SOME PROBLEMS OF UNEVEN LOAD DISTRIBUTION IN WIRE ROPE OF MULTIROPE FRICTION DRIVES

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ABSTRACT

Some selected problems concerning unequal load distribution in wire ropes used with the multi-rope drives have been presented in the paper. By means of a simplified analysis of stresses in wire ropes a considerable effect of axial loads on the life time of wire ropes has been shown. Some methods used in practice have been described for determining the loads in wire ropes. From some exemplifying load distributions the most frequent reasons of an unequal load distribution have been given.

THE EFFECT OF LOADS ON THE LIFE TIME OF WIRE ROPES

The problem of determining the life time of wire ropes has been the subject of theoretical researches of the numerous scientific and research centres. A mathematical expression describing the life time of wire ropes is very difficult due to a great many factors whose influence on the durability of wire ropes is in masy cases impossible to be expressed mathematically. Generally the life time of wire ropes can be given as a function:

$$N = f\,(F_1, F_2, F_3, F_4,) \tag{1}$$

where: F_1 - presents a group of factors connected with material, construction and manufacture of ropes

F_2 - presents a group of factors concerning the elements being in contact with the rope in operation

F_3 - presents a group of factors representing the value of the loads and their character

F_4 - presents a group of factors enclosing the effect of environmental conditions on rope operation.

The most frequently given formula for the life time of wire ropes is

$$N = C \cdot \sigma^{-n} \qquad (2)$$

where: C and n are the factors found by experiment
σ is the equivalent stress

The formulae of that kind are used by Drücker-Tachau, Shitkov, Rosetti, use and the modifications with a similar form by Giovanozzi, Calderale, Luboz [1], [2]. The differences concern the experimental factors C, n and the way of calculation of the equivalent stresses σ.

In some cases the value of those stresses are assumed directly as the ratio of the axial load of the rope and its metallic cross section. In other cases some attempts are made to define the effect of the bending and contact stresses on the rollers and on the sheaves and drums.

Let us try to make a simplified analysis of the stresses acting in rope wires during operation. The axial load in the rope generates tensile stresses whose value can roughly be estimated as:

$$\sigma_t = \frac{S}{F} \qquad (3)$$

where: S is the axial load in the rope
F metallic cross section of the rope.

The actual stresses acting in the individual wires have different values depending on the rope construction and on the standard of manufacture.

Rope operation on sheaves and drums produces stresses. Their value can be calculated from the formula:

$$\sigma_b = \frac{\delta}{2\varrho} \cdot E \qquad (4)$$

where: δ - wire diameter
ϱ - radius of wire curvature
E - Young´s modulus.

The relation presented above can be written in a simplified form as:

$$\sigma_b = k \cdot \frac{\delta}{D} \cdot E \qquad (5)$$

where: k - factos considering the rope construction
D - bending diameter

For the estimating, engineering calculations it is more convenient to use the following relation:

$$\sigma_b = \frac{\delta}{D} \cdot E_r \qquad (6)$$

where: E_r ist the Young's modulus of the rope.

Due to the specific construction of ropes, additional stresses appear in the indicidual wires called the secondary stresses.
For single twisted ropes, those stresses can be calculated from the formula [3]:

$$\sigma_{bs} = \sigma_t \left(e^{\mu \cdot \sin\alpha \cdot x} - 1\right) \qquad (7)$$

where: σ_t - denotes the tensile stresses in wires
μ - friction factor of wires
α - angle of twisting of wires.

The parameter x is calculated from an additional equation which takes into account the bending diameter of the rope.
More suitable formula for assessing the stresses for double twisted ropes are given by Wyss [4]:

$$_{bs} = 570 \frac{\delta}{D} \cdot \sigma_t \quad \text{for 6x19 ropes and}$$

$$_{bs} = 1100 \frac{\delta}{D} \cdot \sigma_t \quad \text{for 6x37 ropes} \qquad (8)$$

Rope bending over sheaves or drums raises contact pressure σ_c' between wires inside the rope and σ_c'' between the outer wires and the groove of the sheave or of the drum.
Based on the consideretions by Wyss [4] and Babel [5] some relations can be given

$$\sigma_c'' = 0{,}836 \sqrt{\frac{S \cdot E}{d \cdot D}} \qquad \text{where} \qquad E' = \frac{2E \cdot E_g}{E + E_g}$$

$$\sigma_c' = 0{,}836 \cdot C_1 \sqrt{\frac{S \cdot E}{d} \left(\frac{C_2}{d} + \frac{1}{D}\right)}$$

where: E and E_g - moduli of elesticity of the wire and of the sheave or drum groove

C_1 and C_2 – factors dependent on the number of strands and on the angle of twisting them.

Some other relations are offered [6] which correspond with the laboratory test results:

$$\sigma'_c = \frac{8k \cdot \gamma}{3\pi \cdot \delta^2} \qquad \text{where} \qquad k = \frac{4h \cdot \delta}{z \cdot d \cdot D} \cdot S \quad \text{and} \qquad (10)$$

h – lay length of the strand

z – number of strands

γ – factor determined experimentally, acc. to Pantuček = 0,09.

From the above introduced, rough analysis of stresses an essential effect of the axial load acting in the rope can be seen. If a particular rope construction is considered which operates in a particular lift, its life time will mainly depend on the value of the axial load. Laboratory tests on the durability of wire ropes, made during the last tens of years show, that the changes of the axial loads in ropes of the order of 20% can be accompanied by the changes of rope durability reaching the valuea from 30 to 200% depending on the rope construction and its operating condition. This is particularly important with the multi-rope lifts when the problem of an equal distribution of loads is neglected or not even noticed. Frequently the user is put off his guard due to the application of a lever attachment of the rope to the lift car. However, in many cases, this type of attachment does not meet requirements and the user blames the rope manufacturer for the untimely change of the rope.

METHODS OF MEASURING LOADS IN ROPES

The numerous methods for the determination of the loads in ropes can be divided into direct and indirect methods.

Direct Methods

These methods consist in mounting the conventional load sensors either with a further connecting link or a bar with strain gauges sticked at the spot of fastening the rope. In fig.1 some spots where the loads are measured are shown. The electric signals received from the sensor can be used for the instantaneous control

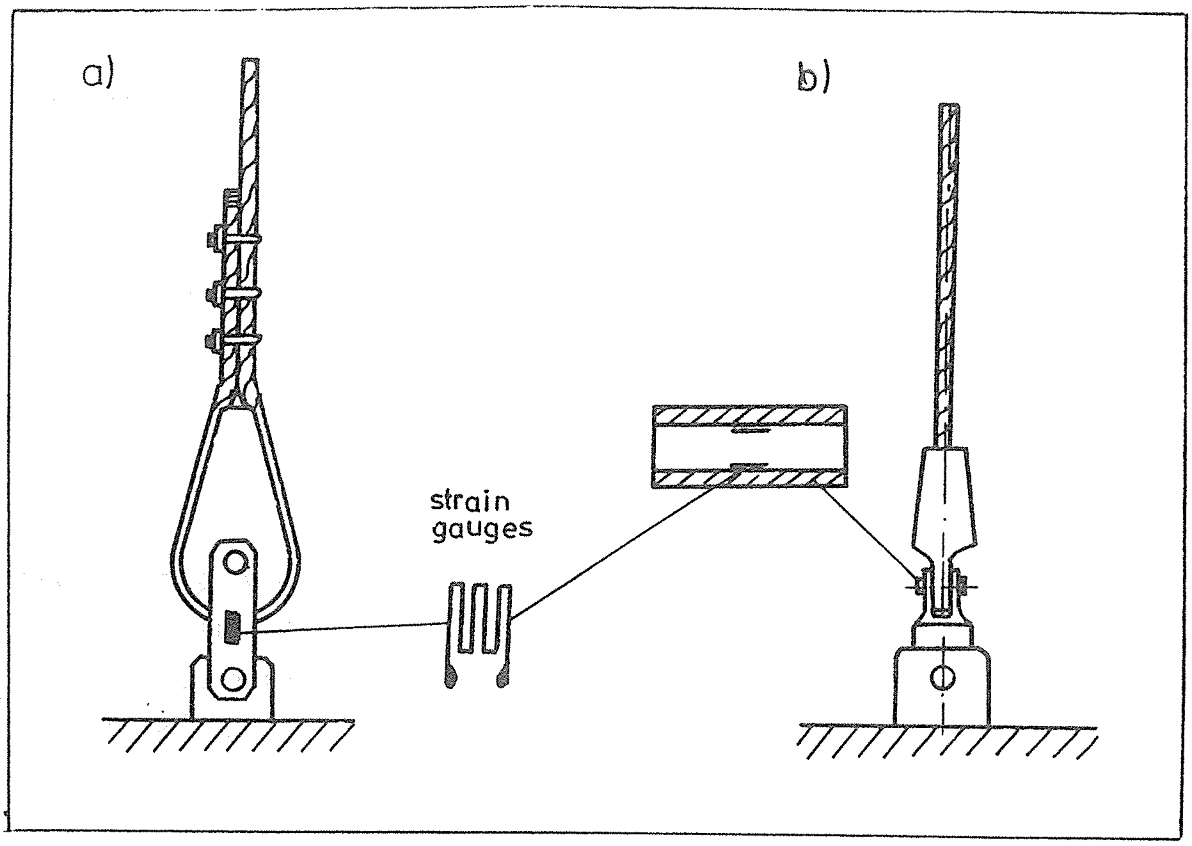

Fig.1. Examples of direct measurement of loads.

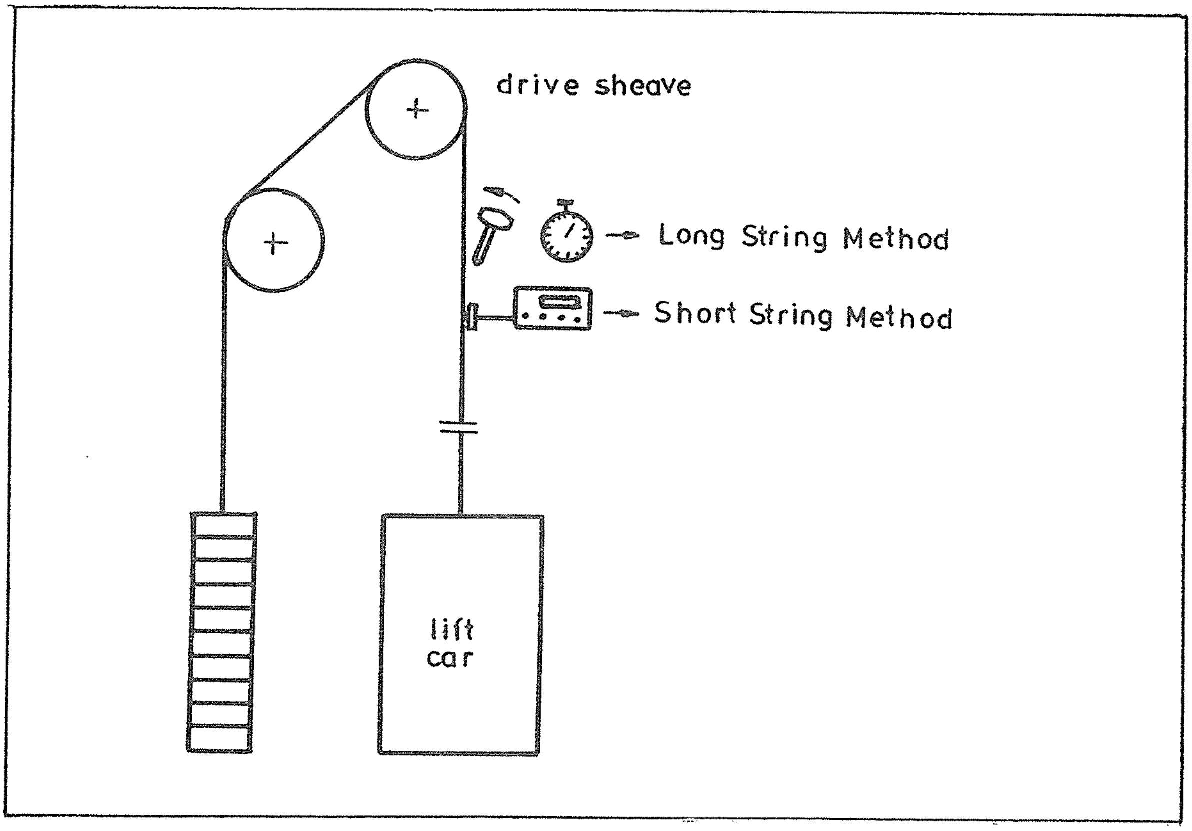

Fig.2. Method of measurements of free vibrations of ropes.

of the load distribution in ropes, or can be transmitted to an automatic diagnostic system. An example of such a system used with the mine hoisting istallations can be the system offered by ASEA[7].

Indirect Methods

A. Measurement of the parameters of free vibrations of rope is based on an empirical relation between the axial load in the rope and the frequency of its transverse vibration. Usually a simplified form of that realtion is used:

$$S = 4 \cdot l^2 \cdot q \cdot f^2 \qquad (11)$$

where: l - length of rope section excited to vibration
q - unit mass of rope
f - frequency of free vibration.

The formula given above is not accurate because it has been derived by the assumption that the rope has no rigidity and no inner damping. However, in many cases, it renders sufficient accuracy for practical purposes.
The practical way of the measurement is presented in fig.2.
A rope section is stimulated to vibration by a blow or a strong jerk and the time of the return wave or directly the frequency is measured.

B. The method of bending aside the rope on three towers is based on the relation between the tensioning load and the force needed for bending it aside by a definite deflection. From the condition shown in fig.3a the following relation can be obtained:

$$S = \frac{P \cdot l}{4W} \left(1 - \frac{B \cdot W}{P \cdot l^3}\right) \qquad (12)$$

where: P - deflecting force
l - distance between towers
W - deflection of rope
B - factor taking into account the flexural rigidity and the way of supporting the rope

In practice, the influence of the rigidity of the rope is usually neglected and the simlified formula is used.
There are numerous constructional developments of measuring devices using the above presented principle like those by Martin Decker, PIAB, ONK, GIG etc. An example of such a device is shown in fig.3b.

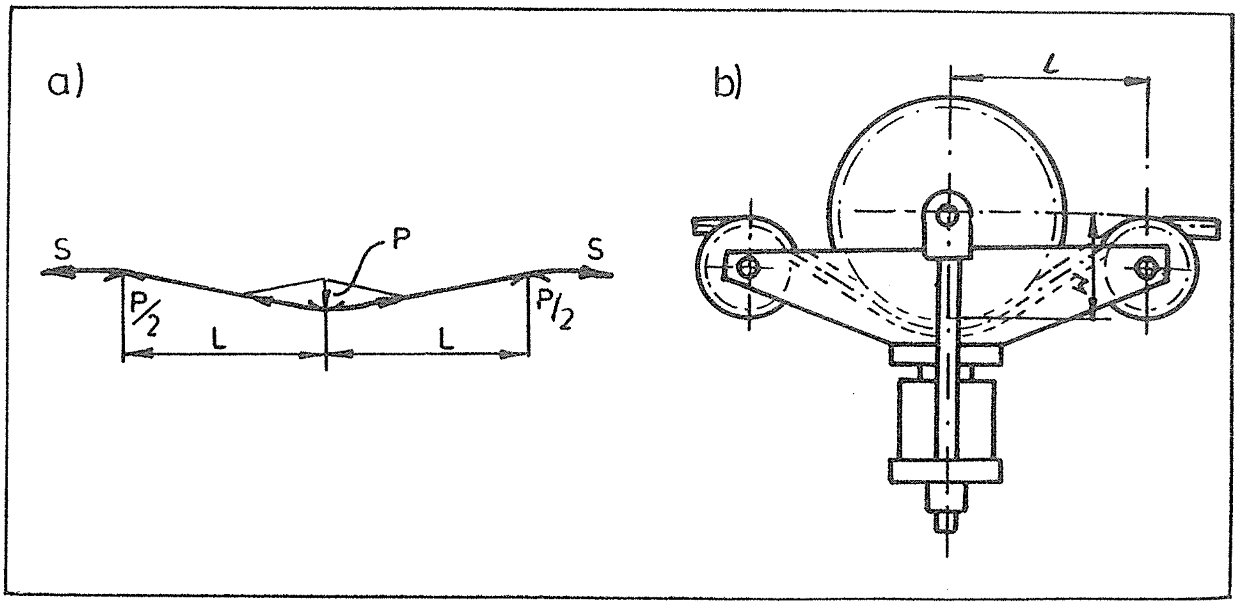

Fig.3. Method of measurement by bending aside the rope.

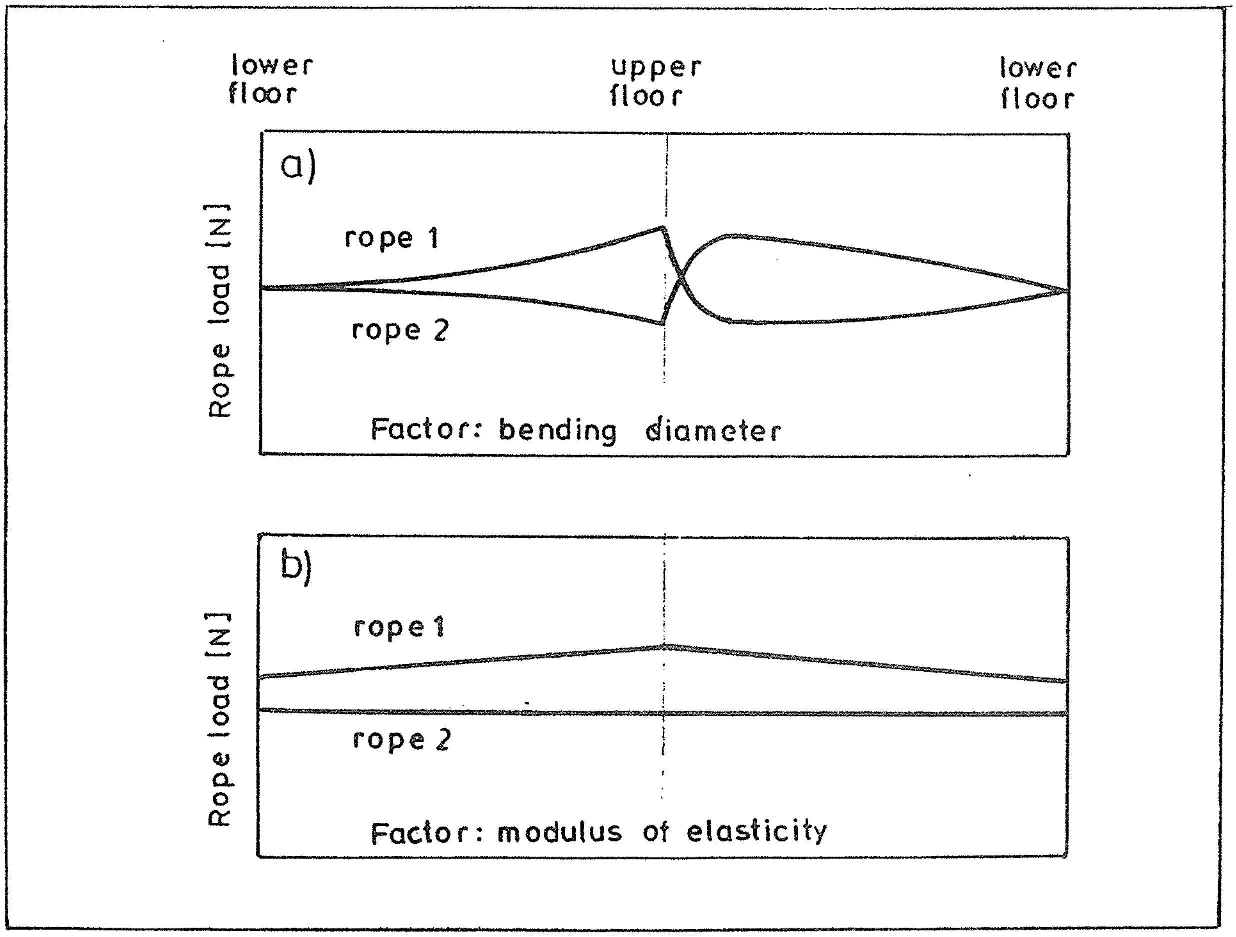

Fig.4. Examples of load distribution runs in ropes.

APPRAISAL OF REASONS FOR UNEVEN DISTRIBUTION OF LOADS

The uneven distribution of loads in multi-rope friction drives depends on many factors. The most important of them are: differences of the real bending diameters on the driving drum, differences of moduli of elasticity of ropes and the differences in elastic properties of the groove lining made often of some substitutes. By the real rope bending diameter it should be understood the sum of the drum diameter measured at the bottom of the groove and the rope diameter. Differences in bending diameters result from the different wear processes of the groove lining and those of the rope. The value of the modulus of elasticity depends on the rope construction, the time of operation, lubrication and the kind and degree of wear.

The influence of those factors on an uneven load distribution of individual ropes can change during operation and the way of those changes is very difficult to be expressed mathematically. By periodic measurements of the loads in ropes the existing conditions of the load distribution can be established and in most cases the factor or the factors responsible for the differences in the individual ropes can be found.

In fig.4 some examples of load changes in ropes of a two-rope lift are presented from which the element causing the uneven load distribution in ropes can explicitly be given.

Fig.4a presents the load differences due to the differences of the bending diameter on the drive drum, and fig.4b features the differences of elasticity of ropes.

It is obvious that an analysis of results obtained by measurements in some cases is not so simple. However such an analysis is indispensable to be able to find and remove the cause of an uneven load distribution of a multi-rope system, which is very unfavourable for the life time of ropes.

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