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Prediction of fatigue fractures diffusion on the cableway haul rope

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ABSTRACT

Monitoring of the rope condition and lengthening its lifetime - it is a requirement of each user. The operator can get information about the current condition of the rope by using the method of non-destructive rope testing (NDT). Parameters (information) gained from non-destructive testing, such as the number and distribution of the fractures, the rope diameter and the winding height, determinate the further operation of the rope. However, it is possible to observe the trends in monitored parameters, if the NDT inspections are performed regularly. We made an attempt to employ these trends to create the prediction model of monitored parameters changes development and to determine a rope lifetime as well. The rope of the aerial cableway is a subject of monitoring. During the regular checks the condition of the rope was evaluated as well as monitoring of the trend in the ruptures increase was carried out. It was found that the rope was showing practically the regular growth of fractures from the particular period of the operation. The course of the trend was generated gradually; its shape was quite a lot resembled to the bathtub curve known from the maintenance practise. The arm of this general curve is having exponential course. This assumption created the base of the model of monitoring the fractures development in subsequent periods. Besides the record of the course of the fracture growth the prediction of development for the next two years was created after every new NDT measurement. The gradual comparison of real fracture growth development with the prediction supported (confirmed) the prognosis of the exponential course; it enabled setting in advance the date of the rope deployment. The regular NDT checks of the rope and creating the fracture growth development prognosis was very important because of the rope utilization in terms of the safe operation of the cableway. The operator in the past to track cableway regularly coordinated its six years of operation. In the past the rope operating on the monitored cableway was regularly changed after six years or working by the operator. The gradual establishment of the prognosis model based on the regular NDT inspections prolonged the safe operation of the monitored rope up to 13 years.

1. Introduction

Wire ropes combine two very useful properties — high axial strength and flexibility in bending. These properties convert wire ropes into indispensable load transmission elements suitable for many industrial applications [1]. It is important to know the condition of the rope in order to provide timely replacement of the rope or to extend the safe working life when the put off criteria have not been reached [2]. Zhang et al. [3] study the issue of the bending fatigue behaviour and failure mechanisms of wire ropes. In their research non-destructive quantitative detection and artificial detection methods were used. Périer et al. [4] dealt with the

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study of drawn steel wires submitted to fretting-fatigue in sodium chloride solution. The experimental tests were conducted to reproduce the contact conditions in spiral strands undergoing free bending deformations and being submitted to corrosion. The same author researched [5] the influence of aqueous environment on fretting behaviour of steel wires used in civil engineering cables.

Wang carried out lots of studies of the hoisting rope failures. He studied the effect of terminal mass on fretting and fatigue parameters of a hoisting rope during a lifting cycle in a coal mine [6]. The same author analysed fretting fatigue damages of steel wires in a coal mine in three corrosive media [7]. Wang et al. [8] studied the effect of strain amplitude on fretting fatigue behaviour of steel wires in low cycle fatigue by employing a fretting-fatigue test rig which was able to apply constant normal contact load. He looked into the effects of fretting parameters on stress distributions of contacting wires during the initial stage of fretting-fatigue of steel wires using the finite element method [9]. The same author realized the finite element analysis of a hoisting rope and three-layered strand for the exploration of fretting fatigue parameters and stress distributions on the cross-section [10].

The effect of displacement amplitude on fretting fatigue behaviour of steel wires in low cycle fatigue at two cyclic strain levels were examined by Wang as well [11]. The same author [12] introduced the simulation model of a rope tension to examine the role of various kinematic parameters in rope tension and tension amplitude during lifting. In addition, he looked in to the effect of the strain amplitude on the fretting-fatigue behaviour of the steel wires in the low cycle fatigue by using the fretting-fatigue test rig which was able to apply the normal contact load [13]. The dynamic stress of the ropes is induced by the change in the velocity of the load motion when lifting and lowering, by the longitudinal and cross-ropes vibration, the impact stress having been formed by the effect of the unevenness of the cabin guides, or by other external forces [14].

Torkar and Arzensi [15] performed the failure analysis of the broken multi strand wire rope from a crane. Elata et al. [16] dealt with the mechanical behaviour of a wire rope with an independent wire rope core. Shen et al. [17] performed the fretting wear tests on the self-made fretting wear rig to investigate fretting wear behaviours of steel wires under friction-increasing grease conditions.

Inspection is also important in investigation of steel rope properties. Christen et al. [18] used three-dimensional localization of defects in stay cables. Commercial instruments for electromagnetic tests are able to highlight small defects but they provide only a rough estimation of their positions. Magnetic flux leakage techniques are used extensively for non-intrusive detection and characteristics of wire rope defects [19]. Taylor et al. [20] applied frequency analysis to the acoustic emission signals resulting from the failure of steel wire ropes and individual wires taken from the ropes. Gu and Chu [21] applied a new technique for detecting wire rope defects. They developed a fluxgate sensor of single-core and single-winding. Wei and Jianxin [22] used a transducer made of fluxgate sensors for testing wire rope defects. Cao et al. [23] used the novel electromagnetic method for local defects inspection of wire rope. Most electromagnetic testing instruments give one-dimensional axial magnetic flux leakage signal losing the circumferential distribution of defects. Two-dimensional magnetic leakage signal of wire rope is acquired via an inspection prototype with the Hall sensor array. Vallan and Molinari [24] described the measurement system based on a video camera and on off line processing algorithm. The camera acquires an image sequence of the running rope; then the image processing algorithm extracts the rope contour and measures both the distance among the rope strands and the whole distance covered by the rope during the test. Radovanovic et al. [25] used the magnetic method of inspection for the system providing full monitoring of wire rope condition according to the prescribed international standards.

Stroffek and Lesso [26] suggested the acoustic method for measurement of Young's modulus of steel wire ropes. Chen and Xu [27] examined a multi-rope hoist wire rope tension on-line monitoring system, which is used to monitor the tension of multi-rope hoist wire rope in real time, thus to calculate the real hoisting load and tension difference.

2. Material and methods

2.1. The rope

The subject of monitoring was the six-stand steel rope with the diameter 26.5 mm and the 6×19S FC 1770 zZ construction; wires had zinc coating. The rope was manufactured under the requirements of the Slovak Technical Standards (STN) and is bearing identification STN. 02 4340.57 in accordance with the STN. The rope parameters are shown in the Table 1.

Table 1
The rope parameters.

The rope			
Number of strands		Strand diameter [mm]	Rope lay length [mm]
6		8.5	181.4
The core			
Type/material of the core		Number of the core strands	Strand diameter [mm]
Fibre core/Polypropylene		3	13
The rope strands			
	Number of wires in a layer	Diameter of wires [mm]	Strand lay length [mm]
The strand core	1	2.50	–
The first layer of the wires	9	1.2	70
The second layer of the wires	9	2.12	70