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HOW TO DEFINE THE MINIMUM NUMBER OF SUSPENSION ROPES IN ELEVATORS AND IMPROVEMENT STRATEGIES FOR IN SERVICE PERFORMANCES

Summary

Checking the technical rules for elevators [1] [2], looking for information about the minimum number of suspension ropes required, we can immediately conclude that: you will need at least two of them, furthermore you have to verify the minimum safety factor.

Are these indications enough to configure properly an elevator system from which to expect a reasonable lifetime in service of at least 600.000 trips per direction? [5]

The elevator designers are not rope experts and they are following the performance standards to make their calculations compliant with the requirements; then in some occasions this will end up in non satisfactory performance of the system in service and the easiest way to deal with that is to fingerpoint the supposed rope quality, using detection of discard criteria as a demonstration that the rope is faulty.

It is really a rope fault what we are observing in such cases? Or is the system as a whole that would require a more educated approach with considerations that will overcome the minimum requirements stated in the technical rules?

With this paper, we intend to answer the question beginning with the historical background, moving onto the evolution of the safety factor, assessing improvement strategies to adopt a more holistic perspective of the elevator system, and ending with some reflections on discard criteria.

1 Introduction

The historical developments of wire ropes and elevators are somehow linked in a parallel way; it is not necessary here to come back to the root of wire rope progressive evolution, but it would be enough to remember that the first successful stranded wire rope was the one devised by Wilheilm Albert in 1834 for a mining elevator in Clausthal (Upper Harz province of Hanover). Since then, the development started and wire ropes became the most common suspension system for elevators. The real ramp up happened after Elisha Graves Otis presented his *Safety Gear Device* at the Crystal Palace in New York during the Exhibition of the all Nations in 1854, with a very impressive demonstration in which he was cutting out the suspension ropes, showing that the cabin was not falling down but remaining stuck to the guide rails [3]. Since this show, the modern era and evolution of elevators for people’s transportation can be rooted back.

The background history being reported, we still have one element to be clarified before tackling with our topic, and it is the technical rule at which we have to refer to.

The main standard to be considered in this area is the EN 81-20/50:2020 [1] [2] that is an European based technical rule, applied as well outside Europe and in a certain sense can be considered similar to a global rule. Reason for which the CEN TC10 is in charge to further develop this standard to make it really global and to come up with a rule that will take the name of ISO 8100-1/2 to be applied globally: the supposed date of publication of this rule is expected for 2025, then there will be at least 36 months of co-existence with EN 81-20/50 and then only the ISO 8100-1/2 will be in place.

This being reported, what we are interested in is understanding how many ropes we have to install based on the applicable standard, and if this requirement will be enough to grant a safe and reliable service to the elevator. To understand this, we have to make a jump in the past, and more precisely in the 1927, when a book published by F.Hymans and A. V. Hellborn [4] settled the groundbase for the modern traction elevators.

2 Specific pressure

The study made in 1927 put in evidence that the main wearing process between the rope and the traction sheave, was allocated in the latter one: for every single elevator trip, the same point on the sheave was touching the rope several times, while the same point on the rope was touching the sheave only once. Furthermore, between the two, the wire rope was the harder partner, and in addition to this the transmission ratio T_1/T_2 was causing the rope to elongate or shorten passing from one side to the other of the traction sheave, giving rise to the so called *Creeping* phenomena, identified as one of the main wearing processes for the traction sheave.

Without entering too deeply into the matter, what is interesting to note here is that to limit, or in another way, to minimize the wearing occurring between traction sheave and wire rope, a certain level of maximum specific pressure allowable was identified.

The reference values being obtained via empirical experiments by F. Hymans [4] and defined based on the expected average usage of the elevator; with this approach in mind 4 different curves were identified for the specific pressure, and a reconstruction of the diagram is repoted in the following illustration, taking into account the 4 different elevator classes represented in the study:

Class 1: People Elevators that run on schedule for 8-10 h a day.

Class 2: People Elevators that can only be used for intermittent traffic.

Class 3: Freight Elevators, the use of which is equivalent to Class 2, but with the difference that the periods of the standstill are estimated longer due to lading and unloading.

Class 4: Freight Elevators, generally with klow travel speed, which are seldomly used.

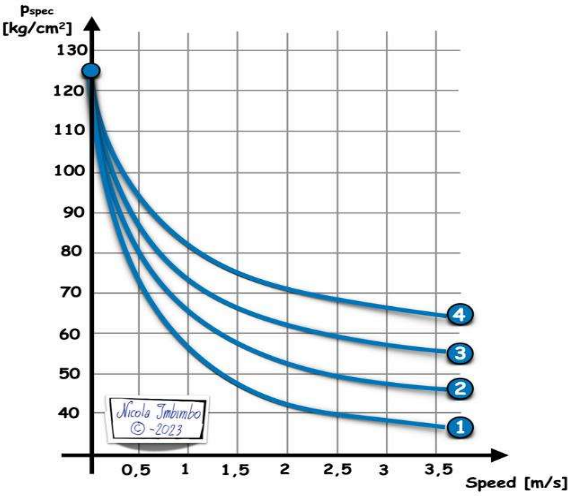


Figure 1 Hymans-Hellborn specific pressure curves for the 4 classes of elevators

From the above repoted diagram, the curve 4 has been interpolated to give rise to the expression of the maximum specific pressure and then in 1985 it has been introduced into the technical rule EN 81-1:1985.

$$p_{spec\text{-}max} <= \frac{12{,}5 + 4\,v_r}{1 + v_r} \left[\frac{N}{mm^2}\right]$$

v_r = Rope speed [m/s]

For every type of formed groove, a formulation for the actual specific pressure value was given, and then with the use of such formulas, it was possible to understand if the required p_{max} was respected or not.

$$p_{spec} = \frac{T}{n\, d_r\, D_t} \cdot \frac{8}{\pi} \qquad \text{For U-plain groove}$$

$$p_{spec} = \frac{T}{n\, d_r\, D_t} \cdot \frac{8 \cos \frac{ß}{2}}{\pi - ß - \sin ß} \qquad \text{For U-undercut groove}$$

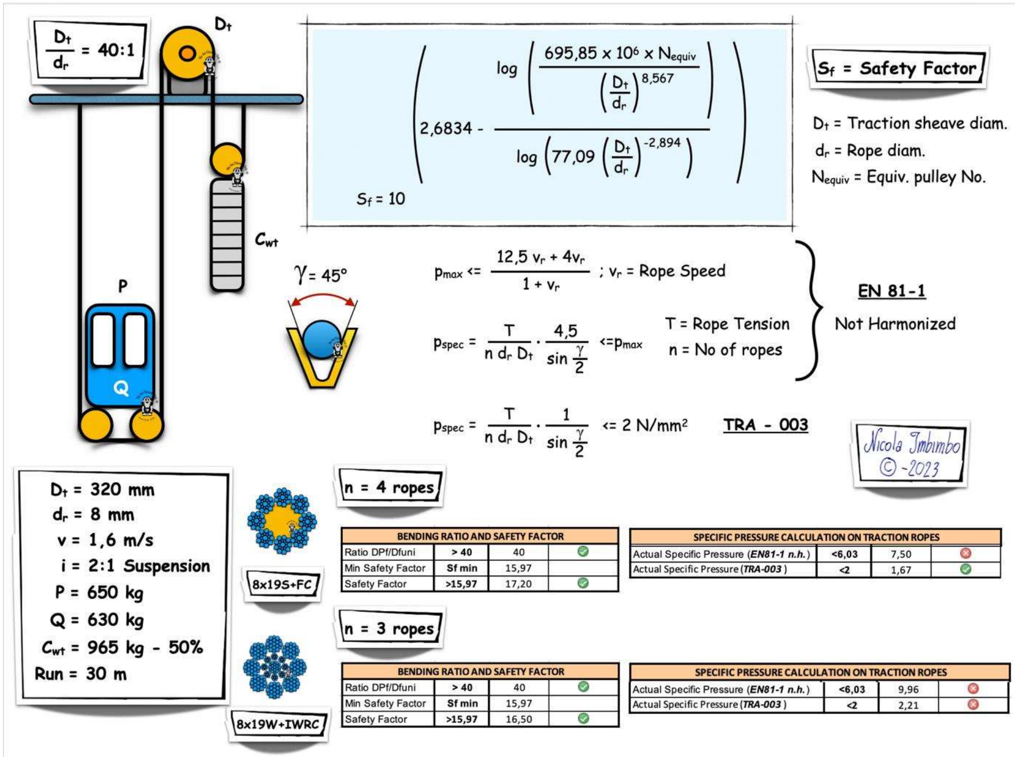
$$p_{spec} = \frac{T}{n\, d_r\, D_t} \cdot \frac{4{,}5}{\sin \frac{\gamma}{2}} \qquad \text{For V-groove}$$

$$\left\{ \begin{array}{l} T = \text{Rope tension} \\ n = \text{No of ropes} \\ d_r = \text{Rope diameter} \\ D_t = \text{Traction sheave diameter} \\ ß = \text{U-Undercut angle} \\ \gamma = \text{V-groove opening angle angle} \end{array} \right.$$

Figure 2 Specific pressure formulas developed by F.Hymans [4] and then introduced in the EN 81-1:1985 (not harmonized rule) where they remained until the rule was harmonized in 1998, then removed and replaced with a different method of calculation [5].

It has to be noted here, that the specific pressure formulation remained in the standard just for a few years, and then it was removed: all the concept being replaced with a new method of calculation with a safety factor expression that was supposed to overcome the specific pressure requirement that by the way was not any longer an explicit value, nor required to be evaluated. The respect of this formula for safety factor was granting at least 600.000 trips of the elevator [5].

Was it a realistic assumption? To understand it, the only possibility we have is to perform some example calculations to see where we will land: the results of which are reported in the following image.



$$S_f = 10^{\left(2{,}6834 - \frac{\log\left(\frac{695{,}85 \times 10^6 \times N_{equiv}}{\left(\frac{D_t}{d_r}\right)^{8{,}567}}\right)}{\log\left(77{,}09\left(\frac{D_t}{d_r}\right)^{-2{,}894}\right)}\right)}$$

$$p_{max} <= \frac{12{,}5\, v_r + 4 v_r}{1 + v_r}$$

$$p_{spec} = \frac{T}{n\, d_r\, D_t} \cdot \frac{4{,}5}{\sin\frac{\gamma}{2}} <= p_{max}$$

$$p_{spec} = \frac{T}{n\, d_r\, D_t} \cdot \frac{1}{\sin\frac{\gamma}{2}} <= 2\ \text{N/mm}^2$$

Figure 3 Safety factor, specific pressure and number of suspension ropes

Although not required by the technical standard in force, it is worth examining what value the *specific pressure* can have, as this parameter is directly correlated with the expected rope lifetime in service (being it the main parameter for the rope/traction groove wearing process as above outlined). To carry out this calculation, we refer both to the formula reported in EN 81-1 not harmonized, and then to the German regulation TRA 003, as for V-groove it provides a formulation which is more permissive than the one included in EN 81-1:1985, and it has been proven over time to be a valid reference providing acceptable pressures for the installations for which it has been applied. The results of such evaluations being reported in the Figure 3 are self-explanatory and give us the evidence that at increasing rope MBL (from FC to IWRC) the reduction of rope number from 4 to 3 is having a severe effect on the specific pressure and consequently to the rope lifetime in service.

If on top of that we add as well that starting from 2022, the new version of ISO 4344:2022 [6] has introduced the possibility of using as suspension ropes even those with a tensile grade of 1960 (previously the maximum tensile was 1770) and those with a PWRC core, things start to become definitively more complicated referred to the values of the specific contact pressures between ropes and friction grooves. Obviously, this will affect the rope lifetime sensibly, and not for quality reasons, but for configuration reasons.

3 The case of small diameter suspension ropes

Since 1999, when the new approach directive allowed the possibility to deviate, with a risk assessment procedure, from the parameter reported in the technical rule, in the market the elevator configurations have been more and more leaning toward small diameter ropes in combination with reduced bending ratio between the traction sheave and the suspension ropes: $D_t/d_r<40$.

To understand the reason and the meaning for this trend, it would be interesting to perform a sort of experiment called the "*bucket challenge*", to get a feeling of the concept of motor torque and how much this will affect the size of the motor itself.

Just to start our experiment, we have to fill 2 buckets of water and hold them parallel to our body, to evaluate how long we could keep them in this position: most likely we will be able to keep the position for several minutes.

If the former one was easy, now it comes the most difficult task: let us try to spread our arms to keep them as horizontal as possible. The effort for our shoulders to keep the position is now tremendously increased, and we will not be able to keep this set up for more than few seconds.

The effort our shoulder has felt when spreading the arms, can be compared to the torque increase required to the elevator motor when the traction sheave increase in diameter. For this reason, it is quite straightforward to understand why small diameter ropes are taking the lead: reduced diameter traction sheaves bring to smaller motor that are consequently lighter to be installed and give more space to the elevator cabin, that in the same shaft dimension could have a higher capacity. It is like a domino effect. Just as a reference to grasp this concept, give a look at the following illustration that represent visually what we have just outlined.

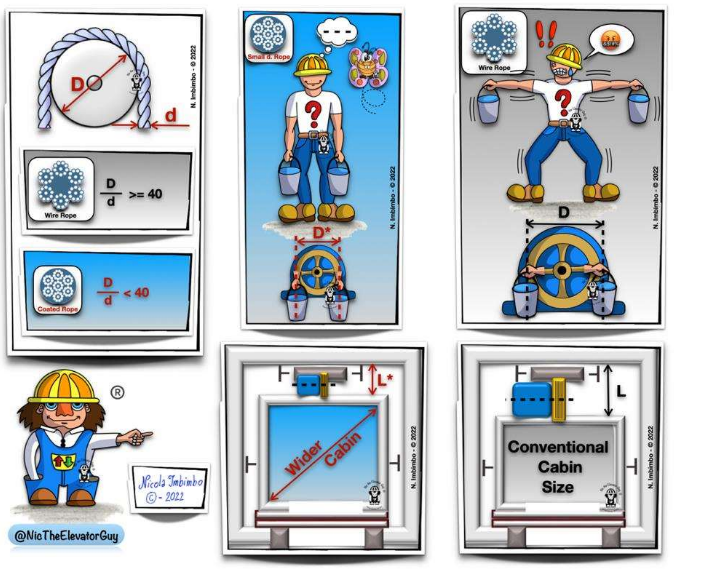


Figure 4 Small diameter ropes and the effect on elevator anatomy

Now that we have understood the reason for this trend, it would be worth to perform some calculations, as for the case of the conventional ropes, to understand how much the design parameters will be affected by this variation in introducing small diameter ropes.

3.1 Safety factor and specific pressure considerations: how things will change with the use of small diameter suspension ropes.

Let's consider the same elevator configuration as before, with the only modification that in this case we will use, as suspension means, a rope d.6,5 mm 8x19W+IWRC with a reduced bending ratio $D_t/d_r<40$; this will change dramatically the requested minimum number of ropes to be installed to be compliant with the code requirements, because the formulation we have seen before for the safety factor, will take into consideration the bending ratio, and it will give a higher requested minimum safety factor. Despite of that, we will notice that by increasing of one element the number of the installed ropes, then there will be a noticeable increase in the expected lifetime of the configuration (the number of trips has been calculated with the information provided in the type certification of the rope in which for every safety factor, sheave diameter and groove geometry it is provided the expected lifetime in service).

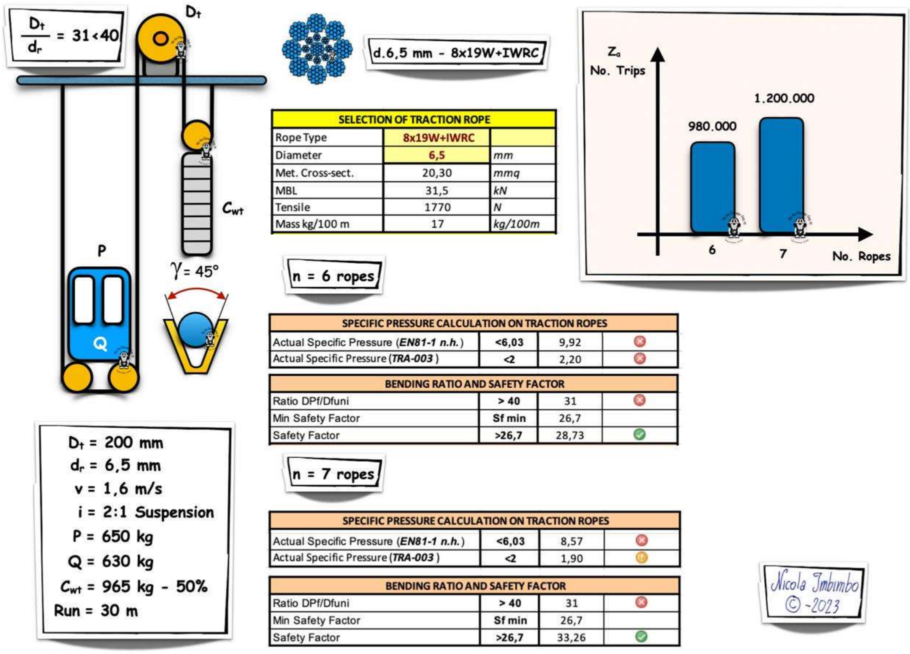


Figure 5 Parameters and rope lifetime in increasing the number of ropes from the minimum n=6 to n=7

3.2 Elongation-Tensile curve

A service parameter, that in some cases is claimed by the final users, is the elongation of the ropes when the passengers are entering the cabin, causing the displacement from the floor level. Is that again something that could be corrected with a configuration modification? This is what we would like to learn in this paragraph.

Let us start with the observation that all the ropes are subjected to permanent and elastic elongation, but considering that the permanent elongation will fade out after the first weeks of service, let us concentrate to the elastic part of this behaviour trying to understand in which way we can cope with this. To get a feeling of the possible elastic behaviour that the ropes could have in the specific configuration taken as an example, some laboratory tests have been performed to simulate the same loading spectrum of the one under analysis.

To accomplish this task, we wanted to interpolate the elongation curve with some mathematical expression, and after a certain number of laboratory experiment, it has been noted that: into the working area for elevator application (2%-10% of MBL), the elongation-tensile curve is having a non-linear shape that could be roughly approximated by a 3rd grade polynomial function.

The results of the calculation, after the laboratory experimental stage, are reported in the following illustration, in which we could approximate the rope elongation performance after the increase of the number of ropes installed from 6 to 7.

As the number of wire ropes in getting up, the apparent E-modulus is reducing, nevertheless the cabin displacement for elastic rope behaviour is reduced: this is possible since increasing the number of ropes, there is an increase of the total value of the metallic cross-section that is having a higher effect compared to the reduction of the E-modulus. Even if this unfortunately, will bring the working condition further into the non-linear part of the diagram. But in any case, with a configuration strategy we were able to mitigate the supposed elastic behaviour of the ropes.

The results obtained shall be considered in the aim of the laboratory experiment, in any case they are giving a guideline in case of claim management for corrective actions.

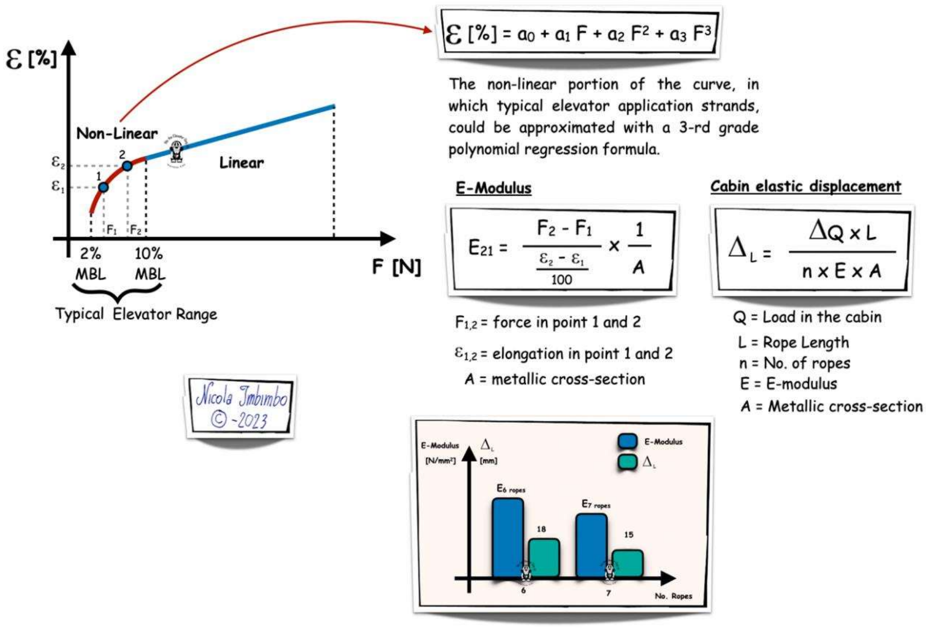


Figure 6 Purely indicative values of E-modulus and Cabin elastic displacement, with one rope more.

3.3 Rope torsion and the effect on elongation characteristics

From time to time in the market some anomalies about the rope elastic behaviours are detected, in which, the same rope in the same elevator configuration but in two different buildings, was displaying a different elastic performance. What could have been possibly gone wrong?

Generally, when this happen the first thought goes to the installation procedure, for which during the paying off of the rope some torsion is accumulated. To give consistency to this hypothesis, some laboratory tests have been performed in detecting the *Load-Extension* curves for the rope with the nominal lay length, and then with two torsioned configuration in which the lay length has been shortened and increased by roughly 3% in respect to the nominal value. The result of this experiment is reported in the following illustration, together with the laboratory set-up [7].

The general understanding is that ropes manufactured with shorter lay lengths generally behave in a more elastic way compared to the same rope manufactured with slightly longer lay length. The laboratory experiment gave us a result that was looking counterintuitive compared to this experience observation and that can be based on the following consideration: when a rope is manufactured with a certain lay length that in service is forced to be lengthened by torsion, then in this latter case the rope will behave in a more elastic (or "springy") way.

Elevator ropes are having, in certain production batches, a "*line marking*" painted on their surface: this is an aid to understand if during the installation, the rope has been subjected to induced torsions. If this is the case, it is recommended to restore the initial situation getting the line as straight as possible to get the best performance referred both to the lifetime and to the elastic performances (please refer to the specific wire rope manufacturer instructions to understand which are the permissible maximum number of turns per length for this line).

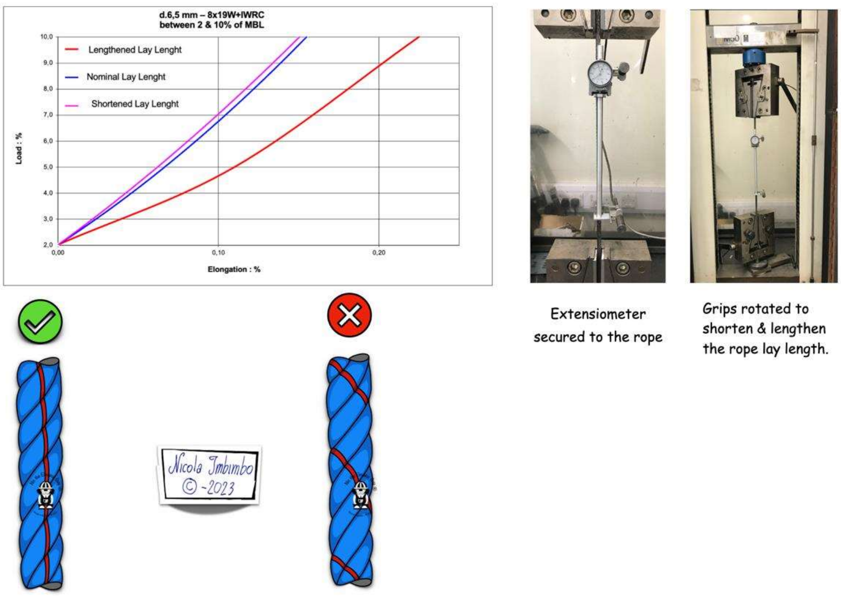


Figure 7 Rope Elasticity due to the lay lenght shortening and lengthening

3.4 Equal tensioning: effect on the service perfomances.

In the paragraphs it has been reported, that the wearing process between the rope and the traction shave, is mainly allocated on the traction sheave itself, and as a consequence of this the gooves are modified over the time compared to their original shape. The effect of this difference is that in the set of ropes, some of them are carried out with higher tension compared to others, and these phenomena will worsen over the time.

The operation of equal tensioning, is one of the first recommendation to be carried out at regular intervals to ensure that the set of ropes is working in an equal manner and could perform in the expected way. If this will not happen, it will cause reduced rope lifetime and non-homogeneous performance parameters referred to the elongation, noise and accelerated uneven groove wearing process.

A set of ropes is considered equally tensioned when between the most and the least tensioned rope there is a range of +/-5% in tension compared to the average tension in the whole set of ropes. Even if this is a quite narrow tolerance, considering the groove uneven wearing process so, the recommendation is to try to stay as close as possible to this value, even if in a groove setup affected by wear this will not be possible to be obtained.

Attention shall be paid to the fact that the equal tensioning process is an iterative one: once the tensioning is performed by adjusting the sockets springs, this will not overcome the first pulley below the cabin (sketch on the left in the following illustration). At this point, the elevator shall perform a couple of runs up and down to dilute the equal tensioning created in the first fall over the complete length of rope. Then the operation shall be performed again, for other few times until the system becomes stable. In case this will not happen, then an in-depth investigation of the traction groove wearing shall be performed.

As already repoted, it is important to re-check the tensioning at regular intervals to ensure the stability of the system.

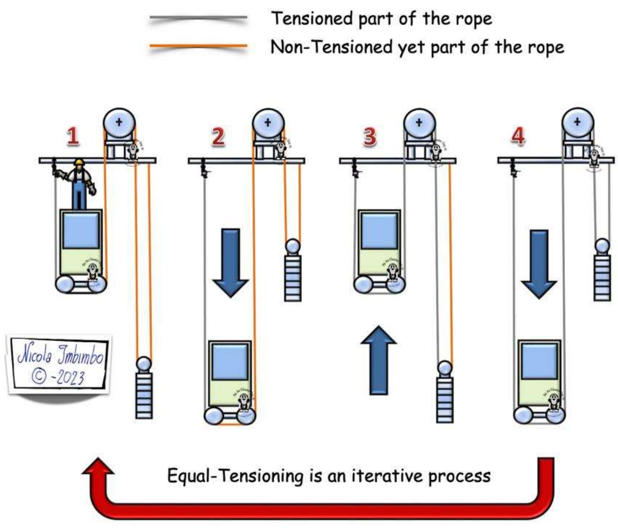


Figure 8 Eual tensioning of the set of ropes is an iterative process

4 Discard criteria as main method to evaluate the rope quality?

Based on the above developed discussion, we have learned how many factors are affecting the rope lifetime and performance in an elevator, even if not all of them have been listed in this paper for space constraint reasons.

Discard criteria for elevator wire ropes are reported in Annex G of the ISO 4344:2022 [6], that is having a normative profile (just as a reference, in the previous version of the ISO 4344:2004 the discard criteria were reported in the Annex E that at that time was having an informative profile). Clearly this is not an application standard, and beside the discard criteria the root causes that have generated them are not reported in full details; the knowledge and the understanding is left to the final user or to the professionals' expert in the field of proper application.

It is not possible to develop here a fully detailed investigation on discard criteria, that will deserve a complete paper dedicated to the topic; what is important here to address is that the link between the detection of the discard criteria and the root cause that has generated it, should be something the wire rope inspector being familiar with, in order to improve the working conditions and safety for passengers. After that some consideration shall be devoted to the corrective actions to be put in place to improve the situation in case the lifetime was considered not satisfactory.

What above reported, outlines the fact that discard criteria can in some cases spot out quality issue, but the experience in the elevator industry is showing that the early occurrence of a discard criteria is seldomly related to quality issue and more frequently related to application and configuration problems. In some cases, increasing the number of installed ropes compared to the minimum required by the code, as reported in the developed examples, can improve the situation. But it is not the only strategy.

5 Conclusions

From all that we have seen so far, and with the consideration that in the elevator industry, for the new installations, the trend is to lean toward more and more reduced bending ratio, we can conclude that the lifetime of the suspension ropes will be sensibly affected by the challenging operative parameters that shall be an important point of a complete assessment: increasing the number of installed ropes in some instances could bring increased lifetime cause the single rope is less stressed, even though this will make the installation a bit more complicated. These are the reasons why in the modern elevator development, designers are leaning toward alternative suspension means like belts or PU-Coated ropes. In this way they can obtain longer lifetime without the problem of installing too many wire ropes.

Design configuration and working conditions of the ropes are playing an important role to define the expected lifetime in service, and as we have seen, the standard requirements are not completely addressing this topic. The removal of the specific pressure calculation, replaced with a very complex formula for the safety factor, is creating confusion in the elevator designers, that are not fully understanding which is the background and which effects could have on the lifetime the modification of some of the parameters. In this light consideration shall be developed to evaluate if bring back specific pressure calculations into the recommended verification.

An elevator suspension means inspector shall have a solid understanding of which are the parameter that are affecting the rope lifetime in service and being able to correlate the discard criteria detected with a corrective action on the elevator itself to ensure that the replaced rope will have a reasonable lifetime in service.

To overcome the limits that wire ropes are having on bending ratio and expected lifetimes, a new generation of suspension means for elevators is under strong growth and will it be as well included into the new technical rule for elevators ISO 8100-1/2 : the coated suspension means (e.g.: PU-Coated ropes and Coated Steel Belts). These new items will bring several challenges to both designers and inspectors, due to the fact that the small cords are coated with TPU and the fact that this new material will have quite different performances compared to the historical steel-to-steel contact we were used to deal with until now. A complete new set of competences shall be developed and user instructions, discard criteria and corrective actions in case of troubleshooting shall be part of the development.

Are we running into the direction in which the elevators will not use any longer wire ropes as suspension means? For sure the new installations will be mainly devoted to this new type of coated suspension means, but there is still a very solid base of installed elevators that will continue to require conventional wire ropes, furthermore there will be situations for which the coated suspension means cannot be used, and so the wire ropes will be still part of the equation. We have to be prepared, because in the future the trend will be more and more in the direction of hybrid materials, and it will come the point in which the suspension means will not be any longer called "*Wire Ropes*". Still some time to get to this point, but better be ready for this shift of paradigm that will require a new set of competences.

6 Acknowledgements

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Experimentation on E-modulus with a 3-rd grade polynomial regression curve, could have not been possible without the support of the Global Design Centre of Usha-Martin in Italy, and for this reason I have to sincerely thanks all the team there: Laura Lombardi, Franco Clerici and Federico Paglia (who performed the annoying test required by myself).

To all of them goes my most sincere thanks!

7 References

[1] EN 81-20:2020 Safety rules for the construction and installation of lifts — Lifts for the transport of persons and goods. Part 20: Passenger and goods passenger lifts.

[2] EN 81-50:2020 Safety rules for the construction and installation of lifts - Examinations and tests - Part 50: Design rules, calculations, examinations and tests of lift components.

[3] https://en.wikipedia.org/wiki/Elisha_Otis

[4] F. Hymans, A.V. Hellborn, Der neuzeitliche Aufzug mit Treibscheibenantrieb: Charakterisierung, Theorie, Normung, Berlin, 1927.

[5] G. Schiffner, EN 81-1 Anhang N: Ermittlung des Sicherheitsfaktors von Tragseilen, Lift Report, March/April 2000.

[6] ISO 4344:2022, Steel wire ropes for lifts - Minimum requirements.

[7] Brunton-Shaw internal test report, “Elongation characteristics Vs lay length variation, Worksop (UK), 2022.

8 Author introduction

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Nicola Imbimbo is the Global Applications Manager for Prysmian Group’s Elevator & Escalator Business Unit, which is comprised of the Draka Elevator and EHC Global brands.

He began his career in the vertical transportation industry as an apprentice in the family business, Imbimbo Ascensori, which was a FIAM elevator dealer at that time. He earned a degree in mechanical engineering from Polytechnic of Turin in 2001 with an experimental thesis dedicated to non-destructive monitoring of wire ropes. Upon graduation, Nicola served as a design engineer with an international manufacturer of specialty lifts. Prior to joining the Prysmian Group in 2011, Nicola worked as a technical application engineer with several leading international companies involved in the production of wire ropes for lifting and transporting people.

Nicola is an active member of the Italian UNI and international CEN / ISO / ASME A.17 working groups for the technical standardization of the lift sector and has published numerous articles and delivered speeches at international forums dedicated to vertical transportation. He is the co-author of several books dedicated to lift design and technical training and has trained operators, technicians and inspectors on rope-based systems designed for lifting and transporting loads and people.

In his spare time, he teaches training courses for the lift industry as an independent consultant and is active on social networks platforms where he publishes content related to the elevator and escalator sectors. He is the creator of the character “NicTheElevatorGuy” ®.