Change of the Dynamic Elongation in Steel Wire Rope Traction Systems over the Lifespan, Influencing Factors and Mitigation Measures

Michael Eibel[1], Erich Spirgi[2]

[1]Lift ENGINEERING Michael EIBEL e.U., Schimannstrasse 4, AT 3104 St.Pölten-Harland, Austria.
[2]3i Business Solutions AG, Rossmarktplatz 1, CH 4500 Solothurn, Switzerland

Keywords: Steel Wire Rope, dynamic elongation, rope lifespan, total costs, elastic modulus.

Abstract. Essential characteristics of a Steel Wire Rope (SWR) Tractions System are the minimal breaking force, the permanent and dynamic elongation and the number of bending cycles projected prior to reaching the discard criteria. This paper focuses on the *change in the dynamic elongation of a SWR Traction System (SWRTS) over its lifespan*. It identifies, explains, and describes the impact of influencing factors. Since the cause of the change with the factors are identified, also corresponding mitigation measures are explained. Understanding and applying the mitigation measures is critical to ensure that the SWRTS can stay longer within the range of the required performance, extend its lifespan, lead to longer replacement intervals, and reduce therefore the overall operating costs of lifts.

1 INTRODUCTION

This paper examines the change in dynamic elongation over the lifespan of the SWRTS and identifies the factors that influence this change. The paper explains the impact of these factors and provides corresponding mitigation measures to ensure that the SWRTS can maintain its required performance, extend its lifespan, and reduce overall operating costs.

SWR constructions are commonly used in traction lifts due to their mechanical design, which is defined by the steel material and complex geometry. Mathematical models [1,10] can be used to calculate the deformation and elongation of wire rope under known tension, and the elastic modulus of a steel rod is well-defined. However, in practical use, imperfections and influencing factors can lead to a change in dynamic elongation.

The paper identifies these factors through observation and sample measurements in real lift installations. The impact of these factors is illustrated qualitatively. Corresponding mitigation measures are provided to ensure that SWRTS lifts sustain their overall performance over their lifespan.

2 PERMANENT AND DYNAMIC ELONGATION OF A SWRTS

We need to differentiate the terms "permanent" and "dynamic" elongation.

2.1 Permanent Elongation

Any new rope during the commencement of loading elongates permanently and in addition, dynamic elongation occurs, which will become evident after releasing the load. The permanent elongation is caused by the various components during the "*setting process*" with a corresponding reduction in overall rope diameter. The amount mainly depends on the type and construction of the rope and the range of loads. Most of the permanent elongation occurs early in the life of a "*running rope*": around 4 to 6 weeks in operation and an equivalent number of bending cycles. Slight permanent elongation will occur throughout the lifespan of the rope. Fibre core ropes show significantly more permanent elongation than ropes with a steel core. The initial permanent elongation of a rope cannot be accurately determined by calculation and entirely depends on the rope manufacturer.

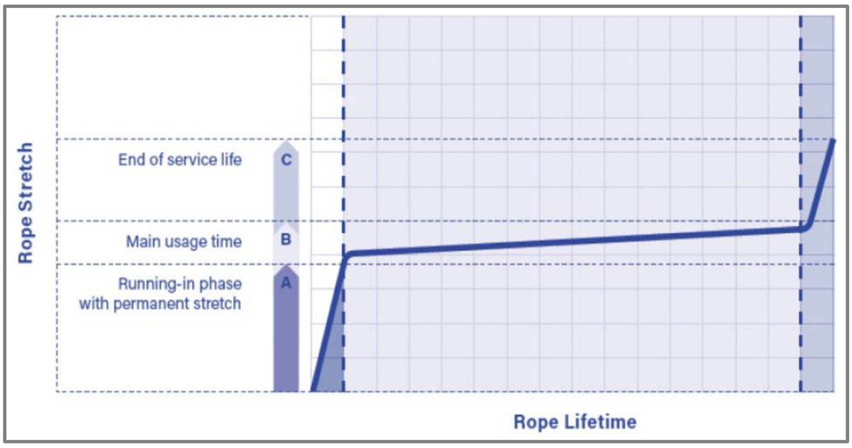


Figure 1: Permanent Elongation [2]

The "*setting process*" is also based on the rope manufacturer's process parameters. During the rope closing process, the strands are retarded in the machine baskets, therefore the closed rope must be pulled out of the spinning point. There are significant forces acting (see Figure 2) at the closing point, e.g., between 5% to 10% of the minimum breaking load of the wire rope. When the rope is spoiled onto the reels, the outer strands are without tension, hence, the diameter increases according to the tolerances of EN 12385-5 [3].

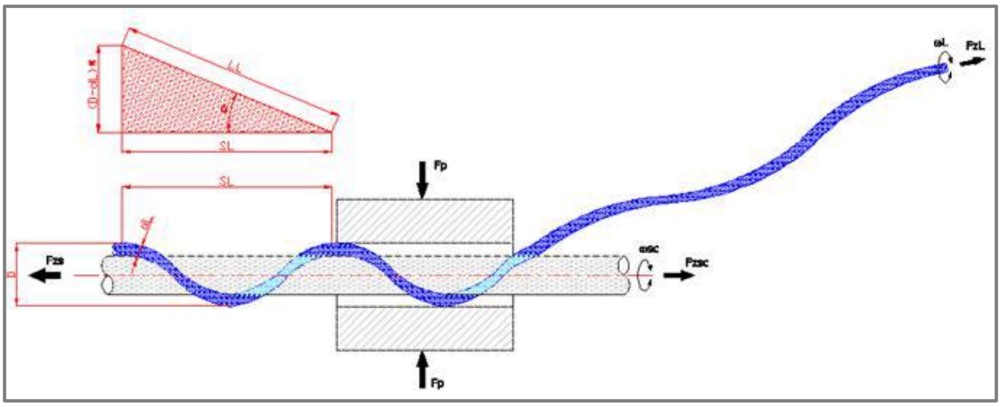


Figure 2: Forces of Spinning Point

2.2 Dynamic Elongation

Dynamic elongation is one of the most frequently misunderstood terms [5,6,11] for lifts, and the cause of much confusion. This is because there is no existing unequivocal elasticity module (E-Modulus) for SWR and SWRTS that can predict the elongation of the rope over its complete service life.

It is the main purpose of this paper to explain dynamic elongation better, with the identification of the many influencing factors as shown in chapter 3.

2.3 E-Modulus and Rope Modulus

The term E-Modulus (Elasticity Module) is only applicable in conjunction with the elasticity behaviour of materials. For SWR and SWRTS, the term elongation module (rope modulus) has been selected here due to the redundant arrangement of the supporting wires.

The elastic modulus is measured according to ISO 12076 [7], where the reference point is between the load of 10% Minimum Breaking Load (MBL) and 30% MBL. Between this range, ten cycles of loading and unloading are applied. At the same time, the degree of elongation is recorded. The elastic modulus recorded by the tensile machine already follows this regulation:

$$E_{10-30} = l_i \frac{F_{30\%} - F_{10\%}}{A_c(x_2 - x_1)} \tag{1}$$

The purpose of these loading cycles is to "*settle the ropes*", and they are not recorded.

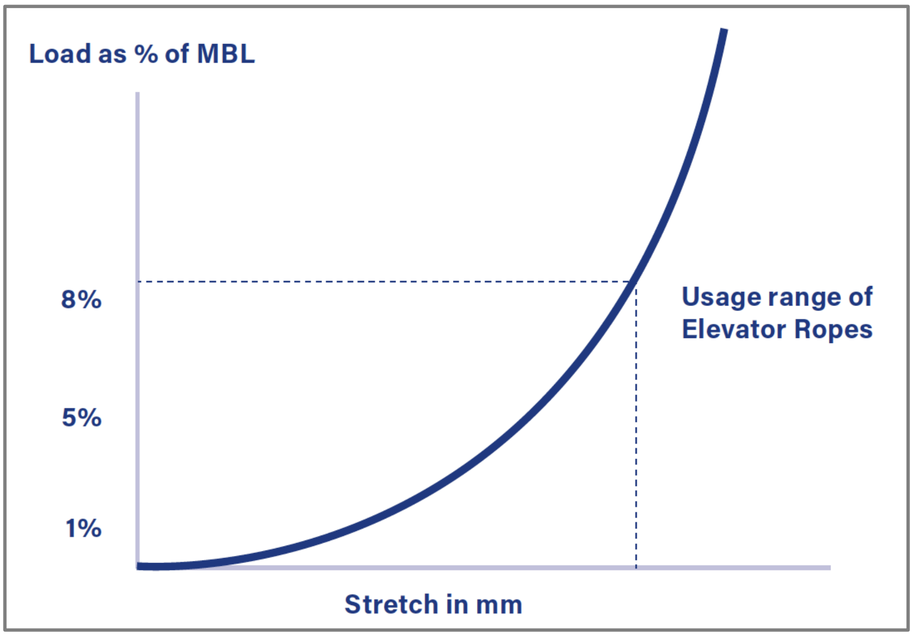


Figure 3: Nonlinear Dynamic Elongation (Stress-Strain Diagram) [2]

The required safety factor of lifts and generally not fully loaded cars, lead to operating the rope in a lower range of MBL.

As shown in Figure 3: At this working point the dynamic elongation is non-linear and therefore the rope modulus of a SWRTS has different values depending on the load.

2.4 Lay-Length Factor and Dynamic Elongation

The following considerations refer to the rope length as a single lay length of the rope. This makes the relationship more transparent. This approach is acceptable because the rope length can be interpreted as a multiple of the lay length. The standard ISO 4344 (2004) [4] indicates that the lay length shall not be greater than factor 6.75 of the nominal rope diameter. For instance, Ø16 [mm] x 6.75 = 108 mm lay length.

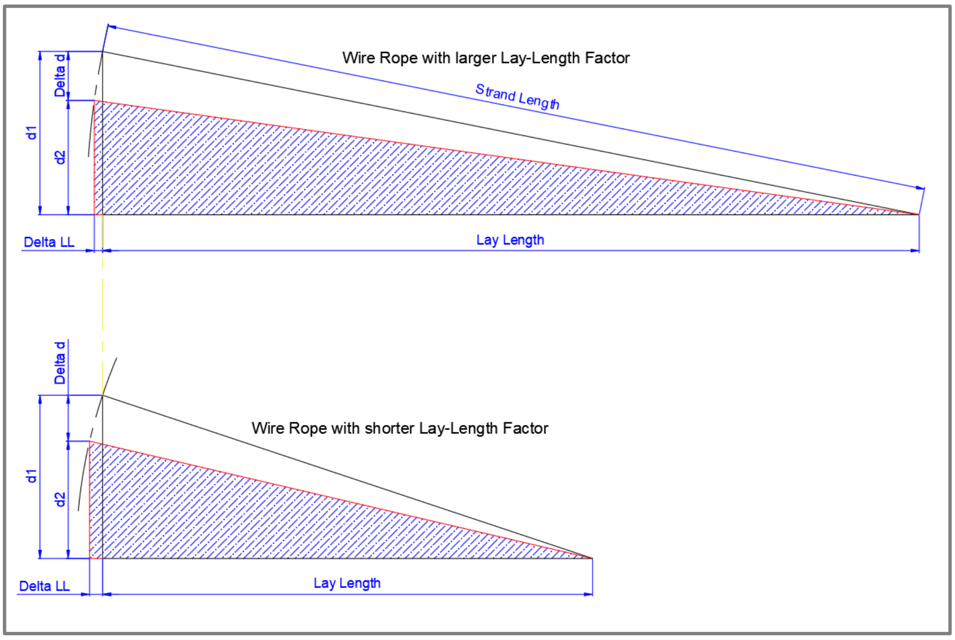


Figure 4: Elongation behaviour with different Lay-Length Factors

The resulting rope elongation in percentage due to diameter reduction is larger when the lay length is shorter. The calculation of the dynamic elongation is as follows:

$$\Delta L_E = \frac{S \cdot L}{A \cdot E_S} \tag{2}$$

where:

S	is the applied tensile load in N
L	is the overall rope length in mm
A	is the cross-section of the rope in mm²
E_S	is the Modulus of Elasticity in N/mm²

3 INFLUENCING FACTORS

The dynamic elongation of a SWRTS can be influenced by several factors. Each factor can cause a deviation in the rope's characteristics, mainly by changing its geometry suddenly or over time. This can result in an imperfect distribution of load to the individual wires within the steel wire rope, causing unequal stress on the wires.

Under ideal conditions, the elastic modulus of the SWRTS would be identical to a theoretical value calculated based on the elastic modulus of the original material and an individual wire.

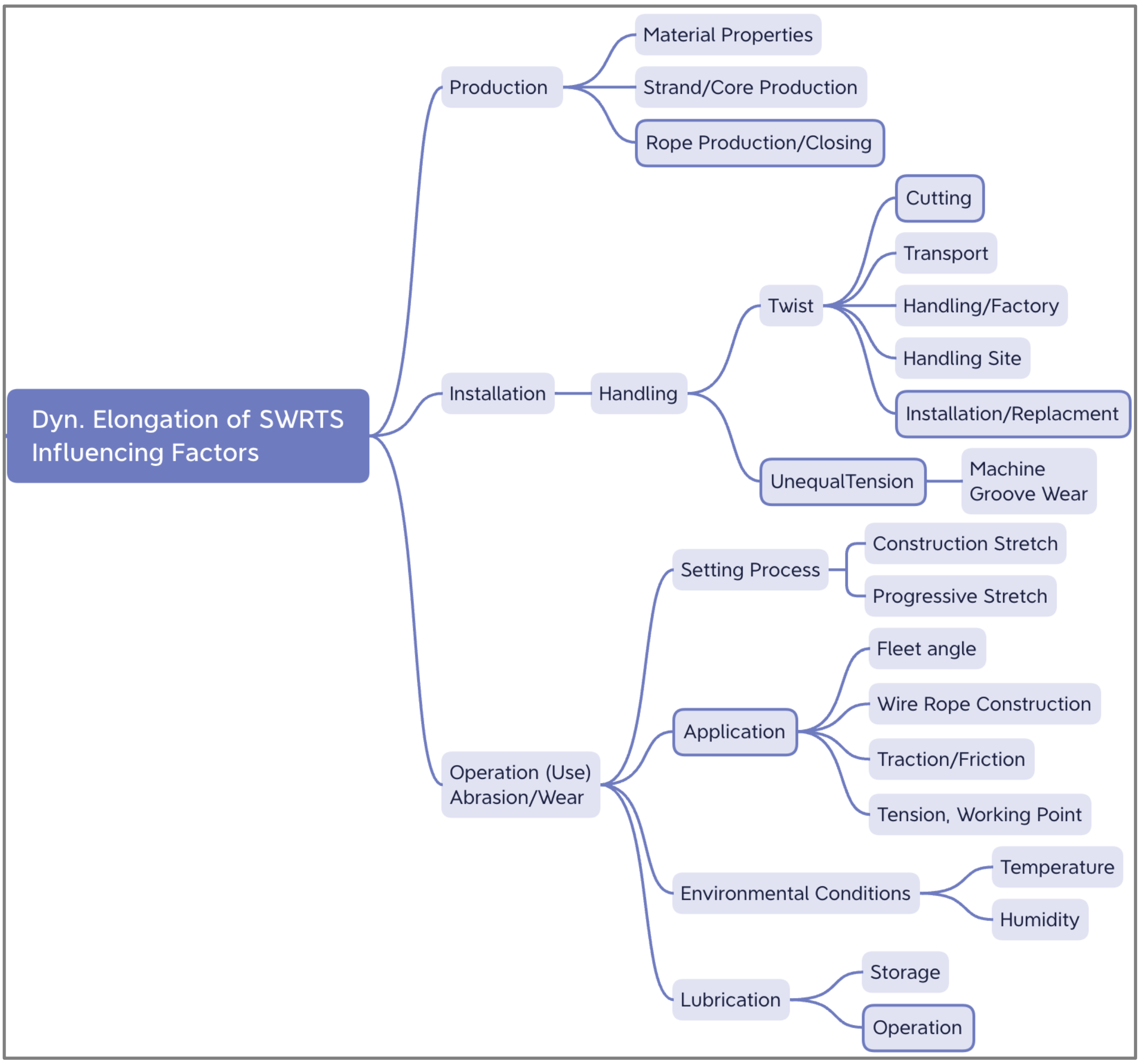


Figure 5: Influencing Factors to the dynamic elongation of an SWTS

As shown in the mind-map in Figure 5. We are dividing the factors into three stages of the rope's lifespan.

During *production*, the deviation of material properties of wires and core material is negligible if there is a basic quality control in material selection and production. More relevant is the impact of the stranding and closing process on rope elongation, which leads to construction stretch and uneven tension of strands and wires even within one production batch.

Construction and progressive stretch are compensated during the setting phase under load, either during production or after *installation* in lifts when load is applied. The setting process is indicated by a decrease of the rope diameter, permanent elongation, and decreasing dynamic elongation. During and after installation, it is essential to handle individual ropes carefully to avoid rope twist and therefore maintain the rope's geometry until load is applied.

During *operation***,** ropes are loaded only within a small part of the MBL (maximum 8.3% with full carload due to safety factor 12). Therefore, the overall setting process may take several months.

During this process, it is essential to distribute the load equally among the ropes. Failure to equalize tension and allowing rope twist can lead to uneven machine groove wear and further accelerate uneven rope tension and deterioration.

Matching the rope construction to the application is also relevant. Knowing the dynamic behaviour of the traction system over the lifespan is essential when designing the most economical lift configuration, particularly when considering the total cost of ownership. Environmental impacts, such as humidity, dust, and dry air in air-conditioned machine rooms, can change the lubrication effect [8], accelerate abrasion (e.g. rouge), increase elongation, and shorten the lifespan of the rope.

3.1 Attempt to Quantify the Factors

The factors explained above account for the deviation of calculated rope modulus from observed measured elongation values in a real lift system. As mentioned in the introduction, our focus is to provide a qualitative overview of the factors rather than compiling a set of quantitative measurements from real installations. A significant effort would be required to make a scientifically relevant statement on the extent of the phenomena. However, having such data is essential to accurately calculate and consider the impact of dynamic elongation over the lifespan and guarantee specified values when optimizing the total cost of a traction system.

Based on experience and sample measurements, some numbers can be shared to give a rough idea of the phenomena in real installations:

1. *Production*: The deviation of the rope modulus within a production batch can be as high as 5-20%. This can mainly originate from the production steps of producing and closing the strands. It is expected that this deviation will be reduced during the setting process once the ropes are installed. These values can be verified with a series of measurements after production and after installation.

2. *After Installation*: The difference between individual SWRTS (lifts) with the same configuration can be as much as -20% up to +25%, even after the setting process and before relevant wearing effects (see Figure 6).

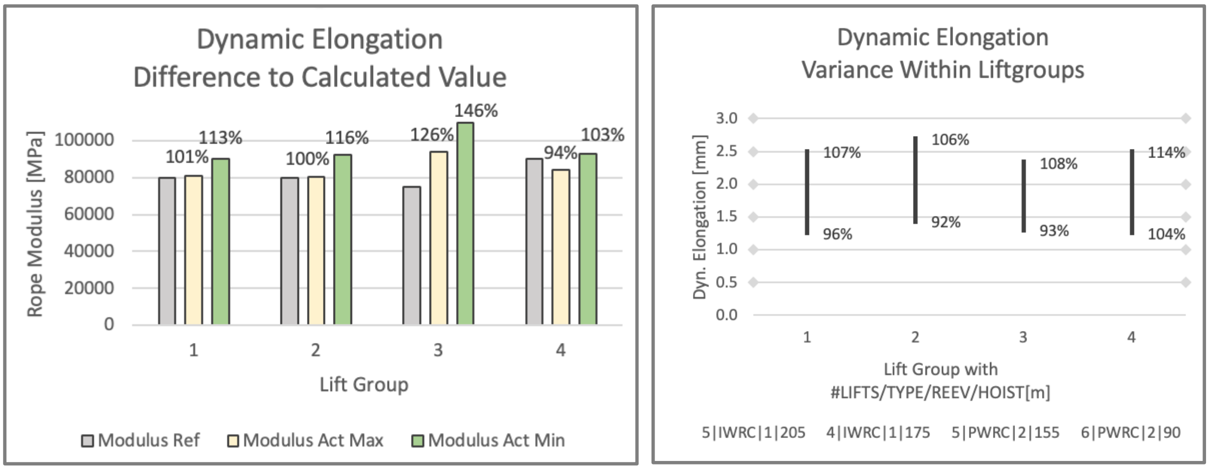


Figure 6: Dynamic Elongation: Variance within Lifts in the same Group

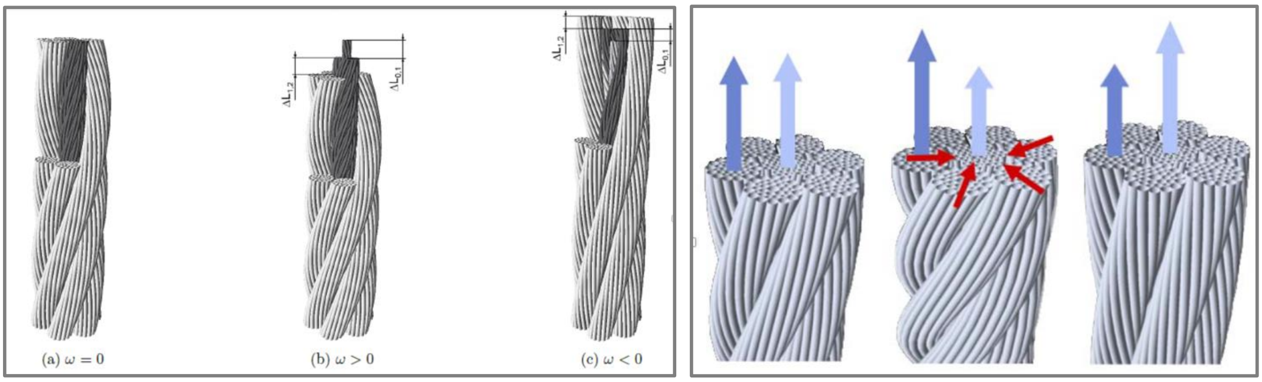


Figure 7: Influence of Twist to Elongation and Stress [9]

As visualized in Figure 7, a main part of the elongation difference after the installation can be explained by rope twist (ω>0 means twist in closing direction/shorter lay), which can lead to uneven and different lay lengths of the strands(ΔL), unequal tension, and stress between wires, strands, and ropes [9].

3. *In Use*: Measurements of an SWRTS with full steel IWRC ropes have shown an increase in elongation by factors (up to 4) when the diameter is still within the tolerated value of -10%. The deterioration can be explained by abrasion, internal wire breaks, and uneven tension. Other constructions with mixed and fibre cores show a longer increase in stiffness and a less dramatic decrease before reaching the discard criteria.

Figure 8 shows the core of an IWRC full steel rope after the elongation became excessive. Clear signs of wear to the individual wires are visible. This wear typically leads to steel powder and the well-known rouge/bleeding of the ropes. At the same time, not only the diameter decreases, but also the entire integrity of the rope is changed which can explain the rapid deterioration of the stiffness of the rope.

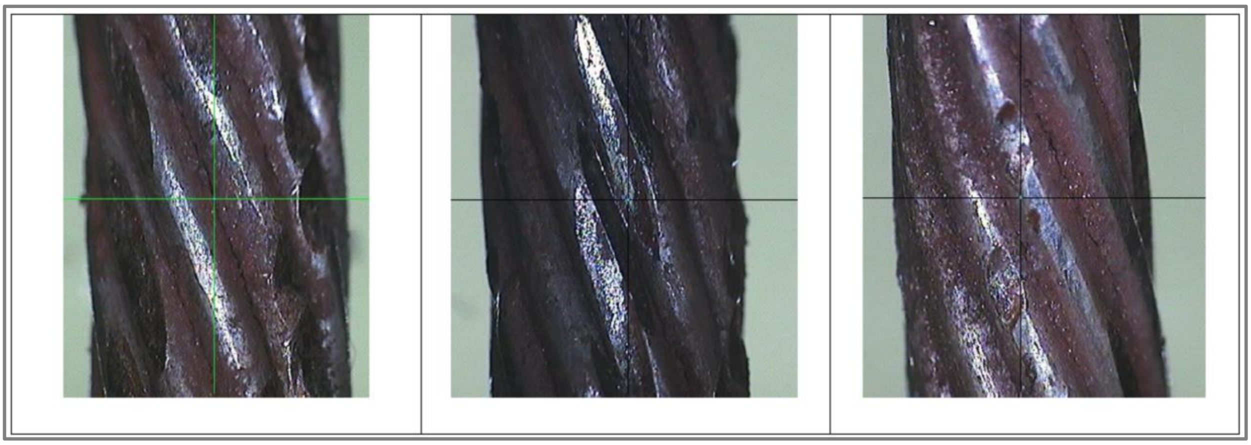


Figure 8 IWRC rope core: signs of wear

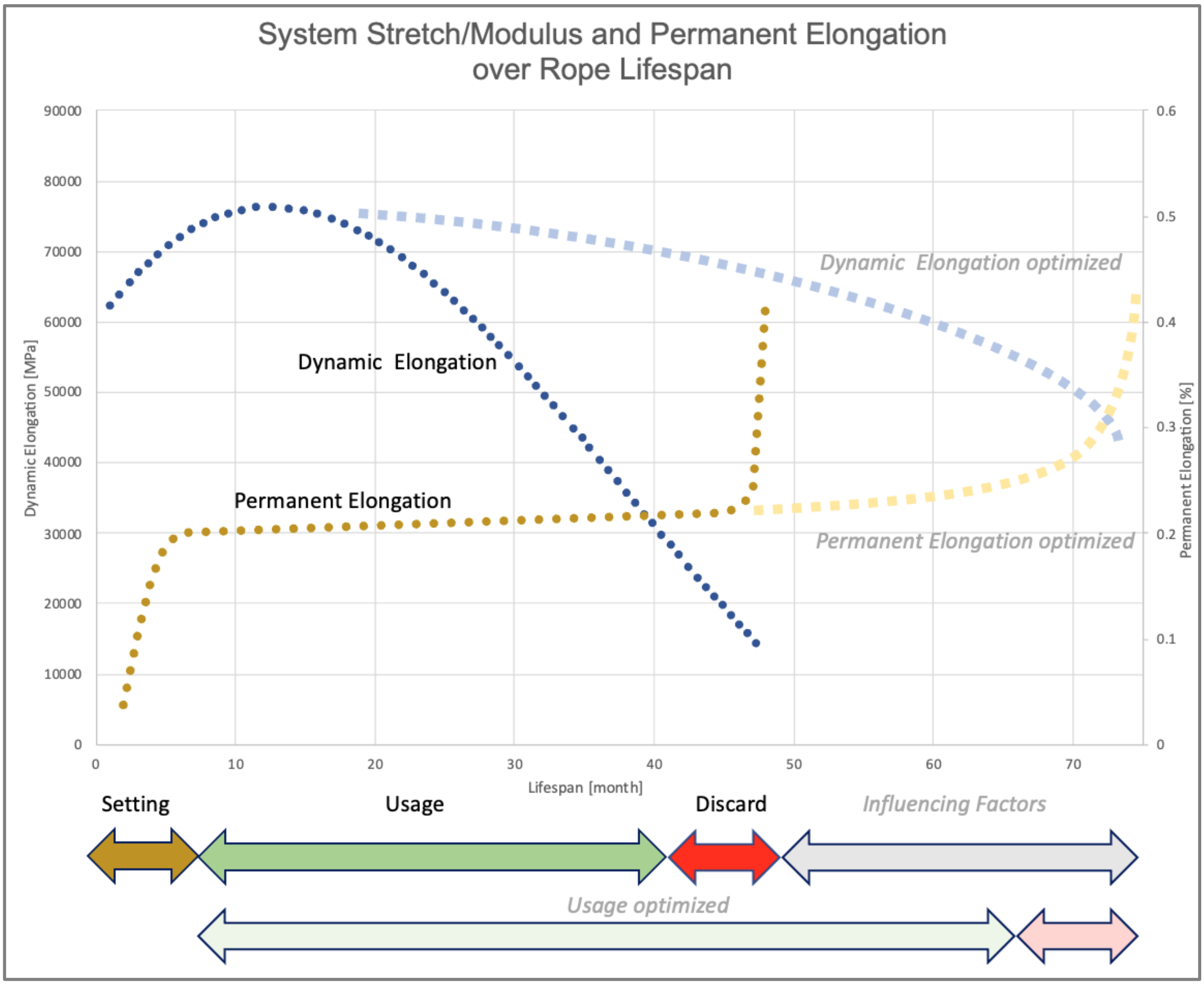


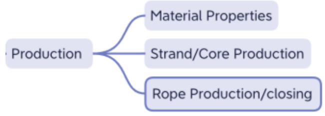
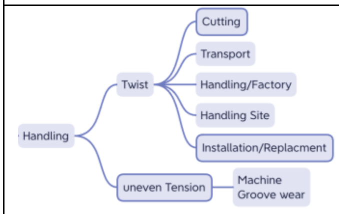
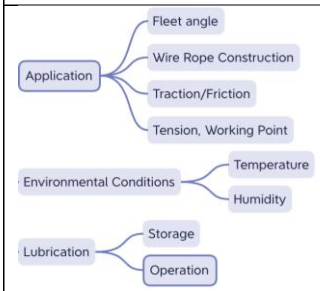
Figure 9: Dynamic Elongation Increase Over Time

Figure 9 shows how the dynamic elongation can increase due to wear in a non-optimized case and how this effect can be minimized when mitigating the influencing factors.

The setting process during the first weeks is indicated by a sharp increase in permanent elongation and stiffness of the ropes, while wear leads – depending on the configuration – to a decrease of the stiffness over time until the end of the rope life. The permanent elongation is rather stable until discard of the rope.

4 MITIGATION ACTIONS

With the given list of root causes that influence the dynamic elongation of an SWRTS, related mitigation actions can be derived. However, not all of these actions are directly applicable, so the most effective and tangible ones are marked with a bold border in Figure 5. While most of these actions are well described in manuals from rope suppliers and lift companies, we highlight the most important actions in the table below, to provide practical value to this paper.

Mitigation Action	Description	Impact
	Rope producers' core skills include monitoring the strand production and rope closing process to ensure consistent batch production with minimal deviation from the theoretical value to the rope modulus	*Medium impact.* Consistent production with perfectly bedded wires in the strands and equal strand tension eases the setting process.
	Any step in handling the rope, from transport and cutting to end finishing and installing, must focus on avoiding twist and changing the rope structure.[8] Once installed, rope tension must be equalized over a longer period until the setting process is over. Automatic tension equalizers (hydraulic or mechanical) are available on the market and serve this purpose perfectly. Highly recommended immediately after installation is a run-in program with maximum load, to accelerate the setting process and simplify maintenance of uneven tension.	*Big impact*. Avoiding twist and uneven rope tension is the most important task when installing and maintaining an SWRTS. Equalizing rope tension is crucial to maintaining the overall performance of the SWRTS. Failing to maintain equal tension may even lead to uneven traction sheave wear and drastically shorten the lifespan of both ropes and traction sheave.
	To calculate and optimize a traction system, it is important to understand the dynamic behaviour of steel wire ropes. The goal is to balance lifespan, elongation over time, and traction system material to achieve the best total costs. Lubrication is also important, and there is a lot of literature available on the topic. Re-lubrication during operation can compensate for the fading effect of factory lubrication. It is essential to maintain part of the rope within the most stressed bending section.	*Big impact*. The construction of the rope can vary significantly in terms of performance, so it is crucial to match the application and the rope properties. From experience, good lubrication can extend the rope's lifespan by up to 50% and slow down the effect of progressive stretch.

By implementing these mitigation actions, the overall performance of the SWRTS can be maintained, and its lifespan can be extended, leading to longer replacement intervals and reduced operating costs.

5 CONCLUSIONS

Understanding and predicting the value of elongation over time in steel wire ropes and traction systems is very difficult due to the complexity with many influencing factors.

This paper gives an overview of the factors, explains why it's difficult and provides practical tips to minimize some critical factors to maintain the expected performance.

To better understand these factors, lift companies and rope suppliers are advised to conduct *measurements over time* with different rope types. This research would help to understand the setting process and the impact of wear on SWRTS more accurately. This activity would also make economic sense, given the potential cost impact of a non-optimized SWRTS on lift maintenance.

REFERENCES

[1] Weiguo Wu, Xin Cao, *"Mechanics model and its equation of wire rope based on elastic thin rod theory,* School of Mechatronics Engineering, Harbin Institute of Technology, China

[2] Brugg Lifting *"Elevator_Ropes_General_Catalogue_EN_141022"*, 2022

[3] ÖNORM EN 12385-5 (2008). *"Steel wire ropes – Safety – Part 5: Stranded ropes for lift",*

Edition: 2008-02-01 Vienna Austrian Standards.

[4] ISO 4344, *"Steel wire ropes for lifts - Minimum requirements"*, ISO 4344:2004(E)

[5] Scheunemann, W., Vogel, W. and Barthel, T., "*Steel Wire Ropes for Traction Elevators: Part Three*", 2009[online].

[6] W.Vogel, "*Rope elongation in Traction Sheave Lifts*", Lift Report 35 Jahrg 2009

[7] ISO 12076 "*Determination of the actual modulus of elasticity"*

[8] M. Molkow, "*Why Wire Ropes Part II Elevator Ropes in Operation"*, Elevator World 4/1994

[9] Tobias Weber, *"Beitrag zur Untersuchung des Lebensdauerverhaltens von Drahtseilen unter einer kombinierten Beanspruchung aus Zug, Biegung und Torsion"*, September 2013

[10] Z.H. Zhu/ S.A. Meguid, *"Nonlinear FE-based investigation of flexural damping of slacking wire cables*, 2006

[11] M. Raoof and T J Davies, *"Simple determination of the axial stiffness for large diameter independent wire rope core or fibre core wire ropes"*, Loughborough University 2003

BIOGRAPHICAL DETAILS

Michael Eibel, Lift Engineering Michael Eibel e,U. Austria

Vertical Transportation Consultant

Michael is an Austrian lift engineer who has held leading positions in global companies. He has been working in the field of lift technology for 20 years. Michael has expertise in planning, project management and installation as well as extensive international lift experience in Asia. In addition, he runs his own consulting office for lift technology, is a lift inspector and is a certified expert witness for lift technology. Michael graduated from the University of Northampton with a degree in Lift Engineering and has extensive experience in wire ropes.

Erich Spirgi, 3i Business Solutions AG, Switzerland and Hong Kong

Senior Partner / Vertical Transportation Consultant

Erich is a Swiss Engineer with more than 25 years of experience in the E&E industry in Asia and Europe.

He was a development engineer and team leader with expertise in motor control technology and was Global Product Manager for electrical systems at a large OEM. Erich also completed an EMBA at the Western University (IVEY), London, Ontario.

He found his passion to tackle complex technical and commercial topics in High Rise buildings and offers independent vertical transportation consulting services in Asia and Europe.