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EXPERIMENTAL AND FEA RESEARCH OF STRESSES ON ELEMENTS OF HELICOIDAL SHELL SHAPE

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ABSTRACT
This paper introduces an approach for experimental research on the machine elements of a helicoidal shell shape. Three shapes are chosen for the experimental investigation: model A represents a helicoidal shell on the cylindrical shell, model B an annular shell on the cylindrical shell, and model C a rectangular shell on the cylindrical shell. To assure normal pressure on the shell surface, a twin helicoidal shell structure with a special airtight element (seal) was designed. The strain measurement was carried out using the strain gauges. The comparable results obtained by FEA software Pro/MECHANICA are given in this paper, too. The described approach confirmed that the proposed method assures effective stress/strain measurement on the structural elements of the helicoidal shell shape loaded by pressure. The applied method can be used for experimental research on helicoidal shells of variable thickness and on different conoidal shells as well.
Keywords: Helicoidal Shell, Displacement, Radial Stress, FEA

1. INTRODUCTION

The working parts of the helicoidal shell shape are applied on the devices of continual transport, helicoidal transporters, in the specialized snow blowing machines, and so forth. Analytical methods to calculate dimensions of the loaded shells are well known in the mechanics of a deformable body.

Despite a number of scientists who have investigated shells, only a few of them worked on the helicoidal shells. A significant contribution in this field was made by: A.L. Goldenveizer [1], A.C. Вольмир [2], T.S. Timoshenko [3], P.M. Naghdi [4], В.И. Феодосеев, [5], W.S. Wlassow [6].

A couple of papers addressing this problem have been published by J.W. Cohen [7,8] and S.G. Mikhlin [9]. J.W. Cohen developed a relation between strains and displacements by comparing relevant geometric features in deformed and non-deformed structures. The constitutive equations that relate the strain parameters to the stress parameters given by Cohen [7] were not obtained using the principle of a minimum deformation of work for shells that is widely used in the restricted theory of shells. Therefore, the equations obtained using these two methods are different. Conversely, the ordinary Love’s constitutive equations were used by S.G. Mikhlin [10] in his work.

There are no papers in scientific and professional literature that address the experimental investigation of helicoidal shells. An approach for experimental investigation of machine elements in the shape of helicoidal shell is presented in this paper. The results obtained from the experimental analysis of the deformation of the helicoidal shell model are compared with the results obtained form finite element analysis (FEA) using the software package Pro/MECHANICA.

2. MODEL DESCRIPTION FOR EXPERIMENTAL INVESTIGATION

A helicoidal shell shape is a part of the conoidal helicoidal surface that is connected to a cylindrical shell along its helical line. In this case, the conoidal helicoid is generated by a straight line passing through the z-axis as a directrix, parallel to Oxy plane as a directory one, and passing through a helical line as a leading one. The equation of this surface is:

$$z = \frac{H}{2\pi} \arctan\left(\frac{y}{x}\right) \tag{1}$$

where H is the pace of the helical line.

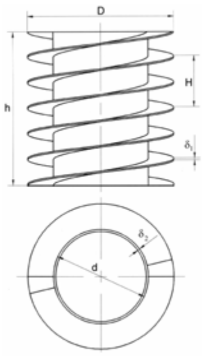


Fig. 1. Experimental helicoidal shell on cylindrical shell model

Helicoidal shell on cylindrical shell model were chosen for experimental investigation, where helicoidal shell stiffly fixed on a cylindrical shell represents a along the helical line with a constant pace of H=140 mm (Fig. 1). The chosen model is with diameters: D=400 mm, d=260 mm, height h=420 mm, thickness δ_1=3.6-4 mm, and b=70 mm.

The load acting on the shell may be concentrated, continuous, or combined and of an arbitrary direction. The cross-section of the assembly with the model in which loading of the model were performed by surface pressure is shown in Fig. 2. One of the major problems at the beginning of the experiment planning was how to load the helicoidal shell by surface pressure. In such a double shell structure, the air under pressure was introduced into the space between the two shells, so the shells were exposed to the pressure only from one side. In order to seal the space under pressure between the two shells, the special rubber sealing elements were glued to the helicoidal shell edges, and the structure was inserted into a chamber. The chamber was closed by two round plates connected with five long screws to make an assembly as illustrated in Fig. 2.

3. EXPERIMENTAL INVESTIGATION

The experimental investigation was carried out on the model under optimal microclimatic conditions. As a source of the pressurized air, a 60-dm^3 capacity compressor operating at the max pressure of 0.8 N/mm^2 was used. The shells investigation was carried out at the pressure increments of 0.05, 0.1, 0.12, 0.14, 0.15, 0.16, 0.18, 0.2, 0.22, 0.24, and 0.25 N/mm^2. A device for precise pressure adjustment was used to regulate the pressure level on the shells. It was installed on the pipe that led air from the compressor to the experimental assembly. A barometer for precise pressure measurement was placed on the chamber. It was designed as a device with a mercury column having an operating range up to 0.25 N/mm^2. A measuring unit that accepts up to 30 strain-gauge bridges was used to measure the strain.

The model with the placed and connected strain guages is shown in Fig. 3; whereas, the complete experimental setup prepared for investigation is shown in Fig. 4.

Figure 2. Experimental assembly for model

Figure 3. Model prepared for experiment

Figure 4. Experimental setup

Ninety strain gauges were used for tensiometric investigations. Starting from the fact that for the analyzed models the strain value does not depend on the polar coordinate φ but only on the radial coordinate r at the observed point, the strain measuring was performed in a radial direction, a circular direction, as well as in a direction at an angle of 45° with respect to a radial direction at the two points of the same radius r value. A control of the obtained results is made possible in this way. A greater concentration of strain gauges was in the critical shell zones, close to the edge and to the cylindrical shell, where the values of the circular and radial strains are greater. Thanks to the strain measurement in the three different directions at the points with the same radial coordinate r, it is possible to determine the directions of the main strain without using the classical rosette strain gauges.

4. EXPERIMENTAL RESULTS

The experiment was performed under an optimal temperature of 19 °C. After the tensometric investigation was completed, the shell deflection was measured. A device for the deflection measurement was located at the starting point with r=197 mm; from that point, r was varied in the range of 195–140 mm in increments of 5 mm.

The strain values $\mu\varepsilon$ measured on the steel shell structures during the experimental investigation are presented here, where coefficient $\mu=10^{-6}$. These strain values represent the bending strains. Membrane shell strains are negligible in these models. Taking into consideration the character of the stress state, the stress values can be calculated using the relations valid for a two-axial stress state:

$$\sigma_1 = E\frac{1}{1-\nu^2}\left(\varepsilon_1 + \nu\varepsilon_2\right),\ \sigma_2 = E\frac{1}{1-\nu^2}\left(\varepsilon_2 + \nu\varepsilon_1\right) \qquad (2)$$

The diagrams of the radial stress are presented on Fig. 5a. Fig. 5b shows the displacement diagrams in an axial direction.

a) b)

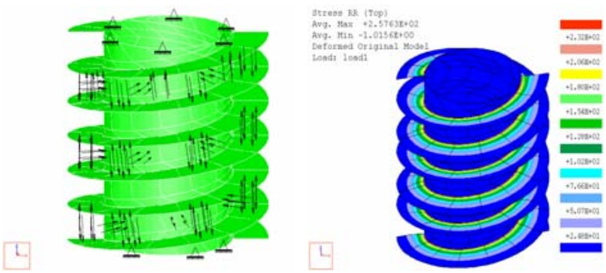
Figure 5. Experimental results for model A at pressure range 0.05 – 0.25 N/mm^2: a) radial stress, b) displacement in an axial direction

5. NUMERICAL ANALYSIS RESULTS

Using FEA software Pro/MECHANICA with the pre-processor that enables an automatic mesh generation for a helicoidal shell on a cylindrical shell model were performed. In the analysis, steel DIN C45E (1.1191) was used as a material for the helicoidal shell.

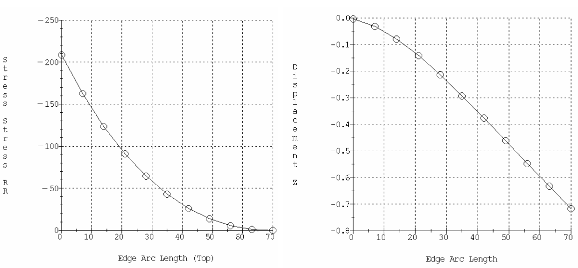
In Fig. 6a, the meshed model with constraints and loads are presented. The distribution of the radial stress obtained from the FEA is presented in Fig. 6b.

The stress and displacement distribution along the line in the radial direction on the helicoidal shell is presented in Fig. 7 for shell thickness h_h=4 mm. Also, experiment done with shell thickness and h_h=3.6 mm. The starting point of a 70-mm long interval has the coordinate r=130 mm, while the last point is on the outer helicoidal shell contour and has the coordinate r=200 mm.



a) b)

Fig. 6. FEA for model and helicoidal shell thickness h_h = 3.6 mm: a) meshed model with loads and constraints, b) distribution of the radial stress



a) b)

Fig. 7. FEA diagrams across the helicoidal shell of the thickness h_h = 3.6 mm for a) the radial stress, and b) the axial displacement

6. COMPARISON BETWEEN EXPERIMENTAL AND NUMERICAL RESULTS

The diagrams of the stress components distribution obtained from tensometric analysis are in good agreement with the numerical simulation. The results confirm that the radial stress has the maximum stress at the contact zone between the helicoidal and cylindrical shell. Therefore, the geometric parameters of the helicoidal shell can be obtained using limited stress values in that zone as a criterion.

The comparisons of the radial stress σ_r and circular stress σ_c as well as the displacement for the experimental model is given in Table 1. The experimental and numerical results show a good agreement.

Table 1. Comparative values for stress and displacement for the model

		Radial stress σ_r [N/mm^2] for r=140 [mm]		Displacement [mm] for r=195 [mm]	
H [mm]	h_h [mm]	FEA	Experiment	FEA	Experiment
140	4	-117.1967 (Fig. 7a)	-	-0.4909 (Fig. 7b)	-
140	3.6	-144.8671	-136.59 (Fig. 5a)	-0.6578	-0.40 (Fig. 5b)

The discrepancy between the experimental and numerical results for the radial stress is 5 %, 13 %, and 4 % for the model. An experimental investigation of numerous models with a variety of geometric parameters would give better insight into the behavior of the helicoidal shell.

The displacement values obtained from the experiment for the model (-0.40 mm) is lower in comparison with the numerical results. This discrepancy can be a consequence of a difference between real geometric parameters of the experimental model and their nominal values.

7. CONCLUSION

The approach of the experimental investigation presented in this paper has justified the efficiency of the deformation analyses for mechanical elements in the shape of a helicoidal shell exposed to normal pressure. An agreement of the results from experimental analyses and calculations by finite elements method was shown.

In experimental research, it has been shown that the directions of the main stresses are very close to the radial and circular directions. The strains in an axial direction for a rectangular shell are lower than ones in a circular direction for helicoidal shell.

The presented approach can be completely applied to an experimental research of helicoidal shells of variable thickness. This approach opens the possibilities for the experimental research of the shells in the shape of a conoidal surface whose generetrixes need not be parallel to the Oxy plane as well as for the research of other shapes of conoidal surfaces.

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