct proportion from 0.5 to 1.5 Hz.

3. It is investigated that the maximum amplitude of the forced oscillations of the reinforced cylindrical shell is inversely proportional to the frequency of the applied load and decreases three times with increasing frequency from 10 to 20 Hz.

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# ЕКСПЕРИМЕНТАЛЬНЕ ДОСЛІДЖЕННЯ ВИМУШЕНИХ КОЛИВАНЬ АФІННО-ПОДІБНОЇ МОДЕЛІ ПІДСИЛЕНОГО ТОНКОСТІННОГО ЦИЛІНДРА

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***Резюме.*** *Проведено експериментальне дослідження вимушених коливань афінно-подібної моделі, яка підсилена з середини стрингерами та шпангоутами. Для проведення експериментальних досліджень вимушених поперечних коливань горизонтально орієнтованої циліндричної оболонки використано модифікацію запропонованої раніше методики. Експериментальна модель розроблена на основі I ступеня ракети-носія, довжина якої становить 6300 мм, а діаметр – 1800 мм, товщина стінки – 1,5 мм. Розміри афінно-подібної моделі, виходячи з масштабного коефіцієнта й геометричних параметрів випробувальної машини, такі: довжина порожнинного циліндра L=1500 мм, діаметр D=400 мм. Товщина стінки модельного підсиленого циліндра аналогічна реальній конструкції й становить t=1,5 мм. Поздовжні підсилюючі елементи моделі – стрингери, виготовлено у формі рівностороннього кутника розмірами 10x10x1,5 мм. Стрингери розміщували, зберігаючи тотожне відношення між площами підкріплених і вільних ділянок моделі та дійсного об'єкта.*

*Для вимірювання параметрів коливань (віброприскорення та віброшвидкості) використано віброметр ВВМ-201 – прилад з цифровою індикацією, призначений для зняття показів у широкому діапазоні частот від 0,2 до 4000 Гц від працюючого обладнання, машин та інших об'єктів у лабораторних і виробничих умовах у різних галузях промисловості.*

*Для вимірювання амплітуди використано ЕВМ-БП2 електричний балансувальний віброметр, призначений для вимірювання величини і фази неурівноваженості обертових частин двигунів і машин при їх балансуванні на стендах у цехових і лабораторних умовах.*

*У результаті проведеного експерименту отримано значення частот (рис. 6) та амплітуди (рис. 7) вимушених коливань моделі підсиленого циліндра від дії зовнішнього зусилля величиною F=0.15 кН та при сталоамплітудному переміщенні штока S=1 мм. Частота прикладання зусилля варіювалася від 10 до 20 Гц. Виявлено, що вимушена частота підсиленого циліндра знаходиться в діапазоні від 0,5 до 1,5 Гц. Значення амплітуди становить 0,3 мм при частоті 1,5 Гц та 0,8 мм при 0,5 Гц.*

***Ключові слова:*** *підсилена циліндрична оболонка, вимушені коливання, стрингери, рами.*

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