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# ASPECTS REGARDING THE LIFE-TIME OF WIRES BELONGING TO A STEEL WIRE ROPE

**Abstract:**
*The paper presents an analysis regarding the influence of working typical factors about the shallow destruction phenomena between wires in contact. It was studied the influence of contact pressure and the relative displacement between wires concerning the life-time of wire ropes.*
*There is presented as a conclusion that the life-time of wires is decreasing at the increasing of the average pressure between the wire rope and the wrapping up roll. The destruction phenomenon of wires is increasing when increasing the frequency of the alternant bending process of wire rope around the roll.*

**Keywords:**
*wire rope, shallow destruction, life-time, contact pressure, fretting corrosion*

## INTRODUCTION

The fretting corrosion belongs to the range of phenomena going to fracture of steel machine parts under different variable forces. The fretting corrosion conduce to decreasing of fatigue limit to (1,5...3) times.

The above mentioned phenomena takes place between contact surfaces in a relative motion, when friction forces are acting on small contact areas due to roughness of joining surfaces. In the same time, heat is locally emitted producing punctual welding processes. A transfer of metallic powder between contact surfaces is produced. Because of chemical reactions with the oxygen included in atmosphere, the metallic powder is turning into oxides and nitrides. The degree of wear has high values in case of dry fretting, and small values in case of lubrication [3]. For wire ropes the influence factors about the fretting corrosion are as follows: the contact pressure, the amplitude and the frequency of relative displacement, the state of stress in the common contact area.

The interpretation of the fretting corrosion phenomena is based on the observation that high values of the contact stresses are located in the contact area. These stresses in correlation with relative displacements of contact surfaces are producing fractures of small particles. Taking into account the influence of the emitted heat, because of friction, the oxides are produced going to a wearing effect and facilitating the appearance of the fatigue cracks.

For the steel wire ropes subjected to a tensile test, the fretting corrosion is produced between the component wires as well between the external wires and the wrapping up roll. The favorable effect of lubrification about the life-time of wire ropes is unanimously accepted.

## THE FACTORS OF INFLUENCE CONCERNING. THE DESTRUCTION PROCESSES INTO THE CONTACT AREAS

### Contact pressure

*The contact compression, together with other loadings, conduces to a three-axis state of stress. The final result may be the appearance of the critical state, going to fracture, in layers as far as a half of the breadth of the contact ellipse [1]. Hertz's formula is usually used in order to calculate the maximum contact pressure between the wire rope and the wrapping up roll. The relation is valid only for elastic deformations:*

$$p_0 = \frac{3 \cdot P_0}{2\pi \cdot a \cdot b} \quad [N/mm^2], \qquad (2.1)$$

*where:*
*Po [N] - pressing on force between bodies in contact;*
*a, b [mm]- half-axis of the contact ellipse:*

$$a = 1{,}4 \cdot \nu \cdot \sqrt[3]{\frac{P_0}{E \cdot \sum \rho}},$$

$$b = 1{,}4 \cdot \nu \cdot \sqrt[3]{\frac{P_0}{E \cdot \sum \rho}} \qquad (2.2)$$

*$\nu = 0{,}33$ - Poisson's ratio;*
*$E = 2{,}1.10^5$ $N/mm^2$ - Young's modulus;*
*$\sum \rho$ - the amount of curvatures of contact surfaces.*

*The average pressure between wire rope and wrapping up roll is expressed as:*

$$p_m = \frac{2 \cdot T}{D \cdot d} \quad [N/mm^2], \qquad (2.3)$$

*where:*
*T [N] - traction force;*
*D [mm] - diameter of roll;*
*d [mm] - diameter of wire rope.*

*The formula may be used for multi-layer wire ropes. The maximum contact pressure between wires may be written as $p_{0\max} = 2\sigma_r$, where $\sigma_r$ [N/mm²] represent the strength at fracture of wire. When exceeding this value, the momentary destruction is not produced, but a decreasing of the life-time always appears.*

### The friction between wires

*The estimation of friction coefficient at high pressures on the surfaces of wires is very necessary especially for the manufacturing process of wires.*
*The influence of the diameter of wire about the friction coefficient may be neglected. It may be considered that the well known dependence between friction coefficient and perpendicular force remain still valid.*
*As a lubricant very often used for wire ropes, the oil ensure suitable values for the friction coefficient.*

### The relative displacement of wires

*The amplitude of relative displacement between the contact surfaces of wires is due to different values of stretching stresses in wires as well to different deformations of adjacent wires because of the bending process at different diameters [4]. The relative displacement of wires is caused by the diameters of layers, the length of the volute line for a single step having the following formula:*

$$L = 2 \cdot \pi \frac{r}{\cos^2 \alpha} \qquad (2.4)$$

*where:*
*r [mm] - the radius of the layer;*
*$\alpha$ - the wrapping up angle of wires in a layer.*

*There is very difficult to take into account all the above mentioned influence factors for the destruction phenomena of wires. The difficulty is caused by the relative dependence between factors.*
*So, the principle of superposition regarding the effects of the influence factors may not be used.*
*It is of a great practical importance to establish perceptually the decrease of the fatigue limit of wires when the wires are separately leaded in comparison with the same parameter for the wire as a component part of the wire rope.*

## THE EXPERIMENTAL ANALYSIS OF THE INFLUENCE OF PRESSURE AND RELATIVE DISPLACEMENT ABOUT LIFE-TIME OF A WIRE ROPE

*There are considered the following stresses:*

- *traction produced by the force T, going to the stress in wire rope*

$$\sigma_t = \frac{T}{A} \quad (2.5)$$

- *primary bending because of the wrapping up around the roll with a diameter D, going to the stress in wire rope*

$$\sigma_i = \pm E \frac{\delta}{D} \quad (2.6)$$

*$\delta$ [mm] - diameter of wire;*
*$E = 2{,}1.10^5$ N/mm$^2$.*

*The fatigue tests conduce to fractures of wires especially in the contact area between the wire rope and the drain of roll. So, this contact zone will be analyzed. For fatigue and life-time tests, loading cycle is characterized by the following parameters:*

$$\sigma_{max} = \sigma_t; \quad \sigma_{min} = \sigma_t - \sigma_i;$$
$$\sigma_{med} = \sigma_t - \sigma_i/2 \quad \text{and} \quad \sigma_{am} = \sigma_i/2$$

*For the particular case $\sigma_t = \sigma_i$ a pulsate bending cycle is obtained.*

*Moreover, a pulsate compression cycle will be added having the maximum pressure $p_0$ in the volute zone and 0 in the stretching zone of the wire rope. So, the life-time $N_s$ of wire, which was loaded under a pulsate cycle with $\sigma_{max} = \sigma_t$, may be compared with the life-time $N_c$ of a wire, which was loaded under a similar cycle and an added pulsate pressure (0...$p_0$).*

*Because only the fatigue limit for a symmetrical cycle may be estimated for wires, the Soderberg's diagram is used. The diagram is approximated as a part of an ellipse having the half-axis $\sigma_{-1}$ and $\sigma_c$. Instead of $\sigma_c$ may be used the strength at fracture $\sigma_r$.*

*So, the following formula will be obtained:*

$$\sigma_{-1Nc} = \frac{\sigma_0 \cdot \sigma_r}{\sqrt{4 \cdot \sigma_r^2 - \sigma_0^2}} \quad [N/mm^2], \quad (2.7)$$

*The fatigue tests have been performed [2] in the Laboratory of Strength of Materials from the Mechanical Engineering Faculty of Timisoara.*

*A loading machine Schenk has been used for fatigue tests in the framework of life-times in the proximity of the value $N = 10^6$ cycles. The method of loading steps has been preferred in order to estimate the fatigue limit. The principle of the method consists in modifying the level of loading function of the level of stress obtained for the previous test. If the previous specimen has been fractured, the following specimen will be loaded at a smaller level of stress. For the opposite case, it will be used a higher level of stress. The test will continue until the whole range of specimen will be loaded. Results are presented in Table 1.*

*The advantage of the method consists in grouping the results around an average value. The drawback consists in the impossibility to perform simultaneously different specimens. So, the result of the previous test is necessary.*

*Table 1*

| **$\sigma$** [N/mm$^2$] | fractured wires • not-fractured wires **0** | | **N=10$^6$ cycles** | | | |
|---|---|---|---|---|---|---|
| | | | **$i = \sigma_i - \sigma_0$** | **n** | **i.n** | **$i^2$.n** |
| 350 | | | 50 | 1 | 50 | 2500 |
| 340 | | | 40 | 2 | 80 | 3200 |
| 330 | • • | • | 30 | 5 | 150 | 4500 |
| 320 | **0** • • **0** | • | 20 | 7 | 140 | 2800 |
| 310 | **0 0** | **00** | 10 | 4 | 40 | 400 |
| 300 | | **0** | 0 | 1 | 0 | 0 |
| | | | $\Sigma =$ | 20 | 460 | 13400 |

*The fatigue limit of wire may be calculated by using the following formula:*

$$\sigma_{-1Ns} = \sigma_1 + \frac{\Sigma(i \cdot n)}{\Sigma n} = 300 + \frac{460}{20} = 323 \quad [N/mm^2], \ (2.8)$$

*where: $\sigma_1$ - is the reference level of stress, arbitrarily estimated for the smallest value of loading during the test.*

*The fatigue tests of wire ropes have been performed on a special loading machine designed by the lamented prof.dr.eng. Lazar Boleantu [2]. An usual wire rope 17 - 6x37 -160 S-Z, STAS 1513-80, with the diameter of a single wire $\delta = 0{,}8$ mm and the area of the cross-section $A = 112$ mm$^2$, has been tested.*

*There is emphasized in Figures 1 and 2 the life-time of wire rope for three different loading steps characterized by the stress $\sigma_t = T/A$ and by the diameter of roll. For every step, three specimens* *have been tested. The dispersion of results for a single loading step is located into the area of a rectangle. The hachure indicates the loading step for a fatigue pulsate cycle. It may be observed a relative small difference between the averages values of life-time for the two loading frequencies as well a favorable effect of low loading frequency about the life-time of wire rope.*

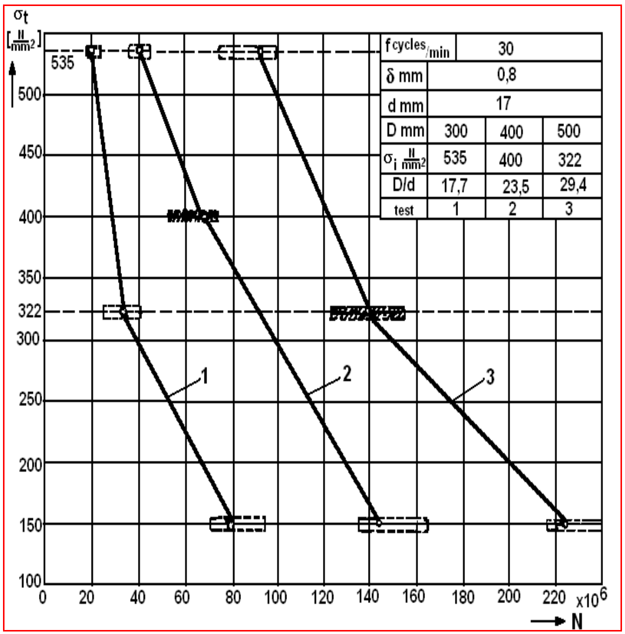


*Fig. 1. Tests performed at frequencies of 30 cycles/min*

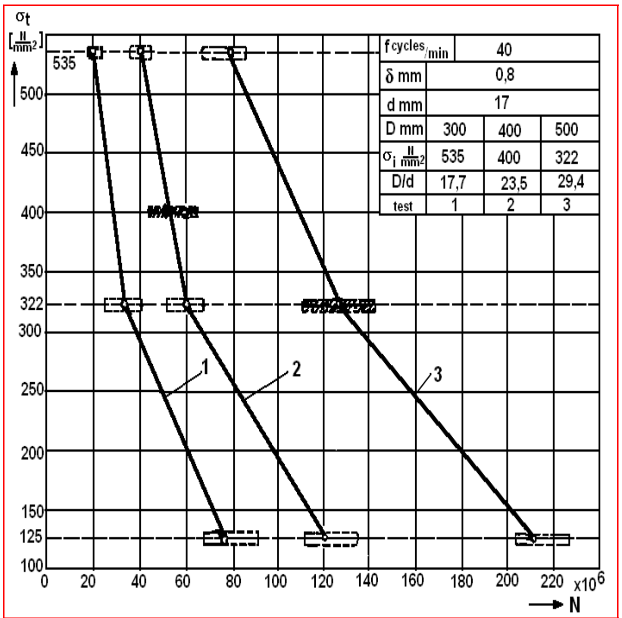


*Fig. 2. Tests performed at frequencies of 40 cycles /min*

*The decreasing coefficient, regarding the fatigue limit of a wire belonging to a wire rope in comparison with the strength of a single wire for life-time N = 10⁶ cycles, has been calculated according to the formula:*

$$c_\sigma = \frac{\sigma_{-1Ns}}{\sigma_{-1Nc}} \qquad (2.9)$$

*Results are presented in Table 2.*

*Table 2.*

| Test | 1 | 2 | 3 |
|---|---|---|---|
| D[mm] | 300 | 400 | 500 |
| $\sigma_0 = \sigma_t = \sigma_i = E\delta/D$ | 535 | 400 | 322 |
| $\sigma_r$ [N/mm²] | 1600 | | |
| $\sigma_{-1Nc} = \frac{\sigma_0 \cdot \sigma_r}{\sqrt{4 \cdot \sigma_r^2 - \sigma_0^2}}$ [N/rnm²] | 266 | 208 | 163 |
| $\sigma_{-1Ns}$ [N/mm²] | 323 | | |
| $c_\sigma = \frac{\sigma_{-1Ns}}{\sigma_{-1Nc}}$ | 1,23 | 1,55 | 1,98 |
| $N_s$ [cycles] | $10^6$ | | |
| $N_{cmediu}$ | (19968) 19748 | (68058) 51684 | (138764) 124096 |
| $C_N = N_s/N_c$ | 50 | 14,75 | 7,24 |
| $p_m$ [N/mm²] | 22,4 | 13,2 | 8,55 |
| $p_0$ [N/mm²] | 7850 | 6420 | 5540 |
| $\Delta\varepsilon = \frac{2\delta^2}{D(D+2\delta)}$ | $1,39.10^{-5}$ | $0,8.10^{-5}$ | $0,5.10^{-5}$ |

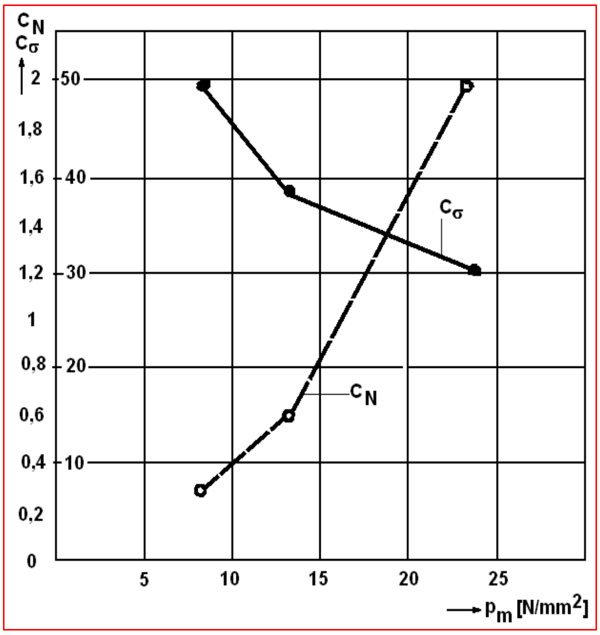


*Fig.3. The variations of $c_\sigma$ and $C_N$ for the pulsate testing cycle*

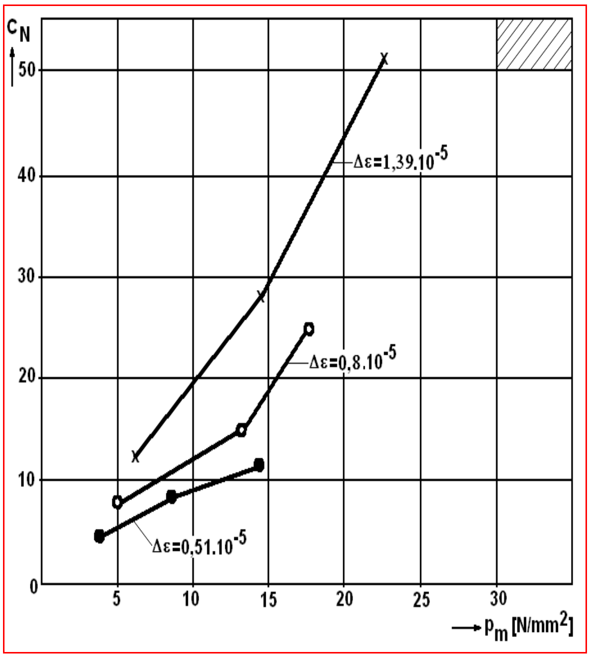


*Fig.4.The variation of $c_N$ function of the average pressure $p_m$*

*There are presented in Fig. 3 the variations of $c_\sigma$ and $C_N$ for the pulsate testing cycle $\sigma_o = \sigma_t = \sigma_i$, corresponding to the average pressure $p_m$. It may be observed that if $c_\sigma$ is increasing, $C_N$ is decreasing. In the same time, the increasing of $p_m$ has a non-favorable influence about the life-time of wire rope.*

*There is presented in Fig. 4 the variation of $C_N$ function of the average pressure $p_m$ between wire rope and wrapping up roll.*

*The parameter $\Delta\varepsilon$ is representing the relative displacement between the layer of wires in contact with the roll and the internal layer located in the near vicinity, divided by the unit of length.*

*There is ascertained a high value of the increasing slope of $C_N$ when increasing the average pressure $p_m$, for high values of $\Delta\varepsilon$.*

## CONCLUSIONS

- *The life-time of wires belonging to a wire rope is decreasing at increasing of the average pressure between the wrapping up roll and the wire rope. The dependence is valid for bending pulsate loading cycles (Fig. 3), as well for an uneven loading cycle (Fig. 4).*
- *At constant pressure, the life-time of wire rope is decreasing at increasing of $\Delta\varepsilon$, the relative displacement between the layer of wires in contact with the roll and the internal layer located in the near vicinity (Fig.4). As increase because of the bending loading of wires due to wrapping up and bending of wire rope around the roil.*
- *Tests performed at frequencies of 30 respectively 40 cycles /minute prove that the destruction process increase when the frequency increase too, going to decreasing the life-time of wire rope. The reason consists in increasing the level of friction force between wire rope and roll because of increasing the angular acceleration. In the same time because of increasing the friction force, there is also increasing the local maximum pressure but is decreasing the elliptical contact surface. Both consequences have a non-favorable influence about the life-time of wires due to increasing the amplitude of contact pressure.*
- *A strongly increasing of the value of coefficient **$c_N$**, in case of bending loading cycles, is observed after a comparative analysis between a pulsate cycle (Fig.3) and an uneven cycle (Fig.4). A favorable effect about the life-time of wire ropes is obtained by superposing a compression or a traction stress over a contact compression stress.*
- *After analyzing the dispersion fields of the number of cycles (the rectangles in Fig.1 and 2) it may be observed the increasing of dispersion when increasing the number of cycles until the appearance of fracture. The explanation consists in the timely cumulative effect of wear. That is because the contact pressure and the bending-traction effects have an insufficiently importance.*
- *The wear is strongly dependent on the friction coefficient between wire rope and wrapping up roll, as well between wires of the same wire rope. So, in order to decrease the level of wear it is necessary to decrease the friction coefficient by using a suitable lubrication. In the same time it is necessary to decrease the starting and the breaking accelerations which have an important influence about the relative sliding between the wire rope and the wrapping up roll.*

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