SLIPPING RESISTANCE OF MONOCABLE AERIAL ROPEWAY CARRIER GRIPS

Jacques Dubuisson, Michel Cantin

Introduction

Since 1987, the French Ministry of Transport has provided a program of study and research in order to make its contribution to improvements in the design and functioning safety of monocable aerial ropeway carrier grips.

An important testing machine has been conceived and presented at the OITAF congress of 1987 in Grenoble [1].

In 1993, during the previous congress in Barcelona, we gave testing results showing the grip slipping resistance decrease when wire ropes are subjected to a twisting moment [2].

This new paper is about :

- A new investigation on the grip slipping resistance sensitivity when the wire rope is subjected to a twisting moment: the local conditions of contact and slipping between jaws and rope, and the influence of jaw gripping force and geometry are analysed.

- The presentation of a sensor and measurement results of the grip twisting moment of one chairlift and five gondola lifts.

- A study on the stability of a grip loaded with its carrier and attached to an inclined rope subjected to a twisting moment: the characteristics of the twisting moment necessary to « initiate slipping » and « made the twist pass » are analysed.

The rope samples necessary to those researches were provided by the TREFILEUROPE company.

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**Grip slipping resistance**

The grip slipping resistance opposes the carrier weight and the rope twisting moment.

When grips are designed in the research department, their slipping resistance is determined from the following hypothesis: jaw contact pressure on the rope is uniform, and according to the classic friction laws, the adhesive strength ratio values and, by approximation, the slipping friction coefficient values are constant and equal to 0.18.

Practically, the slipping friction coefficient depends on the local conditions of the jaw contact and slipping on the rope, and the grip slipping resistance is influenced by the jaw gripping force and geometry.

**Contact and slipping local conditions**

The outer surface of a wire rope is not a cylinder but a regular structure composed of helicoïdal strands.

Let us consider a 140 mm long grip jaw made of 35 NCD6 steel and with a 120° angle at center of contact arc with a 40 mm diameter Lang lay rope of 6 strands of 17 non galvanized wires each on a compact core.

Through gripping, the outer wires of each of the rope strands - the rope being itself under tension - imprint themselves into the jaw material, leaving rather elliptically shaped prints, spread on the jaw surface as is shown on figure 1.

![Figure 1](image.png)

**Figure 1**: Schematization of rope wire print position on the developed inner surface of a grip jaw.
The main axis of the ellipse makes an angle of approximately 34° with the rope axis, in the direction of the strand outer wires.
In the rope axis, there are about 47 mm between each print, that is to say one sixth of the lay length.
In the strand axis, the prints are out of line with each other with an interval between them of about 3.5 mm transversely - a value equal to the diameter of the strand outer wires - and of about 20 mm longitudinally - which is one sixth of the strand lay length.

Size of prints is approximately constant on all the jaw surface. Their width is about 1 mm. Their length and depth vary according to the rope tension and the gripping force. For a 200 kN rope tension and a 60 kN gripping force, length is 10 mm and depth 0.015 mm [1].

The grip slipping resistance is equal to the sum of the resistance at the level of each of the wire prints in the jaws.
When the rope is not subjected to a twisting moment, slipping occurs along the rope axis, the wire « slipping » on the jaw surface. On the contrary, when the rope is subjected to a twisting moment slipping occurs in an oblique direction, the wire « digging » in the jaw material.

Consequently, the slipping friction coefficient through « digging », when the rope is subjected to a twisting moment, is higher than the one through « slipping », when the rope is not subjected to a twisting moment.

**Gripping force and geometry of grip jaws.**

To a gripping force $S$ of the grip jaws corresponds a resistance $R$ to which are associated a slipping resistance $R_g$ and a resistance $-T$ to the rope twisting moment $C$ (figure 2).

![Figure 2: Schematization of the forces applied on the grip](image)
For a constant slipping friction coefficient and for a given gripping force, the resistance $R$ is constant. Consequently, the slipping resistance $R_g$ decreases when the rope twisting moment increases.

In 1993, during the OITAF congress in Barcelona [2], on an experimental basis of 100 different series of six testings, we showed that, in accordance with the previous analysis: in a range of normalized gripping pressures of 5,3 to 10,5 MPa, the slipping resistance decreases when the rope twisting moment increases.

The normalized pressure is the ratio between the gripping force $S$ and the developed inner surface of the jaw.

Since that time, a similar experimental study on the measuring of the grip slipping resistance value according to the rope twisting moment, has been carried out for different jaw lengths and for a range of higher normalized gripping pressures. Jaw lengths are 140 and 200 mm. Angle at center of contact arc between jaw and rope is 120°.

The 40mm diameter Lang rope is composed of six strands of 17 non galvanized wires each, on a compact core.

Gripping forces are respectively 34 - 68 - 102 kN. Gripping pressures are 7 - 14 - 21 MPa for 140 mm long jaws, and 4,9 - 9,8 - 14,7 MPa for 200 mm long jaws.

Whereas the gripping pressure generally adopted when industrial grips are designed is about 10 MPa.

Slipping resistance values measured according to rope twisting moment, for a slipping speed of 2mm/s, appear on figure 3.
This study shows that:

- For 140 mm long jaws with a normalized gripping pressure of 7 MPa, slipping resistance decreases when the rope twisting moment increases.

If gripping pressure is 14 MPa, slipping resistance is practically constant according to rope twisting moment.

For a normalized gripping pressure of 21 MPa, slipping resistance increases according to rope twisting moment.

It turns out as if the gripping force increase induced a slipping friction coefficient increase « through digging », of resistance \( R \) and slipping resistance \( R_g \).

Let us note that the gripping pressure of 21 MPa cannot be used in practice, for it would lead, among others, to « digging » and to wear jaws and rope very badly when grips and carriers are attached and detached in the station.

- As far as 200 mm long jaws are concerned, the variations of slipping resistance according to rope twisting moment for different gripping forces, are globally identical to those obtained for a grip with 140 mm long jaws.

As far as design is concerned, the noteworthy difference lies in the fact that slipping resistance insensitivity, according to rope twisting moment, is reached for a normalized gripping pressure of 9,8 MPa, equivalent to the industrial gripping pressure generally adopted. For this gripping pressure value, wire prints made in jaws during gripping, « digging » and wear of jaws due to rope slipping when the grip is attached and detached in the station, are acceptable.

Everything happens as if the jaw length increase had the same effect as the gripping force increase.

From the industrial practice point of view, grip slipping resistance - with jaw lengths varying from 120 to 140 mm - decreases of about 20% for a 300 mN twisting moment value. Slipping resistance of today grips - with jaw lengths over 180 mm - is only slightly affected by the rope twisting moment.

For the first time this year, we even noticed that an industrial grip with 250 mm long jaws had an increasing resistance when the rope was subjected to a twisting moment.

We plan to confirm the effects of jaw length increase on grip slipping resistance, particularly for ropes with six strands of 26 and 31 galvanized wires.
Sensors and measure results of grip twisting moment

The grip puts up a slipping resistance to the carrier weight and a resistant moment to both twisting moments of ropes up and down the grip. Those twisting moments are functions of the rope tension up and down the grip and of the twisting moments imposed on the rope by the towers.

The twisting moments imposed on the rope by the towers induce friction phenomena influenced, randomly, by many parameters: carrier loading, equipment of tower balanciers, temperature and hydrometry conditions...

Since 1955, we have been making an experimental study for measuring and analysing statistically the twisting moment of the grips of ten gondola lifts and chairlifts, to complete the previous measure results concerning some chairlifts. This study aims at confirming a rough estimate of the twisting moments of high performance gondola lift grips, at validating the mathematical model of the grip twisting moment in the spans and at defining an approximate value of the twisting moment imposed on ropes by towers in order to obtain a reliable calculation of the twisting moment of grips.

Sensors measuring rope and grip twisting moments (figure 4), were realized in collaboration with the « Centre Technique des Industries Mécaniques » - CETIM of Saint - Etienne. The principle on which the sensor works, consists in fixing on both sides of the grip, parallel to the rope, a mechanical device composed of a bolted jaw and a sensor with a much more important torsional rigidity than the rope. Electrical strain gages stuck on the sensor allow to measure the rope twisting moment. Measure sensors are calibrated on the testing machine presented during the congress in Grenoble [1].
Figure 4: Schematization of two sensors measuring the twisting moment of the ropes placed up and down the grip

The twisting moments of the ropes are measured continuously all along the line without dismantling the measure sensors when ropes are passing towers. Three round trips of carriers allow to take into account possible variations in time of the rope twisting moment on towers.

Six measures have been made on one chairlift and five gondola lifts. For each each of them, measure results indicate the variations, according to time, of the twisting moments of ropes up and down the grip, in the spans and when passing towers. Table 1 shows the main characteristics of the six investigated installations with the maxima of the measured twisting moments of the grips.

<table>
<thead>
<tr>
<th>Rope diameter</th>
<th>Distance between carriers</th>
<th>Maximal length of spans</th>
<th>Maximum twisting moment of grip</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 seats gondola lift 54 mm</td>
<td>259 m</td>
<td>469 m</td>
<td>280 mN</td>
</tr>
<tr>
<td>12 seats gondola lift 54 mm</td>
<td>259 m</td>
<td>469 m</td>
<td>280 mN</td>
</tr>
<tr>
<td>15 seats gondola lift 55 mm</td>
<td>108 m</td>
<td>450 m</td>
<td>200 mN</td>
</tr>
<tr>
<td>12 seats gondola lift 50 mm</td>
<td>270 m</td>
<td>303 m</td>
<td>240 mN</td>
</tr>
<tr>
<td>12 seats gondola lift 50 mm</td>
<td>95 m</td>
<td>203 m</td>
<td>170 mN</td>
</tr>
<tr>
<td>4 seats gondola lift 40 mm</td>
<td>36 m</td>
<td>196 m</td>
<td>8 mN</td>
</tr>
</tbody>
</table>

Table 1: Main characteristics of the six investigated installations with the maxima of the measured twisting moments of the grips

This study attests that:

- The grip twisting moment of the high performance gondola lifts of today, under nominal operational conditions, reaches a value of 280 mN; while it fluctuates from 50 to 80 mN for traditional chairlifts. The 80 mN value confirms the values of previous measures carried out on other chairlifts.

- The mathematical model [3] of the evolution of rope and grip twisting moments in the spans between each tower has already been validated. Grip twisting moment is proportional to rope diameter and linear density, to slope and distance between carriers as well as to length of the span between towers and carrier weight. Consequently, grip twisting moment of high performance gondola lifts of today, in operational conditions of reduced hourly capacity, can exceed the 280 mN value.

The statistical analysis of twisting moments imposed on rope by towers, necessary to realize in the future a reliable calculation method of grip twisting moments, is already being investigated at present.
**Study of the stability of a grip loaded with its carrier on an inclined rope subjected to a twisting moment**

The regulation on the continuous movement aerial ropeways published by the « Département Fédéral Suisse des Transports » (the Swiss federal department of transport), imposes that grip jaws be conceived as to « let the twist pass », that is to say allow the rope to turn in the jaws in order to reduce its twisting moment.

The French Ministry of Transport operation and construction regulation of passenger aerial ropeways leaves aside any possible grip slipping in relation to the rope. This stability study imposes the « rope twist passing » through the grip, and analyses how to initiate, continue and stop the grip slipping in accordance with its slipping safety factor.

Practically, the rope twisting moment up the grip is increased until it overtakes the twisting resistance limit of the grip. « The twist passes » through the grip which slips along the rope.

The slipping safety factor of a grip is defined as the ratio between its slipping resistance - when the rope is not subjected to a twisting moment - and the carrier weight projection in the rope axis.

The Ministry of Transport regulations of all countries imposes a grip slipping safety factor over 3.
In this study, the safety factor varies from 3,35 to 1,65.

The experimental conditions schematized on figure 5, show the case of a grip loaded with its carrier gripped on an inclined rope subjected to a twisting moment.

This study is carried out with the experimental grip and the testing machine presented during the 1993 OITAF congress in Barcelona [2].

The 40 mm diameter Lang rope is composed of six strands of 17 non galvanized wires each on a compact core. The jaw length is 140 mm and the angle at center of the contact arc of a jaw with the rope is 120°.

Two parts of this study have already been realized. The first part results are presented below.

The second part, which result analysis is being carried out at the present, concerns : the effect of an additional load representing a braking force, the influence of the rigidity of the jaw gripping system, the effect of a rope twisting moment down the grip and the influence of the rope twisting moment variation speed up the grip.

In this first part of the study, the rope twisting moment variation speed, up the grip, is 5 mN/s. It is slightly over the maximal rope twisting moment variation speed which is 3 mN/s, a value measured in the spans between towers, for the chairlift and the five gondola lifts we talked about in the previous study.
A recording of the rope twisting moments up and down the grip, initialized at 0 when tests started, is schematized on figure 6. The grip twisting moment is equal to the rope twisting moment differential up and down the grip.

At time $t_0$, the rope moment up the grip increases at a speed of 5 mN/s.

At time $t_1$, the grip twisting moment «when slipping is initiated» is reached.

To time $t_2$, corresponds the maximum of the grip twisting moment «when rope twist is passing», while the grip slips along the rope.
The average results of the measure concerning the twisting moment of the grip « when slipping is initiated » and « when rope twist is passing », according to the value of its slipping safety factor, are indicated in table 2.

<table>
<thead>
<tr>
<th>Grip slipping safety factor</th>
<th>Grip twisting moment « when slipping is initiated »</th>
<th>Grip twisting moment « when rope twist is passing »</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.35</td>
<td>350 mN</td>
<td>400 mN</td>
</tr>
<tr>
<td>3.06</td>
<td>313 mN</td>
<td>378 mN</td>
</tr>
<tr>
<td>2.78</td>
<td>264 mN</td>
<td>344 mN</td>
</tr>
<tr>
<td>2.49</td>
<td>178 mN</td>
<td>288 mN</td>
</tr>
<tr>
<td>2.21</td>
<td>150 mN</td>
<td>240 mN</td>
</tr>
<tr>
<td>1.93</td>
<td>130 mN</td>
<td>188 mN</td>
</tr>
<tr>
<td>1.65</td>
<td>100 mN</td>
<td>400 mN</td>
</tr>
</tbody>
</table>

Table 2: Twisting moments of the grip « when slipping is initiated » and « when rope twist is passing » according to the value of its slipping safety factor

This first part of the study allows to show that:

- The grip resistant moment « when slipping is initiated » is lower than the resistant moment « when rope twist is passing ».
  For a slipping safety factor variation of the grip from 1.65 to 3.35, its resistant moment « when slipping is initiated » varies from 100 to 350 mN, while its resistant moment « when rope twist is passing » varies from 150 to 400 mN.

- When the grip slips, its translation speed is approximately constant and equal to 1.5 mm/s. The rope rotating speed in the grip is about 0.1 turn/s. The rope turned twice in the grip for each of the tests.

- No grip instability phenomena was detected; that is to say, when the increase of the rope twisting moment stops up the grip, the grip always stops slipping.

The result analysis taking place at the present concerning the second part of this study, could throw back into question those first results.
For a slipping safety factor of 1.65 and a rope twisting moment variation speed of about 40 mN/s, we have actually noticed that the resistant moment of the grip « when rope twist is passing » became null. The grip slipping speed reaches 20 mm/s and the rope rotation speed in the grip about 0.2 turn/s.
Such a quick variation of the rope twisting moment could be reached on the occasion of carrier passing on the towers; its analysis, mentioned in the presentation of the previous study, is taking place at the present.

Therefore, a third part of study on the influence of the twisting moment variation speed and on the stability of a chairlift grip subjected to an accidental slipping in 1981, is planned already.
Conclusion

Since 1987, the French Ministry of transport has been providing a specific program of study and research on the grip slipping resistance of carriers.

This paper refers to three studies carried out at the present. The first one concerns the geometry of jaws and their adaptation to the rope twisting moment, the second one deals with the measure and analysis of the rope twisting moment, and the third one with the study of the stability of a grip gripped on an inclined rope subjected to a twisting moment.

Partial lessons drawn from these three studies and projects concerning them have already been reported at the conclusion of their presentations.

More generally, these studies bring to the fore a possibility of grip jaw conception in which the slipping resistance is not lessened because of the rope twisting moment, and the importance of this conception is confirmed for the high performance gondola lifts existing now.

Further studies should be carried out to demonstrate the adaptation of this conception which consists in « letting the rope twist pass » without affecting the grip stability.

Moreover, a study planned for five consecutive years, on the evolution of the slipping resistance and on the tribological characteristics of the contact and wear of grips made by two constructors, has started in 1997 in collaboration with the « Laboratoire de Mécanique des Contacts » - LMC in Lyon.

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