VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

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THE INVESTIGATION OF WIRE ROPE DEFECT USING CONTACTLESS DYNAMIC METHOD

SUMMARY OF DOCTORAL DISSERTATION

TECHNOLOGICAL SCIENCES,
MECHANICAL ENGINEERING (09T)

VGTU
LEIDYKLA
Vilnius TECHNIKA 2013

Doctoral dissertation was prepared at Vilnius Gediminas Technical University in 2009–2013.

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The dissertation will be defended at the public meeting of the Council of Scientific Field of Mechanical Engineering in the Senate Hall of Vilnius Gediminas Technical University at 2 p. m. on 23 January 2014.

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The summary of the doctoral dissertation was distributed on 20 December 2013.

A copy of the doctoral dissertation is available for review at the Library of Vilnius Gediminas Technical University (Saulėtekio al. 14, LT-10223 Vilnius, Lithuania).

VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

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PLIENINIŲ LYNŲ DEFEKTŲ TYRIMAS TAIKANT BEKONTAKTĮ DINAMINĮ METODĄ

DAKTARO DISERTACIJOS SANTRAUKA

TECHNOLOGIJOS MOKSLAI,
MECHANIKOS INŽINERIJA (09T)

VGTU
LEIDYKLA
Vilnius TECHNIKA 2013

Disertacija rengta 2009–2013 metais Vilniaus Gedimino technikos universitete.
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Disertacija bus ginama viešame Mechanikos inžinerijos mokslo krypties tarybos posėdyje 2014 m. sausio 23 d. 14 val. Vilniaus Gedimino technikos universiteto senato posėdžių salėje.

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Disertacijos santrauka išsiuntinėta 2013 m. gruodžio 20 d.
Disertaciją galima peržiūrėti Vilniaus Gedimino technikos universiteto bibliotekoje (Saulėtekio al. 14, LT-10223 Vilnius, Lietuva).
VGTU leidyklos „Technika“ 2216-M mokslo literatūros knyga.

Introduction

Topicality of the problem

Contemporary technology operational and safety requirements are becoming increasingly strict. As the service life of the product grows longer and the materials improve, relative load on the equipment increases and therefore, early detection of faults and periodic diagnostics amount to a large part of technology operating costs. Wire ropes used in lifting and transportation equipment are among such components. Their faults are specifically regulated; however, the efficiency of detecting the faults of wire ropes and especially the number of broken outer layer wires per cable length unit and the speed of examination remain a significant technical problem. In order to create such method of rope inspection, many new scientific and technological problems have to be solved. When carrying out the numerical and experimental analysis of a wire rope with broken wire, one has to deal with developing a sophisticated analytical model of the analysed system and calculation problems.

The research of wire ropes, where a fragment of tense wire rope is considered to be a dynamic system, allows detecting the changes of the dynamic qualities of the system caused by the broken surface wires. Since a rope contains many wires (from 7 to 342), the impact of one wire on the whole dynamic system of the cable fragment is negligibly low; technically difficult to establish the fact of breaking wire from change of amplitude-frequency characteristics of wire rope fragment. It is likely that this method will replace the long and expensive continuous wire rope inspection method.

Object of research

The subject of the research is the tensioned wire rope with broken wire in the surface of rope.

Aim and tasks of the work

The aim of the work is to create the methods of detecting broken wires and their location and to analyse the properties of a tense wire rope with broken wires of the outer layer. To achieve aim, the following task was fulfilled:

1. Overview and analysis of scientific literature on the defects of wire ropes and the ways and methods of their detection carry out.
2. To estimate transverse and rotational oscillations occurring when the rope is excited perpendicularly to the axis of the tense cable.
3. The methods that allow detecting a broken wire in the outer layer of the rope by contactless sensor when the fragment of tense wire rope is excited by necessary form of oscillation propose.

4. An experimental stand for testing the oscillations of tense wire ropes and their broken wires create.
5. Practically find out of detection capabilities of tense wire rope defects using the proposed methods and the created stand.

Methodology of research

In the work, theoretical calculations were carried out based on the principles of theoretical mechanics, oscillation theory, and measure theory using the analytical, empirical, and numerical research methods.

The experimental material is comprised of the oscillation measurement data of the stand, tense wire rope and a broken wire. The experiments were carried out in the laboratories of the Department of Machines Design of the Faculty of Mechanics of Vilnius Gediminas Technical University. Measurement technology of Danish companies Brüel & Kjær and Hottiger were used to measure the parameters of oscillation.

Scientific novelty of the work

1. The method of detecting the wires broken at one end from the wire rope and their location was proposed and researched.
2. Dynamic properties of tense wire rope fragment and test stand that allow realizing the proposed diagnostic methods of the amount of broken outer wires of the wire rope and their location were determined.

Practical value of research

When applying the proposed method of detecting outer broken lines of a tense wire rope, the process of detection of defects of tense wire ropes is automated. This process allows avoiding subjective features of the operator on the quality of rope inspection. The time of periodical inspection of a rope may be reduced by 5–15 s per one metre of the rope depending on the diameter of the rope. Timely detection of broken outer wires of wire ropes used in lifting equipment may increase the service life of the ropes as they may be replaced taking into account the number of broken wires and not the resource of operation or the age of the cable.

Defended propositions

1. The new method of detection of broken outer wires of a tense wire rope based on the analysis of the forces oscillation concept of the rope.
2. The created experimental methods allow evaluating the number and location of broken outer wires of a wire rope.

3. Using the proposed method of detecting broken outer lines of a tense wire rope and the created testing experimental methods the detection of wire rope defects is effective.

The scope of the scientific work

The dissertation consists of the introduction, three chapters, and the generalisation of results. There are three appendices. The volume of the work is 82 pages excluding the appendices, 31 numbered formulas, 51 figures and 2 tables are presented in the work. 110 literature sources were used when writing the dissertation. The first chapter is dedicated to the overview of literature. It presents the defects of ropes and diagnostic methods used for the ropes as well as the overview of analytical-computer research of the ropes. The conclusions are presented at the end of the chapter and the objectives of the dissertation are specified. The second chapter describes the methods of theoretical research of wire ropes. The third chapter presents the experimental tests of wire rope defects using the contactless dynamic method and their results.

1. Review of the investigation and analysis of wire rope and their defects

Wire ropes are flexible elements used most widely in lifting equipment to elevate the loads and passengers. Their longitudinal elasticity mitigates the impacts that occur during operation. The reliability of wire ropes in operation is based on the fact that they do not break immediately, but individual wires start breaking instead. Wire ropes are twisted into strands out of high-quality thin 0,52 mm wires and the strands are twisted into a cable.

According to the structure, wire ropes may be of single, double, and triple twist. The ropes with double twist are used most often. The wires of single-twist ropes are twisted around a single central wire. The wires of double-twist ropes are first twisted into strands and then into a rope. The strands are twisted around nylon, hemp, asbestos or soft steel core. Fibre core is usually saturated by oil so that the wires are lubricated when the rope is bent.

The organic core protects the wire rope against water, abrasive particles, corrosion; the rope becomes universal and suitable for use under extreme conditions. The core prevents the contact between the steel wires of the rope and protects the inside wires from breaking. This decreases the wear-and-tear of the wire rope and its service life is extended. During operation, the rope decreases the emitted vibrations to the operating equipment and motors. Wire ropes operate continuously and silently under any speed. The elasticity of the ropes decreases the dynamic load at starting and stopping.

The contact of wire rope with the pulleys, other ropes, metal surface with sharp edges causes various rope defects:

- mechanical wear-and-tear;
- breaking from fatigue of cable bending;
- rope corrosion;
- break due to rope tension overload;
- break of one or several wires;
- break of rope strand;
- loosening of one or several wires;
- bending the rope;
- other defects.

Mechanical wear-and-tear of the ropes occurs due to the contact between the ropes or the rope and the pulley. In a long run under unfavourable conditions, a wire rope loses its properties. Metal wires of the rope get fatigued both inside and outside of metal and micro-fractures occur. As the micro-fractures expand, the wire breaks and the surface of the rope becomes rough and loses its operating qualities.

Each wire rope is bent or otherwise deformed during operation. Most often, fatigue damage occurs on the outer wires of the rope. The more the wires are bent, the more they get weaker and break. Rope fatigue tension increases with the increase of the speed of the engine and with the decrease of the outer wire layer. During bending deformation, outer wires of a rope are affected by higher loads than the inner ones and therefore, the structure of their steel material gets fatigued sooner and rope wires break.

Without proper maintenance of wire ropes and under operation in the conditions the ropes are not designed for, corrosion focuses may occur on outer and inner strands of the rope. The ropes affected by corrosion lose their power and flexibility. Fatigue fractures tend to occur on corrosion-affected ropes more often than on corrosion-protected surfaces.

Nominal and highest lifting capacity of a wire rope are determined by carrying out laboratory tests – pulling the rope until the breaking point. Rope breaking point is a key parameter of rope operation, which is the factor that the safety of employees working with the wire rope depends on. Tension overload fractions occur when the axis load exceeds the fracture strength of the wires. Those wires are generally related to the decrease of wire cross-section at individual points of the wire. In the event of wire rope fracture, the ends of wires characteristic only to breaking occur on the wires. The visible defects allow ascertaining whether the rope has broken due to exceeded permitted manufacturer's load or was severely damaged by other deformations, which caused the breaking of the rope.

Different methods and practical equipment are used to detect and diagnose wire rope defects. Visual inspection method is the oldest, the simplest, and the cheapest; moreover, it is universal and expedient. It may be applied during operation of the mechanical system or after it is stopped. The diagnostics of faults of any mechanical system is generally started with the initial non-destructive control. During visual inspection, the arrangement of individual parts, nodes, units, and elements are checked as well as the trajectory of motion, the condition and cleanliness of the surfaces, deformations, fractures, the position of fastenings and fittings. The efficiency of the visual inspection method depends on the experience and the ability of the operator to concentrate on individual details. The biggest drawback of visual inspection is relatively low resolution, hard-to-reach places are difficult to inspect, low sensitivity under insufficient illumination, and the necessity of focus for longer than 20 min.

Diagnostic methods based on the interaction of magnetic fields are rather universal and may be widely used. Defectoscopy methods of magnetic fields are the oldest and most analysed methods for checking the integrity of wire ropes. Most frequent defects – the breaking of individual wires or their strands, the decrease of efficient cross-section – are found based on the anomalies of the magnetic field or the change of voltage or phase as the rope moves in the centre of the defectoscope of eddy currents in order to determine the area of rope cross-section, wire contacts, and breaks of rope wires. During the examination of the rope, the detector must move evenly along the rope. Broken wires are found within the detector, in the magnetic field as the increase or decrease of the magnetic field is registered by magnetic sensors.

Moreover, a lot of attention is given to the development of mathematical models of wire ropes with and without defects and their analysis by finite element method. Simulation and analysis of wire ropes by finite element method is very complicated due to the complex geometry of the ropes. Therefore, different researchers were evaluating different rope parameters when analysing the mathematical model of the wire rope.

It was found that most attention is given to creating new means of detecting wire rope defects and improving the existing ones. It was also found that most focus is on the mathematical calculations of the wire ropes themselves by assessing different parameters of wire ropes and experimental research – improvement of devices with electromagnets used for detecting the defects of wire ropes. However, no attention has been given to the examination using dynamic methods.

2. Analytical-numerical research of wire rope

The goal of analytical-numerical research is to analyse the transverse and rotational oscillations of a tense wire rope. The parameters of the oscillations are necessary for the diagnostics of quality of a wire rope. In order to achieve the goal, transverse and rotational oscillations of a tense rope were analysed. Moreover, the mathematical model of a strand of a wire rope with a broken outer wire was developed and the static simulation of the strand was performed.

Dynamic properties of the rope have been studied for a long time and the subject of research is the transverse and longitudinal oscillations of the line. Different diagnostic methods based on the change of dynamic properties of a rope are known and applied. Regardless of abundant theoretical and computer studies of rope properties, the examination of rope integrity (detection of broken wires) remains a complicated problem.

When analysing transverse oscillations of a rope, a tense rope was approximated to a tense weightless elastic cord with point bodies of equal weight attached to it at equal intervals. It was assumed that rope oscillations are induced by a harmonic force and the rope is oscillating on a vertical plane. Rope tension force does not change during its deformation, i.e., it does not change as the weighted bodies are oscillating.

Transverse oscillations of a rope was determined that as the rope is oscillating by harmonious oscillations $y = A_1 \sin \nu t$, the forms (modes) of its oscillation take the shape presented in Figure 1 and the amplitude-frequency characteristics is presented in Figure 2.

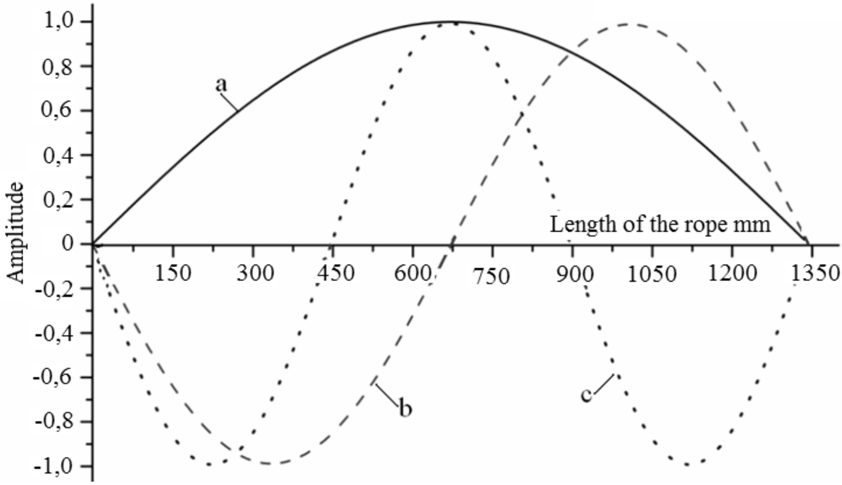

Fig. 1. Vibration forms of the wire rope: a) first; b) second; c) third

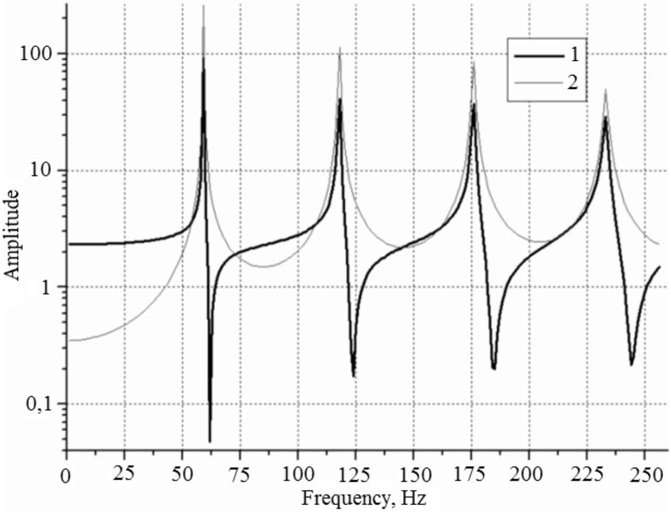

Fig. 2. Amplitude-frequency characteristics of wire rope theoretical calculations: 1 – wire rope remote 64,05 mm frome right rope support; 2 – wire rope remote 192,15 mm from left rope support

A rotational oscillation of a rope was determined that the rope rotates when stretched. It was found that the rotation of the rope is approximately linearly dependent on the change of its length. When harmonious transverse of free oscillation is induced, the rope is stretched to the maximum and contracts twice in the period of one transverse oscillation. As the rope is oscillating in harmonious oscillation, its rotational oscillation takes the shape presented in Figure 3.

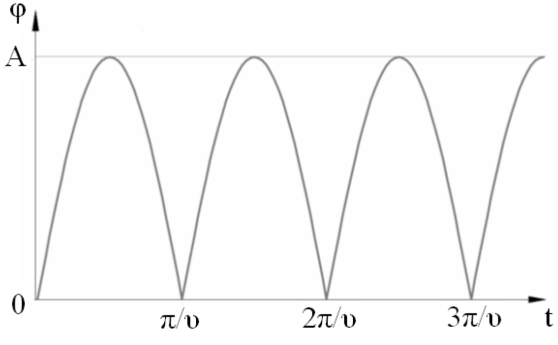

Fig. 3. Twist angle φ variation regularity schema of the wire rope

As we see, the main frequency is 2υ and the amplitude of this harmony is approximately 5 times higher than the amplitude of 4υ frequency. Therefore, the component with the frequency 2υ is predominant in rope torque oscillation. It is clearly distinguished from other components by higher frequency. Prominent wire oscillations occur when transverse harmonious oscillations of the rope are resonant. This effect is observed in experimental research.

3. Experimental research of wire rope

Oscillation measurement means of Danish company Brüel & Kjær were used to measure oscillation parameters. Figure 4 presents all oscillation measurement means: 1. Stand; 2. Left cable holder; 3. Right cable holder; 4. Rope; 5. Holder of the transducer Tr4; 6. Linear displacement transducer Hottiger Tr102; 7. Linear displacement transducer Hottiger Tr4; 8. Power amplifier 2706; 9. Amplifier Hottiger KWS 503 D; 10. Generator 1027; 11. Electrodynamic mini vibration stand 4810; 12. Holder of the transducer Tr102; 13. Broken wire.

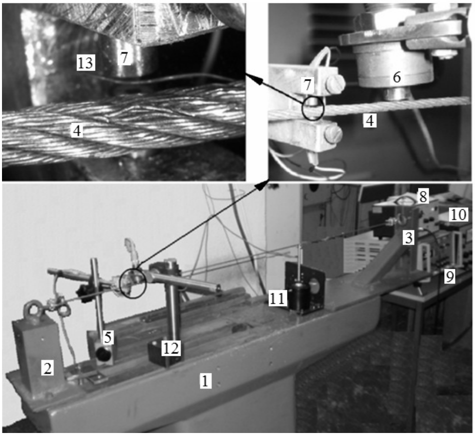

Fig. 4. Test rig vibration measuring diagram

The holders 2 and 3 are firmly affixed to the analysed rope 4 on the stand 1. One end of the rope 4 is affixed to the holder 2 and extended horizontally by the tensioning screw in the holder 3 affixed to the other end of the rope. Rope tensile force is approximately 5 kN. The electrodynamic mini vibrator 11 is firmly pressed against the analysed rope for using a rod; the electrodynamic mini vibrator 11 is affixed to stand 1. Oscillation excitation frequency is selected so that the analysed rope 4 would oscillate in one of its resonant frequencies. At the same time, intense transverse oscillations of the ends of wires 13 broken off the tense rope strands are induced. The oscillation of the excited wire rope is measured by linear displacement transducer 6, which is firmly fixed in the holder 12 and placed on stand 1. Induced transverse oscillations of broken wire are measured by linear displacement transducer 7, which is fixed in the holder 5 and placed on the stand 1. The signals obtained by linear displacement transducers 6 and 7 and amplified by the amplifier 9 are transferred to the computer, where the data is processed and visualised. The gap between the sensitive surfaces of the transducers 6 and 7 and the measured surfaces 4 and 13 is selected so that the signal (reading) of the transducer was clear enough.

The research of broken wires of different lengths was carried out. The aim of the research was to measure the relative oscillation of broken outer wires of a wire rope obtained by harmonious excitation of the tense wire rope in the interval of 50–2000 Hz frequency. The research was carried out in three stages. In the first stage, all displacement amplitudes of the excited tense wire rope and broken wire under different frequencies were measured. Research results are presented in Figure 5.

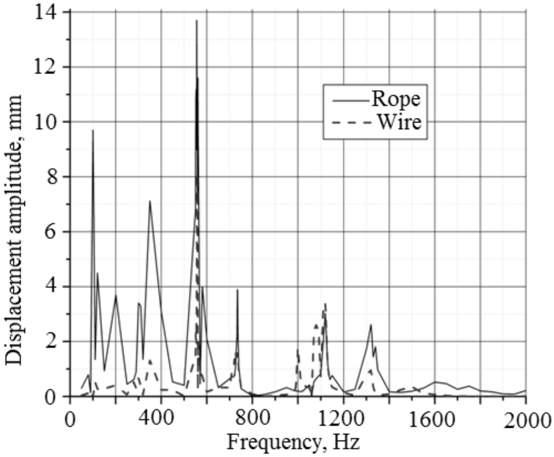

Fig. 5. Amplitude-frequency characteristics of whole rope and single wire in whole tested frequency range

The presented graph indicates that the amplitude of oscillation of broken wire is larger than the oscillation amplitude of the wire rope in the frequency interval from 900 Hz to 1125 Hz and from 1440 Hz to 1512 Hz, when the whole rope fragment is excited by harmonious excitation in the frequency interval from 50 Hz to 2000 Hz.

In the second stage, amplitude and frequency characteristics of oscillation of broken outer wires of different length of a tense wire rope under excitation of the rope by 50µm displacement amplitude in the frequency interval from 50 Hz to 2 kHz measuring the displacement amplitudes of the tense rope and broken wires at the same time. Obtained research results are presented in Figure 6.

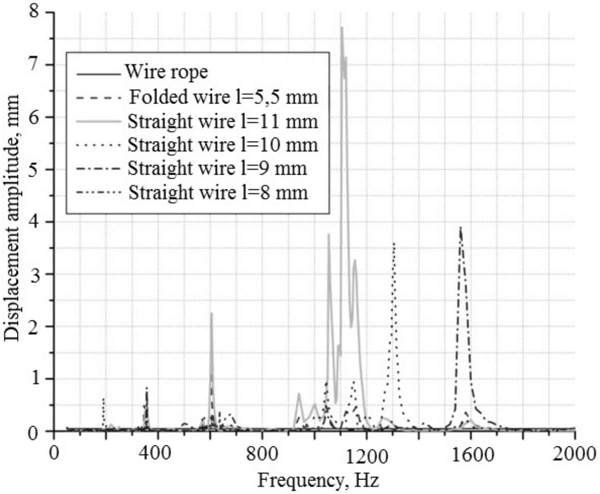

Fig. 6. Spectrum of frequencies of broken wire vibration for different length of wire, whole vibration amplitude – 50 µm

The presented graph indicates the change of the range of frequency of broken wires as the tense rope is oscillating in 50 µm amplitude under harmonious excitation of the rope in the frequency interval from 50 Hz to 2 kHz.

Obtained experimental research results indicate that when the tense wire rope is excited by harmonious excitation, the oscillation of broken wires is induced. It was found that the shorter the broken wire is the higher natural frequency of the wire is.

It was experimentally determined that the tension of the wires of the inner layers of the rope have an influence on the natural frequency of the broken wires of the outer layer of the rope. The more tense the rope is, the higher resonant frequency of the broken wire is.

When using the newly developed non-destructive quality control method of wire ropes, the oscillation displacement amplitude of a tense rope, a broken wire of the tense rope and loose rope with broken wire mechanically attached to the tense rope were measured in the whole frequency interval. The goal of the research was to establish the influence of the stub fixation of the broken wire on the frequency of its natural oscillation and to analyse how the natural oscillation of the wire is different from the natural oscillation of the rope.

The measurements were carried out in two stages. In the first stage, the displacement amplitudes of the tense rope, broken wire of the tense rope and the broken wire on the fragment of rope, where 50 mm long rope fragment was mechanically attached to the tense rope, were measured.

In the second stage, the oscillation displacement amplitudes of the tense rope, broken wire of the tense rope and the broken wire on the fragment of rope, where 50 mm long rope fragment was mechanically attached to the tense rope, were measured. Obtained research results are presented in Figure 7.

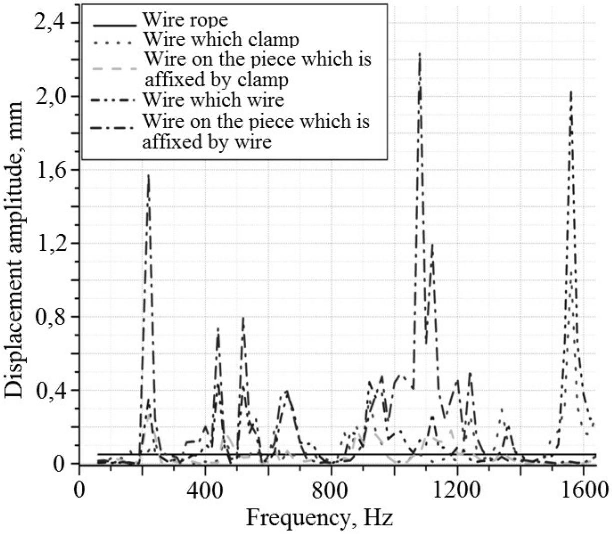

Fig. 7. Amplitude-frequency characteristics of broken wire on the wire rope and on the piece of wire rope

In the presented graph we can see the change of amplitude and frequency characteristics of the broken wires of the tense rope and an individual fragment of rope mechanically attached to the tense rope under oscillation of the rope in the amplitude of 50 µm in the frequency interval from 50 Hz to 2 kHz.

The obtained results indicate that the tense rope has a great influence on the resonant oscillation frequency of the broken wire. The inhibition of the dynamic system ‘broken wire-rope’ is low and therefore, under resonant frequency, the amplitude of the broken wire is 2,01 mm with the excitation amplitude of 50 µm. The performed experimental research and obtained results indicate that additional weight attached to the tense rope has a great influence on oscillation displacement amplitude of broken wires – the greater the weight attached to the tense line is, the smaller the oscillation displacement amplitude of the broken wires is, if the tense line is excited in the constant 50 µm amplitude.

When a wire rope is in the drive, it is being periodically strained when lifting the load and released when removing the load. Permanent deformation of different pitch strands of wire ropes was determined using the finite elements method. Based on the obtained results of the theoretic research, it was attempted to experimentally determine the permanent deformation of the rope occurring due to the release of the rope. The measurements of the displacement of the wire rope were taken at the same time at different place using two indicators by straining the rope by tensioning screw using axial force, which was increased-decreased at the pitch of 0,5 kN. Obtained research results are presented in Figure 8.

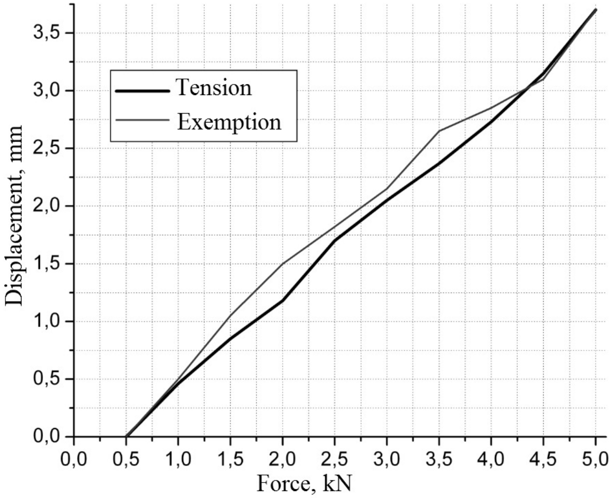

Fig. 8. The results of two indicators impressions difference of the experiment of wire rope tension- exemption

Since a rope has a specific shape, its wires are twisted into strands around the central wire, and the strands are twisted into a rope around the central strand (core), the elements of strained and released rope tend to rotate around the central rope axis in the angle *φ,* depending on the rope torque *M.* The torque of

1350 mm long rope was experimentally determined and the stiffness coefficient of the rope was calculated. Obtained results are presented in Figure 9.

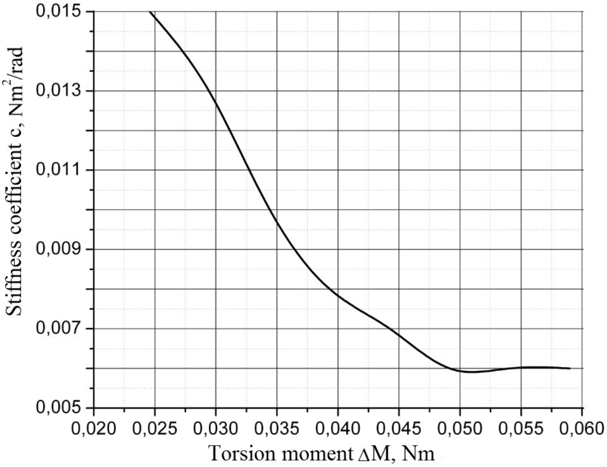

Fig. 9. Diagram of wire rope stiffness coefficient dependence on the rotation moment

The presented Figure 8 indicates the change of the force displacement characteristics of the rope when measuring the displacement of rope strain and release. The presented graph of rope stiffness coefficient (Fig. 9) indicates the change of rope rotational stiffness coefficient depending on the torque of the rope.

The obtained results indicate that the dependence of rope strain and release displacement on the force is non-linear and the release of the rope causes permanent deformations. As the rope is strained, the rotation angle of rope elements increases and therefore, rope stiffness coefficient decreases as the force increases and vice versa.

General conclusions

1. Having carried out the analysis of the literature on wire ropes, rope defects (broken wires on the outer layer of the rope) and the methods of their diagnostics, we have found that most common are the electromagnetic diagnostic methods; however, all broken wires on the outer layer of the rope are detected using this method not completely reliable in this time. The use of dynamic methods to detect the outer broken wires of ropes is not researched.
2. Proposed a new method to detect broken wires on the outer layer of the strand of wire rope by using the dynamic properties of a tense wire rope.

A rope is excited by harmonious force perpendicularly to the rope axis and maintaining a given size of wire rope excitation amplitude, which excites the wire rope for the rotational oscillation, the broken wires start oscillating

3. It was determined that the number of broken wires on the outer surface of a strand have to 17,4 % impact on the characteristics of the rope as a dynamic system by inducing rotational oscillation of the rope.
4. By experimental was determined that using the proposed method can detect different length of broken wires. Dynamic characteristics of different lengths of broken wires are different. The displacement amplitudes of 4 mm diameter wire rope of 8–11 mm investigated length broken wires are 1,2–45 times larger than the 4 mm diameter wire rope displacement amplitude 575–675 Hz, and 1,5–154 times 920–1230 Hz, and 4–78 times 1510–1680 Hz frequency intervals.
5. Experimental researches have shown that the proposed method is stable with rotary oscillation frequency of the wire rope is almost independent of the number of broken wires on the wire rope surface.
6. Diagnostic of different types and diameters of wire ropes need to be adapted for rotary resonant oscillation frequencies, the choice of a different length of rope fragment.
7. Experimental researches have shown that it is possible to create diagnostic equipment to realize the proposed broken wire detection method.

List of published works on the topic of the dissertation

In the reviewed scientific periodical publications

Bučinskas, V.; Šutinys, E.; Kilikevičius, A. 2010. Experimental research of steel rope dynamic. *Journal of Vibroengineering*. 12(4): 676–682. ISSN 1392-8716. (ISI Web of Science).

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In the other editions

Bučinskas, V.; Šutinys, E. 2010. Research of defects in non-uniform mechanical systems using dynamic methods, *in the 15th international* *conference "Mechanika – 2010". Selected Papers (8–9 April 2010, Kaunas. Lithuania)* 1: 96–99. ISSN 1822-2951 (ISI Proceedings).

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Šutinys, E.; Bučinskas. V. 2013. Lyno išoriniame sluoksnyje nutrūkusių vielų tyrimas taikant dinaminį metodą. *Science – Future of Lithuania/ Mokslas – Lietuvos ateitis.* (Accepted).

Patent

Augustaitis, Vytautas Kazimieras, Bučinskas, Vytautas; Šutinys, Ernestas, *Method and equipment of steel rope quality diagnostics*/ išradėjai: Vytautas Kazimieras Augustaitis, Vytautas Bučinskas, Ernestas Šutinys; pareiškėjas: Vilniaus Gedimino technikos universitetas. Nr. PCT/LT2012/000001.

Augustaitis, Vytautas Kazimieras, Bučinskas, Vytautas; Šutinys, Ernestas, *Plieninio lyno kokybės diagnostikos būdas ir įranga*/ išradėjai: Vytautas Kazimieras Augustaitis, Vytautas Bučinskas, Ernestas Šutinys; pareiškėjas: Vilniaus Gedimino technikos universitetas. LT 5962 B.

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PLIENINIŲ LYNŲ DEFEKTŲ TYRIMAS TAIKANT BEKONTAKTĮ DINAMINĮ METODĄ

Problemos formulavimas

Šiuolaikinės technikos eksploatacijos ir saugumo reikalavimai tampa vis griežtesni. Ilgėjant gaminių eksploatacijos laikui bei tobulėjant medžiagoms, santykinės įrenginių apkrovos didėja, todėl ankstyvas gedimų nustatymas ir periodinė diagnostika sudaro didelę technikos eksploatacijos išlaidų dalį.

Kėlimo ir transportavimo įrenginiuose naudojami plieniniai lynai yra vieni iš tokių įrangos elementų. Jų defektai yra specialiai reglamentuoti, tačiau plieninių lynų defektų, o ypač nutrūkusių išorinio sluoksnio vielų skaičiaus lyno ilgio vienete nustatymo efektyvumas ir tyrimo greitis išlieka svarbia techninė problema. Siekiant sukurti tokį lynų patikros metodą, tenka išspręsti daug naujų mokslinių ir technologinių uždavinių. Atliekant plieninio lyno su nutrūkusia viela skaitinę ir eksperimentinę analizę, susiduriama su sudėtingu tiriamos sistemos analitinio modelio sudarymu bei skaičiavimo problemomis.

Plieninių lynų tyrimas, laikant įtempto plieninio lyno fragmentą dinamine sistema, leidžia surasti sistemos dinaminių savybių pokyčius, atsiradusius dėl nutrūkusių vielų jo paviršiuje. Kadangi lyne yra pakankamai daug vielų (nuo 7 iki 342), vienos vielos įtaka visai lyno fragmento dinaminei sistemai yra nykstamai maža, techniškai sunku nustatyti vielos trūkio faktą pagal lyno fragmento amplitudinės-dažninės charakteristikos pokytį. Tikėtina, kad šis metodas gali pakeisti ilgą ir brangią ištisinės lynų apžiūros metodą.

Tyrimų objektas

Tyrimų objektas – įtemptas plieninis lynas su paviršiuje nutrūkusiomis vielomis.

Darbo tikslas ir uždaviniai

Šio darbo tikslas – sukurti nutrūkusių vielų bei nutrūkusių vielų vietos nustatymo tyrimų metodiką ir ištirti įtempto plieninio lyno su išoriniame sluoksnyje nutrūkusiomis vielomis savybes. Darbo tikslui pasiekti sprendžiami šie uždaviniai:

1. Atlikti mokslinės literatūros apie plieninių lynų defektus, jų nustatymo būdus ir metodus apžvalgą ir analizę.
2. Įvertinti įtempto plieninio lyno fragmento skersinius ir sukamuosius virpesius, atsirandančius žadinant lyną statmenai įtempto lyno ašiai.
3. Pasiūlyti metodiką, leidžiančią bekontakčiu jutikliu aptikti nutrūkusią vielą lyno išoriniame sluoksnyje, kai įtempto plieninio lyno fragmentas sužadinamas reikiama virpesių forma.
4. Sukurti eksperimentinį stendą, skirtą įtempto plieninio lyno ir jo nutrūkusių vielų virpesiams tirti.
5. Taikant pasiūlytą metodiką ir naudojant sukurtą stendą praktiškai išsiaiškinti įtempto plieninio lyno defektų nustatymo galimybes.

Tyrimų metodika

Darbe atlikti teoriniai skaičiavimai pagrįsti teorinės mechanikos, virpesių teorijos ir matavimų teorijos principais, pritaikant analitinius, empirinius ir skaitinius tyrimo metodus.

Eksperimentinę medžiagą sudaro stovo, įtempto plieninio lyno ir nutrūkusios vielos virpesių matavimo duomenys. Eksperimentai buvo atlikti Vilniaus Gedimino technikos universiteto Mechanikos fakulteto Mašinų gamybos katedros laboratorijose. Virpesių parametrams matuoti buvo naudota Danijos firmos „Brüel & Kjær” ir „Hottiger” matavimo įranga.

Darbo mokslinis naujumas

1. Pasiūlytas ir ištirtas išorinių vienu galu nuo plieninio lyno atitrūkusių vielų ir atitrūkusių vielų vietos ant lyno paviršiaus nustatymo metodas.
2. Nustatytos įtempto plieninio lyno fragmento ir tyrimo stendo dinaminės savybės, leidžiančios realizuoti pasiūlytą plieninio lyno išorinių nutrūkusių vielų kiekio ir jų vietos diagnostikos metodiką.

Praktinė reikšmė

Taikant pasiūlytą įtempto plieninio lyno išorinių nutrūkusių vielų nustatymo metodą, automatizuojamas įtemptų plieninių lynų defektų nustatymo procesas. Toks procesas leidžia išvengti subjektyvių operatoriaus savybių įtakos lynų patikros kokybei. Lyno periodinės patikros laikas gali būti sumažintas iki 5–15 s vienam lyno ilgio metrui, priklausomai nuo lyno diametro. Savalaikis plieninių lynų, naudojamų keliamuosiuose įrengimuose, išorinių nutrūkusių vielų nustatymas gali pailginti lynų darbo trukmę, nes jo keitimą galima atlikti atsižvelgiant į nutrūkusių vielų skaičių, o ne į atidirbtą resursą ar lyno amžių.

Ginamieji teiginiai

1. Pateiktas naujas įtemptų plieninių lynų išorinių nutrūkusių vielų nustatymo metodas pagrįstas lyno priverstinių virpesių principais.
2. Sukurta eksperimentinio tyrimo metodika leidžia įvertinti plieninio lyno išorinių nutrūkusių vielų skaičių ir vietą lyne.
3. Naudojant pasiūlytą įtemptų plieninių lynų nutrūkusių išorinių vielų nustatymo metodą ir taikant sukurtą eksperimentinio tyrimo metodiką, plieninių lynų defektų nustatymas yra efektyvus.

Darbo apimtis

Disertaciją sudaro įvadas, trys skyriai ir rezultatų apibendrinimas. Taip pat yra trys priedai. Darbo apimtis yra 82 puslapiai be priedų, tekste panaudota 31 numeruota formulė, 51 paveikslas ir 2 lentelės. Rašant disertaciją buvo panaudota 110 literatūros šaltinių. Pirmasis skyrius skirtas literatūros apžvalgai. Jame pateikta lynų defektai ir lynų diagnostikos metodai, bei atlikta lynų analizinių-skaitinių tyrimų apžvalga. Skyriaus pabaigoje formuluojamos išvados ir tikslinami disertacijos uždaviniai. Antrajame skyriuje aprašomi teorinių plieninių lynų tyrimų metodika. Trečiajame skyriuje pateikti eksperimentiniai plieninių lynų defektų tyrimai taikant bekontaktį dinaminį metodą, bei jų rezultatai.

Bendrosios išvados

1. Atlikus mokslinės literatūros apie plieninius lynus, lynų defektus (lyno vijos išoriniame sluoksnyje nutrūkusios vielos) ir jų diagnostikos metodų analizę, nustatyta, kad plačiausiai paplitę elektromagnetiniai diagnostikos metodai, tačiau šiuo metu šie diagnostikos metodai nutrūkusioms vieloms lyno išorėje nustatyti dar nėra visiškai patikimi. Dinaminių metodų taikymas lyno išorėje nutrūkusioms vieloms aptikti nėra ištirtas.
2. Pasiūlytas naujas metodas įtemptų plieninių lynų vijos išorinio sluoksnio nutrūkusioms vieloms nustatyti, naudojant įtempto plieninio lyno dinamines savybes. Tiesiogiai žadinant lyną statmenai lyno ašiai harmonine jėga ir palaikant užduoto dydžio lyno žadinimo amplitudę, kuri įtemptą lyną sužadina sukamajai virpesių formai ir nutrūkusios vielos pradeda švytuoti.
3. Nustatyta, kad nutrūkusių vielų kiekis vijos išorėje turi iki 17,4 % įtakos lyno kaip dinaminės sistemos charakteristikoms, sukeliant sukamuosius lyno virpesius.
4. Eksperimentiškai nustatyta, kad naudojant pasiūlytą metodiką galima aptikti įvairaus ilgio nutrūkusias vielas. Skirtingo ilgio nutrūkusių vielų dinaminės savybės skiriasi. Tirtos 4 mm skersmens lyno nutrūkusių 8–11 ilgio vielų poslinkio amplitudės yra 1,2–45 karto didesnės už tiriamojo 4 mm skersmens lyno poslinkio amplitudę 575–675 Hz, 1,5–154 karto didesnės 920–1230 Hz ir 4–78 karto didesnės 1510–1680 Hz dažnių intervaluose.
5. Eksperimentiniais tyrimais įrodyta, kad siūlomas metodas yra stabilus: lyno sukamųjų virpesių dažnis beveik nepriklauso nuo lyno paviršiuje nutrūkusių vielų skaičiaus.
6. Skirtingų rūšių ir skersmenų lynų diagnostikai atlikti reikia suderinti lyno rezonansinius sukamųjų virpesių dažnius, parenkant kitokį lyno fragmento ilgį.

7. Eksperimentiniais tyrimais įrodyta, kad galima sukurti diagnostinę įrangą siūlomam lynų nutrūkusių vielų nustatymo metodui realizuoti.

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Summary of Doctoral Dissertation
Technological Sciences, Mechanical Engineering (09T)

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Daktaro disertacijos santrauka
Technologijos mokslai, mechanikos inžinerija (09T)

2013 12 20. 1,5 sp. l. Tiražas 70 egz.
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