WIRE ROPE TECHNOLOGY AACHEN



The influence of wire rope fatigue research on crane standards

The influence of wire rope fatigue research on crane standards and crane performance

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1. Summary

The performance of a steel wire rope on a crane amongst other factors depends on the design factor of the rope, the load spectrum, on the ratio between sheave diameter and nominal rope diameter D/d, on the number of sheaves bending the most stressed rope section, on the frequency of the lifting operations and on the fatigue resistance of the rope.

Most national and international crane standards only consider some of these factors of influence. Cranes for the same lifting task designed according to the different standards therefore end up with completely different rope and sheave diameters, resulting in sometimes extremely different fatigue performance of the ropes.

This paper analyses the differences between cranes designed according to standards based on a "design factor mentality" and cranes designed according to standards influenced by bending fatigue research.

2. The influence of wire rope fatigue research on crane standards and crane performance

The service life of a crane hoist rope is influenced by a great number of factors. The most important factors are

- the design factor of the rope
- the load spectrum
- the sheave diameter
- the number of sheaves
- the frequency of crane use and
- the fatigue resistance of the rope design.

One should expect that the different national and international standards applicable to the design of the reeving system of a crane will consider at least these six most important factors. In addition, one should expect that reeving systems designed for the same lifting purpose in different industrialised countries based on the different national and international standards would all have about the same dimensions, comparable design factors and provide about the same level of wire rope service life to the crane user.

Nothing could be less true.

For a long time, wire rope fatigue life has been of no great importance to crane designers in the United States. Why build a crane with great sheave and drum diameters and with a low specific line pull if the wire rope will be destroyed anyway when spooling on an ungrooved drum? As a result, out of the six most important factors of influence on wire rope service life the American B 30 (ANSI/ASME 830.3, 1984) standards only reflect two. The minimum breaking strength of the rope which is calculated by multiplying the maximum load by a prescribed design factor. In addition, a minimum sheave diameter is calculated by multiplying the rope diameter by a prescribed minimum D/d ratio (Fig. 1).

In Europe, on the other hand, the Universities of Karlsruhe and Stuttgart have had a long history in wire rope fatigue research. The works of Donandt, (1934) Womle (1929) and especially Müller (1952) have influenced the European, the international and the German standards to different degrees.

The European standard FEM 9.661 (1986) and the international standard ISO 4308 (1986) reflect four of the six most important factors of influence on wire rope service life: Here, the design factor of the rope and the D/d ratio vary depending on the load spectrum and the frequency of the cran~ use (Fig. 1).

As in FEM 9.661 and ISO 4308, in the German standard DIN 15 020 (1974) the design factor of the rope and the D/d ratio vary with the load spectrum and the frequency of the crane use. In addition, DIN 15 020 reflects the number of sheaves bending the most stressed rope section during a typical lift (Fig. 1). If the number of bends per lift is between 6 and 9, the sheave diameters must be increased by 12%, if it is greater than 10, by 25%.



Fig. 1: Design factors addressed in different crane design codes.

DIN 15 020 requires about 10% greater sheave diameters for rotation resistant ropes compared to non rotation resistant ropes, reflecting the average difference in fatigue performance between these two classes of steel wire ropes.

As a summary of what we have discussed so far we can state that the different standards reflect the different factors of influence on wire rope service life to different degrees. Not one of the standards, however, considers all major factors of influence.

In order to analyse the strengths and weaknesses of the different standards, we will now compare the design factors, the sheave dimensions and the resulting wire rope fatigue lives of three different cranes designed according to three different standards:

- US standard B 30
- International standard ISO 4308 and
- German standard DIN 15020.

We will analyse:

- a simple, rarely used crane with only one sheave, let us call it a ,boat lift' (Fig. 2)
- a crane with four part reeving and a moderate frequency of use, e. g. a mobile crane (Fig. 3) and
- a heavy duty crane with a larger number of sheaves, e. g. a tower crane, pouring concrete 24 hours a day at a construction site (Fig. 4).



Fig. 2: Schematic diagram of the "boat lift" crane system.

Fig. 3: Schematic diagram of the mobile crane.



Fig. 4: Schematic diagram of the tower crane.

For the sake of simplicity, the line line pull has been set to 40,000 N (approx. 4t) for all cranes.

Fig. 5 shows the rope diameters, the design factors as well as the drum and sheave diameters for the different cranes designed according to the different standards.

Whilst the American cranes end up with design factors of 3.5 or 5, the design factors vary between 3.5 and 9.2 for ISO and between 3.1 and 11.7 for DIN.

The D/d-ratios of the American designs are 16 in all cases, whereas they vary between 11.2 and 28 for ISO and between 11.2 and 31.5 for DIN.

In order to determine the differences in wire rope fatigue performance caused by these extreme differences in design factor and in D/d-ratio, the number of cycles until rope discard has been calculated using a program for wire rope service life prediction based on the Feyrer formula (Feyrer, 1988 and 1993).

As can be seen in Fig. 5, the American lifting devices achieve between about 20,000 and 24,000 cycles, whereas the numbers of cycles vary between 9,000 and 340,000 for ISO and between 8,000 and 840,000 for DIN.

The factor between the numbers of cycles of the rarely used boat lift and the heavy duty tower crane is only 1.2 for the American standard, whereas it is about 38 for the international standard and 105 for the German standard.

In order to calculate the numbers of lifts until rope discard, the numbers of cycles have to be divided by the number of cycles per lift. In order to obtain the numbers of working weeks until rope discard, again, these figures have to be divided by the number of lifts per week.

As can be seen at the bottom of Fig. 5, the American lifting devices achieve service lives between 3,700 and 2 weeks, whereas the service lives vary between 1,750 and 32 weeks for ISO and between 1,550 and 80 weeks for DIN.

For the boat lift, ISO and DIN achieve comparable wire rope service lives, whereas the American boat lift is extremely overdesigned. Here, the wire rope will be destroyed by corrosion before it will have worked enough to fatigue.

For the mobile crane, all three standards achieve about the same wire rope service lives.

On the tower crane designed to ISO 4308, a wire rope will achieve a service life of about 8 months, on the tower crane designed to DIN 15 020 it will achieve a service live of about one and a half years. On the tower crane designed to the American standard the wire rope will only survive for 2 weeks!

Where do these tremendous differences come from? Let us look at the different standards in more detail:

As discussed above, the American standard B 30 does not consider the frequency of crane use, the fatigue resistance of the rope design or the number of sheaves the rope travels over during one lift. As a result, a lifting device with a low frequency of use and a small number of sheaves (like our boat lift) will be tremendously overdesigned. A lifting device with a high frequency of use and a great number of sheaves (like our tower crane), on the other hand, will be so underdesigned that the wire rope has no chance of survival. This is one of the reasons why all tower cranes operating in the USA are European made. With a wire rope service life of two weeks only, every customer of tower cranes designed to American standards must be bankrupt by now!

International standard ISO 4308 does not consider the fatigue resistance of the rope design and the number of sheaves the rope travels over during one lift. Therefore, a crane designed according to ISO 4308 will have a lower performance compared to a DIN crane with increasing number of sheaves and whenever rotation resistant ropes are used.

Verreet: The influence of wire rope fatigue research on crane standards and crane performance

Example	Simple crane	4-part crane	Heavy duty
	(boat lift)	(mobile crane)	tower crane
Number of cycles per lift	3	6	10
Number of lifts per day	1/4	2	150
Rope dia. US Standard	14	14	17
Rope dia.ISO	14	15	23
Rope dia. DIN	13	15	26
Design factor US Standard	3.5:1	3.5:1	5,0:1
Design Factor ISO	3.5:1	4.2:1	9,2:1
Design Factor DIN	3.5:1	4.2:1	11,7:1
Drum/sheave dia. US Standard	16 x d	16 x d	16 x d
Drum/sheave dia. ISO	11.2 x d	16 x d	28 x d
Drum/sheave dia. DIN	11.2 x d	16 x d	31,5 x d
Number of cycles US Standard	19,600	19,600	23,900
Number of cycles ISO	9,300	23,800	338,800
Number of cycles DIN	8,000	23,800	842,900
Number of lifts US Standard	6,500	3,300	2,400
Number of lifts ISO	3,100	4,000	33,900
Number of lifts DIN	2,700	4,000	84,300
Number of weeks (yrs) US Stand.	3,700 (70)	236 (4.5)	2 (-)
Number of weeks (yrs) ISO	1,750 (34)	286 (5,5)	32 (0.6)
Number of weeks (yrs) DIN	1,550 (30)	286 (5,5)	80 (1.5)

Line pulls 40,000 N (approx .4 t)

Fig. 5: Design parameters for three crane types to different design codes, with predicted rope life.

ISO 4308 is currently under revision. The future version will reflect five of the six most important factors of influence on wire rope service life (Fig. 1). In addition to the existing standard it will include so-called ,rope type factors' considering the different fatigue performances of different rope designs. These factors represent an average for qifferent classes of steel wire ropes and for the different groups of mechanisms and have been calculated using software based on the Feyrer formula. For example, if a crane is being designed to work with a four strand rope, the sheave diameter will have to be increased by 25% compared to a crane using a six or eight strand rope.

This increase in sheave diameter will compensate for the four strand rope's lower fatigue performance.

With modern wire rope service life prediction methods, it is not only possible to define minimum requirements for both the design factor and the D/d ratio, but a greater number of combinations of these parameters leading to the same service life. Feyrer (1996) has proposed such an improved method of designing the reeving system as a basis for a new CEN standard.

In this proposal, for every combination of parameters the level of service life will be maintained within every group of mechanisms. Whenever the crane designer worsens one of the conditions, he is forced to improve another. So, if the crane designer introduces additional sheaves into system, he will be forced to compensate for the additional bending cycles by reducing the effect of every single bend, e. g. by using a rope with a higher fatigue resistance or by increasing the rope and sheave diameters.

The interactions of these factors of influence are quite complex, but Prof. Feyrer's design proposal is a collection of formulas and tables which every crane designer should be able to handle with the help of a pocket calculator or a spreadsheet.

Our increasing knowledge of steel wire rope fatigue behaviour and the modern facilities to predict the rope's performance on cranes has influenced crane standards and crane design in the past and it will do so even more in the future. Therefore the work of OIPEEC and its members is of great importance to the crane industry.

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How the technical director proposed it



How the chief engineer improved it



How it was installed at the customer



How the project team modified it



How it was changed in production



How the customer wanted it

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