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THE INFLUENCE OF THE LOCAL COMPRESSION EFFECT ABOUT THE WORKING LIFE OF THE COMPONENT WIRES IN A WIRE-ROPE

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ABSTRACT: Steel ropes are important elements for the functioning of the machineries and of the equipment for transportation: mineral-drawing installations, boring plants, cranes, elevators, excavators, funiculars. Examining the wires of an out-of work steel rope, they noticed that the local compression stress in between the wires had such high values that it produced an impression on the wire in the contact area. The contact stress appears between the wires of the same rope strand, of two adjacent rope strands and between the wires and the rope take-up roller. The paper shows the research regarding the induced and deforming stress at the moment of contact between wires and the traction cable take-up roller. The results will be used to calculate the fatigue crack propagation and to estimate the steel rope working life.
KEYWORDS: contact pressure, working life, finite element method, stress-strain state, numerical analysis

❖ INTRODUCTION

The wire ropes' durability, equated with the service life of the wire ropes, is determined to some extent by their appropriate choice and their rational exploitation. Using the best types of steel ropes, in different industrial areas, finding better ways for improving their quality and their exploitation conditions, will lead to the increase of their durability, the safety of the exploitation and to the achieving of great savings for the industry. These savings may come from the reduction of the rope consumption, thus from the reduction of quality steel consumption and from the cutting of break times in production, necessary for replacement of used ropes. During operation we encounter a supervised behaviour of the ropes because terms for replacing used ropes are always followed and the quality of the wire components is periodically checked. Withdrawing the rope from exploitation is operated when one or more of the following conditions are fulfilled:

- ❖ ropes reaching their service life, evaluated in tones-kilometres or kilometres- time in connection with the weight per meter of cable.
- ❖ reaching a certain number of broken wires per cable pace.
- ❖ the decrease of the safety coefficient of the cable at a certain value, the decrease of the real laceration force of the cable and diminishing of the number of bents until the breaking of the wires settles at the regular control testing. If during one of these current tests 25% of the wire components do not fit the standards, the cable is quashed.
- ❖ if during a macroscopic examination the deterioration of a strand is found, the breaking of the wires on a certain section is accelerating or an accentuated wear is found in one of its areas due to rust and corrosion.

During the examination of the wires that make up an out of order cable, evidence was found that the request of local compression between wires had such high values that a print appeared on the wire on the contact area. Contact requests appear among wires of the same strand, among wires belonging to bordered strands and among wires and the cable winding reel. The parameters involved in the evaluation of the voltage state and wear, belonging to wires in contact, may refer to: the geometry of contact elements, the statistic and tribology of the contact, mechanical characteristics of the materials, operating factors. These parameters possess a simultaneously influence during contact, conditioning and influencing each other, which leads to a mingling of the result of their action.

❖ METHODOLOGY

The estimation of the real stresses in the cross-section of the wire rope is very difficult because the wires are placed under different angles reported to the axes. There are subjected not only to traction, but also to bending and torsion. So, the state of stress in the wires is very sophisticated after the wiring manufacturing process. According to the hypothesis which fundament the strength calculus, the mechanical loads in the wires of a wire rope are considered as statically loads type Saint-Vénant: traction, bending and secondary bending because of the support of a wire to other two adjacent wires, respectively the static contact loading type Hertz or Steuermann. *The classical contact theory between elastic bodies proposed by Hertz* (Fig.1), which did not take into account the non-linear aspects of every contact problem, is comparatively presented with *Steuermann's and Panton's theories* for the contact under a straight common line, typically for the contact between an external and an internal cylinder surfaces.

A comparison between the results obtained by Steuermann and Hertz (Fig.2) leads to the following conclusion: when the ratio $\frac{q}{E(R_2 - R_1)}$ increase, the difference between the results (according to the above mentioned theories) also increases. Anyway, there is a relative good agreement between the results for contact angles less than 20^0.

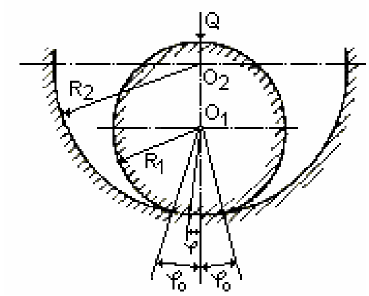

Fig.1. Contact between a cylinder and a cylinder cavity

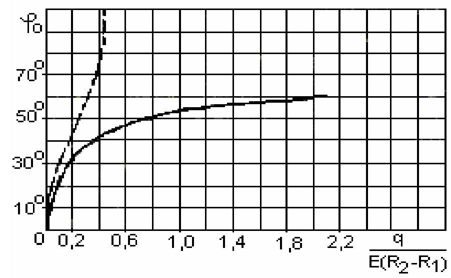

Fig.2. Comparison between Steuermann's and Hertz`s results

For the particular case when the two cylinders are manufactured from the same material, E. Panton proposed the following approximate formula:

$$Q(\varphi) = \frac{Q}{R_1(\sin\varphi_0 \cos\varphi_0 + \varphi_0)} \cos\varphi \qquad (1)$$

There is presented in Fig.3 the distribution Q(φ) for three values of the contact angle: $\varphi^0 = 30^0$, 50^0 and 60^0 according to Panton`s (non-continuous line) and Steuermann`s theories (continuous line). It may be observed in Fig.3 that the results according to the above mentioned two theories are in a perfect agreement when increasing the contact angle φ_0.

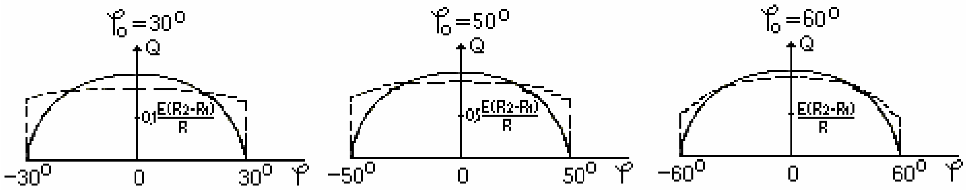

Fig.3. The distribution Q(φ) according to Panton`s (non-continuous line) and Steuermann`s theories (continuous line)

The purpose of the *experimental research by photoelasticity* about the state of stress in the component wires of a wire rope consist in the estimation of the percentage deviations of the contact stress calculated values according with Hertz's, Panton's and Steuermann's theories in comparison with the real values of the stresses. This type of experimental research would ease the choice of the best relation depending on the size of the contact angle φ_0. In terms of contact problems, the location of the maximum tangential stresses is associated with the initiation and propagation points of several cracks, which require the accurately determining of the voltage spectrum in the immediate vicinity of the contact area.

In view of the photoelastic analysis were made two discs having the diameters of 15 and 20 mm and concave surfaces with beams of 26; 20,1 and 15,15 mm. They were made out of optical active and translucid materials. For the achieving of the isochrones photos an installation with two polaroids was used. The polaroids consisted of Ø 150 mm of monochromatic light produced by a bulb with downloads of sodium vapours. This installation is part of the endowment of The Laboratory of Strength of Materials from the Mechanical Engineering Faculty belonging to Polytechnic University of Timisoara (Fig.4).

A specimen was made for the calibration of the photoelastic material. This specimen was tested during a pure bending thus determining the photoelastic constant of the material σ_0 = 2,65 MPa, with a 6 mm thickness. During the tests the goal was not to induce contact requests which could lead to plastically strains. The tests ensured the reproductively of the results, reproductively checked by the lack of residual stress state in the parts after the download, a fact easy found in polarized light.

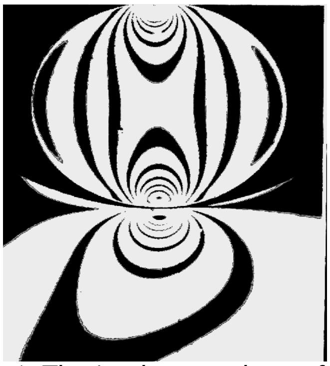

Fig. 4. The isochrones photos for R_1/R_2 = 0,58 at q=74,21 N/mm, the higher level of isochrone n=8 φ_0

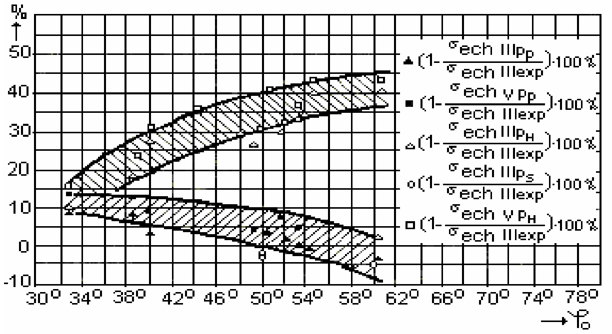

Fig.5. The deviation variation of theoretical results from the experimental tests depending on the contact angle for two contacts R_1/R_2 = 0,58 and R_1/R_2 = 0,75

The Fig.5 diagram represents the deviation variation of results from the experimental ones depending on the contact angle φ_0 for the two contacts R_1/R_2 = 0,58 and R_1/R_2 = 0,75 where Hertz's hypothesis is not valid.

From this representation results the fact that the values σ_{ech} calculated after Panton and Steuermann are grouped in an area of deviation of (+10%...-5%), while when using Hertz's formulas they leads to deviations of approximately (+15%) at $\varphi_0 = 33^0$ up to approximately (+40%) at $\varphi_0 = 60,5^0$.

This percentage error of the results decreases with the rising of the application and with the rising of the maximum order of the isochrones, up to a stresses value of approximately 10 MPa. This leads to an increase due to the value of variation of the elasticity modulus reaching an error of 10% at 20 MPa. This error is introduced by the asymmetry request wich couldn't be completely eradicated. The error is compensated by the average between the readings of the isochrone's order from the two edges of the contact area.

The fatigue alternant loading is the main reason of the degradation of the wire ropes. The results of the compression contact fatigue tests, performed on the Nădăşan-Boleanţu testing machine placed in the Laboratory of Strength of Materials from the Mechanical Engineering Faculty, are plotted in a diagram (Fig.6) which expresses the dependence between the life-time of a wire with a 1 mm diameter versus the compression contact stress. A statistical analysis according to the log-normal distribution law has been performed.

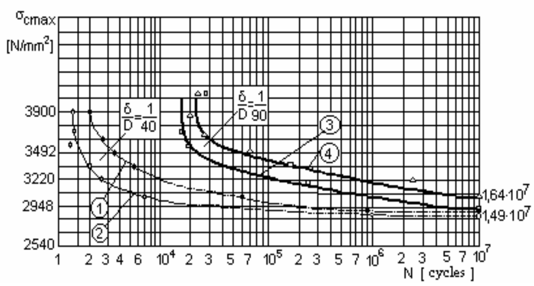

Fig.6. The results of wires fatigue testing on NB machine

The value of the life-time of the wires belonging to a traction wire rope obtained after the linearization of the distribution curve is in a perfect agreement with the life-times indicated in the special references when the wire rope considered as an element with a restricted life-time because of the typical working conditions.

The finite element numerical analysis about the local compression effect is the solution for the contact problem between two wires with different or same diameters in contact. Also the contact problem between an external and an internal cylinder shape bodies (Fig.7) has been analyzed by using a hybrid technique considering the contact without friction for all the cases which have been presented above.

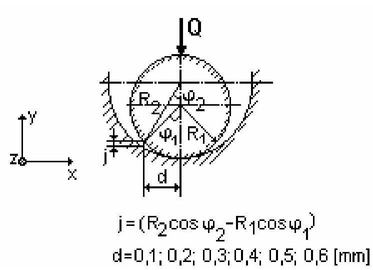

Fig.7. The objective geometry

At first the meshing of two wires with same diameters in contact and the calculus model has been performed. After the running on of the software, all the components of stress and deformation tensors have been performed for 9 equal representation steps in function of the maximum and the minimum variation limits of stresses and deformations (Fig.8). Results are presented as special tables and diagrams about the stress and deformation fields. It can be observed that the state of stress and deformation is similar for every two adjacent wires in contact.

From the analysis of the graphical processing of the results we can reach the following conclusions:

- The equivalent von Mises stress σ_{VM} [N/mm^2] has a maximum value in the center of the contact surface, decreasing to its extremities;
- The tangential stress τ_{xy} [N/mm^2] is zero in the center of the contact surface, where the triaxial compression appears [1]. The maximum value of the tangential stress corresponds to the value of the half-breadth of the contact surface b = 0,0545 mm, decreasing to its extremities;
- The vertical movement is greatest possible in the middle of the contact surface, situation that can be visualized by representing the deforming state by bands of equal movement on the deformed position of the cylinder (Fig.9).

The analysis about the life-time of the component wires of a steel wire rope by finite element numerical analysis presents the opportunities to use dedicated software, which is typical for the analysis of the behavior of wires under variable loading as well for the life-time estimation. The finite element numerical analysis of the degradation of the wires because of an alternant loading has been performed for the contact between two wires with same diameters of 1,25 mm, for 9 loading cases. The fatigue phenomenon because of the maximum σ_y stresses which are perpendicular on the contact area has been analyzed after the loading fatigue block (Fig.10) has been imposed (σ_{ymax} - in function of the number of cycles). After the running on of the software, the cumulative degradation coefficient for every loading step and the total cumulative degradation coefficient have been performed.

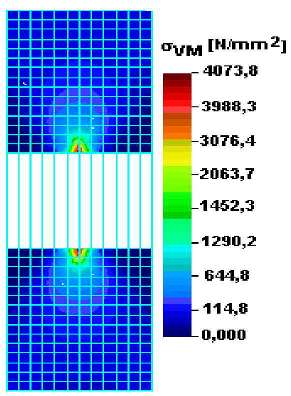

Fig. 8. The equivalent von Mises stress σ_{VM} [N/mm^2] for the considered stress model, case of loading Q = 45 N

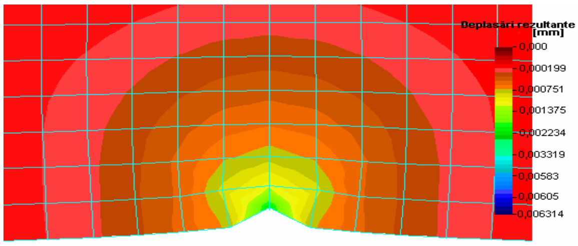

Fig. 9. The resultant displacements [mm] for the cylinder of radius R_1 = 0,625 mm, case of loading Q = 45 N

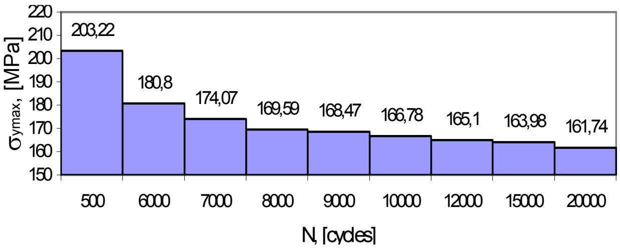

Fig.10. Loading fatigue block σ_{ymax} - N

During this program the fatigue limit curve (Fig.6-curve 1) for an alternative-symmetrical loading cycle of a non-torsion wire, bent on a segment lacking a channel and with the diameter of 40 mm, was used.

The calculus performs the link between state of stress in wires produced by the request of contact compression and of the wires' working life belonging to the steel wire ropes which are subjected to multiple and different requests encountered during the functioning of the operating wire ropes.

❖ CONCLUSIONS

The static processing of the results coming from the fatigue attempt along with the contact compression of wires on the NB testing machine, accepting a normal distribution of life-time, provided that the values of wire's life-time obtained after the lining of the distribution right are fitting in the range of accredited values by specialists in the market.

The paper also presents the numerical modeling with the finite elements of the contact request between a cylindrical surface and a concave one, achieved in order to visualize the state of displacements and stresses.

The finite elements numerical analysis of degradations which appear inside the steel wire ropes because they are subjected at variable loading was performed in order to obtained the cumulative degradation coefficient for every loading step.

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