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Study of the Operation of a Movable Navel of a Rotor Spinning Machine

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ABSTRACT: An intensive increase in demand for OE based yarns of a wide assortment requires the improvement of spinning machines on which the processes of its formation is carried out. Recently, as a result of a sharp increase in the speed of OE spinning, the productivity of the machine has increased, and the quality indicators of the yarn produced have deteriorated, i.e. unevenness in its structure and properties increased [1-4]. A number of works [5-18] are devoted to studies on the assessment of the structure and properties of OE yarns. The features of the forming structure are described, for the study of which microscopy, a method of transverse sections has been used, and the migration of fibers in the yarn was evaluated [5-10]. The structure of the yarn is also evaluated by the results of the processes of its formation and determination of its properties [11-12]. Studies have also been carried out to determine the influence of the parameters of the spinning chamber on the structure and properties of yarn. The structural engineering features of combined OE yarn were also studied [13-16]. However, in the above-mentioned studies, there are no recommendations for improving the structure and properties of OE yarn, and reducing unevenness produced at high yarn speeds. In order to improve the structure and properties of OE yarns and increase the competitiveness of manufactured textile products from it, there is a need to improve the design of the working bodies, which directly affect the structural changes and the yarn tension. To achieve this goal, a device of a thread-returning mobile navel has been developed [17], and as a result of the study, the advantage of its use has been proved [18].

I. INTRODUCTION

With an increase in the rotational speed of the spinning chamber, the unevenness in the properties and in the tension of the thread in the cylinder increases, which in its turn, leads to a change in the tension of the fibers in the torsion triangle. Under the influence of variable yarn tension, it must be assumed that the arrangement of the fibers at its open end changes. This is a source of structural unevenness of the yarn, to reduce which it is necessary to reduce the change in the tension of the thread in the container. One of the methods to reduce the tension of the thread is the use of a movable navel on an elastic element in the zone of formation of yarn. A movable navel has been developed (Fig. 1) on elastic element 2, due to which it is possible to freely move along its axis under the influence of yarn tension [5].

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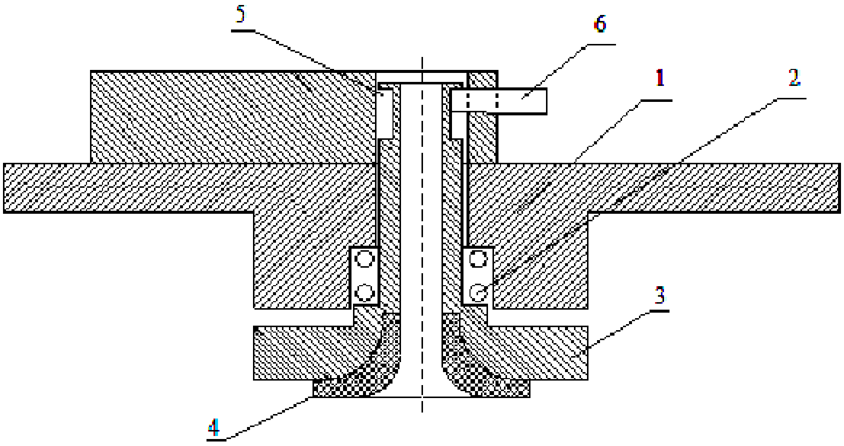
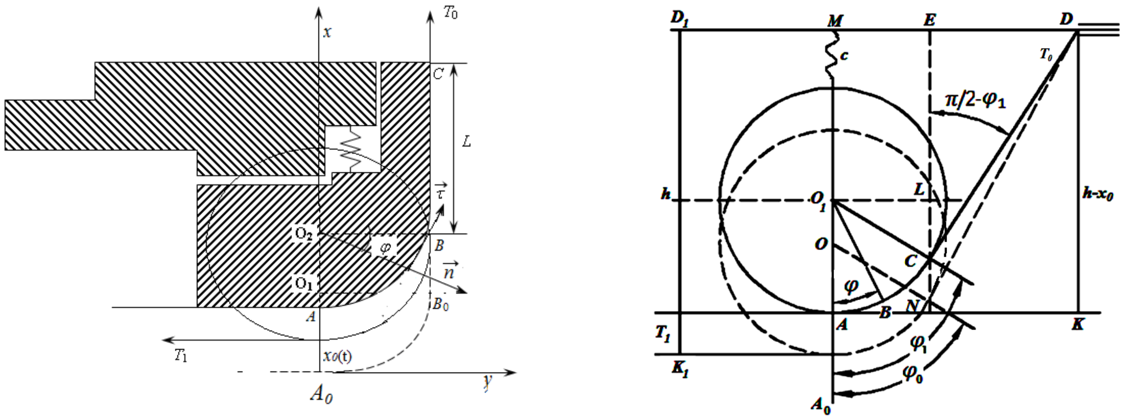


Fig. 1. Yarn movable navel on an elastic element.
1- housing separator, 2- spring, 3- navel base, 4- navel, 5- notch, 6- retainer.

II. THEORETICAL PART

To determine the tension fluctuations of the yarn formed in the spinning chamber, a diagram was drawn up (Fig. 2a) and the work of a movable navel was analytically studied. The following assumptions were made: 1) It is assumed that the length of the rectilinear zone of the thread BC repeatedly exceeds the length of the arc of contact of the thread with the surface of the navel $L >> \breve{AB}$ 2) The body only moves in the vertical direction.
The origin is set at a fixed point and the axis is vertically directed upwards. Let each point of the thread moves at high speed along the arc of the movable part of the navel, making a vertical movement according to the formula $x = x_0(t)$ (Fig.2a)



a) b)

Fig. 2. Diagram of the analysis of the work of a movable navel on an elastic element

The speed of the point of the thread, with the coordinate being the Euler variable, is represented as the sum of the local and convective components. Consider the problem of contour movement of a thread on the surface of a navel, which is an arc of a circle. In this case, the arc makes a vertical movement along the $0x$ axis at speed $v(t) = \dot{x}_0(t)$. The contour movement of the thread is studied by the Euler method. The motion of the thread in Euler coordinates is described by partial differential equations with two arguments s, t (*s*- arc length, *t*- time), and its contour motion is described by an ordinary differential equation with one argument. We introduce the natural unit coordinates $\vec{\tau}$ and $\vec{n}$, and direct respectively along the tangent and normal of the contour (Fig. 2a) and record the portable speed of the thread in these directions.

ISSN: 2350-0328
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Vol. 7, Issue 5 , May 2020

$$\vec{v}_e = \dot{x}_0(t)(\vec{\tau}\sin\varphi - \vec{n}\cos\varphi) \qquad (1)$$

The full acceleration of an arbitrary point of the thread is represented as the sum of the accelerations of the joint with the arc (figurative) $\vec{w}_e$ and relative accelerations $\vec{w}_r$

$$\vec{w} = \vec{w}_e + \vec{w}_r$$

In this case, the projections of the portable and relative accelerations on the connected axes $(\vec{\tau},\vec{n})$ have the following form

$$w_{r\tau} = \frac{dv_r}{dt} = \dot{v}_r,\; w_{rn} = \frac{v_r^2}{R},\; w_{e\tau} = \ddot{x}_0(t)\sin\varphi,\; w_{en} = -\ddot{x}_0(t)\cos\varphi \qquad (2)$$

where, R is the radius of the circular arc. The equation of motion of the thread, taking into account (2), will be presented in the following form:

$$\frac{\partial T}{\partial s}\vec{\tau} + \frac{T}{R}\vec{n} + \vec{f} = \mu[(\dot{v}_r + \ddot{x}_0\sin\varphi)\vec{\tau} + (\frac{v_r^2}{R} - \ddot{x}_0\cos\varphi)\vec{n}] \qquad (3)$$

where, $T = T(s,t)$ is the thread tension, H , μ is the linear mass of the thread, $\vec{f} = f_\tau\vec{\tau} + f_n\vec{n}$, f_τ and f_n the intensity of the tangential and normal forces acting on the thread. If we accept the Amonton law, then we should assume $f_\tau = kf_n$ (k (is the coefficient of friction between the thread and the navel), then equation (3) regarding the tension in the variable takes the form $\varphi = s/R$

$$\frac{\partial T}{\partial\varphi} - kT = \mu[R\dot{v}_r - kv_r^2 + R\mu\ddot{x}_0\sin\varphi \qquad (4)$$

Equation (4) is integrated under the condition $T(0) = T_1$ when $\varphi = 0$ and its solution depends on the relative velocity v_r . For a given, it is necessary to determine the movement $x_0(t)$ of the navel, which satisfies the equation of motion

$$m\ddot{x}_0 = -mg - cx_0 - \eta\dot{x}_0 + F \qquad (5)$$

where, m is the mass of the moving part of the navel, c and η are the stiffness and viscosity coefficients of the elastic element respectively, F is the contact force acting on the navel from the side of the thread, which is determined by the formula

$$F = \int_{0)}^{\varphi_1(x_0)} qR(k\sin\varphi + \cos\varphi)\exp(k\varphi)d\varphi \qquad (6)$$

To determine the angle $\varphi_1(x_0)$, we use Fig. 2c, where $l = MD$ and $h = D_1K_1$ is the distance from the center of the navel (point O_1) and the base (point K) respectively to the point of entry of the thread into the torsion zone which is denoted by D , where R is the radius of the navel.

From Fig.2c, we can find

$$l = ED + R\sin\varphi_1 = ECctg\varphi_1 + R\sin\varphi_1,\; EC = LE + R\cos\varphi_1 = h - x_0 - R(1-\cos\varphi_1)$$

From these equalities we establish the relationship between the angle φ_1 and the displacement x_0

$$l = [h - x_0 - R(1-\cos\varphi_1)]ctg\varphi_1 + R\sin\varphi_1$$

Having solved this equality in relation to φ_1, we can obtain

ISSN: 2350-0328
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Vol. 7, Issue 5 , May 2020

$$\varphi_1 = \arcsin\frac{h - R - x_0}{\sqrt{l^2 + (h - R - x_0)^2}} + \arcsin\frac{R}{\sqrt{l^2 + (h - R - x_0)^2}},$$

Next, it is believed that $v_r = v_0$. Let the navel move from the moment, $t = 0$ i.e. it must be assumed that $x_0(t) = x_{00}$ with $t < 0$. Then the tension of the thread and the normal force $N = qR$ until the movement of the movable navel along the arc of contact are distributed according to the formulae.

$$T = (T_1 - \mu v_0^2)\exp(k\varphi) - \mu v_0^2, \quad (7)$$

$$N = (T_1 - \mu v_0^2)\exp(k\varphi) \quad \text{at} \quad 0 < \varphi < \varphi_0 \quad (8)$$

где, $$\varphi_0 = \arcsin\frac{h - R - x_{00}}{\sqrt{l^2 + (h - R - x_{00})^2}} + \arcsin\frac{R}{\sqrt{l^2 + (h - R - x_{00})^2}} \quad (9)$$

where x_{00} is the movement of the movable navel till the moment its motion begins, which is determined from the equilibrium equation $mg + cx_{00} - F_0 = 0$

In this case, the force F_0 acting on the moving navel in the equilibrium state is calculated by the formula (6), where $\dot{x}_0 = \ddot{x}_0 = 0$,

$$F_0 = (T_1 - \mu v_0^2)\exp(k\varphi_0)\sin\varphi_0 \quad (10)$$

By supplying the expression of force F_0 to equation (10) with allowance for equation (9), we can compose an equation to determine the coordinate of the point x_{00} in the equilibrium state of the navel

$$x_{00} = [-mg + (T_1 - \mu v_0^2)\exp(k\varphi_0)\sin\varphi_0]c$$

Table 1 shows the indicators for various values where, x_{00}(мм) of radius $R(мм)$ and tension T_1(cH). In the calculations it is accepted that: $l = 0.01м$, $h = 0.009м$, c = 100 Н/м ; $m = 5\cdot 10^{-3}$ кг ;

$l = 0.01м$, $h = 0.009м$, c = 100 Н/м , $k = 0.2$, $\mu = 25\cdot 10^{-6}/кг$, $v_0 = 200м/м$

The table shows that with an increase in the radius of the movable navel and an increase in the thread tension at the entrance to the contact zone, the equilibrium values of the navel displacement on the elastic element also increase. It follows that the radius of the navel and the tension of the thread determine the operation of the movable navel.

Table 1 Values x_{00}(мм) for various navel radius $R(мм)$ and thread tension T_1(cH)

	$T_1 = 25cH$					$T_1 = 30cH$				
R(мм)	1	2	3	4	5	1	2	3	4	5
$x_{00}(мм)$	1.27	1.31	1.36	1.41	1.47	1.57	1.62	1.67	1.73	1.8
	$T_1 = 35cH$					$T_1 = 40cH$				
R(мм)	1	2	3	4	5	1	2	3	4	5
$x_{00}(мм)$	1.85	1.9	1.96	2.0	1.21	2.12	2.16	2.22	2.3	2.36

Figure 3 shows the curves of the dependence of the angle φ_0 on displacement $x_{00}(м)$ for two $h = DM$ and different values of the radius of the navel $R(м)$.

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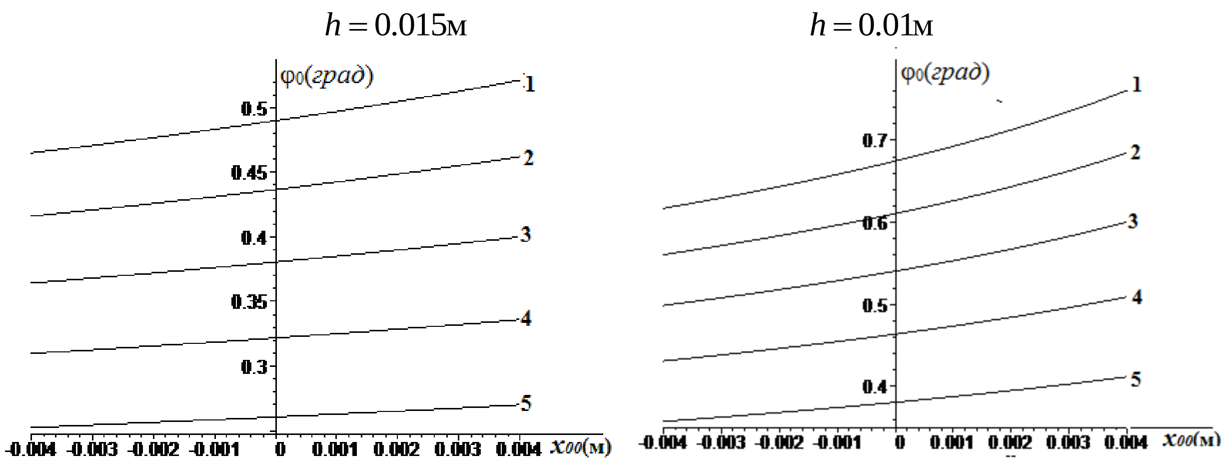

Fig. 3. Depending $\varphi_0\,(град)$ on the equilibrium movement $x_{00}\,(\text{м})$ of the moving navel for two distances $h(\text{м})$ and different values of the radius of the navel $R(м)$:

$1 - R = 0.001$, $2 - R = 0.002$, $3 - R = 0.003$, $4 - R = 0.004$, $5 - R = 0.005$

From the curves, presented in fig. 3, it follows that the equilibrium value of the navel displacement substantially depends on its radius, the distance between the center of the thread conductor and the point of entry of the thread into the torsion zone. In this case, with an increase in the equilibrium value of the displacement of the mobile navel, a monotonic increase in the angle is observed φ_0.

For an arbitrary point in time $t > 0$, the tension T and the normal force N are determined by the formulas

$$T = (T_1 - \mu v_0^2)\exp(k\varphi) - \mu v_0^2 + \mu R\ddot{x}_0(\exp(k\varphi) - \cos\varphi - k\sin(\varphi)]/(k^2+1)$$

$$N = (T_1 - \mu v_0^2)\exp(k\varphi) + \mu R\ddot{x}_0(\exp(k\varphi) - \cos\varphi - k\sin(\varphi)]/(k^2+1) - R\mu\ddot{x}_0\cos\varphi$$

The value μR has an order 10^{-6}, and in this regard, $\mu R \approx 0$ is assumed in the future calculations. Then the expressions for tension T, normal force N, and the force acting on the moving navel F are determined by formulas (7), (8) and, where the equilibrium angle φ_0 ,should be replaced by φ_1, depending on the movement of the moving navel $x_0(t)$

$$\varphi_1 = \arcsin\frac{h - R - x_0}{\sqrt{l^2 + (h - R - x_0)^2}} + \arcsin\frac{R}{\sqrt{l^2 + (h - R - x_0)^2}}$$

Here, the displacement $x_0(t)$ according to formula (5) satisfies the equation

$$\ddot{x}_0 + 2n\dot{x}_0 + \omega^2 x_0 = -g + (T_1 - \mu v_0^2)\exp(k\varphi_1)\sin\varphi_1 / m \qquad (11)$$

Equation (11) is nonlinear, which integrates numerically with the initial conditions $x_0(0) = x_{0н}$, $\dot{x}_0 = 0$.

The fig. 4 shows the curves of the dependence of tension $T_0 = T[\varphi_1(t)]$ on time for two values of the stiffness coefficient $c(H/\text{м})$ of the elastic element. In the calculations $\eta = 1Hc/\text{м}^2$ are additionally accepted. From the analysis of the curves it follows an oscillatory character with a damping amplitude of the change in tension over time at the point of its vanishing from the surface of the mobile navel. The presence of a damper in the elastic element leads to a rapid decrease in the fluctuation of tension, moreover, its limiting value is less than static by 10-12%. In this case, the damping properties of the element mainly affect the time at which the oscillation amplitude reaches the limiting value.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 5 , May 2020

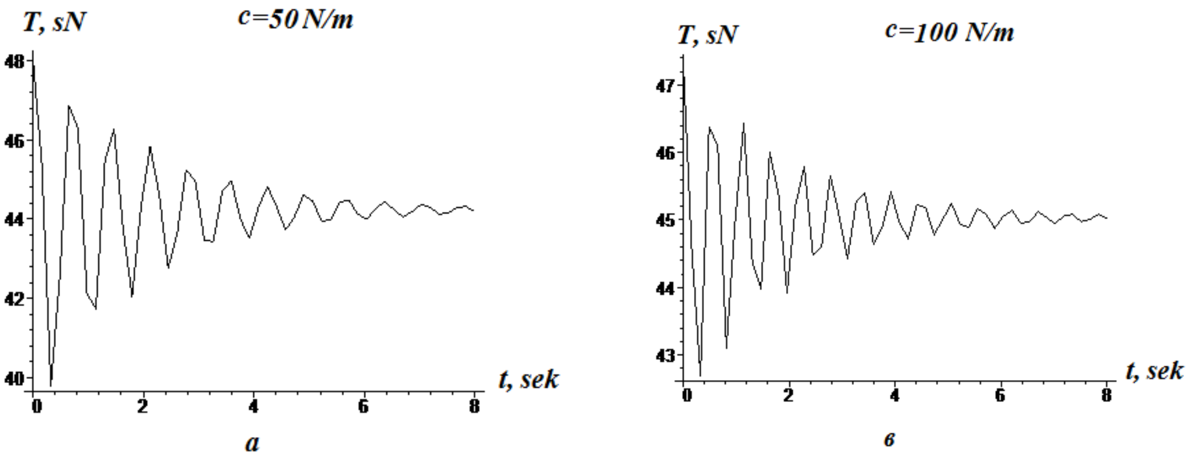

Fig. 4. Dependence of the thread $T_0 = T[\varphi_1(t)]$ tension at the point of its descent from the surface of the navel on time t(сек) for two values of the stiffness coefficient of the elastic element

The dependence of the thread $T_0 = T[\varphi_1(t)]$ tension on time for two values of the coefficient of friction f is shown in Fig. 5. This shows that the increase in the coefficient of friction leads to an increase in tension by 10-12%.

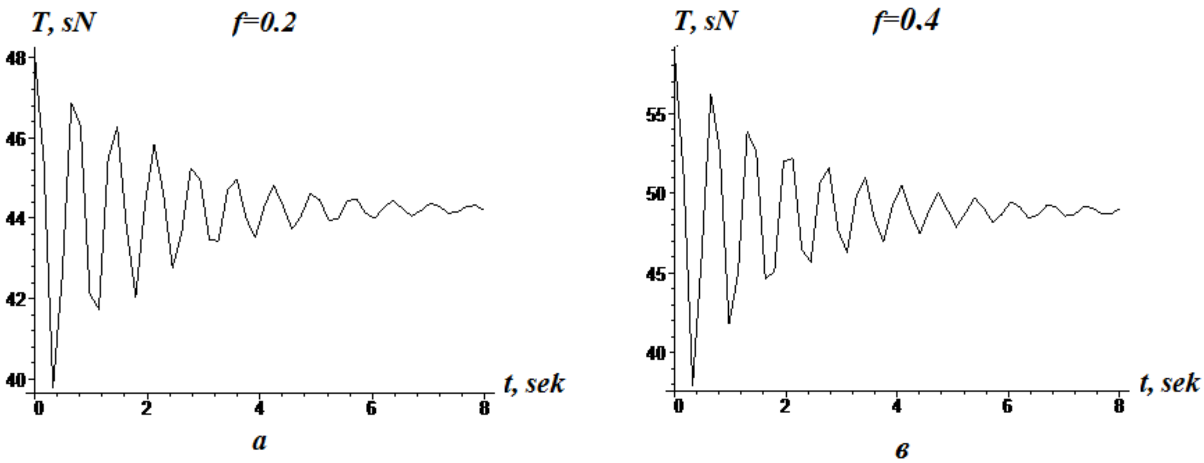

Fig. 5. Dependence of the thread tension $T_0 = T[\varphi_1(t)]$ at the point of its descent from the surface of the thread conductor on time t(сек) for two values of the friction coefficient.

This shows that to reduce the tension of the thread at the point of its descent from the surface of the navel on the elastic element, it is recommended to use an element with less rigidity and reduce the coefficient of friction on the surface of the navel.

Thus, as a result of a theoretical study of the operation of a movable navel on an elastic element, it was found that the movement of the navel under the action of the tension of the thread substantially depends on its radius, the distance between the center of the navel and the point of entry of the thread into the torsion zone. The change in tension is oscillatory in nature with a damped amplitude in time at the point where it vanishes from the surface of the mobile navel. The presence of a damper in the elastic element leads to a rapid decrease in the fluctuation of tension, moreover, its limiting value is less than static by 10-12%.

III. EXPERIMENTAL PART

To verify the results of theoretical studies, an experiment one was performed on an OE spinning machine using a movable navel on an elastic element for two linear yarn densities of 20 tex and 40 tex. The test results of the obtained yarn samples without and using a movable navel are shown in Table 1 and in Fig. 6a and 6c. From table 1 it can be seen that the breaking load of ordinary yarn with a linear density of 20 tex and the yarn obtained using a movable navel

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International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 5 , May 2020

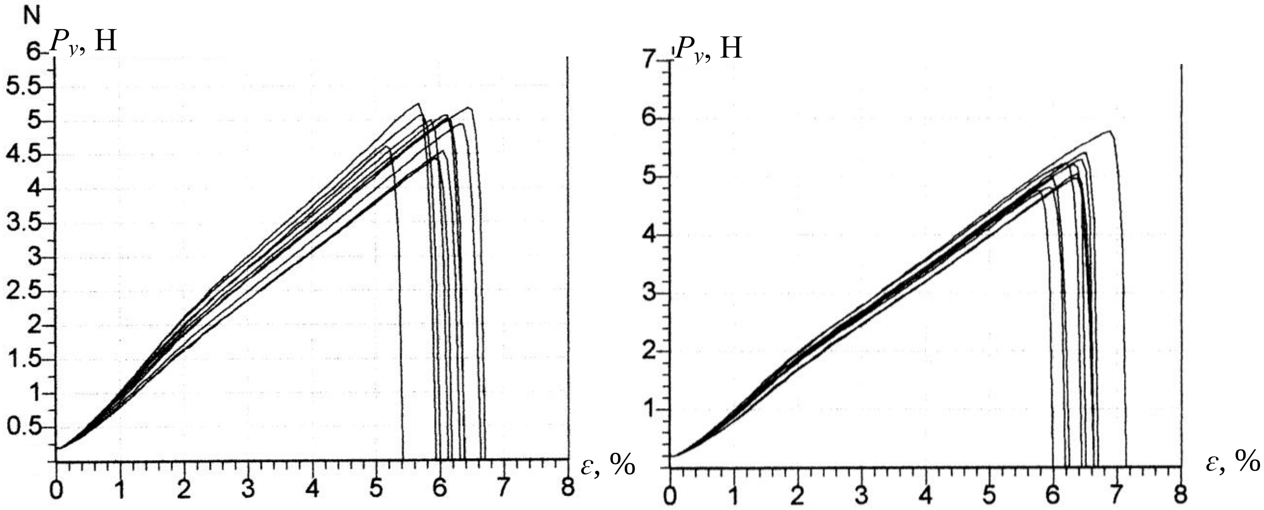
have an almost equal value (242 cN, 248 cN), and the unevenness in the breaking load is noticeably small (7.5%, 3, 6%), which clearly proves the effect of using a movable navel on an elastic element. The unevenness in the breaking load of a yarn of linear density 40 tex was reduced by 16% (from 6.6% to 5.7%), and the unevenness in the breaking load of a yarn of linear density 20 tex was halved.
Considering the results of these experiments, to evaluate the influence of the work of a movable navel on the stress-strain state of the yarn, the tensile curves of yarn of linear densities of 40 tex (Fig.6a) and 20 tex (Fig.6c) have been determined. As can be seen from the figure, the break points of ordinary yarn are noticeably scattered, which show a large unevenness in its breaking load (Fig. 6a, 1; Fig. 6c; 1). The break points of the experimental yarn are concentrated compactly (Fig. 6a, 2; Fig. 6c, 2). It can be seen from this that the movable navel contributes to the damping of the yarn tension fluctuations that occur at high OE spinning speed and, consequently, to the improvement of the structure of the formed yarn.

IV. OE YARN PROPERTIES

Table2 OE yarn properties

№	The name of yarn indicators	Types of yarn			
		conventional		experimental	
1	Linear density, tex	20	40	20	40
2	Breaking load, cN	242	498	248	524
3	CV breaking load, %	7,5	6,6	3,6	6,7
4	Breaking elongation, %	5,13	5,92	6,0	6,25
5	CV tensile elongation, %	6,5	6,3	1,8	5,0
6	Tenacite (Rkm), cN/tex	12,10	12,45	12,40	13,10
7	CV breaking load,%	7,5	6,6	3,6	5,7
8	CV Uster,%	14,73	12,58	14,03	12,40
9	Thin places -50%, pcs / km	40	13	35	10,1
10	Thick places + 50%, pcs / km	66,3	17,5	60,9	8,8
11	Neps, pcs / km	58,6	47,5	48,1	42,0

In addition, as a damper, it smoothes out fluctuations in tension, which ensures greater uniformity in the structure and properties of the yarn.
Therefore, in both cases, the result of the work of the movable navel on the elastic element is clearly visible in the production of yarn uniform in properties and structure.



1) a) 2)

P_y, H P_y, H

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Vol. 7, Issue 5 , May 2020

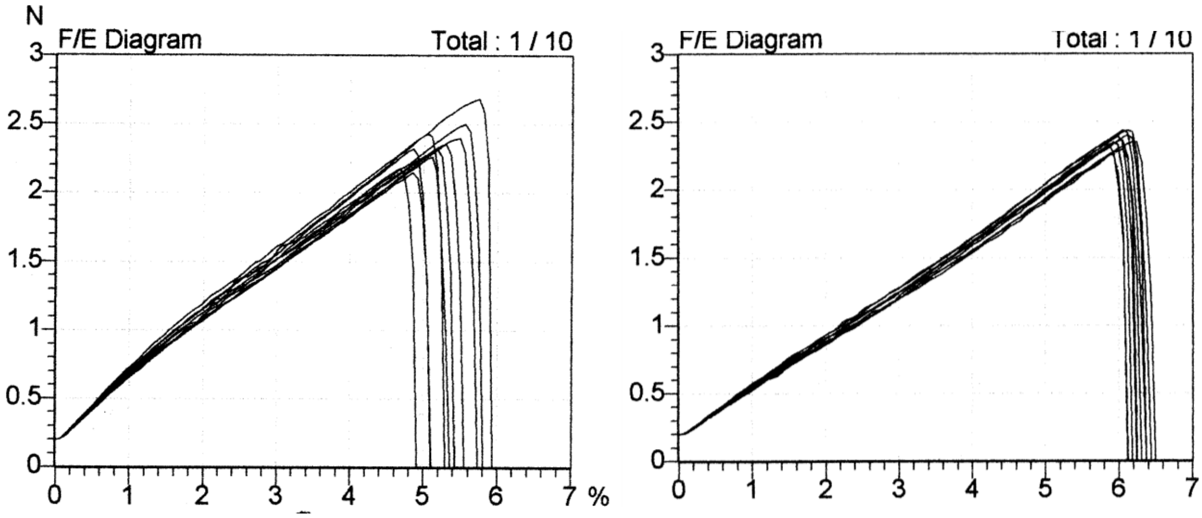

Fig. 6. OE yarn tensile curves

a) conventional yarn 1, experimental yarn 2 with a linear density of 40 tex;

c) conventional yarn 1, experimental yarn 2 with a linear density of 20 tex.

V. CONCLUSION

The operation of a movable navel on an elastic element was theoretically investigated and it was found that the movement of a movable navel under the action of a thread tension depends on the radius of the navel, the distance between the center of the navel and the point of entry of the thread into the torsion zone. The change in tension is oscillatory in nature with a damped amplitude in time at the point where it vanishes from the surface of the mobile navel. The presence of a damper in the elastic element leads to a rapid decrease in the fluctuation of the thread tension. The possibility of reducing unevenness in properties and improving the quality of OE yarn obtained at high spinning speeds has been experimentally proven.

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