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МЕХАНІКА ТА МАТЕРІАЛОЗНАВСТВО

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METHODOLOGY FOR THE EXPERIMENTAL RESEARCH OF REINFORCED CYLINDRICAL SHELL FORCED OSCILLATIONS

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Summary. *In the paper the methodology for experimental studies of forced oscillations of a horizontally oriented cylindrical shell which is reinforced from the inside by stringers and bulkheads using the servo-hydraulic test machine STM-100 is developed.*
Key words: *reinforced cylindrical shell, forced oscillations, stringers, bulkheads.*

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Statement of the problem. Cylindrical shells reinforced by stringers have been widely applied in different branches of the national economy, rocket building in particular, for manufacturing rocket carrier fairings and shells. Such constructions are designed for the protection of rocket carrier inside elements and sputniks while launching them on the orbit. Thin shells are reinforced by stringers and bulkheads from the inside. Under general conditions of operation reinforced shells are subjected to the aerodynamic loadings caused by the gas environment and engines. Besides, while transporting to the place of launching the shells are subjected to different loadings, the characteristic of which is specified by the type of transporting carrier. Thus, being transported by the air transport they experience both free and forced oscillations, caused by the air non-uniformity (turbulence) while flying, as well as the plane engine operation, vertical acceleration (overloading).

Analysis of the available investigations. The papers [1 – 4] deal with the investigations of dynamics of the shell rocket carrier elements and reinforced shell elements. Investigations of linear accelerations, measured while transporting of the rocket carrier “Zenit-3SL” by sea are presented in the paper [5], the results of analysis of linear accelerations in particular, measured while transporting the rocket carrier „Zenit-3SL“ by the sea. Statistic processing of the maximum values of the measured accelerations on the installation stands during 29 missions, has been carried out. It was shown, that accelerations are of the polyharmonic nature with the variable in time frequencies and amplitudes, the main contribution to the dynamic loading of the rocket carrier being that of low-frequency oscillation of the launching platform. Analysis of the experimental methods of investigation is presented in the papers [6 – 8]. Thus, taking advantage to the method of holographic interphotometry, the low and medium range of the oscillation scale of regularly reinforced shells has been investigated in the paper [6].

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The papers in question deal with the general investigations of the construction elements of the rocket carrier and while transporting by sea. Taking into account special operating conditions and transporting of the reinforced shells, the estimation of the frequencies and forms of forced oscillations and, accordingly, their strength and durability, is carried out in every particular case, which shows the importance of development the method for experimental investigations of forced oscillations of reinforced cylindrical shells while transporting by plane.

The Objective of the work is the development of the method for experimental investigations of forced oscillations reinforced by stringers and bulkheads of the cylindrical shells. This objective is caused by the need to solve the task of estimation of the stress-strain state and the fatigue strength of the reinforced cylindrical shells while transporting by plane.

Statement of the task. To interpret the dimensions and construction of the model of the reinforced shell, as well as the platform for its mounting and the system for measuring the parameters of oscillations while testing on the basis of the servo-hydraulic testing machine STM-100.

Experimental model. While developing the model the 1-st stage of the rocket carrier with the length 6300 mm, diameter 1800 mm, wall thickness 1.5 mm [1] is chosen as the basis. Affine similarity is used – generalised option of the geometric similarity, where unequality of scale coefficients along some coordinates is acceptable. The dimensions of the model were chosen taking into account the geometric characteristics of the testing installation. The length of the hollow cylinder is 1500 mm, diameter 400 mm. The cylinder wall thickness 1.5 mm was chosen to provide necessary rigidity. In the reinforced model the stringers were those of 10×10×1.5 mm equilateral bar, which were mounted on the inside surface of the shell symmetrically with the regular step, providing identic relation between the squares of reinforced and free areas of the model and real installation. Joint bulkheads as the 1.5 mm thick and 1000 mm wide joint bars were stuck inside on the ends of the shell.

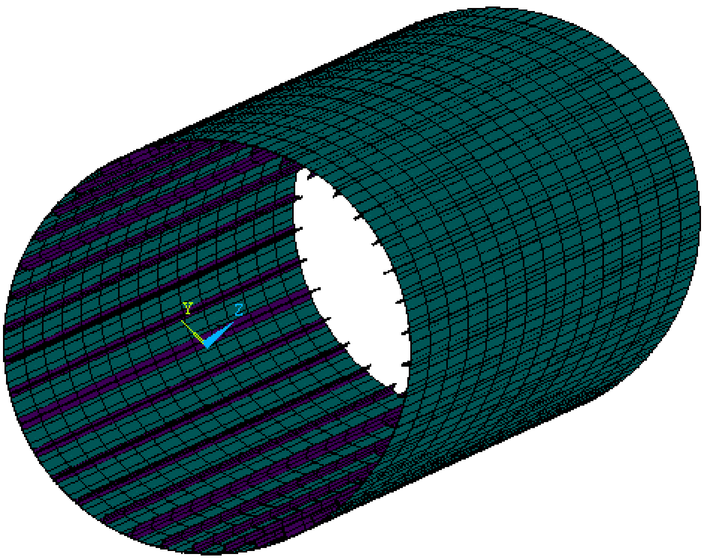

Figure 1. Finite-element model of full-sized cylindrical shell

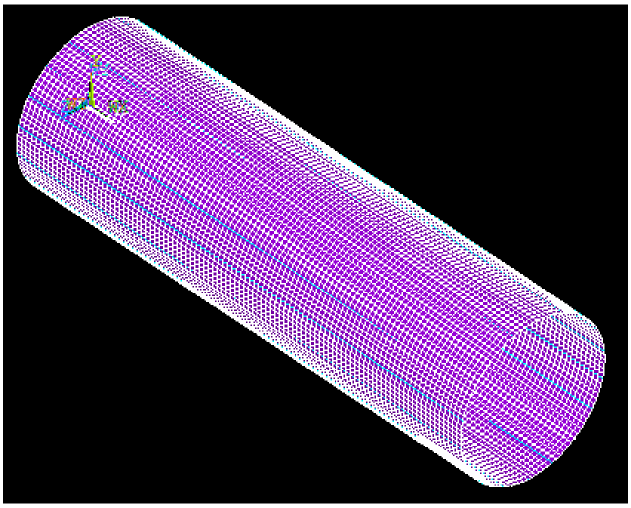

Figure 2. Finite-element affine-like model of reinforced shell

To produce the model of shell and stringers aluminium alloy D16AT with such mechanical properties was used: Young's modulus E = 7.2×10^5 MPa; Poisson's ratio ν = 0.3; ρ= 2.7·10^4 N/m^3.

To interpret the dimensions and construction peculiarities of the model using the method of finite elements (MFE) and software ANSYS the natural oscillation frequencies of the full-sized cylindrical shell (Fig. 1) and the model cylindrical shell have been studied. As it is seen from the results of investigation (Table 1), natural oscillation frequencies of the model are in one order higher than those of the natural frequencies of the full-sized cylindrical shell. To reduce the natural oscillation frequencies, the polyurethane filler was placed into the model cylindrical shell with the following physical-mechanical properties: ρ = 1.0·10^3 N/m^3, Young's modulus E = 1.6 MPa.

In the last column (Table 1) the results of MFE modeling of the natural frequencies of the model shell are presented, which are of the same order as those of the natural oscillation frequencies of the full-sized shell.

Table 1

Natural frequencies of the full-sized and scale reinforced shells taking into account its own weight with a filler and without it (in Hz)

№	Natural oscillation frequency of the full-sized reinforced shell	Natural oscillation frequency of the reinforced model of the model (without filler)	Natural oscillation frequency of the reinforced shell (with filler)
1	14.2	153.7	7.2
2	14.2	153.7	9.1
3	14.9	162.1	9.8
4	14.9	162.1	10.9
5	16.5	-	11.0
6	16.5	-	12.0
7	19.9	-	12.1
8	20.2	-	12.7
9	20.2	-	12.7
10	20.7	-	13.2
11	24.9	-	13.3
12	24.9	-	14.1

The experiment is performed on the testing machine STM-100, characteristics of which are presented in Table 2. General appearance of the machine is presented in Fig. 1.

Table 2

Technical performance of the servo-hydraulic machine STM-100

Maximum static stress	100 kN
Maximum cyclic loading force	80 kN
Operation frequency of cyclic loading	0,005...100 Hz
Maximum stress of hydrosystem	27,5 MPa
Hydro station efficiency	12...22 l/min
Electromotor consumed power	11 kW
Operation rod stroke	0...100 mm
Piston movement range	0...100 mm
Control parameter scale	1:1; 2:1; 5:1

A space truss platform is attached on the testing machine rod (Fig. 3), on which experimental model of the reinforced cylindrical shell is mounted, on which necessary meters of stress and displacement are placed. To decrease the inertia forces and displacement the truss was made of 10×10×1 mm aluminium stringer bar.

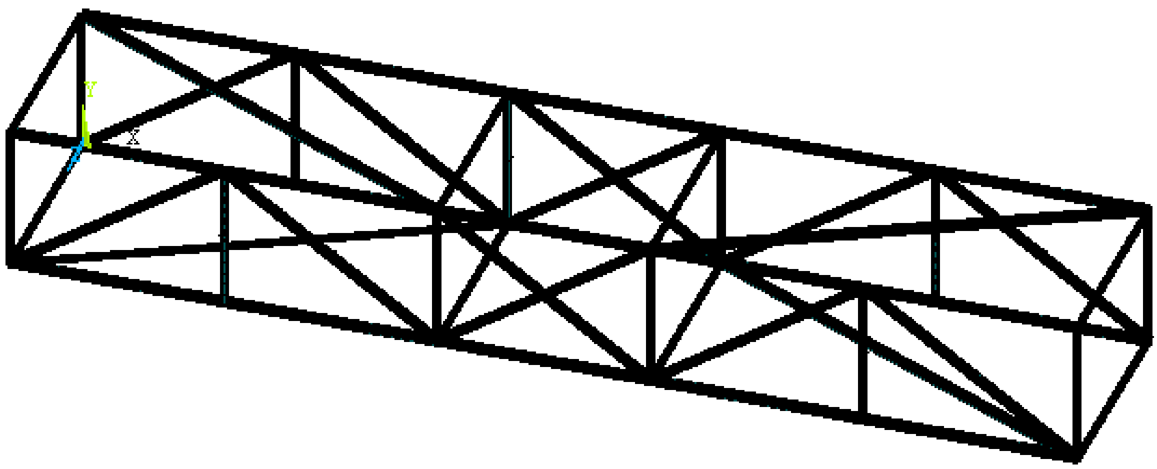

Figure 3. Space truss for placement of reinforced cylindrical shell

The scheme of attachment the shell model, location of meters and the method of data processing is presented in Fig. 5. The model is attached by means of special compressing device, which imitates hinged attachment of shell duct.

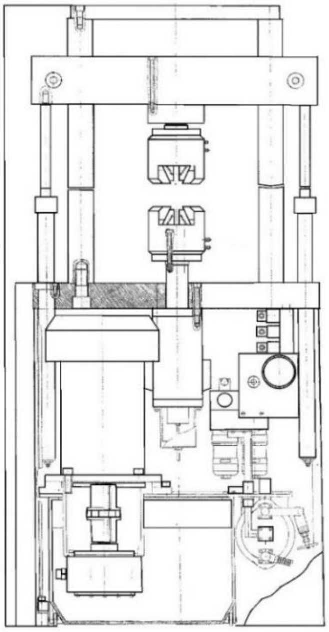

Figure 4. General appearance of the testing machine STM-100

Taking advantage of this complex the following parameters can be controlled: force (*F*), rod displacement (*S*) and deformation (*E*), which can provide both rigid and soft loading and loading cycle asymmetry from *R* = -1…+1 choosing one of the cycle form: sinusoidal, linear or rectangular.

It is possible to scale the control parameter in the range: 1:1; 2:1; 5:1 and to measure the values *F*, *S*, *E* by the magnetic carriers and output information in real time regime on the two-coordinate self-registed H-307/1 type potentiometer. The error of the input channel and the error of controlled values do not exceed 1% of the maximum value of the determined scale range.

The cyclic loading regime is provided automatically from the PC control software, operation software icon is presented in Fig. 6. It is possible to take current results on the display while testing, to stop the program and to start it again from the point of stop, to make other changes if necessary.

After finishing investigations it is possible to present testing data graphically, scaling being possible.

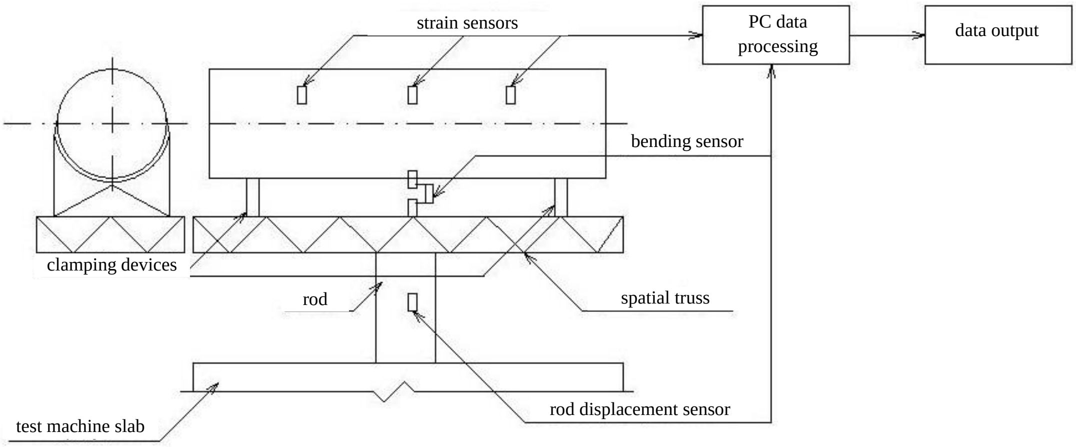

Figure 5. Scheme for model fixing, registering of loading and deformation parameters

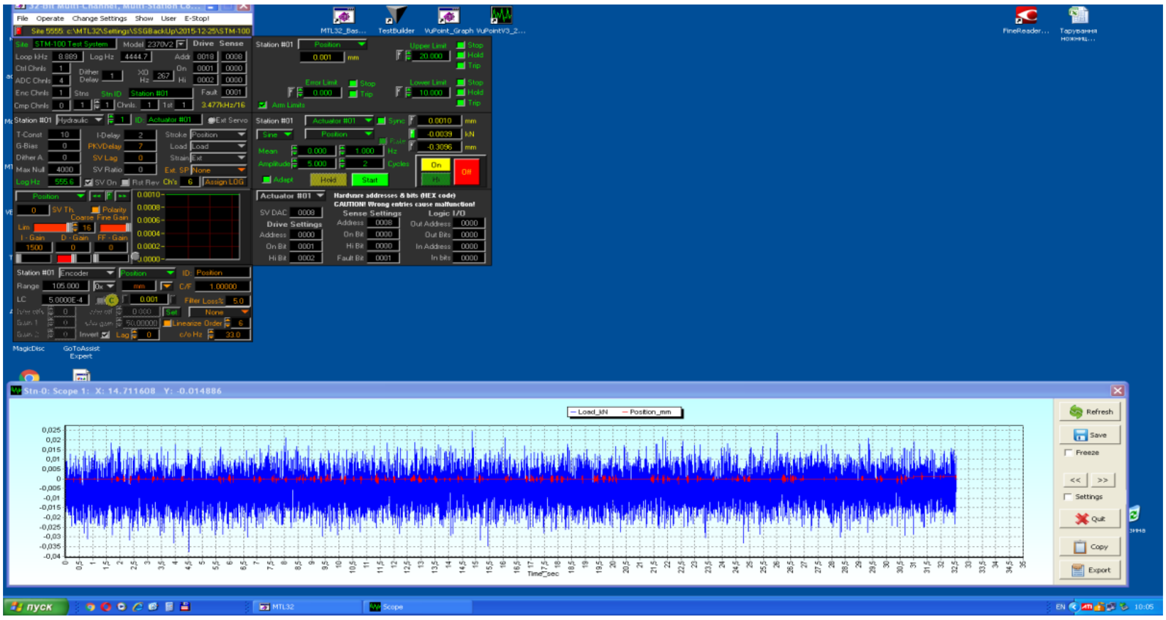

Figure 6. Control software icon of the testing machine STM-100

Conclusions

1. The method for experimental investigations of the reinforced shell forced oscillations on the basis of the servo-hydraulic testing machine STM-100 has been developed.

2. Dimensions and construction characteristics of the reinforced cylindrical shell model have been interpreted. To decrease the values of natural oscillation frequencies of the model to the full-sized shell the polyurethane filler was proposed to be used.

3. Taking advantage of the finite-element method the natural oscillation frequencies have been calculated for the basic full-sized reinforced cylindrical shell, as well as for the shell model with the filler and without it.

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МЕТОДИКА ЕКСПЕРИМЕНТАЛЬНИХ ДОСЛІДЖЕНЬ ВИМУШЕНИХ КОЛИВАНЬ ПІДСИЛЕНИХ ЦИЛІНДРИЧНИХ ОБОЛОНОК

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Резюме. *Розроблено методику експериментальних досліджень вимушених коливань горизонтально орієнтованої циліндричної оболонки, яка підсилена з середини стрингерами та шпангоутами на базі серво- гідравлічної випробувальної машини STM-100.*

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

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