

Influences on lifetime of wire ropes in traction lifts

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Abstract. Traction lifts are complex systems with rotating and translating moving masses, springs and dampers and several system inputs from the lifts and the users. The wire ropes are essential mechanical elements. The mechanical properties of the ropes in use depend on the rope construction, the load situation, nonlinearities and the lift dimensions. The mechanical properties are important for the proper use in lifts and the ride quality. But first of all the wire ropes (for all other suspension means as well) have to satisfy the safety relevant requirements sufficient lifetime, reliable determination of discard and sufficient and limited traction capacity. The lifetime of the wire ropes better the number of trips until rope discard depends on a lot of parameters of the rope and the rope application eg use of plastic deflection sheaves and reverse bending layouts. New challenges for rope lifetime are resulting from the more or less open D/d-ratio limits possible by certificates concerning the examination of conformity by notified bodies. This paper will highlight the basics of wire rope technology, the endurance and lifetime of wire ropes running over sheaves, and the different influences from the ropes and more and more important from the lift application parameters. Very often underestimated are the influences of transport, storage, installation and maintenance. With this background we will lead over to the calculation methods of wire rope lifetime considering the actual findings of wire rope endurance research. We'll show in this paper new and innovative facts as the influence of rope length and size factor in the lifetime formular, the reduction of lifetime caused by traction grooves, the new model for the calculation in reverse bending operations and the statistically firmed possibilities for machine roomless lifts (MRL) under very small bending conditions.

1. The lifetime of a running lift rope

The ropes are central mechanical elements in traction lifts. The cabin and the counterweight, both connected to the building by guidance, are joined one with another by means of ropes and are connected to the drive sheave by the way of friction. The difference force resulting from the forces produced by the masses of cabin and counterweight will have to be transferred to the rope by the possible friction of the sheave groove geometry and the deflection angle.

When running over sheaves the suspension means are subjected to fluctuating bending and tension stresses, pressures and those stresses tend to force the suspension means to assume an oval cross-section. This is in sum a complex stress collective. The wear between the wires or the fibres in service has made it impossible until now to calculate the life time of the suspension means even where exact



information is available about all stresses in the wires or fibres. The lifetime and the point of discard of the suspension means has to be established in series of bending fatigue tests. The statistical analysis of the bending fatigue tests lead to special lifetime formula depending of the test parameters. In real lift service the conditions will normally deviate from the test conditions. In preparation for forecasting lifetime for a lift which is being planned or has been built, the influence of the system parameters on the suspension means will have to be known; they will have to be taken account of by employing adjusted correction factors when calculating the number of trips.

2. Feyrer's lifetime formula for steel wire ropes

The life time of a running rope is dependant upon rope parameters as rope design, rope diameter d , rope core, nominal wire strength, lubrication, etc. and upon parameters of the system traction lift such as diameter ratio sheave to rope D/d , tension force S , bending length, deflection angle, incline angle, groove profile, type of bending, etc.. Bending fatigue machines are in use to do the endurance tests on running ropes. The bending machines and the test procedure are described in [2].

The lifetime of steel wire ropes running over sheaves, that is the number of bending cycles until breakage under defined test conditions found in the tests, can be calculated for wire stress levels less than the so called Donandt force, i.e. before the yield stress of the wire is exceeded, using Feyrer's first formular

$$\lg \bar{N} = b_0 + \left(b_1 + b_4 \lg \frac{D}{d} \right) \left(\lg \frac{S d_0^2}{d^2 S_0} - 0,4 \lg \frac{R_0}{1770} \right) + b_2 \lg \frac{D}{d} + b_3 \lg \frac{d}{d_0} + \frac{l}{b_5 + \lg \frac{l}{d}} \quad (1)$$

Feyrer's formula was found by regression analysis. The parameters rope tension force S , nominal wire strength R_0 , diameter ration sheave to rope D/d and bending length l are included.

Actually there is another lifetime formular very similar to eq (1) but with subtile destintion was created following developments of eg. rope industry. There is a scale factor for small rope diameter and the bending length. The performance in bending cycles is higher than expected with eq. (1). The new formula is

$$\lg \bar{N} = b_0 + \left(b_1 + b_4 \lg \frac{D}{d} \right) \left(\lg \frac{S d_0^2}{d^2 S_0} - 0,4 \lg \frac{R_0}{1770} \right) + b_2 \lg \frac{D}{d} + \lg f_d + \lg f_L + \lg f_c \quad (2)$$

The components f_d , f_L and f_c are discribing the scale influences of bending lenght and rope diameter. In detail the influence of bending length is

$$\lg f_L = \frac{1,54}{2,54 + \left(\frac{\ell/d - 2,5}{57,5} \right)^{-0,14}} \quad (3)$$

and the influence of the rope diameter is

$$\lg f_d = \frac{0,52}{-0,48 + \left(\frac{d}{16} \right)^{0,3}} \quad (4)$$

The regression coefficients in eq. (1) and eq. (2) have been calculated for the often used and the standardized rope designs on the basis of a lot of bending tests with different ropes of different manufacturers. We differ between the number of bending cycles until breakage and the number of

bending cycles until discard. The individual results deviate around the calculated mean values. The test results must be statistically limited in N_{10} and N_{A10} . This means that with a safety of 95% only 10% of the ropes break earlier (N_{10}) or reach earlier the discard point (N_{A10}). The corresponding coefficients are summarized in [2].

3. Calculation of rope lifetime as per EN 81-1 and EN81-20/50, Annex N

Why two different formulars here? The reason is simple and explainable based on the works actualizing european lift standards. The working groups reveising EN81-1 finished their work before the new formular was common. But there is no safety problem and further works of the working groups with an additional ammendment for the EN81-50 are possible.

Actually both standards EN81-1 and EN81-20/50 are valid. This allows a dimensioning following both standards. The situation is tricky because both standards are covered in the moment by lift directive 95/16/EU until 19.04.2016. The the lift directive 2014/33/EU is then valid, only EN81-20/50 is valid and very important for manufacturer: without any time gap.

The method used to calculate the rope lifetime described in [2] is based on the statistical analysis of the bending fatigue tests, along with the consideration of the stresses in service and particular rope drive parameter which influence the rope lifetime. With detailed requirements for the minimum number of trips (3 years at $Z=200.000$ in one direction, [3]) this calculation method for steel wire ropes is used for dimensioning the rope drive concerning to the diameter ration sheave to rope D/d and the safety factor S_f in annex N, [1] and [4].

The most stressed rope zone is identified within the rope drive. This is the zone which experiences the most bends during a trip. The influence of the drive sheave on rope lifetime will be expressed as an equivalent number of sheaves with round groove. The equivalent number of sheaves for the rope drive sheave is determined by the type of groove (V-groove, round groove with undercut) and the geometric parameters for the groove. The correction factor from [2] are converted without change to achieve the equivalent number of pulleys $N_{equiv(t)}$. When determine the equivalent number of sheaves it is necessary to take into account the diameters of sheaves and the type of bending (simple bends N_{ps} , reverse bends N_{pr}). The damage potential of reverse bends is assigned by a factor of 4. Differing diameters at the drive sheave and the deflection sheaves are taken into account by the factor K_p . The safety factor S_f can be calculated using the equivalent number of sheaves N_{equiv} , the traction sheave diameter D_t and the rope diameter d_r . The basis are the regression coefficients from [2] and [4] for the statistical limited number of bendings until dicard for a rope with 6 parallel lay strands, 19 wires per strand and a fibre core.

In EN81-1, Annex N and EN81-20/50, Annex N the equivalent number of sheaves are equal in the case of grooves with undercut. The equivalent number of sheaves N_{equiv} of the grooves with V-profile are in the future higher. The reasons are new results of research works [5] and longterm experiences of the lift manufacturers.

4. Reducing the diameter ratio D/d

Against the background of cost reduction on the drive side the trend in lift industry is to reduce the sheave diameter either by smaller rope diameter under adherence to the $D/d=40$ in accordance to EN81-1 [1] or by reduction of the D/d -ratio. Both measures have a big influence to rope lifetime and often underestimated. It is a well-known fact in traditional rope research that for steel wire ropes running over sheaves, the number of bending cycles decisively increases in proportion to an increase in the diameter ratio 'sheave to rope' (D/d) owing to decreasing bending stresses. Given an exemplary rope Filler 8x19 with a fibre core with a nominal rope diameter of $d=12\text{mm}$, the number of bending cycles is amplified by a factor 8, approximately, and this in proportion to an increase in the diameter ratio from $D/d=25$ to $D/d=40$ with a given safety factor of $v = 12$.

But: the market is asking for smaller sheave diameter, smaller rope diameter and lower motor moments. Additionally the lift manufacturers are asking for more freedom in construction issues eg. with the wish reducing the number of ropes which decreases the safety factor. This is totally out of the

calculation methods of the standard. New challenges for rope lifetime are resulting from the more or less open D/d -ratio limits possible by certificates concerning the examination of conformity by notified bodies. These certificates are based on series of endurance tests, statistical calculations with rough statistical limitations. Important for the dialogue between rope manufacturer, lift manufacturer and user are the impressions about the consequences by reducing or downsizing the dimensions of the rope drive. Here decision graphs as shown in [6] where the maximum number of trips are a function of the traction capacity and the safety factor. The number of trips are maximal possible but not guaranteed because other possible negative effects from transport, storage, handling, installation and maintenance have big influences to the rope performance.

5. Applications with reverse bendings

The steel wire ropes used in traction lifts are exposed to bending fatigue as they pass over the traction and deflection sheaves. As regards the bending sequence, attention must be paid to the occurrence of simple and reverse bending, which exert a greater or less impact on rope lifetime. In traction lifts reverse bendings occur in the steel wire ropes when running over the traction and deflection sheave where the traction sheave is arranged above or below next to the travel path. Reverse bending processes also have to be assumed in situations where an additional deflection sheave is needed to increase the wrapping angle to increase the traction capacity. Another reason is the change from a “big machine” to a machine with small traction sheave diameter. An additional deflection sheave with reverse bending and a horizontal rope length between the deflection sheaves which is in some cases critical for vibration effects. We call this the result of retrofitting with smaller dimensions on the machine side. Also the esthetical aspect of building without a machine room is another reason for this reverse bending because the space in the bottom of the building beside the shaft is used. In [8] a method for the calculation of the rope lifetime – better number of trips until discard – is described. The comparison between field observation and the calculation with the model showed high accuracy

6. Discard

The Discard is an essential safety-relevant requirement for safe operation. Visually detectable wire breaks on reference lengths and diameter reduction are of continual importance for steel wire ropes. Service time may well be a discard criterion in aforementioned far reaching tests. This fits only in special cases and applications.

Very often the lift manufacturers use plastic deflection sheaves instead of the steel or cast iron deflection sheaves. What are the effects? Using plastic deflection sheaves leads to an transmission of the highest stress in the contact zone rope - groove surface to the inner parts of the rope. The lifetime increases but the discard detection by wire breaks on the surface of the rope is not given in all cases. The increase in lifetime is lower than expected because the number of bends is normally higher than in other application eg in cranes where plastic sheaves show bigger advantages. In lifts the cost factor is dominant using plastic sheaves. The disadvantage discard criteria with plastic sheaves by wire break is a leak and often discussed. Normally the plastic sheaves are combined with a traction sheave of steel or cast iron. In [7] results showed that with this combination the discard determination is reliable.

7. “Soft facts” – further influences on rope lifetime

Until now we highlighted the different influences from the ropes and more and from the lift application parameters on lifetime of the ropes. The life of a running lift ropes starts earlier than in use only. Also very often underestimated are the influences of transport, storage, installation and maintenance. It's very important keeping the ropes away from heat, water and dust during storage until installation. The ropes and in the case of master reels the handling must happen without damages. Here damages are also local deformation on several wires with the result in operation of a high number of wire breaks on short reference lengths. Installation must happen without eg untwisting the ropes to avoid damages of the rope and strand structure leading to unequal load carrying from wire to

wire. During operation the ropes need a sufficient but also limited relubrication. Dry ropes have a low lifetime and produce very often rust as an irreversible fact.

8. Conclusion section

This paper examined the lifetime of steel wire ropes running over sheaves, the influences specific to lifts on rope lifetime – in particular the reduction of the D/d-ratio and the rope safety factor – and the method used to calculate rope lifetime in the application and with the relevant parameters. An examination against the background of the international standardization in lift engineering was given. Also an overview is given about the influences on rope lifetime and the reasons for that. Combined with the experiences with reverse bending operation and lifetime reduction by grooves found in a lot of field near tests here a new collection of several lifetime influences of steel ropes in traction lifts are bundled.

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