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Problems related with migration of internal layer wires of steel-cord for compact structures

Difficulties related with run-out of central wire or core (for example, 1+6) during cutting of rubber-coated cloth are caused by the presence of internal compressive stresses in central elements of compact steel cord. These effects are linked with lay kinematics by the method of double twisting which are mainly used for the purposes of present-day production of steel cord. Double twisting of really and orderly arranged wires results in different layered shortenings of wire: it is maximum for external layer wires and it is zero for central wire. In order to offset compressive stresses, wires of internal layers are subjected to tensile forces, which are much higher than those applied to external wires. However, it is also essential to adjust for elastic residual stresses both for internal wires and external lay. Complex types of lay-related deformation result in different anchorage indirectly dependent behaviors of wires spiraled into steel cord. It is concluded that it's possible to use various technological methods to control migration tendency of steel cord central layers in the course of steel cord production and that the main reason for reduction of central structures anchorage is weakening of external lay wires under the effect of compressive stresses in wire. Additionally, squeezing moment of elastic come-back on steel cord central structures from external lay wires can be produced through obtainment of optimum difference in tensions and residual torques with the use of fine twisting in rotary unwinding.

Key words: *wire, steel cord, double twisting, internal layers, core, external wires, anchorage, compressive stresses, tensile forces, squeezing moment, residual torques.*

It has become widespread to use compactly arranged steel wire cord to produce tires. These structures involve linear inter-wire contact which promotes optimum fretting corrosion. However, it is of critical importance to avoid migration of central wires in multi-layer steel cord which is used for commercial tire belt. It is typical for steel cord wires to move laterally in steel cord of compact structures. Migration ability of steel cord central layers is determined through anchorage test.

Anchorage rate is generally assumed to be the force to pull core wires out of layers of outer wires. Low anchorage rate reduces endurance ratio and causes problems for processing of rubber-cord cloth.

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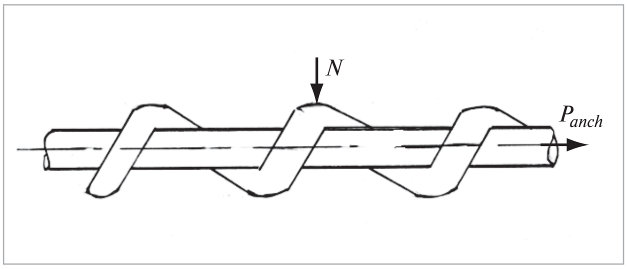

Fig. 1. Forces interaction pattern for steel cord elements

The values of wires residual tension and elastic strain level have direct impact on central wire anchorage force. Indirect method for estimation of residual deformation value implies on determination of curving of wires wound out of a number of layered steel cord. **Fig. 1** shows external laid wires — central structure interaction pattern.

In accordance to the given pattern, anchorage force (Panch) is to be determined by the following formula:

$$P_{anch} = nF = nNf, \quad (1)$$

where n — number of internally layered wires; F — friction force, H; N — normal load, H; f — coefficient of friction between internally layered wires and central wire (0.2–0.3).

Relationship between normal force and residual curving of stranded wires shall be determined with the following formula [1]:

$$K_r = K - \frac{M_f}{EJ} = K - \frac{N\sqrt{t^2 + (\pi d)^2}}{2}, \quad (2)$$

where K_r, K — residual curving of wires and curving of steel cord wires, m^{-1}; M_f – moment of flection, Nm;

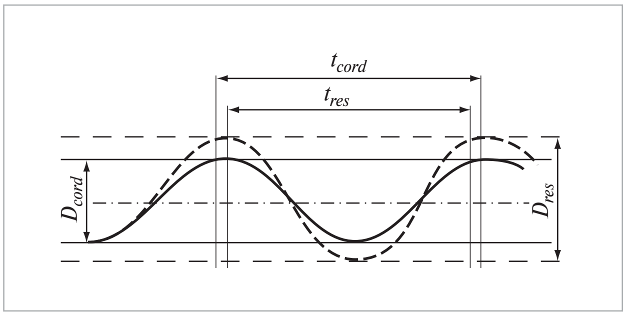

Fig. 2. Changes in spiral curving after wire winding out of steel cord

E — modulus of steel elasticity ($9.8 \cdot 10^6$ Pa); J — moment of inertia, kg·m^2; t, d — length and diameter of lay, m.

Thus, based on the analysis of changed curving of wire after its lay and wind out of steel cord, it is possible to predetermine normal pressure force which means anchorage value as well:

$$N = \frac{2(K - K_{res})EJ}{l}. \qquad (3)$$

One of the basic requirements to the manufacture of steel cord structures is to ensure dense structural arrangement of wires. Structure density can be determined on the basis of behavior of cord elements after their out-cording.

Thus, the degree of adhesion of wires to central layers can be determined on the basis of wire curvature in winding and out steel cording state **Fig. 2**). The less is residual curving of out-wound wires in relation to steel cord curvature of these wires, the more is dense steel cord structure.

Steel cord 0.20+18×0.175 (pitch is 10 mm); 0.20+18×0.175 ST (pitch is 10 mm); 0.20+18×0.175 (pitch is 12.5 mm) has been used as a reference substance to test for changing residual wire curvature in order to prove theoretical assumptions (see **Table 1**). The variation values of total curvature and twisting are practically identical, which is mainly the evidence of elastic torque moment being presented in wires. Sign "–" shows that wires tend to reduce total spiral curvature, i.e. to make adherence to steel cord center more firm and thus to improve wire anchorage and to decrease tendency towards central wires migration.

Residual curvature level is subject to the level of compressive stresses of wire material and lay-related deformation processing depth. Stretching determined by rewinding conditions is one of the basic types of deformation characterizing manufacture of stranded products. It is important to be allowed for inter-layer wire tension distribution [2]. In order to take into account impacts of accumulated tension and inter-layer wire difference in tension, it has been proposed to use loading ratio, which is to be calculated by the following formula:

$$\xi = K_n K_r, \qquad (4)$$

where K_n and K_r are coefficients which account for value of aggregate load and difference in tension between external lay wires and central wire.

Table 1. Processing of measured values of wire residual curvature in steel cord 0,20+18×0,175 with different pitches and breaking strength

Sample	Lay pitch, mm	Steel cord layer	Lay diameter, mm	Diameter of layer, mm	Curvature, mm^{-1}	Twisting, mm^{-1}	Total curvature, mm^{-1}	Variation of curvature, mm^{-1}	Variation of twisting, mm^{-1}	Variation of total curvature, mm^{-1}
Calculated	10.0	1	0.375	0.550	0.07301	0.61972	0.62400	—	—	—
	10.0	2	0.620	0.795	0.11796	0.60533	0.61672	—	—	—
	10.0	3	0.725	0.900	0.13605	0.59733	0.61263	—	—	—
Strength NT*	10.10	1	0.697	0.872	0.12880	0.59410	0.60790	0.0558	–0.0257	–0.0161
	10.29	2	0.639	0.814	0.11490	0.58850	0.59960	–0.0031	–0.0168	–0.0171
	10.15	3	0.727	0.902	0.13270	0.58940	0.60410	–0.0034	–0.0080	–0.0085
Strength ST*	9.93	1	0.399	0.574	0.07860	0.62260	0.62750	0.0055	0.0029	0.0035
	11.02	2	0.735	0.91	0.11450	0.54630	0.5581	–0.0035	–0.0591	–0.0586
	9.69	3	0.839	1.014	0.16430	0.60380	0.62570	0.0282	0.0065	0.0131
Calculated	12.5	1	0.375	0.550	0.04696	0.49823	0.50044	—	—	—
	12.5	2	0.620	0.795	0.07650	0.49073	0.49666	—	—	—
	12.5	3	0.725	0.900	0.08865	0.48650	0.49451	—	—	—
Strength NT*	13.78	1	0.353	0.528	0.03650	0.45320	0.45460	–0.0105	–0.0451	–0.0458
	12.54	2	0.619	0.794	0.07590	0.48930	0.49510	–0.0006	–0.0014	–0.0015
	13.11	3	0.768	0.943	0.08530	0.46350	0.47130	–0.0033	–0.0230	–0.0232

* NT (normal tensile); ST (super tensile)

$$K_n = \frac{P^{\tilde{o}}_{sum}}{P^{0}_{sum}}, \quad (5)$$

where P^{0}_{sum} and $P^{\tilde{o}}_{sum}$ are wire total tensions for initial and concerned options of laying, H.

$$K_r = 1 - \frac{P_n}{P_c}, \quad (6)$$

where P_c and P_n are tensions of central wire and outer lay wire, H.

Table 2 shows anchorage dependency of loading ratio and central wire deformation for steel cord 0.20+18×0.175.

The research results have demonstrated that harshness of central wire has a major role for enhancing anchorage ability. In addition, the following tendency is observed: the higher is central wire loading ratio, the higher is anchorage force of central wire.

Fig. 3 shows variation in anchorage force with external lay wires tension being increased (Pout.) and tension of central wire and internal lay wires being unchanged (Pint.). Higher anchorage level is apparently related to increase of residual curvature of outer lay wires and thus to increase of normal pressure.

It has been experimentally proven that degree of residual torsionally elastic deformation is equally important for anchorage level of internal layers wires. Twisting value is adjusted with ratio of rotary speed of rotational unwinding to rotor speed of laying module of rope twister.

It is common knowledge that torsions which, as it is known from literal sources, tend to contribute to less dense arrangement of wires (they result in a kind of structural loosening), are used in laying machines to eliminate elastic torque moments [3]. Therefore, the less is level of elastic torque moments, the less torsion effect is required. **Fig. 4** shows comparison of effects of elastic torque moments for different levels of fine-twisting of various layers wires being laid.

Table 3 shows the research data on residual twisting by steel cord layers for different laying techniques.

Table 2. Effect of loading ratio on central wire anchorage value

Option	P_{sum}, H	P_c/P_n	Loading ratio	Central wire riffling	Anchorage, H
1	309	0.800	0.246	–	4.1
2	292	0.429	0.664	+	7.9
3	260	0.500	0.518	+	8.3
4	324	0.400	0.774	+	9.1
5	329	0.343	0.861	+	19.0

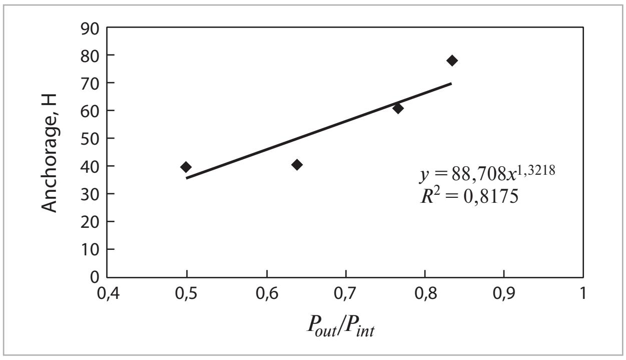

Fig. 3. Dependency of anchorage force on wire tension proportion of external and internal layers

As Table 3 shows, the moment occurring in middle layer of experimentally manufactured steel cord is in the direction opposite to the upper one. This correlation of moments results in variation of residual curvature of wires of inner and outer lays contributing to closer inter-layer wire contact, thus strengthening anchorage of layer 1+6.

To prove that, an experiment on the manufacture of steel cord 0.20+18×0.175ST has been conducted during which variation range of rotary unwinding speed has been determined with compact arrangement of wires in the structure and unwinding ability of outer lay wires (**Fig. 5**).

To obtain anchorage level above 10H it is necessary to set the ratio of machine's laying rotor speed to wire rotary unwinding rate at no more than 1.3.

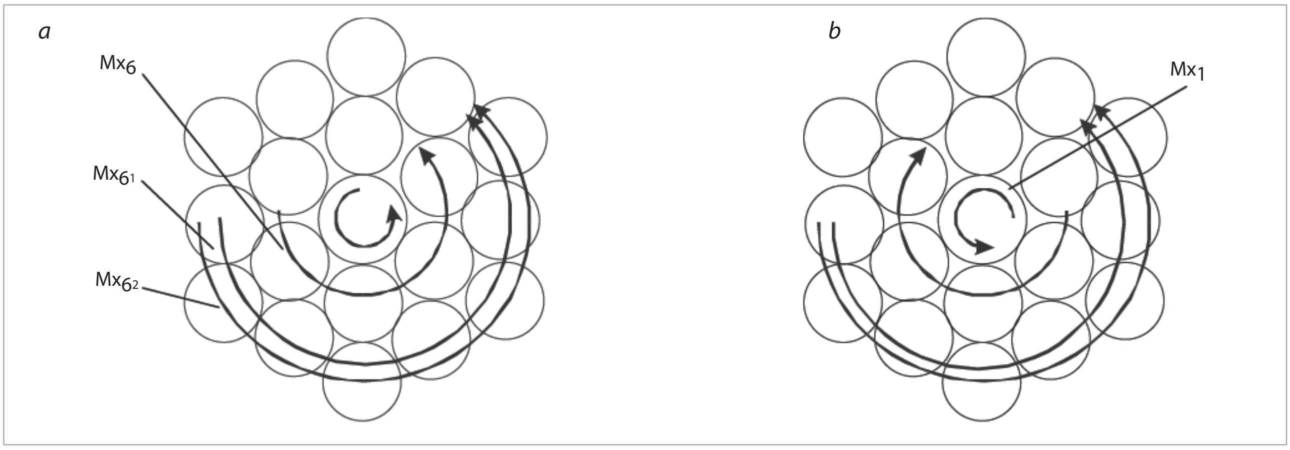

Fig. 4. Direction of torque moments in steel cord laid:
a — with fine twisting of all internal and external lay wires; *b* — without fine twisting of internal lay wires

Table 3. Distribution of twisting moments by layers			
Technique	Residual twisting by layers, rev/6m		Difference in layers, revolutions
	1+6+12	1+6	
With fine twisting of all internal and external lay wires	–0.75	–0.5	0.25
Without fine twisting of internal lay wires	–0.5	+1.5	2

Note: for "Z" lay the sign "+" means spiral unwinding (increase in $D_{res.}$); "–" means spiral winding and N increase (see Figures 1 and 2).

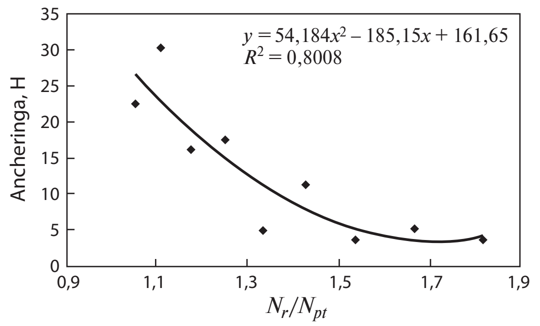

Fig. 5. Dependency of central wire anchorage force on ratio of rotational speed of machine's laying rotor (N_r) to rotation velocity of wire pre-twister (N_{pt})

Based on the above mentioned information, the following conclusions can be made:

1. It is possible to use various technological methods to control migration tendency of steel cord central layers in the course of steel cord production.

2. The main reason for reduction of central structures anchorage is weakening of external lay wires under the effect of compressive stresses in wire.

3. Squeezing moment of elastic come-back on steel cord central structures from external lay wires can be produced through obtainment of optimum difference in tensions and residual torques with the use of fine twisting in rotary unwinding.

This problem is of particular actual importance for the manufacture of steel cord out of wire with strength level 3800–4200 MPa.

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On new mathematics methods in the analysis of microstructures of eutectoid colonies in pearlitic steels

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The paper describes an algorithm for the mathematical description of microstructures of pearlitic steels. The purpose of this work is the development of a method for mathematical description of the microstructures in pearlitic steels for their quantification. It is proves the fact that the mathematical models of microstructures, developed using the frequency distribution of eutectoid colonies in pearlitic steels depending on interlamellar distances, allow estimating the degree of heterogeneity of a microstructure. It is known that microstructures of pearlitic steels, obtained under non-equilibrium conditions, consist of eutectoid colonies formed after decomposition of austenite and incoherently distributed in the plane of the section. At the same time, in different parts of microstructure, the sizes of interlamellar distances of "ferrite-cementite" system can differ by several times. In these circumstances, establishment of relationships between the characteristics of microstructure and steel properties is virtually impossible, if using the traditional approaches based on qualitative analysis of microstructure. Simple averaging of microstructure parameters equalizes structural features of eutectoid colonies and the study of relationship between the properties of steel and its