EXPERIMENTAL TESTING OF STEEL WIRE ROPES

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The construction of the steel rope is a complex set which characteristic features, functional ability and life are based on the co-ordination of the separate elements from which the rope is made - steel wires. The paper is focused on fatigue testing of steel ropes. After the fatigue tests, the properties of the wire material, rope erasure and wire strength were determined. Steel ropes were subjected to a cyclically tensile and bending test during the test, while the sample is rotated around the axle to ensure a uniform wear on the surface of the rope. For specific steel wire tests, the mechanical tests of wires from the fatigue straps and the positive influence of lubrication on steel ropes were evaluated by the Cpk Index. Lubrication creates an oil film between the wires, which reduces the internal friction between the wires and prevents the formation of premature notches on the wires that are the cause of fatigue wire breaks.

KEYWORDS
steel wire rope, mechanical tests, competence coefficient

1 INTRODUCTION

The quality of steel ropes is currently subject to ever-increasing requirements, as they have to work very often under unfavourable conditions (dusty and bumpy environments, increased static and dynamic stresses, etc.). [Fedorko 2016]. The P5-GIG3 Friction Machine is designed to test steel ropes with a diameter of 12-25 mm. Based on Polish drawing documentation, it was constructed in an unnamed enterprise. [Tomkova 2001]

The friction machine in Fig. no.1-2

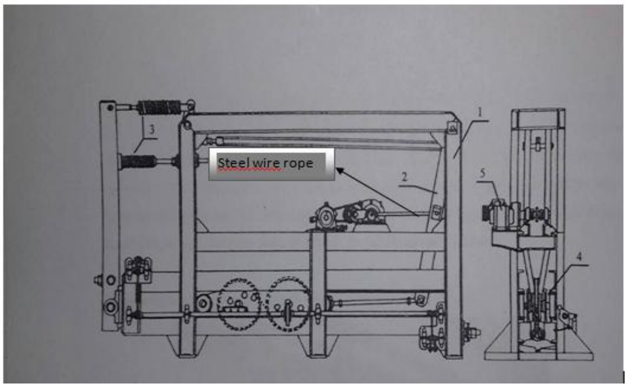

Figure 1. Fatigue machine P5-GIG3 1-Steel frame, 2-arm, 3-springs, 4-wheelchair, 5-drive [Zrnik 2000, Tomkova 2001]

Figure 2. Fatigue machine P5-GIG3 [Zrnik 2000, Tomkova 2001]

In the laboratory testing of steel ropes STN EN 12385-1 + A1 was used with a diameter of 20 mm of structure 6. (1 + 6 + 12 + 18) + v, sisal ducts. The tested ropes were dry, with Elaskon lubricant according to STN 024324.41 bare wire, counter-coiled rope right, Rm 1570 MPa material 12 050, 12 061 drawn patented material. [Tomkova, 2001]
The characteristics of the Elaskon lubricant are in Table 1. The ropes were poured into the end caps prior to insertion into the fatigue machine. The cable end is a machine element into which the cut end of the rope is inserted and which serves to transfer the forces from the rope to the follower. The end of the rope is fastened to the end piece by pouring. Wire can be wound with circular cross-section with bare or galvanized wires, used can be new or embedded (end caps can be cast only 4 times). If a new end cap is poured, a duly authenticated material test and a defectoscopic test report must be supplied. After rolling, the surface is checked, then the rope is inserted into the fatigue machine where the test conditions have been calculated and set.
The rope samples were then loaded with the number of selected fatigue cycles of 5,000, 10,000 and 16,000. Upon completion of the tests, the rope being tested was removed from the fatigue machine, cut off the rope ends by spreading the structure according to the individual layers. [Tomkova 2001, Nenadal 1998].

2 STATISTICAL QUALITY MANAGEMENT

A fair assessment of the capacity of the process is an index of competence. [1]. [Tomkova 2001] Considerable attention must be paid to minimizing the risk and the occurrence of damage caused by the defective product or by improper handling or maintenance of the product. One of the effective and easy to apply quality management methods is the assessment of process capability. Determining process capability can not be degraded simply by placing the values in the relevant relationships for calculating the index of its capability. The first limiting condition is that the evaluated process is in a stacked state, the second condition is that the distribution of the quality sign must correspond to the normal distribution. Quality management methods can also be suitably applied to assess the quality of the new steel rope produced, since these methods actually evaluate the quality of the rope production process. Therefore, if statistical quality management methods are applied to a completely new untested rope, information on its quality, resp. about the quality of its production process. When we apply the same methods to the same rope that has undergone fatigue tests, we will get information about its quality after the appropriate number of fatigue cycles.

3. PROCEDURE FOR THE ASSESSMENT OF PROCESSING

The following procedure can be used to assess process capability: [Nenadal 1998]

I. Selecting a Quality Sign.

II. Data collection.

III. Assessing the statistical mastery of the process.

IV. Verification of the normality of the distribution of the quality character.

V. Calculation of the Indexes of Competence and their Comparison with the Required Values.

Select a quality character

A character should be chosen whose value reflects the success of the process under review and is decisive for the product whether it is customer-specified or critical in terms of product characteristics or in terms of the follow-up to the next technological process.

Data collection

It is necessary that the selected quality marker data is obtained over a period of time in order to reveal common sources of variability affecting the process, change of operator, change of environment, change of technological parameters, etc.

Assessing the statistical mastery of the process

The data obtained must correspond to a statistically mastered process in which the variability of the quality trait is caused only by random causes. Only in this case is the "right" capability of a process that characterizes its natural behaviour and is usable for prediction in the future. To verify statistical mastery, regulatory diagrams are used to identify changes in the quality sign caused by random causes from changes caused by definable causes.

Verification of the normal distribution of the quality tag

Verification can be approximated based on the built-in histogram. If a single-circle, symmetric histogram of the bell-shaped shape is obtained, it can be expected that the distribution of the values of the quality trace will correspond to the normal distribution.

Calculation of competence indexes and their comparison with the required values

If the normal (Gaussian) statistical distribution of the quality tag is considered, then if the actual variability of the quality tag is 6 σ , it means that in the case of a given distribution, the area in which the 99.73% probability is found is all values. Proficiency ratings are used to assess the suitability of processes, among which the most frequently used index of competence C_{pk} [Tomkova 2001]. It takes into account the variability as well as the location of the values of the quality mark in question in the tolerance field and thus characterizes the actual capacity of the process to adhere to the prescribed tolerance limits.

$$C_{pk} = C_{pL} = \frac{\mu - LSL}{3\sigma} \qquad (1)$$

where μ is the mean value of the quality trace followed, LSL is the lower tolerance limit, σ is the standard deviation.

$$C_{pk}=C_{pU}= \frac{USL - \mu}{3\sigma} \qquad (2)$$

where USL is the upper tolerance limit

$$C_{pk}= \min\{ C_{pL;}\, C_{pU} \} \qquad (3)$$

where CpL is the lower quality tolerance limit, CpU is the upper tolerance limit of the quality sign.

The Cpk capability index expresses the ability of the process to ensure that the quality trace is within tolerance boundaries. The specific calculation algorithm for Cpk determination is given e.g. in [Nenadal 1998]. Specific numerical results of wire tests, their statistical processing and Cpk values are shown in Tables 4 and 5.

4. PARAMETER OF TESTED STEEL WIRE ROPES

In the laboratory testing of steel ropes, ropes were used according to STN EN 12385-1 + A1.. [Tomkova 2001].

Technical values	Units	Elaskon 20
Slipper temperature	ºC	65
The temperature of brittleness	ºC	30
Penetration	10^{-1}	250
Flash point	ºC	200
Corrosion according to the KASTERNICH test	-	negative

Table 1. Characteristics of the Elaskon lubricant

The experimentally obtained physicochemical values were subsequently evaluated by means of the competence coefficient $C_{pk.}$ [Tomkova 2001]

The results of the experimental measurements and the calculation values in the form of tables are presented in the following.

Table 2 and 3 summarize the physic-mechanical properties of the wires tested before loading on the fatigue machine and after completing selected fatigue load levels after 5,000, 10,000 and 16,000 fatigue cycles according to the experience of accredited steel wire ropes. The term "rope condition" in the tables indicates whether the rope was dry or whether it was using a lubricant, ELASKON.

The calculated values of the load capacity of 1 wire in (N) and the average values of the number of bends and crowns of the selected test wires for the individual cases of the rope state and for the selected load cycles are given in tab. 2 and 3.

In tab. 4 and 5, the calculated values of the Cpk competence coefficient are given, with an evaluation statistic program applied. The Cpk values were obtained in such a way that the input variables of the computational program were specifically numerical values from a set of measured load, bending and torsion statistics. In both of these tables, in the lines labelled "Load Capacity", the Cpk values related to the statistical evaluation are experimentally (tensile test) of the obtained wire load values. Similarly, it applies to rows called "bends" and "bends".

Rated parameter	The state of the rope	
	Elaskon	**Dry**
Average load capacity of the rope (kN)	234,2	231,2
Average carrying capacity of 1 wire (N)	1055,2	1041,5
Average wire strength (MPa)	1659	1637
Number of non-compliant wires	-	-

Table 2. Evaluation of dry wires and Elaskon grease before loading on a fatigue machine

Rated para-meter	The state of the rope					
	Elaskon			**Dry**		
	5000	**10000**	**16000**	**5000**	**10000**	**16000**
Average load capacity of the rope (kN)	**232**	225	209	228	**229**	**228**
Average carrying capacity of one wire (kN)	**1,046**	1,018	0,953	1,030	**1,034**	**1,032**
Average wire strength t (MPa)	**1644**	**1669**	1598	1618	1625	**1621**
Number of non-complia nt wires	-	1	2	-	-	-

Table 3. Evaluation of dry wire ropes and Elaskon lubricant after 5,000, 10,000 and 16,000 fatigue cycles

Rated parameter	Cpk Competence Index before Load	
	Elaskon	**Dry**
Carrying capacity	2,24	**2,63**
Bends	2,55	**3,05**
Twist	**2,88**	2,21

Table 4. Capacity Index of Cpk Dry Wire Wire and Elaskon Lubricant before Load on Fatigue Machine

Rated parameter	Cpk Competence Index before Load					
	Elaskon			**Dry**		
	5000	**10000**	**16000**	**5000**	**10000**	**16000**
Carrying capacity	**3,19**	**2,98**	0,32	2,50	1,96	**2,61**
Bends	0,78	1,10	1,35	1,01	1,32	1,58
Twist	1,61	0,73	0,73	**1,88**	0,85	**0,81**

Table 5. Capacity Cpk index for dry steel ropes and Elaskon grease for 5,000, 10,000 and 16,000 fatigue cycles on a fatigue machine

5 ANALYSIS OF RESULTS

It is important to note that the process is usually considered to be eligible if the Cpk value is greater than 1.33. This value is determined by the requirement that the tolerance limits are from the mean value of the quality trace of the quality mark at a distance of 4 σ . For specific steel wire tests, the mechanical tests of wires from fatigue straps were evaluated by the Cpk Index. The Cpk index calculation algorithm was applied to a set of statistical values obtained from the wire, flex and torque tests performed.

It can be stated that the task of lubrication is to create between the wires an oil film, which reduces the internal friction between the wires and prevents the formation of premature notches on the wires which are the cause of fatigue breaks of the wires. [Molnar 2006]

The comparison and analysis of the Cpk values shown in the tables show: [Tomkova 2001]

• The Cpk values are higher for the new rope before the fatigue tests and the more favorable values are for the Elaskon lubricant..

•The Cpk Index of Competence makes it possible to assess the change in the mechanical properties of the wires, that is to say, the ropes as a whole, after completing different levels of fatigue load. This is evident from the relationship between the numerical values of Cpk and the degree of technical risk in the long-term operation of the steel rope.

e) If the Cpk value is more than 1.33, the process under consideration is eligible if the less than 1.00 process becomes inappropriate, and in terms of technical risk it is an unacceptable risk.

For comparison, besides the Elaskon lubricant with another WR4 lubricant in the dissertation thesis Ing. Tomkova, Fatigue Tests for Dry Wire and Grease WR4 were compared.

From the point of view of the statistical quality assessment, it was necessary to calculate the relevant Cpk index values for the individual mechanical tests.

After 5000 fatigue cycles, the highest Cpk load rating for the Elaskon lubricant rope is achieved and the lowest for the WR4 lubricant rope.

After 10,000 fatigue cycles, the Cpk load capacity of the WR4 ropes decreases considerably, and the Cpk crotches decrease with Elaskon, but the Cpk bend increases with the WR4 grease.

After 16,000 fatigue cycles, the Cpk load on the WR4 grease decreases, the Cpk of the dry rope crushes and the Cpk bends in the WR4.

Finally, it can be concluded that the Cpk Index of Competence allows us to assess the change in the mechanical properties of the wires and hence in the steel rope as a whole after completing different levels of fatigue load.

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