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Finite Element 3D Structural and Modal Analysis of a Three-Layered Finned Conical Shells

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ABSTRACT

In this paper, the results of finite element (FE) 3D structural and modal analysis of the three-layered, ribbed shell cones are presented. The middle layer of the shell contains micro-heterogeneous structure. The influence of various material properties on natural frequencies and modes is analyzed. The structural analysis of the shell is carried out.

The special consideration is given to the direct homogenization method, which allows to obtain effective thermal and elastic characteristics of the micro-heterogeneous media.

The research was held within scientific activities and studying finite element method application for multi-layered composite structures with complicated microstructure analysis.

Introduction

A catching cone presents a truncated cone consisting of two duotan layers of different rigidity that are fastened by a cord; circumferential grooves are disposed on the inner surface of a cone. A steel insert providing cone fastening with a shaft is located at the lower part of the cone.

The present paper considers the three-dimensional stress-strain state of the catching cone depending on various layers' rigidity and estimation of its natural vibration and frequencies.

Structural analysis

Finite element model and analysis procedure

A general view of the catching cone construction is shown in Fig. 1. The interior radius of the lower part of a cone is equal to 30 mm; its exterior radius being equal to 60 mm; opening angle of a cone – 5.7^{o}, cord thread diameter – 0.23 mm. A horizontal cord thread is coiled around a cone with a 2 mm - pitch. Vertical cord threads are put on a coil, being 71 in number. A cone is rotated by a shaft rigidly fastened to a steel insert disposed on a construction base.

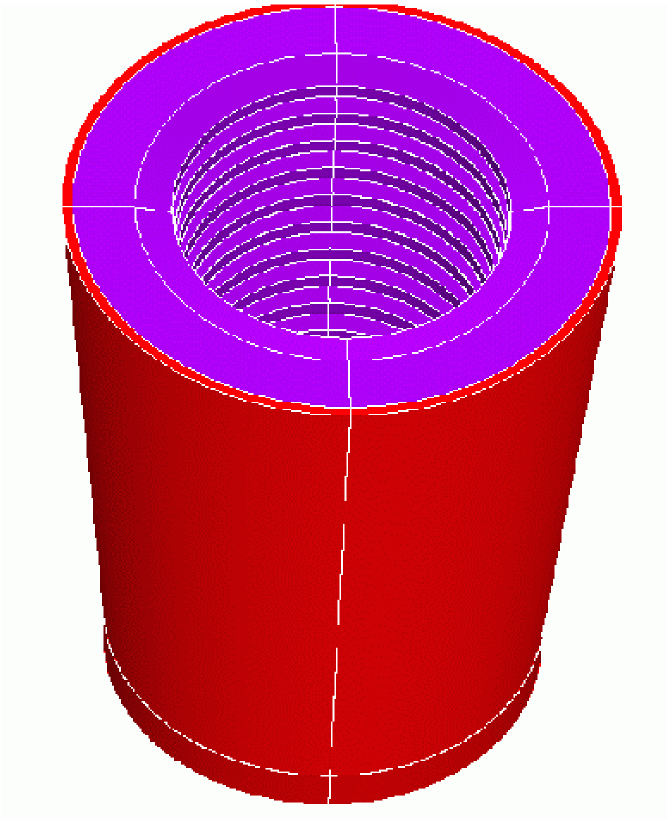

Figure 1 - A general view of the catching cone construction

For simplification of the cord homogenization procedure, taking into account the small value of a coiling pitch, a helical coiling is approximated by circumferential, leaving the same distance between threads (Fig. 2). With the use of the direct homogenization method, cylindrically isotropic material with efficient elasticity characteristics, earlier computed, was substituted for material of a cord-containing zone.

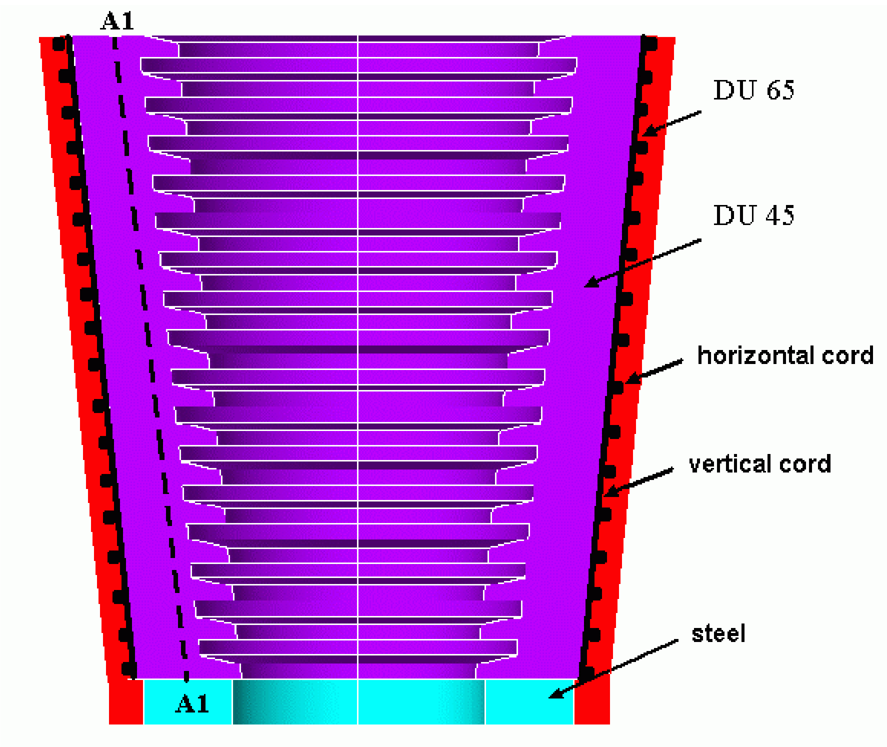

Figure 2 - A view of the location cord

Material properties

The computed elasticity characteristics occurred to be the following:

1) E_{DU45} = 1.1 MPa; E_{DU65} = 2.5 MPa; E_{steel} = 210 GPa - Young's modules correspondingly for Duotan 45, Duotan 65 and steel;

2) ν_{DU45} = 0.49, ν_{DU65} = 0.49, ν_{steel} = 0.3 - Poisson's ratios correspondingly for Duotan 45, Duotan 65 and steel;

3) E_r^* = 5.35 GPa, E_φ^* = 0.04 GPa, E_z^* = 5.35 GPa - Young's modules for a cord-containing zone with horizontal threads in radial, circumferential and vertical directions correspondingly;

4) $\nu_{r\varphi}^*$ = 0.005, $\nu_{\varphi z}^*$ = 0.65, ν_{rz}^* = 0.3 - Poisson's ratios for a cord-containing zone with horizontal threads in planes rφ, φz, rz correspondingly;

5) $G_{r\varphi}^*$ = 0.8 MPa, $G_{\varphi z}^*$ = 0.8 MPa, G_{rz}^* = 2.1 GPa - shear modules for a cord-containing zone with horizontal threads in planes $r\varphi$, φz and rz correspondingly.

Similar efficient elastic characteristics for cord-containing zones with vertical cord threads were obtained the following:

$$E_r^* = 15 \text{ GPa},\ E_\varphi^* = 15 \text{ GPa},\ E_z^* = 0.04 \text{ GPa};\ \nu_{r\varphi}^* = 0.3,\ \nu_{\varphi z}^* = 0.002,\ \nu_{rz}^* = 0.002;$$

$$G_{r\varphi}^* = 5.9 \text{ GPa},\ G_{\varphi z}^* = 0.9 \text{ MPa},\ G_{rz}^* = 0.9 \text{ MPa}.$$

Boundary conditions

The following boundary conditions were assumed:

1) the lower cone end is rigidly fixed;
2) the cone undergoes centrifugal forces corresponding to angular velocity of the rotated cone equal to 180 Hz.

Results

The 3D FE construction model has been developed with the use of ANSYS-software. It contains 2432 20-noded finite elements SOLID95.

Figures 3 and 4 demonstrate distribution of stress tensor components and von Mises stress intensity field for the case when the internal layer is produced from Duotan 45 and the external - from Duotan 65. Figures 5 and 6 show distribution of strain tensor components and von Mises strain intensity field for the same case.

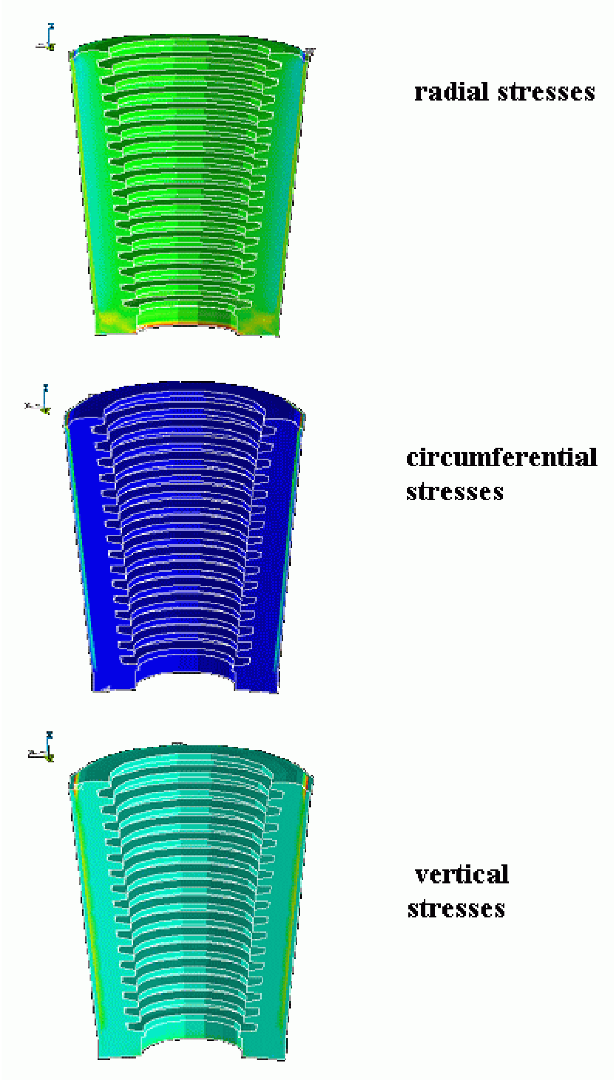

Figure 3 - Distribution of stress tensor components

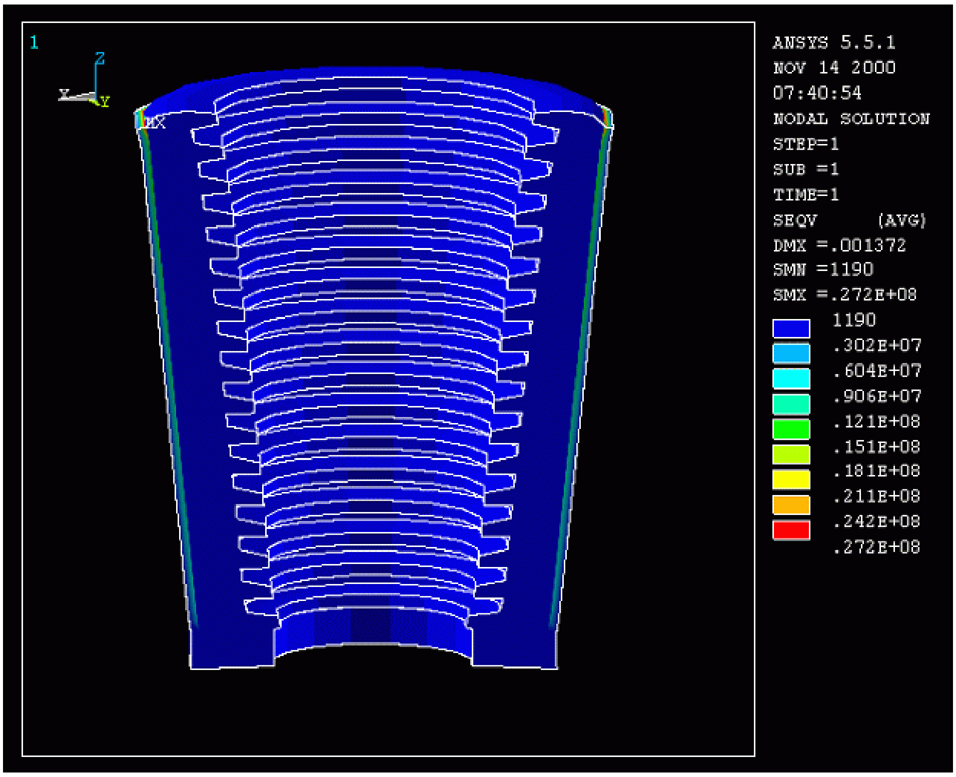

Figure 4 - Distribution of von Mises stress intensity

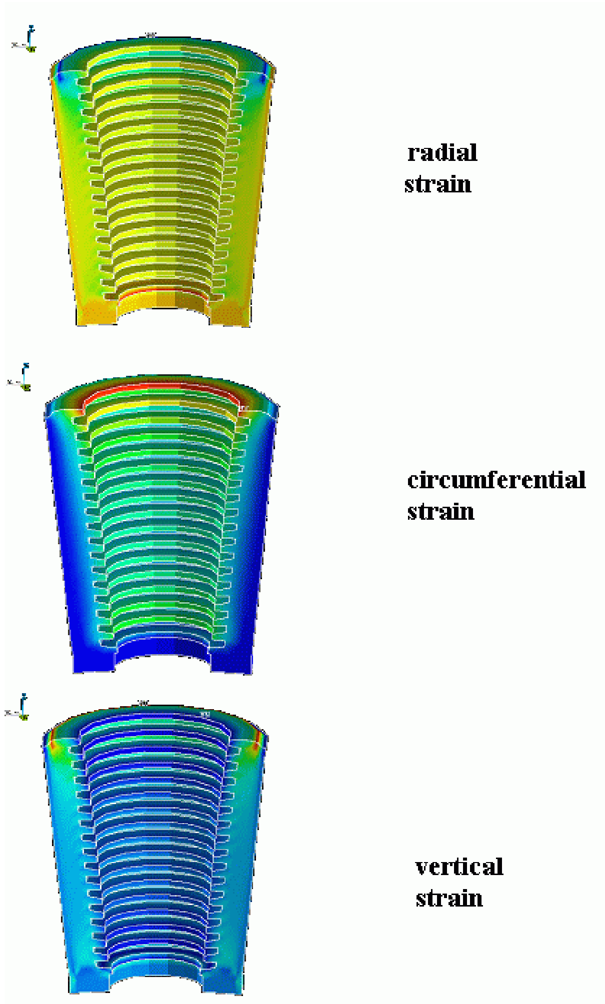

Figure 5 - Distribution of strain tensor components

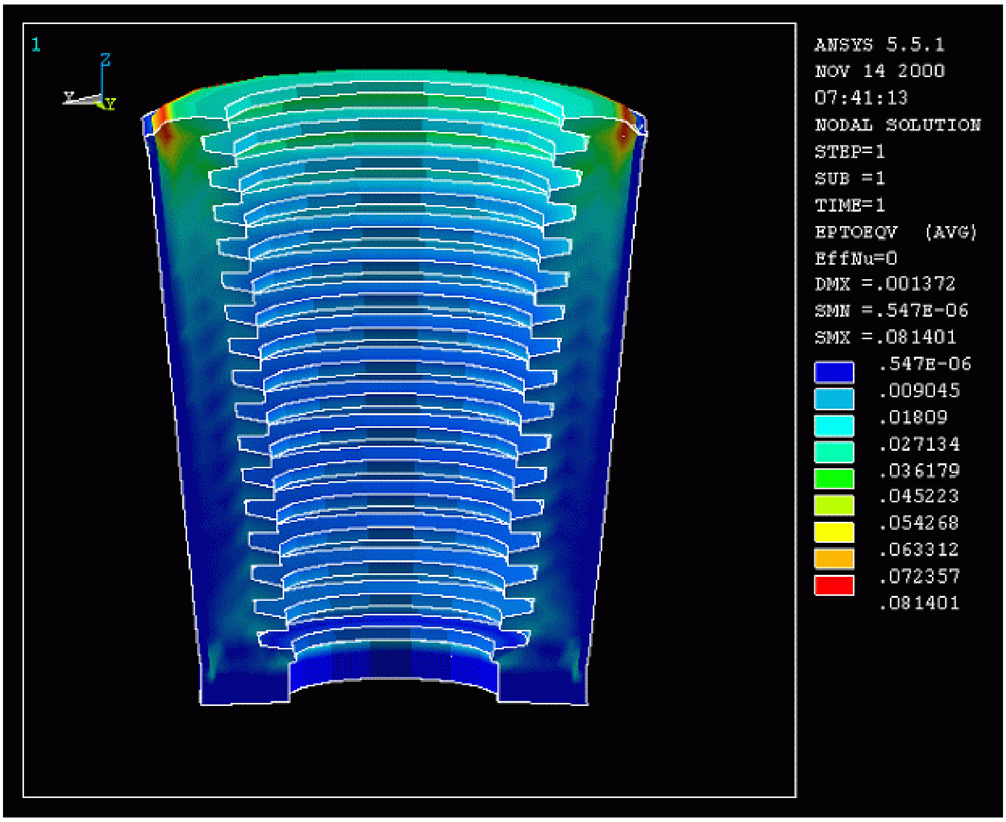

Figure 6 - Distribution of von Mises strain intensity

Fig. 7 presents stress state in cross-section A1-A1 (Fig. 2) and corresponding strain state in this cross-section.

A saw-tooth character of $\sigma_{int.}$ and $\varepsilon_{int.}$ – alterations may be explained by nearness of the cross-section to ribs. It was stated that stress surges correspond to the free end from the upper side and to the steel insert from the lower side.

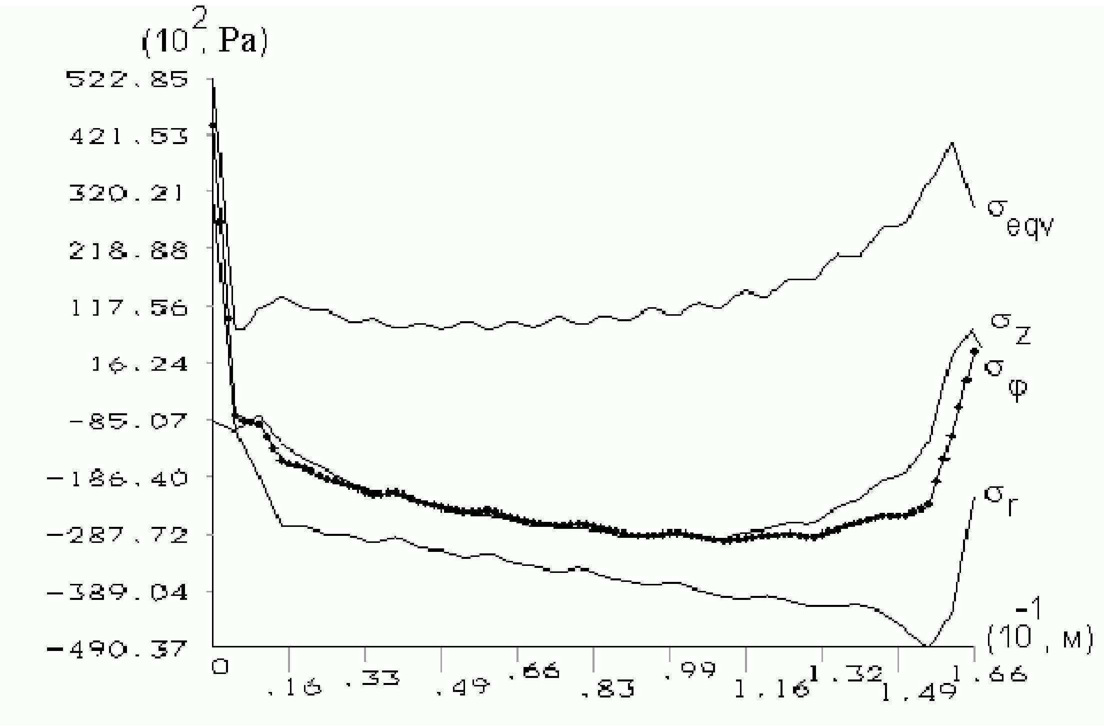

Figure 7a - Stress state in cross-section A1-A1

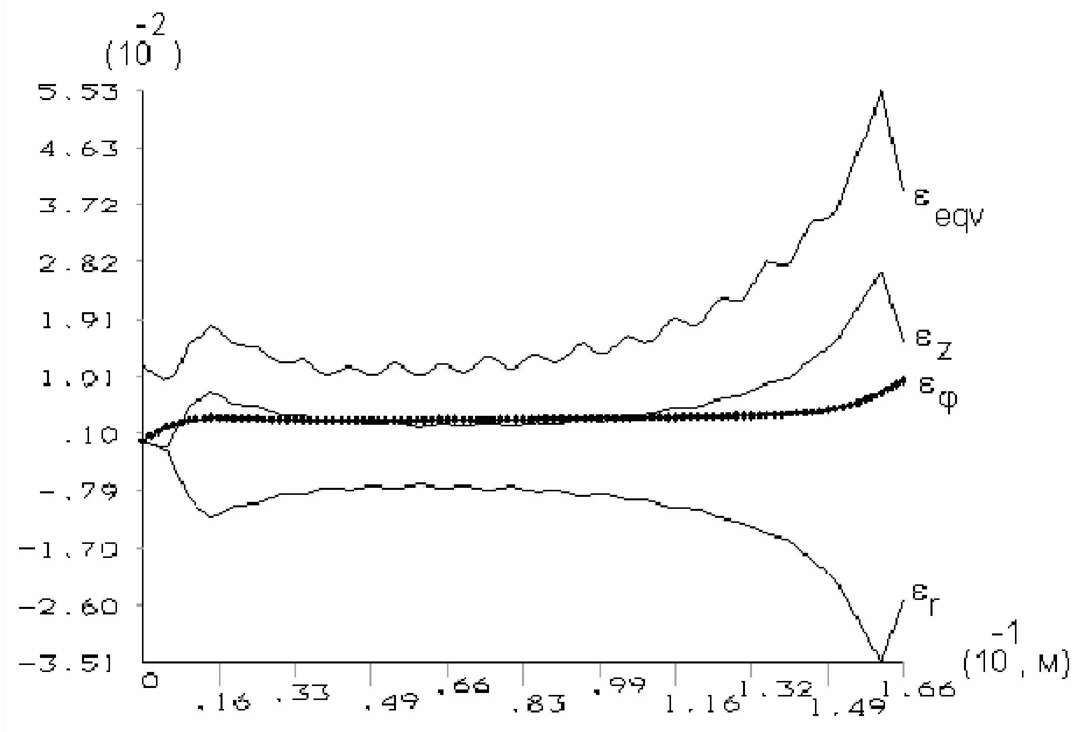

Figure 7b - Strain state in cross-section A1-A1

Modal analysis

Finite Element Model and Analysis Procedure

The research of catching cone natural frequencies is necessary for determination of the construction operational frequency range. Basing on the results of the research performed, it is possible to estimate the effect of various materials on natural frequencies and vibration modes and select a quasi-optimal construction.

Several constructions were considered, viz.:

1) internal layer of a cone with ribs made of Duotan 45, external layer – of Duotan 65 with a cord presence;
2) internal layer of a cone with ribs made of Duotan 45, external layer – of Duotan 65 (without a cord);
3) internal layer of a cone with ribs made of Duotan 65, external layer – of Duotan 65(without a cord);
4) internal layer of a cone with ribs made of Duotan 65, external layer – of Duotan 90(without a cord).

Material properties

The following material characteristics were taken for computations:

$E_{DU45} = 1.1$ MPa; $E_{DU65} = 2.5$ MPa; $E_{DU90} = 8.5$ MPa; $E_{steel} = 210$ GPa - Young's modules;

$\nu_{DU45} = 0.49$; $\nu_{DU65} = 0.49$; $\nu_{DU90} = 0.49$; $\nu_{steel} = =0.3$ - Poisson's ratios;

$\rho_{DU45} =$ 1200 kg/m^3; $\rho_{DU65} =$ 1200 kg/m^3; $\rho_{DU90} =$ 1200 kg/m^3; $\rho_{steel} =$ 7800 kg/m^3 – densities.

Boundary conditions

Boundary conditions were assumed the same as in the previous problem, viz.:

1) the lower cone end is rigidly fixed;
2) a cone undergoes centrifugal forces corresponding to angular velocity of a rotated cone equal to 180 Hz.

Results

Natural frequency calculation within the ANSYS-software was carried out with the use of the Lanczos' block method.

The obtained values of construction natural frequencies are presented in theTable.

Table

Natural frequencies determined for the construction types researched

Number of natural frequency	Natural frequency, Hz for different construction types			
	Type 1 (DU45/65, with cord present)	Type 2 (DU45/65)	Type 3 (DU65/65)	Type 4 (DU65/90)
1	20.4 Hz	23.4 Hz	15.1 Hz	22.7 Hz
2	43.0 Hz	28.1 Hz	40.1 Hz	51.0 Hz
3	57.3 Hz	32.0 Hz	45.1 Hz	52.2 Hz
4	65.1 Hz	45.1 Hz	47.7 Hz	57.0 Hz
5	71.9 Hz	48.2 Hz	65.5 Hz	73.8 Hz

Cone natural vibration modes corresponding to Type 1-construction are shown in Figures 8 through 11. Figures 8 through 10 present vertical displacements, Figure 11 illustrates circumferential ones.

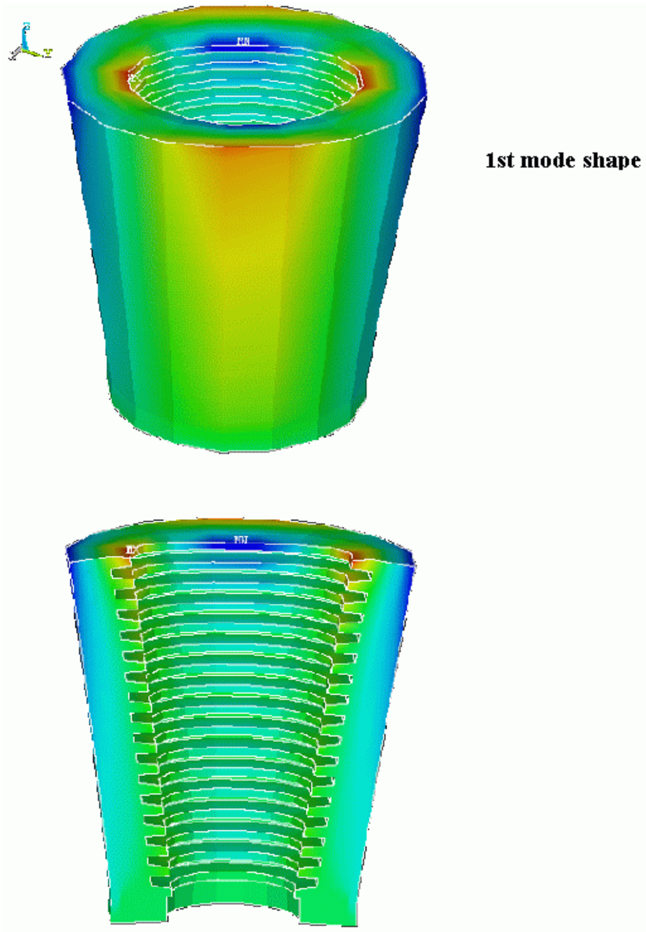

Figure 8 - 1st mode shape of the rotating cone with cord present

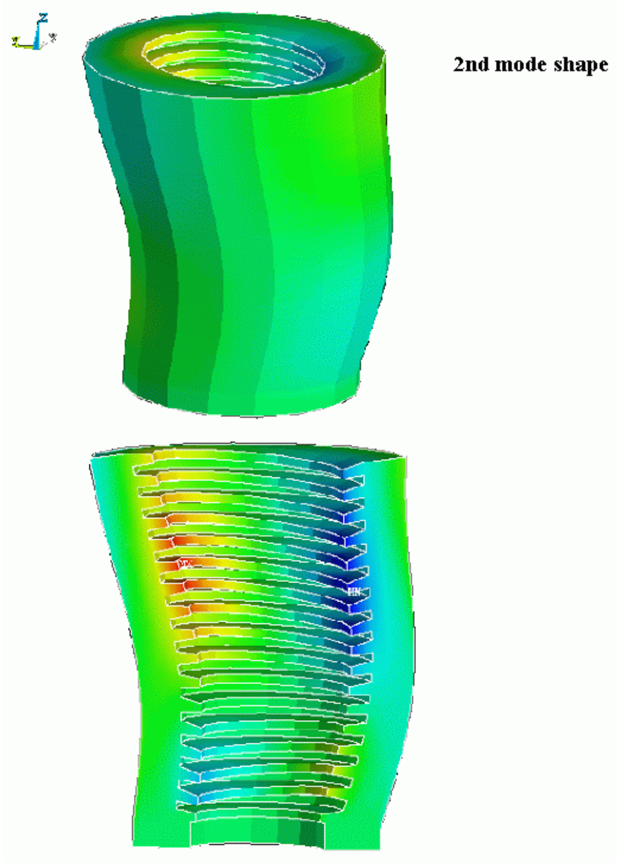

Figure 9 - 2nd mode shape of the rotating cone with cord present

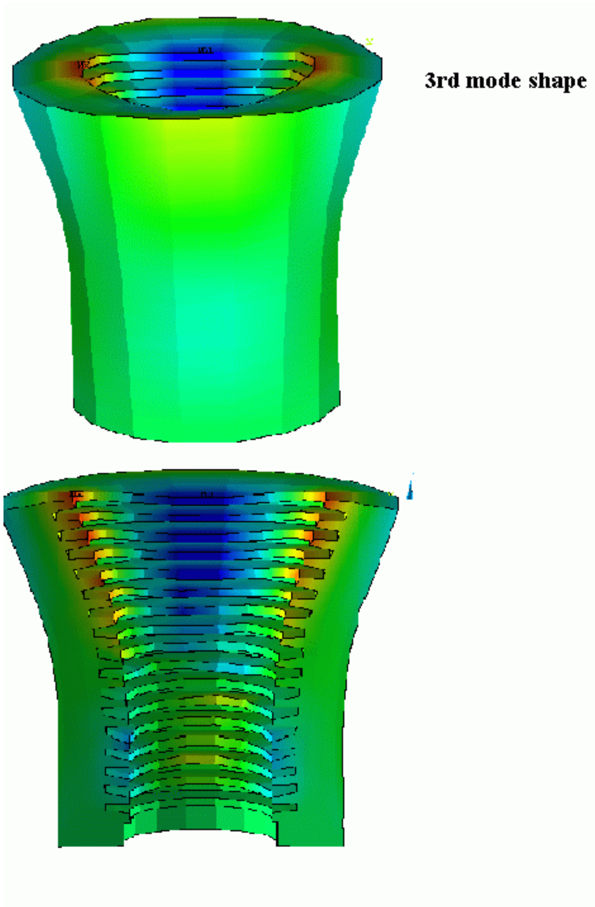

Figure 10 - 3rd mode shape of the rotating cone with cord present

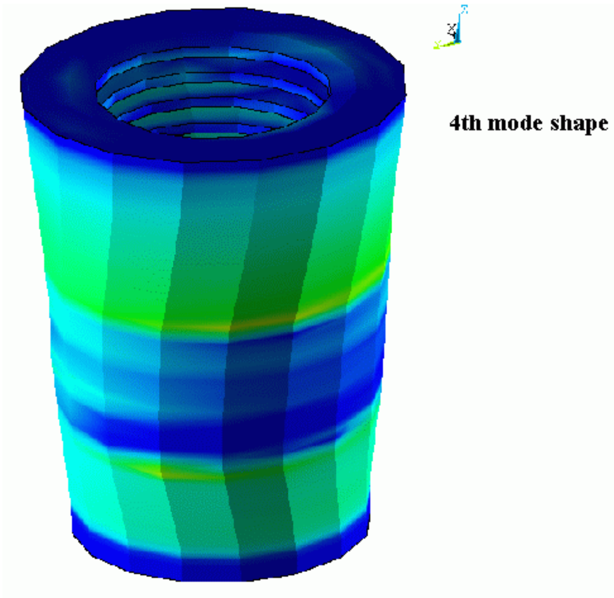

Figure 11 - 4th mode shape of the rotating cone with cord present

For comparison, five natural frequencies and vibration modes of a rotating cone without a cord for different material compositions of internal and external layers are presented in Fig. 12.

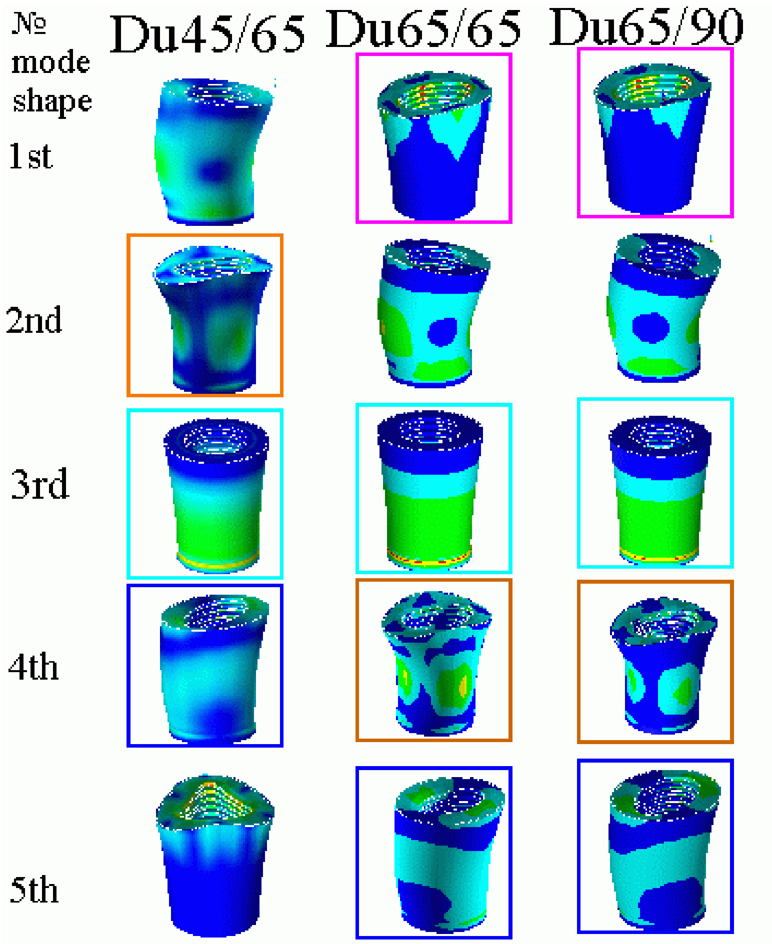

Figure 12 - Five mode shapes of the rotating cone without cord

The computational research performed gives evidence of a strong effect of a cord presence on the spectrum of natural frequencies and vibration modes.