The International Journal of
TRANSPORT & *LOGISTICS*
Medzinárodný časopis
DOPRAVA A LOGISTIKA

ISSN 1451-107X

GEOMETRIC MODEL OF THE ROPE CREATED OF OVAL STRANDS

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Abstract: *A steel rope is a structure composed of individual wires which are grouped into strands of various shapes. The strands form a rope. Hence, when considering geometric construction of the rope it is necessary to focus on the geometry of the individual wires. The paper deals with the mathematical geometric modeling of the steel rope created of oval strands. There is mathematical expression of wires created the oval strands of circular rope derived. The mathematical representation is in form of parametric equations of the wire axes. The equations are implemented in the Pro/Engineer Wildfire v5 software for creating the geometric model of the rope.*

Key words: *wire rope, strand of a rope, oval strand, geometric model*

1 INTRODUCTION

The utilization of advanced technology for design of steel ropes and detection their properties obtain considerable attention recently. Different analytical methods including the finite element method are used. Most of them are dedicated to a simple wire strands or to a rope created from circular strands, where strands are constructed from one or more layers of circular wires helically laid around a circular straight core wire [1], [2], [3]. Only in recent years the ropes formed from the strands other than a circular cross-section has been described [4], [5], [6].

This paper deals with the mathematical models for geometric modeling of wire strands in ropes deriving and subsequently their implementation in the CAD system for the creation of geometric model [7]. The strands have oval cross-section and they create circular rope. The present mathematical models consider the single-helix configuration of individual wires in the strand and double-helix configuration of individual wires within the wound strands of the rope. It will be described geometric construction of the rope and derived the mathematical expression of the centrelines of individual wires. The mathematical representation is in form of parametric equations. Geometric models of the wires, strands and rope by implementation of the derived mathematical expression in the Pro/Engineer Wildfire v5 will be constructed.

2 GEOMETRY OF THE ROPE

Let the circular rope is created by six strands of oval cross-section. The strands are wound around the rope core. We assume that the strands are laid in a helix having a right hand pitch. Winding angle of the strands we denote as β.

Any strand of the rope is made of two layers of circular wires helically laid around a core. The core consists of n_0 wires having a diameter δ_0. First layer is created by n_1 wires with diameter δ_1 and second layer is created by n_2 wires with diameter δ_2. There is the gap Δ_j between the wires. The wires of both layers have the right-hand pitch and the winding angle is α_j.

3 MATHEMATICAL EXPRESSION OF THE WIRE AXES

The surface generated by the wire can be formed by translation of the circle whose center is on the wire axis and the circle lies at the normal plane of this curve. For analytical mathematical expression of wire it is therefore sufficient to express the wire axis curve.

3.1 The single-helical wire

3.1.1 The wire of the first layer

Let the right-hand Cartesian coordinate system $(O;x,y,z)$ be placed so that the axis z is identical with the axis o_S of the strand. The curve of the wire axis consists of straight line segments and helix segments (Fig. 1).

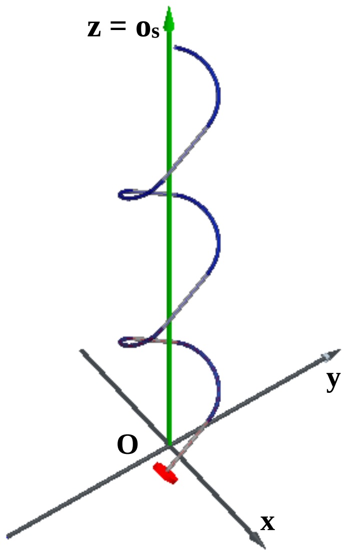

Fig. 1 *Wire axis in the strand*

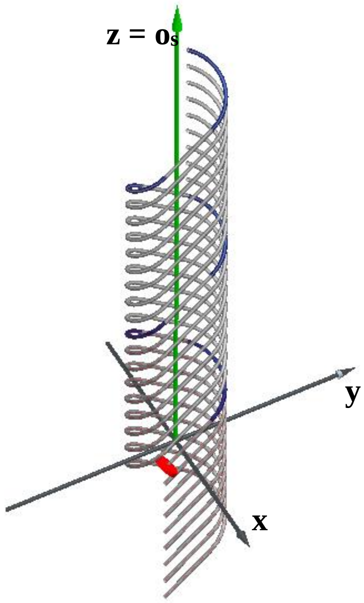

Fig. 2 *The centrelines of wires of one layer in the strand*

The parametric equations of the line segment according to [6] have the form

$$x_{l_1}(\psi)=\frac{\delta_0+\delta_1}{2}, \tag{1}$$

$$y_{l_1}(\psi)=\frac{(\delta_0+\delta_1)}{2}\tan(\psi-\gamma_1), \tag{2}$$

$$z_{l_1}(\psi)=\frac{(n_0-1)(\delta_0+\Delta_0)+(\delta_0+\delta_1)\tan(\psi-\gamma_1)}{2\tan\alpha_1}, \tag{3}$$

where $\psi\in\langle 0;2\gamma_1\rangle$ and

$$\gamma_1=\arctan\frac{(n_0-1)(\delta_0+\Delta_0)}{\delta_0+\delta_1}. \tag{4}$$

The equations of the helix part are obtained as

$$x_{h_1}(\psi)=\frac{(\delta_0+\delta_1)}{2}\cos(\psi), \tag{5}$$

$$y_{h_1}(\psi)=\frac{(n_0-1)(\delta_0+\Delta_0)+(\delta_0+\delta_1)\sin(\psi)}{2}, \tag{6}$$

$$z_{h_1}(\psi)=\frac{(\delta_0+\delta_1)\psi+2(n_0-1)(\delta_0+\Delta_0)}{2\tan\alpha_1}, \tag{7}$$

where $\psi\in\langle 0\,;\pi\rangle$.

3.1.2 The wire of the second layer

For line segment and helix segment of the wire axis curve of second layer they are derived the following relationships in [6]:

$$x_{l_2}(\psi)=\frac{\delta_0+2\delta_1+\delta_2}{2}, \tag{8}$$

$$y_{l_2}(\psi)=\frac{(\delta_0+2\delta_1+\delta_2)}{2}\tan(\psi-\gamma_2), \tag{9}$$

$$z_{l_2}(\psi)=\frac{(n_0-1)(\delta_0+\Delta_0)+(\delta_0+2\delta_1+\delta_2)\tan(\psi-\gamma_2)}{2\tan\alpha_2}, \tag{10}$$

where and $\psi\in\langle 0;2\gamma_2\rangle$ and

$$\gamma_2=\arctan\frac{(n_0-1)(\delta_0+\Delta_0)}{\delta_0+2\delta_1+\delta_2}, \tag{11}$$

$$x_{h_2}(\psi)=\frac{(\delta_0+2\delta_1+\delta_2)}{2}\cos(\psi), \tag{12}$$

$$y_{h_2}(\psi)=\frac{(n_0-1)(\delta_0+\Delta_0)+(\delta_0+2\delta_1+\delta_2)\sin(\psi)}{2}, \tag{13}$$

$$z_{h_2}(\psi)=\frac{2(n_0-1)(\delta_0+\Delta_0)+(\delta_0+2\delta_1+\delta_2)\psi}{2\tan(\alpha_2)} \tag{14}$$

for $\psi\in\langle 0\,;\pi\rangle$.

3.1.3 Any wire in the strand layer

The line segment and helix segment are repeated in the wire axis. Each of them is rotated by the angle $\kappa=k\pi$ and shifted of the length h_{Δ_j} relative to the axis z. The wires of one layer create the same surfaces. Therefore, each wire in the layer is given by the previous one shifted by a particular size h_{w_j} in the axial direction. It can be calculated from the relationship

$$h_{w_j}=\frac{h_{\Delta_j}}{n_j} \tag{15}$$

where for the 1st layer

$$h_{\Delta_1}=\frac{(\delta_0+\delta_1)\pi+2(n_0-1)(\delta_0+\Delta_0)}{2\tan\alpha_1} \tag{16}$$

and for the 2nd layer

$$h_{\Delta_2}(\psi)=\frac{2(n_0-1)(\delta_0+\Delta_0)+(\delta_0+2\delta_1+\delta_2)\pi}{2\tan(\alpha_2)}. \tag{17}$$

So, the curve of any single-helical wire axis of the layer can be expressed by parametric equations

$$x_s(\psi)=x_w(\psi)\cos\kappa-y_w(\psi)\sin\kappa \tag{18}$$

$$y_s(\psi)=x_w(\psi)\sin\kappa+y_w(\psi)\cos\kappa \tag{19}$$

$$z_s(\psi)=z_w(\psi)+kh_{\Delta_j}-ih_{w_j} \tag{20}$$

in which for the first layer we use the equations (1) - (4), $\psi\in\langle 0;2\gamma_1\rangle$ for line segment ($w=l_1$) and the equations (5) – (7), $\psi\in\langle 0\,;\pi\rangle$ for helical segment ($w=h_1$).We use the equations (8) – (11) and (12) – (14) for the second layer. For illustration, the centrelines of nine wires in the first layer of the strand, obtained by the derived parametric equations, are shown in Fig. 2.

3.2 The double-helical wire

Let us consider the right hand lay rope. The strands are helically laid around the core of a rope and at the same time the wires in the strand layer are laid at the right hand direction around the core of the strand. Any centreline of wire is double-wound curve.
In the considered rope let R_s is the lay radius and β the lay angle of the strand. We use the coordinate system transformation to obtain the mathematical expression of wire centreline

curve. The coordinate system $(O;x,y,z)$ used in single helical laid wire we transform to coordinate system $(O';x',y',z')$ where the axis z' is identical with the rope axis as is shown in Fig. 3.

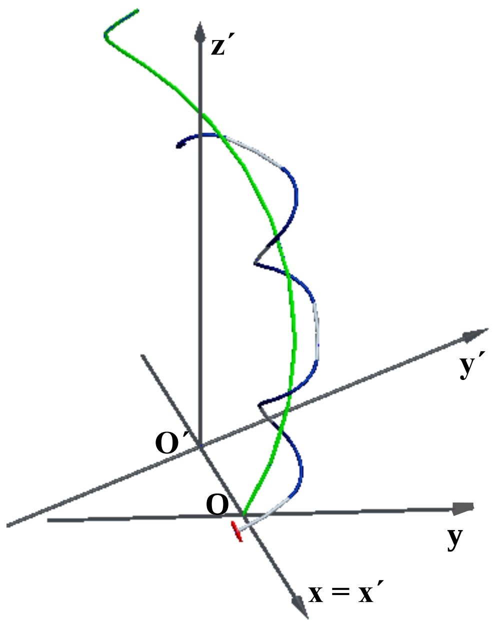

Fig. 3 *Wire axis in the rope*

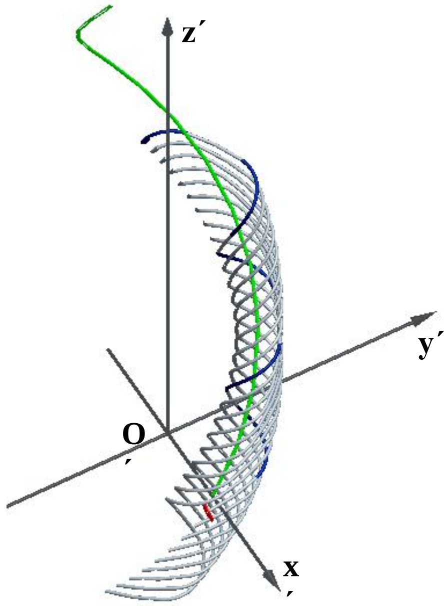

Fig. 4 *The centrelines of wires of one layer*

By this transforming, the parametric equations of the centreline of the wire i in the layer j of the oval strand are obtained

$$x'(\xi) = x_s \cos(\xi - \xi_\Delta) - y_s \sin(\xi - \xi_\Delta)\cos\beta + R\cos(\xi - \xi_\Delta), \tag{21}$$

$$y'(\xi) = x_s \sin(\xi - \xi_\Delta) - y_s \cos(\xi - \xi_\Delta)\cos\beta + R\sin(\xi - \xi_\Delta), \tag{22}$$

$$z'(\xi) = -y_s \sin\beta + R(\xi - \xi_\Delta)\cot\beta, \tag{23}$$

where $\xi \in \langle 0\,,\, 2\pi \rangle$ for one pitch lenght of the strand. Using them, it is necessary the angle ψ occurring in the equations (18) - (20) to express by the angle ξ. To verify the equations, the centrelines of wires of the first layer in the rope are shown in Fig.4.

4 GEOMETRIC MODEL OF THE ROPE

Based on the mathematical expression it is possible to construct the geometric model of the wires and subsequently of the rope. To illustrate the model of the rope 6x(3+9+15) is constructed. In this case the parametric equations are implemented in Pro/ENGINEER Wildfire v5 software for the geometric modelling.

The creation of the rope model consists of following steps:

- establishment of the core wire models of the strand,
- establishment of the models of the wires in the layers,
- composition of partial models to the model of the strand,
- creation of complete geometric rope model.

The process of the modeling is shown in Figures 5 – 7.

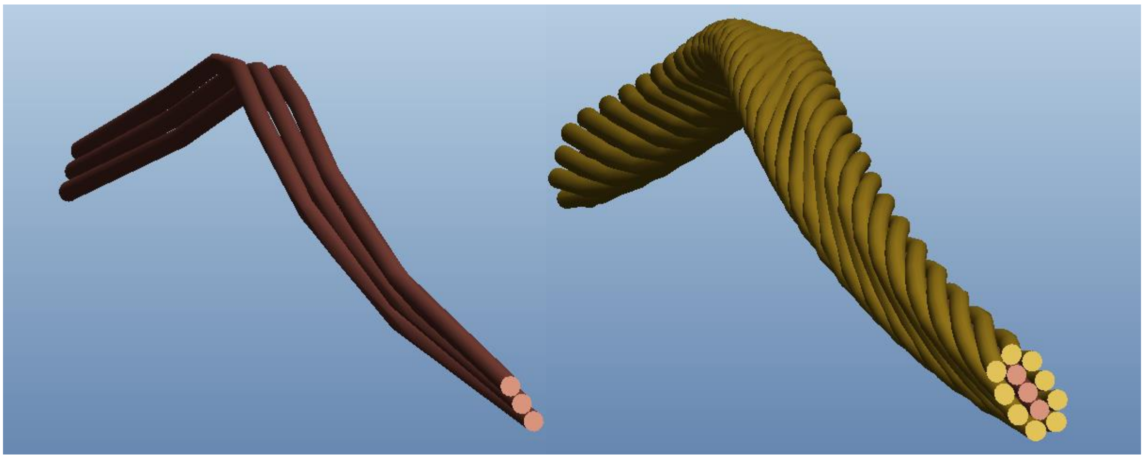

Fig. 5 *Geometrical models of the core wires and of the wires of 1st layer*

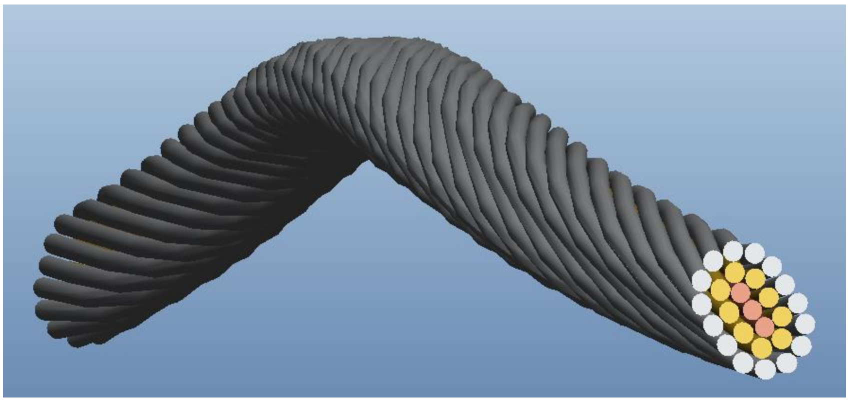

Fig. 6 *Geometrical model of the strand of* 3+9+15 *wires*

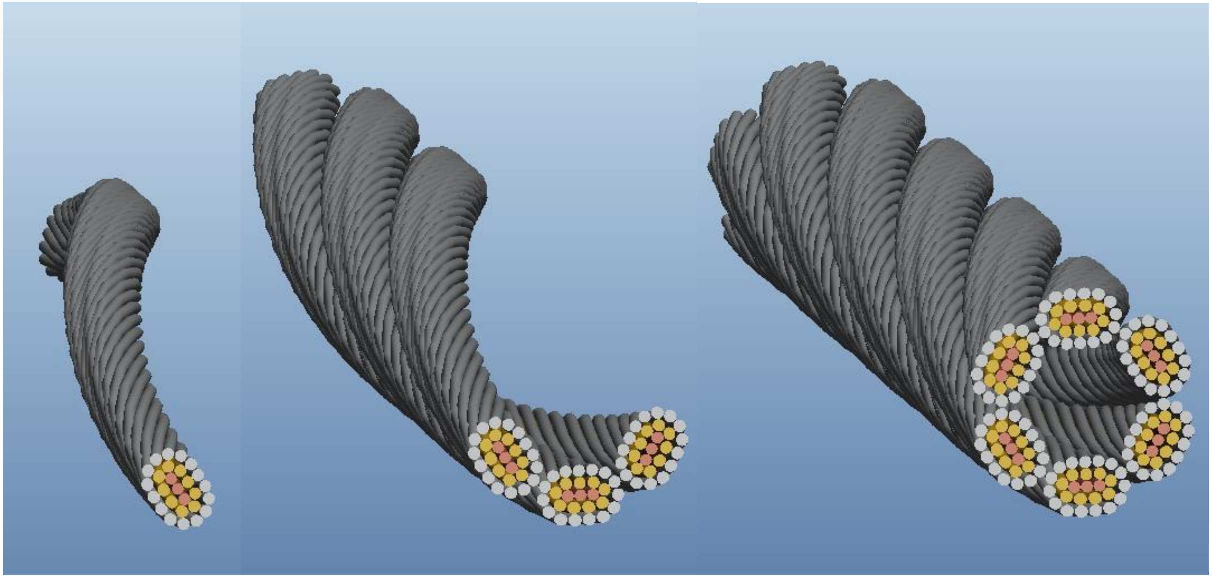

Fig. 7 *Generation of the geometric rope model*

5 CONCLUSION

In order to create the geometric model of the steel rope formed of oval strands, the parametric equations of wire axis have been developed and implemented in Pro/ENGINEER Wildfire V5 software for the modelling. The parametric equations have variable parameters determining the number of wires in the core and in the layers. Developed equations allow us to create the model of oval strand with two layers wound in the rope. Subsequently, using the model of the strand we can create a model of the rope.

For illustration, the strand of 3+9+15 wires was modeled and the geometric model of the rope 6x(3+9+15) was created using the strand model.

The described method can be used to explicit computer modeling and analysis of wire strands and ropes.

Acknowledgements

This work is a part of Research Project VEGA 1/0321/12: Theoretical and experimental analysis of adaptive rope and tensegrity systems under static and dynamic stress with considering the effects of wind and seismic.

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