RESULTS OF EXPERIMENTAL RESEARCH OF TRACTION DRIVE

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ABSTRACT

The rope traction calculation according to the Eytelwein formula is based on a number of assumptions. These assumptions are examined one by one. It is proved that traction forces between sheave and rope are not only transferred in the creep angle but also in a part of the rest angle, where no creep exists. This is favourable with a view to wear of sheave and rope. In practice, however, wear is often increased by an uneven distribution of the car weight over the ropes.
Recommandations are given for optimal combinations of sheave and rope materials to decrease wear.

INTRODUCTION

Some years ago the Research Committee of the Netherlands Institute for Lifttechnology decided to have a research done into the behaviour of steel wire ropes and traction sheaves with a view to study the wear of these components. This was motivated by the wear found in practice, which in some cases showed an alarming increase. The proposed research was aimed to result a number of measurements, by which the process of wear could be better controlled, the lifetime of ropes and sheaves could be prolonged as a consequence of which the safety of lifts could be increased, the maintenance costs decreased and the comfort for the lift passengers improved.

The following aspects were discussed:

1. mechanical factors like forces, deformations, transfer of forces, contact phenomena, relative speeds and vibrations;
2. tribological factors like friction, coefficient of friction, wear and lubrication;
3. material factors like materials for sheaves and ropes, composition, structure, hardness and geometry.

The research was divided into a theoretical part and an experimental part. The aim of the experimental part was to support the theory and, where necessary, to correct or to complete it.

THE THEORETICAL RESEARCH

An important part of the theoretical research was an analysis of the assumptions, made when derivating the Eytelwein's formula. These assumptions are successively:

1. the rope behaves like a smooth cylinder;
2. the rope has no bending stiffness;
3. the coefficient of friction is constant;
4. the transverse section of the rope does not deform;
5. the groove in the traction sheave does not deform.

ad 1. : A steel wire rope is not a smooth cylinder, for it is built of steel wires and a core, each with its own tolerances. Moreover, the inevitable irregularities in the manufacturing process see to it that not all circumferential wire crowns touch the theoretical enveloping cylinder. Because of the same reasons a steel wire rope is not exactly round; also in longitudinal direction differences in diameter are found. The diameter also depends on the value of the rope traction force during the measurement.

ad 2. : As a steel wire rope has a certain bending stiffness, a bending couple is induced near the points of contact, where the rope is running on and off. The bending stiffness of a steel wire rope is caused by the bending stiffness of the steel wires, the strands and also by the friction between these components, that prevents the gliding of wires and strands over each other.

ad 3. : The coefficient of friction is not constant, but depends on the relative speed on the groove: whether the rope is moving or not, and when if so, at what speed. At a traction drive the rope movement occurs in the creep angle. It is found that at low speeds the coefficient of friction decreases when increasing speed. Also increasing compressive pressure between rope and groove causes a decreasing coefficient of friction. Investigations into the influence of the relation D/d showed that, with a constant pressure and creep, the coefficient of friction increases at an increasing ratio D/d.
For example: at a rope diameter of 13 mm an increase of 10% is measured when the ratio D/d increases from 40 to 50.

ad 4. : The cross–section of a rope, owing to forces exerted on the rope in a groove. The extent of the deformation depends on the rope construction and the kind of core.

ad 5. : The groove in a traction sheave also deforms under influence of the forces between rope and sheave. In particular in the case of V–grooves, the rope forces will increase the width of the groove. For the process of transfer of forces between rope and sheave it is important that also in the circumferential direction of the sheave a deformation takes place. This deformation causes a circumferential force, not only in the creep angle, but also in a part of the rest angle. This fact was mentioned in literature by two researchers and now is confirmed by my own experiments.

ENERGY LOSSES CAUSED BY FRICTION

At a point where the rope has a relative speed with regard to the groove and where at the same time a normal force prevails in the contact area, there are energy losses due to friction. According to the Eytelwein theory these losses are:

$$P = -\ (S_2 - S_1)^2.v/2EA$$

where: S_2 and S_1 are rope tensile forces

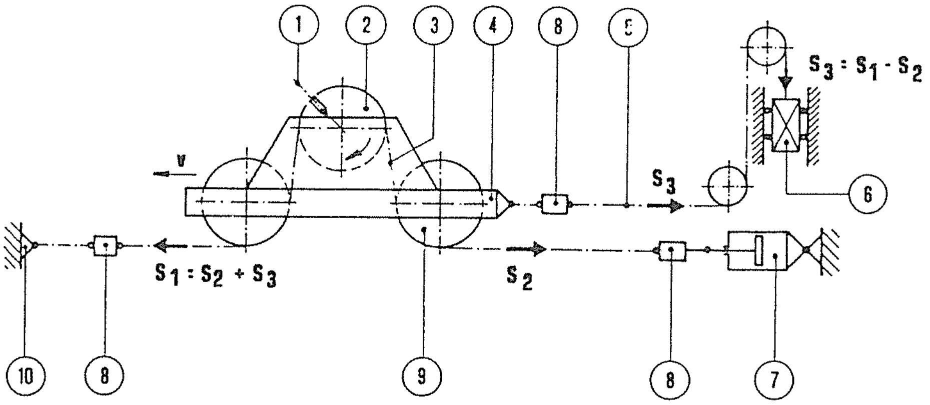
v	circumferential speed of the sheave
E	modulus of elasticity
A	metal area of the rope diameter

This formula is based on the assumption, that the whole tangential force is transferred in the creep angle. We have seen already that this is not exactly right. Yet it is necessary to keep the thus calculated energy, as low as possible.
Therefore, the weight of the cabin and the counterweight at both sides of the traction sheave must be distributed evenly over the ropes. This means, that the running circles of the different ropes must have the same diameter, as I already demonstrated in my paper at the Munich Lift Congress in 1988. Small differences between the running circles in the size of 0,1 mm are the cause of a disproportionate increase of the friction energy and, consequently, of the wear.

EXPERIMENTAL RESEARCH

Two testing machines were built for experimental research:
- a traction testing machine and
- a wear testing machine.

With the traction testing machine (figure 1) we aimed to realize



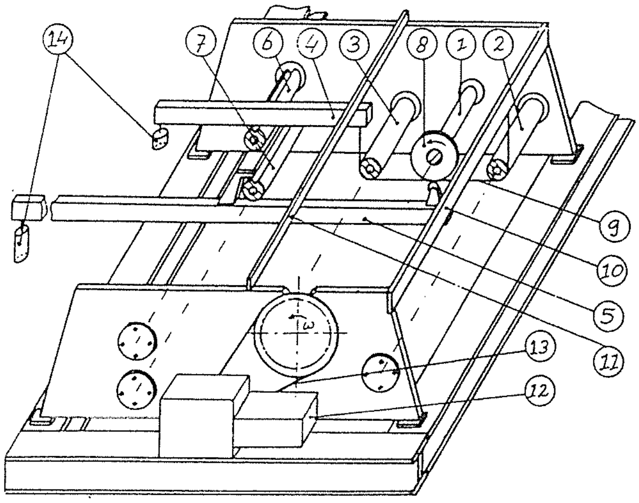
1. measuring element
2. test sheave
3. test rope
4. measuring car
5. auxiliary rope
6. structure with weights
7. hydraulic cylinder
8. dynamometer
9. guiding sheave
10. rope fixation

figure 1: the traction testingmachine

The transfer of forces between the test traction sheave and a single steel wire rope in such a way that it corresponds with normal lift practice. At the same time these forces had to be signalized and recorded with an acceptable accuracy. In the testing machine a number of variables can be adjusted within certain limits, such as the geometry of the groove, the rope construction, the rope traction force, the circumferential force and the spanned angle. In an opening of the groove of the test sheave a measure element had been taken up.
This element has three miniature quartz force transducers for the tangential and radial forces. The part of the element, that is in contact with the rope, has a length of only 8 mm. It is by this small dimension that the behaviour of the rope transfer force can be measured in detail during the passing of the test rope over the sheave, which is not the case when

the measurements are performed with much larger elements, which have a more integral character, but where much details are lost.

A sketch of the wear testing machine is given in figure 2.



1. main shaft
2. guiding shaft fixed side
3. guiding shaft lever side
4. lever for tension force
5. lever for pressure force
6. lever support pos.4
7. lever support pos.5
8. test sheave
9. steel wire
10. pressure roll
11. frame
12. driving unit
13. V–chord
14. adjustable weights

figure 2: wear testing machine

In this machine a steel wire is pressed against a rotating cast iron roll with an adjustable force. The tension force in the steel wire is also adjustable. The materials for the wire and the roll can be chosen freely.
The covered friction distance can be determinated by wanting the number of revolutions of the roll. The circumferential speed of the roll is about 11 mm/s. Because of this low speed there is no influence on the structure of the materials caused by development of heat.
The testing machine was designed in such a way, that ten tests can be made simultaneously. Wear is determined by the amount of material that is worn off the sheave and the wire.

RESULTS OF THE TRACTION TESTS

Figure 3 shows the course of the radial and tangential forces according to Eytelwein, for a creep angle of 60°.

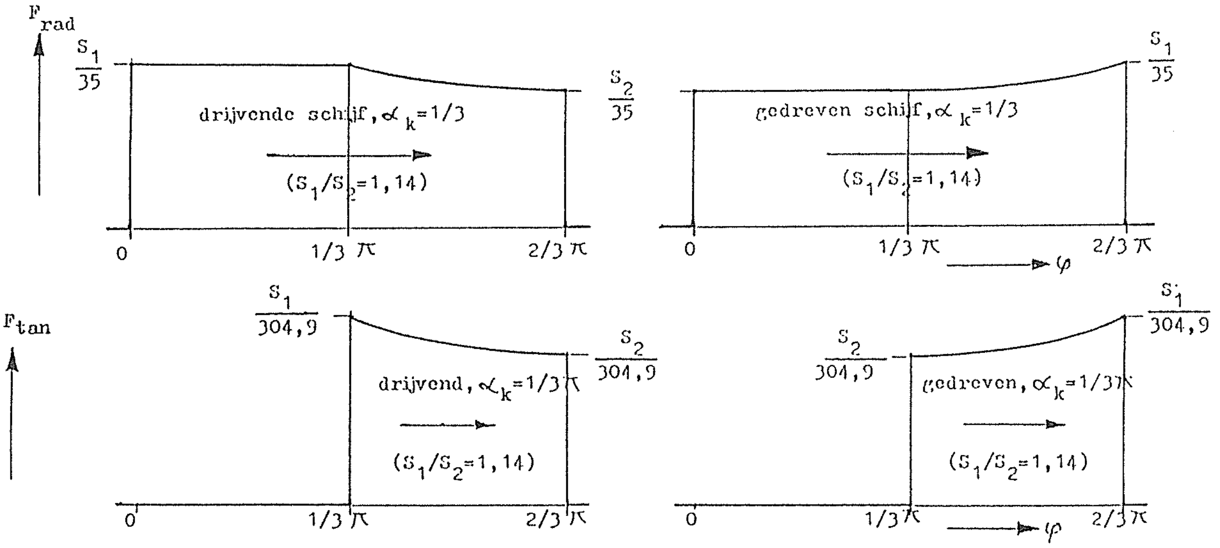
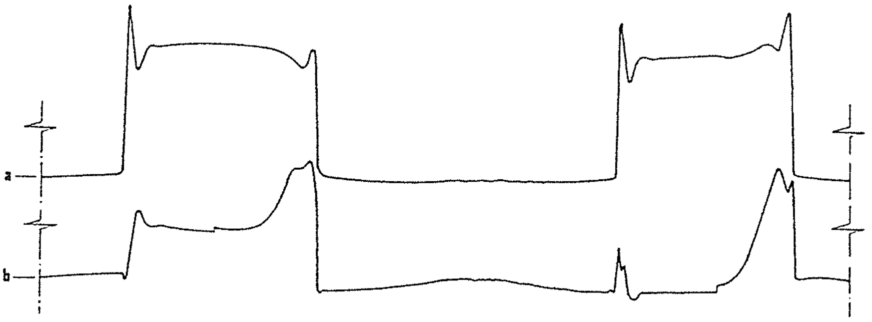


figure 3: radial and tangential forces according to Eytelwein's theory for a creep angle of 60°.

In figure 4 the signals are shown as measued by the traction testing machine.



a. radial force, b. tangential force

figure 4: characteristics of the transfer of forces in the traction testing machine

At both outer points of contact disturbances occur of the expected characteristics. The tangential force does not increase at once as is the case with Eytelwein's model, but gradually reaches its top value. When we suppose, that the creep angle is the starts point where the force increases, this angle turns out to be much larger than the creep angle that can be calculated with the Eytelwein's formula. One could also say that the coefficient of friction is lower than the value that is taken into account by Eytelwein. In reality this is not the case, which is proved by some tests with ropes, slipping over the test sheave. From safety reasons the traction force in the test ropes had to be held very low when doing these tests. A picture of the registration made during these tests is shown in figure 5.

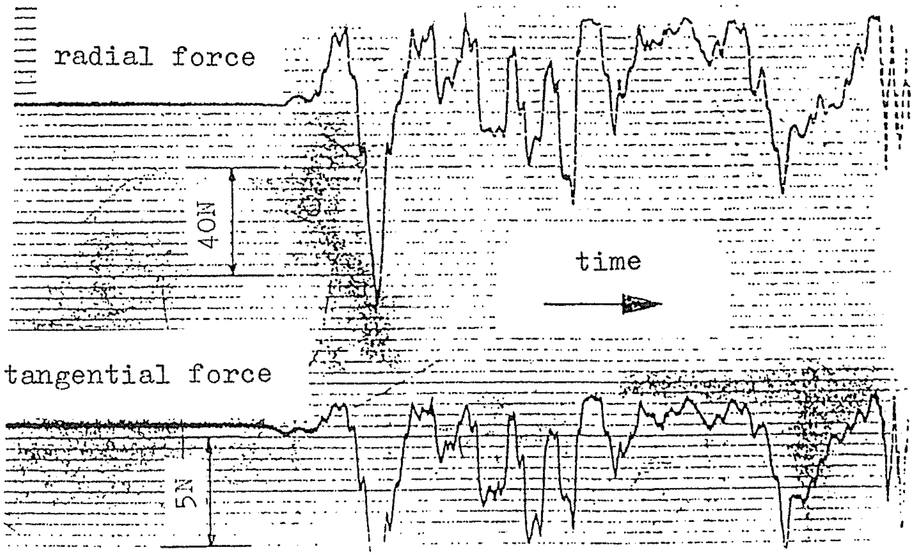


figure 5: registration of a slip test in a halfround groove

The coefficient of friction, determined on the ground of these tests, fluctuates between 0 128 and 0 146, the average value being 57% over the standard value 0.09.
Because Salmon and Petkov have already pointed on the fact that transfer of forces can appear in the rest angle, I have calculated the differences between the measured angles of transfer of forces and the creep angle as determined with Eytelwein's formula. For all average value being 22.7°.
Recently Wiek made some provisional measurements, at which he simultaneously determined the stress in the wires of a steel rope and the relative displacement of the rope with respect to the groove. He also found that the part of the rest angle, where a circumferential force is transferred, lies between 20° and 30°,
It turned out to be a relation between the groove-factor and the differential angle: an increasing groove-factor causes a decreasing differential angle; in other words: when the groove clamps more, the differential angle is smaller. This phenomenon is reproduced in figure 6.

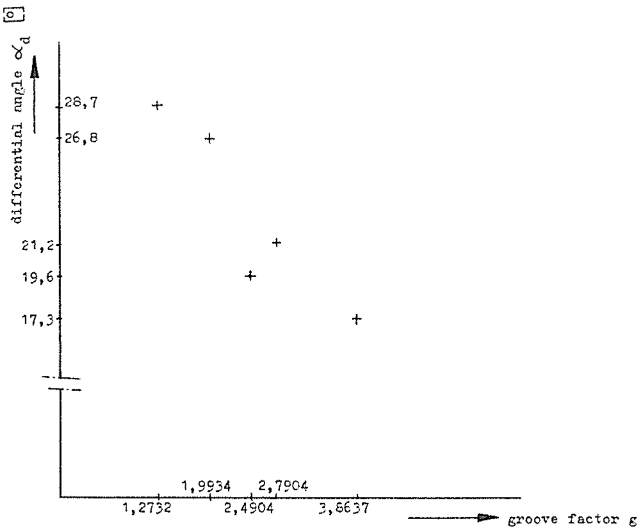


figure 6: relation between the groove factor and the differential angle.

The differential angle also decreases when the circumferential force increases, see figure 7.

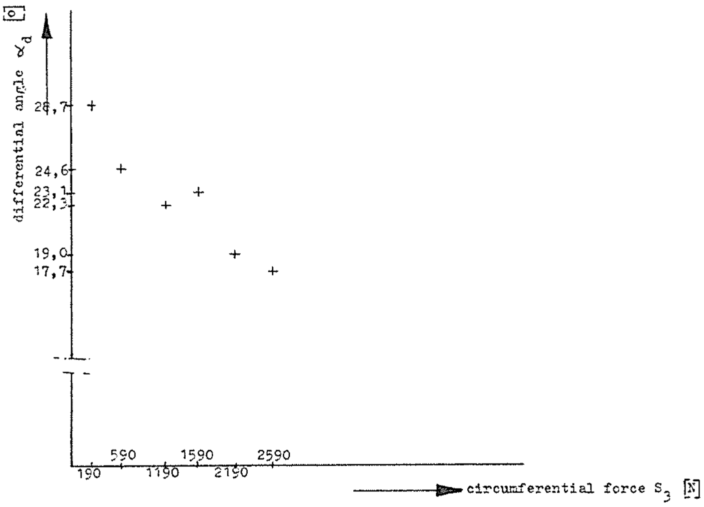


figure 7: relation between the circumferential force and the differential angle.

Further, the differential angle increases when the rope tension force increases. For instance: at an increase of the tension forces from 4 to 10 kN, the differential angle increases from 17,5° to 25°.
These phenomena are also important with a view to wear. When a greater part of the circumferential force is transferred in the rest angle, there will be less wear.

Owing to the abovementioned it is recommanded to choose the safety factor of the steel wire rope as close as possible to the admissable value and to take a halfround groove, where possible.

THE CHOICE OF MATERIALS

The choice of the most suitable combinations of materials for traction sheaves and steel wire ropes is based on the hardness of both components.
Recommended are combinations of:

- steel wire ropes of a hardness of 300 HB with lamellar cast iron of 205 HB;
- steel wire ropes of a hardness of 375 HB with lamellar cast iron of 240 HB;
- steel wire ropes of a hardness of 390 to 450 HB with nodular cast iron of 225 HB.

The relation of the hardness of cast iron to the hardness of the steel wire must stay under 0,75. Therefore, it is necessary to know the hardness of the steel wire. For a good quality of steel wire there is a relation between the breaking stress and the hardness; this relation, however, is not linear as is the case with normal carbon steel.
The wear tests are continued now in order to come to more detailed statements for the choice of the materials.

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