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Defining relationships for reinforcing shell elements of a rubber-cord composite

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Abstract

For a general case of large deformations and arbitrary loading we have established defining relationships for a tensor of specific force arising in the layers of a cord fabric used for reinforcing of rubber-cord shells.

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Rubber-cord shells (RCS) of various designs are widely used in petrochemical and oil and gas mechanical engineering. Reinforcing elements of a rubber-cord composite (cord threads) take almost full load, applied to RCS. Rubber layers provide shell tightness and its protection against mechanical damages. Therefore, in RCS mathematical modeling the defining relationships describing connection between a tensor of specific force (per length unit) and a tensor of a cord fabric layer deformation are very important.

Tensile properties of cord threads, as a rule, are not taken into account in traditional methods of RCS calculation. Therefore, a mathematical model becomes significantly simpler and it is possible to obtain an analytical solution [1-3] in some cases. Neglecting the tensile properties of cord threads is well founded when threads' elongation at rupture is not large. However, for a number of widely used cord capron fabrics the thread elongation at rupture reaches 30%. This circumstance is taken into account in [4-6] with regard to shells of rotation with axially symmetric loading. Thus, the construction of defining relationships for cord fabric layers with large deformations and arbitrary loading is important. It allows one to obtain more reliable data about mechanical characteristics of RCS.

As a cord fabric layer does not work in bending, the main power characteristic is specific force vector $\mathbf{p}_\nu = \mathbf{dP}_\nu / \mathbf{d}l$, where $\mathbf{dP}_\nu$ is the force which affects a contour element of a cord fabric layer with $\mathbf{d}l$ length. The

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element has a basis vector of tangent line $\boldsymbol{\tau}$ and a basis vector of tangential normal $\boldsymbol{\nu}$ (Fig. 1a). Vector $\mathbf{p}_{\nu}$ and basis vector $\boldsymbol{\nu}$ are connected with each other by Cauchy formula [7]:

$$\mathbf{p}_{\nu} = \mathbf{T}\cdot\boldsymbol{\nu}, \tag{1}$$

where $\mathbf{T}$ is the tensor of specific force.

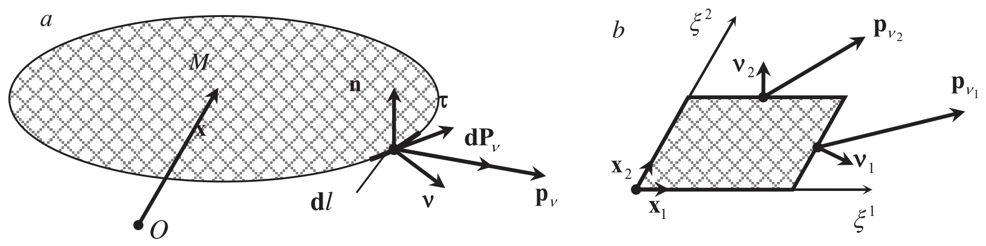

Fig. 1. Geometrical and power characteristics: *(a)* - a shell (cord fabric); (*b*) - an infinitesimal shell element.

Let the shell motion law (a cord fabric layer) be described by equation $\mathbf{x} = \mathbf{x}(t, \xi^1, \xi^2)$, where $\mathbf{x} = \overrightarrow{OM}$ is a radius-vector, t is time, ξ^1, ξ^2 are curvilinear (Gaussian) coordinates of the shell, considered as material (Lagrangian) coordinates. If to select an infinitesimal shell element with the sides, which are parallel to coordinate lines ξ^1, ξ^2 (Fig. 1b), then we can write

$$\mathbf{T} = \mathbf{T}\cdot\mathbf{x}^1\mathbf{x}_1 + \mathbf{T}\cdot\mathbf{x}^2\mathbf{x}_2 \tag{2}$$

Here coordinate vectors are $\mathbf{x}_{\alpha} = \partial\mathbf{x}(t, \xi^1, \xi^2)/\partial\xi^{\alpha}$, reciprocal basis vectors are $\mathbf{x}^{\alpha}$, a basis vector of normal is $\mathbf{n}$ (Fig. 1a):

$$\mathbf{x}^1 = \frac{\mathbf{x}_2\times\mathbf{n}}{|\mathbf{x}_1\times\mathbf{x}_2|}, \quad \mathbf{x}^2 = \frac{\mathbf{n}\times\mathbf{x}_1}{|\mathbf{x}_1\times\mathbf{x}_2|}, \quad \mathbf{n} = \frac{\mathbf{x}_1\times\mathbf{x}_2}{|\mathbf{x}_1\times\mathbf{x}_2|}. \tag{3}$$

According to (1) $\mathbf{p}_{\nu_1} \equiv \mathbf{p}^1 = \mathbf{T}\cdot\boldsymbol{\nu}_1$, $\mathbf{p}_{\nu_2} \equiv \mathbf{p}^2 = \mathbf{T}\cdot\boldsymbol{\nu}_2$ and $\boldsymbol{\nu}_1 = \mathbf{x}^1/|\mathbf{x}^1|$, $\boldsymbol{\nu}_2 = \mathbf{x}^2/|\mathbf{x}^2|$, based on (2) we obtain equation

$$\mathbf{T} = |\mathbf{x}^1|\mathbf{p}^1\mathbf{x}_1 + |\mathbf{x}^2|\mathbf{p}^2\mathbf{x}_2 \tag{4}$$

suitable to define the tensor of specific force.

Let us examine a rectangular representative element of a single cord fabric layer (Fig. 2a) with sizes, $\mathbf{d}L_1 = |\mathbf{X}_1|\mathbf{d}\xi^{\mathbf{1}}$, where $\mathbf{X}_1$, $\mathbf{X}_2$ are coordinate vectors in unloaded condition when $t = 0$. The number of threads in a representative element equals

$$\mathbf{d}N = \frac{\mathbf{d}L_2}{h_0} = \frac{|\mathbf{X}_2|\mathbf{d}\xi^{\mathbf{2}}}{h_0} \tag{5}$$

where h_0 is spacing between cord threads in unloaded condition.