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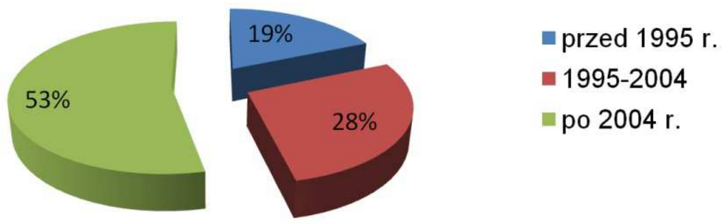
The role of rope research in a safe process operation of cableways

Abstract*:* The article presents the problems connected with the dynamic development of the cableways in Poland in recent years. The authors characterize ropeways which most often are run in Poland. Authors focus on the role of obligatory testing in the operation of ropeways. They pay most attention to steel wire ropes and some elements cooperating with them. The article discusses the main causes of wear of ropes and mechanisms of damage such as fatigue, wear and different corrosion patterns. The examples of such damage and the place in which they can occur are presented. Main attention was placed on visual assessment of damage caused by corrosive wear.

Keywords: rope diagnostics, rope damage, magnetic testing, visual testing, wire ropes

Introduction

In Poland, since the mid-1990s, significant investments have been made in the construction of rope and cable transport equipment. Both new cableways were built by reputable world companies as well as imported and adapted to Polish conditions already used in countries such as Austria and Italy. The dynamics of these investments is illustrated in Figure 1, which shows the number of installation of cableways in three successive periods. Prior to 1995, only 16 cableways were operated. It is little given that the first cable railway in Poland was established in 1936 in Zakopane, and in the following year two more also in Zakopane and Krynica. In the second period covering the period 1995-2004, 28% of the current number of trains were built. In less than 10 years 24 ropes have been installed. The biggest increase in the number of cableways being built is in the third period, ie after 2004. Half of the cableways currently installed in Poland are installed there.



1. Number of cableway installations in Poland

After 2004, cableways in Poland were built according to the uniform regulations in force in the European Union. Prior to this year, cableways were installed in accordance with national technical regulations and manufacturers' guidelines. These regulations were not uniform. In Austria, the technical monitoring of the cableway components was documented in the manufacturer's specific control charts. In the ropeway documents imported from Italy, checks were not always carried out despite the fact that it was necessary to do so. Such activities often did not allow for the reproduction of the history of the operational process of the cableway components.

Special tests are a set of activities and methods aimed at determining the actual state of elements of a given cableway. These tests are always performed before reinstallation. Unfortunately, without the knowledge of the work time and the history of the load on the components, they only allow us to state the current state, but not to deduce the time period for further failure-free work. Any potential failure will certainly generate material losses, but even worse can be a serious threat to health and human life hence the knowledge of the actual state of the equipment is very desirable. The problem of assessing the safe operation of technical objects, including cableways, despite the development of technology and continuous improvement of procedures in connection with the construction of more and more of these devices, is growing, which prompted the authors to undertake in this article this subject.

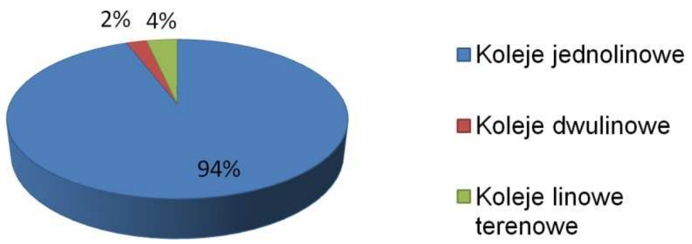
Cableway ropes evaluation issues

Cableways in Poland are mainly used for the transport of people for tourist and skiing purposes. The nature and intensity of the cableway load depend on atmospheric conditions (weather), as well as the location of stations and the reputation of tourist destinations.

An important parameter determining the safety of cableways is the so-called "rope durability" which depends on many factors. This parameter a' priori is difficult to define. It is also not provided by rope manufacturers. The main influence on the durability of the rope is due to fatigue factors, depending on the working time, a number of bends, working loads. Therefore, an important and often unintelligible factor is to determine the ratio of the rope pressure to the discs (discs batteries), after which the rope is threaded during operation to the minimum tensioning force of the rope. According to Austrian law, the ratio [8] is in the range 1 ÷ 60 and according to the Swiss regulations in the interval 1÷80.

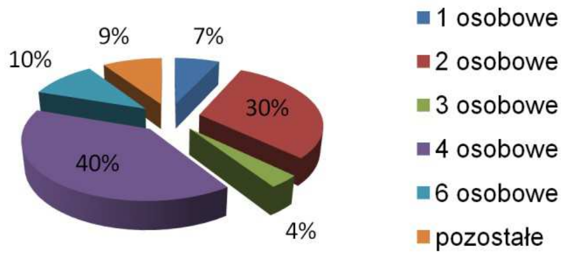
Plainer's research (1972) for 10 railroads in Austria also shows that the durability of ropes in cableways affects not only the load but also the diameter of the discs, the type of lining, the length of the span, the number of discs on the supports, the distance between vehicles. According to information taken from other sources [2][14] ropes of closed construction withstand up to 7 million cycles of overtaking during the journey of vehicles, while rope twisted, made of round wires about 3.5 mln. contra flexures. According to Bleichert [14], the number of bends can be as high as 4 million. However, the number of cycles may vary depending on the pressures and spacing between vehicles.

As already mentioned in Poland (2016) there are over 100 cableways. The most common are circular single-row railways as shown in the diagram in Figure 2.



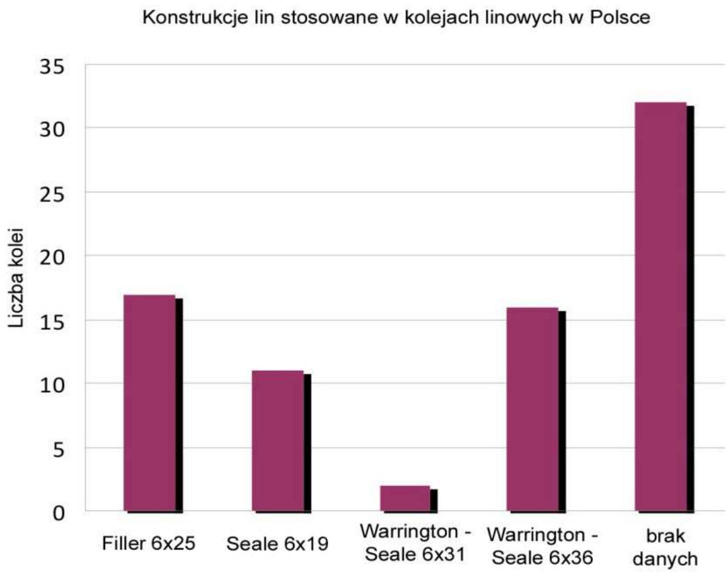
2. Cableway division due to the structure and purpose

Single-row railways are the largest group of equipment operated in Polish ski and tourist stations and can be divided according to the number of persons in the vehicle as shown in the diagram in Figure 3.



3. Division of single-row railways due to the number of passengers

In the group of circular rope trains as much as 83% are non-coupled cableways, and only 17% of cableways are towed. The price of modern cableways is much higher than the traditional ones. There are also higher requirements for components including ropes and bundles. In the cableways operating in Poland, different structures and rope diameters are used. The histogram shown in Figure 4 shows the types of rope construction used in the railway.



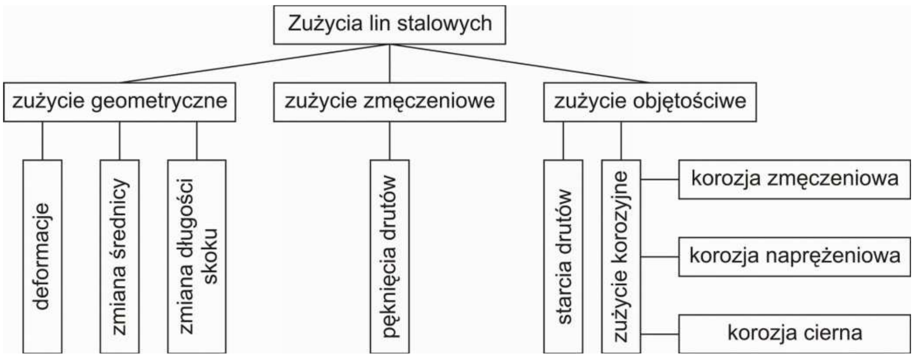
4. Used rope constructions in cableways operated in Poland

The largest group consists of rope construction Warrington-Seale strand (WS) and the filler (F) [4]. Ropes to work in cableways are selected so as to obtain adequate tensile strength to provide appropriate safety margin so specified "safety factor". The minimum value of this factor is given in the standard [16]. The rope diameter of the rope is dependent on the load for which the rail has been designed and is one of the most important parameters characterizing the rail in question. Histogram of distribution of used rope diameters in cableways is presented in the figure 5.

5. Distribution of rope diameters used in rope railway in Poland

Ropes in use in cableways are subject to different wear processes. If for some reason ropes are changed or there are load changes, the system needs to be improved. Changes to the required checks, inspections and tests are necessary and inevitable. Making changes to research in the process of exploitation is not always appropriate and perceived by users. This does not apply to the incorrect assessment of ropes in rope lines, but the fact that every rope in a cableway is different in an operational sense. Only by identifying the wear processes can you infer the failure-free operation of a particular rope. Therefore, it is necessary for the person to know the wear symptoms specific to the rope and the working conditions that inform the wear process. The ultimate goal is to avoid serious accidents.

Steel ropes are the elements of the cableways that are to be replaced as they are worn out during the operation. The damage that may occur in the line during operation causes it to weaken, which affects the safety of work. To ensure the safety of passengers, ropes are subjected to testing and assessment of wear by persons with appropriate and certified competence. During testing, places, where cracked wires or other forms of wear and damage are observed, will affect where the rope has fallen. During the operation of steel ropes, a number of other factors influence the accelerated wear. Variable stresses in the tri-axial state cause micro-cracks in the wires, and consequently fatigue and abrasion between surfaces in their contact area. An additional process of destroying ropes as a result of contact of materials with the surrounding environment is corrosion in various forms of occurrence. The most common causes of rope wear are shown in the figure 6.



6. Types of steel rope wear [6]

The fatigue wear of the ropes is manifested in the form of cracks in the wires. These cracks cause cyclically varying stresses that occur in the wires and at their contact. In ropes, there is a complex triaxial state of stress. Normal stresses are caused by varying loads in the lines from stretching and bending. Tangent stresses are the result of momentary shocks and high pressure. The rope as a system of strands and wires works dynamically and the stresses are cyclical. These are caused by changing the bending radius of the wire rope on the wheels propellants steering discs, friction force at the contact points of wires etc.. The contact stresses come from the pressure at the contact point of the wires with the cable groove and between the wires of the adjacent wires. The complex stress condition is very important for fatigue wear of steel ropes. The rate of this consumption depends on the variability of the loads with respect to their mean value, the number of cycles, and the corrosion processes that accelerate them. The wear rate is specific to the design and installation of the rope.

Difficult to estimate are the values of the pressures occurring between the rope and the raceway. Excessive pressure leads to plastic deformation and, consequently, fatigue wear. On round wires, the formation of so-called "lips". This wear is very dangerous due to changes in the metallographic structure of the material of the wires, which directly leads to the possible occurrence of avalanche cracking of the wires. Figure 7 shows the damage to the rope support rope caused by excessive pressure on the rope in the roping saddle. When the rope is moved from the saddle into the zone where the bending occurs, the rope is relaxed and the wires ruptured in the outer layer. The accident occurred during the inspection drive (minimal load) in the Swiss village of Schilthorn in December 2004. This case is an unexpected but convincing proof that the pressure between the rope and the liner greatly affects the durability of the steel ropes.

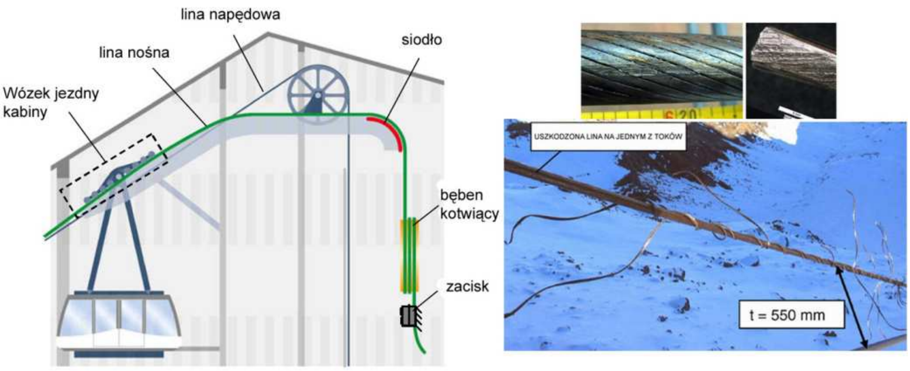
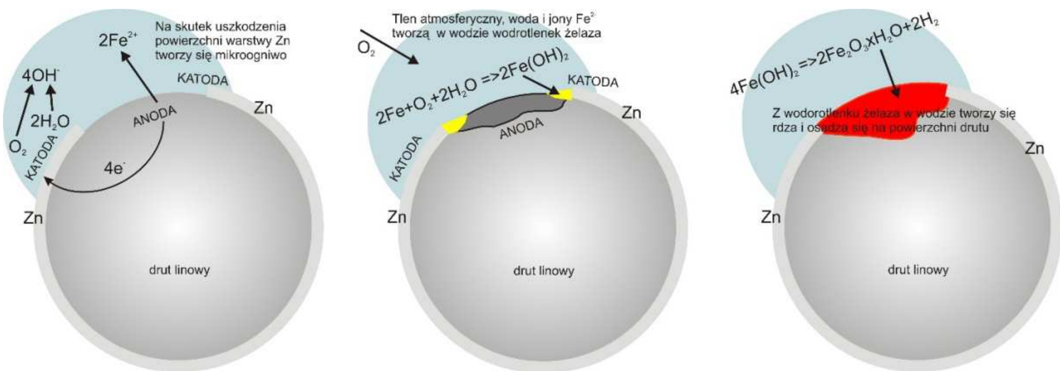


Fig. 7. Crack case of 21 wires in the outer layer the rope of the double-rail closed structure [8]

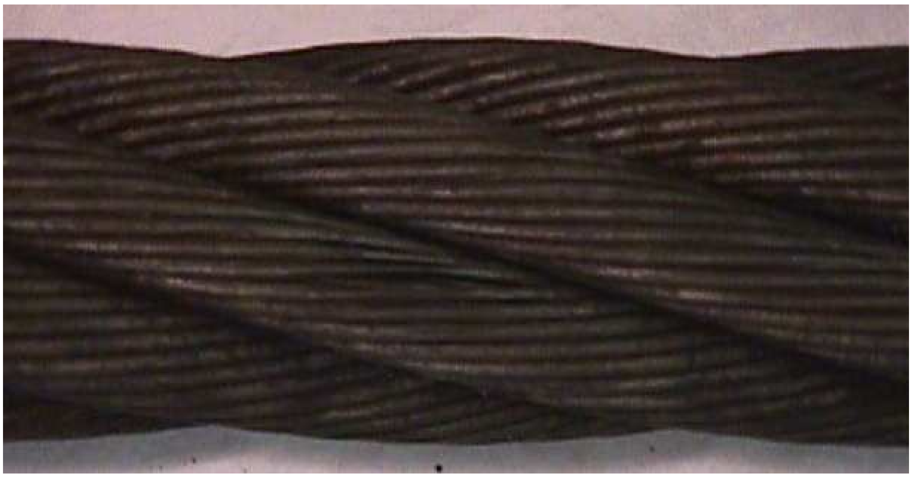
Corrosion is the process of material degradation in which physical and chemical phenomena occur as a result of the chemical interaction of the material with the surrounding environment. Corrosion occurs in materials susceptible to salts and acids and in aquatic environments with the presence of oxygen [16]. Figure 8 depicts the so-called pitting electrochemical corrosion results in the formation of hydrated iron oxides commonly recognized as rust. Such corrosion may occur on every section of the rope. In the case of galvanized wires, the most common are damaged or exploited zinc layers.



8. Phases in the electrochemical corrosion process, until fully oxidized

Stress corrosion cracking is caused by the stresses that occur during the operation of the rope under load and on the corrosive environment (e.g. moisture). As a result of the load, micro-cracks appear, which causes moisture and chemical reactions, causing corroding of wires in ropes.

Fretting corrosion is caused by the tension and displacement of the cooperating surfaces on which corrosion occurs. Under the influence of changes in the rope's wires and changes in friction forces between the wires of the working rope, metal strands and corrosion products are removed from the surface of the wires. Friction is faster than mere corrosion, since the geometry of the wires changes. It occurs primarily in ropes with point contact of wires at variable rope loads. An example of the worn wire of a six-leaf wire rope with a diameter of 76 mm is shown in Figure 9, in which the slits formed by the cutting of the wires are visible in the middle part.



9. Changes in geometry of 76mm rope wires used as a result of fretting corrosion

Variable cyclic pressures between wires, the presence of moisture and lack of lubrication lead to fatigue corrosion. These phenomena are described in several literature positions [3][15]. Ropes in a corrosive environment and subjected to varying loads are much more likely to fail than if these two factors (corrosion and fatigue) were acting separately. As a result of fatigue corrosion, cracks in the wires appear, which are similar to fatigue cracks. The difference is that the surface of the cracked wires is not smooth. The difference between fatigue cracking and corrosion cracking is noticeable. A characteristic symptom of fatigue corrosion is the appearance of cracks in the near distance. An example of such a place on the lines is shown in the figure 10.

10. Cracks in wires due to fatigue corrosion [7]

Ropes always work in the natural environment, which affects them and induces a number of different processes. Most often, corrosion occurs in materials as illustrated in Fig. 2.7. Corrosion of this type in literature is termed atmospheric corrosion. Materials corrosion depends on the climatic conditions in which they are located and the reasons for the process. This is a type of wear that can not be completely eliminated. Proper corrosion protection can only slow down corrosion during operation. A necessary condition for corrosion protection is the knowledge of the factors influencing the kinetics of the corrosion process. The main factors influencing the rate of this corrosion are humidity, variable temperature, and air pressure. The best protection against atmospheric corrosion is for ropes made of galvanized wires and grease. Lubrication should be done carefully and precisely to cut off the oxygen supply. It is now generally recommended to relieve rope during exploration. It both slows down the process itself and reduces the resistance of the movement by lowering friction. As a result, the abrasive wear is also smaller.

The effect of corrosion on fatigue life of ropes is the subject of numerous publications [1][17]. The authors argue that corrosive wear of steel ropes significantly lowers the mechanical properties of wires and fatigue life of ropes, but does not necessarily have a significant effect on the reduction of the rope pulling force in the whole. It follows that properly supervised rope and identified corrosion wear does not jeopardize safe use. It is only negligence and unavoidable exposure to significant corrosion.

Modern rope constructions applied in cableways

In recent years, we have seen rapid development of rope construction, including those for cableways. There are several tendencies in the development of these ropes. A very popular design of ropes used for cableways is the ropes with polypropylene core shown in Figure 11. Their advantage is to reduce friction resistance by using a polypropylene fiber core. Ropes have a high tensile strength while being flexible. Their disadvantage is the tendency to lengthen, especially during the initial operating period, which causes the need to shorten them.

11. 6x25F rope with polypropylene core generally used in cableways

The second group consists of steel ropes with a full core made of plastic. As a result of the research and experience of the companies producing these ropes, they have been shown to have a significantly higher durability than fiber ropes. Such ropes usually carry a much higher number of cycles under the same operating conditions. Use of this type of core reduces the pressure by not contacting adjacent strands. Technically, during the assembly of the core rope is in a state of plasticity, which allows to precisely lay the strands on it, which on the surface of the core constitute a characteristic imprint. The ropes of this design are also characterized by maintaining constant structural parameters of the rope, i.e.: stable diameter, small elongation, invariableness of the moment of the screw. Ropes of this group are commonly used in mono-rail and ski lifts due to the possibility of connecting them to the rope loops with the aid of the cable glands. Figure 12 shows the full polyamide core rope. Some manufacturers produce full cores with a higher density material inside, which further improves the working conditions of the strands.

12. Rope construction 6x25F for cableway with a solid core made of plastic

The third group consists of compact ropes, which are made by plastic deformation (deformation) of the finished strands made of linear contact wires. This process allows increasing the metal cross section by obtaining a higher so-called "rope fill factor". This results in a reduction in the diameter of the rope, an increase in tensile strength by about 10%, the elimination of technological stresses in rope wires, and the multiple expansion of fatigue life for this type of construction. This is due to the fact that at the surface contact between the wires there are significantly less surface pressure compared to the strands of linear contact. These pressures are also significantly smaller in the zone between the rope and the disc and in the clamping jaws. These pressures are smaller as the contact surface increases. The rope diameter in these structures is more stable, i.e. does not decrease during operation. Compact ropes have smaller torque moments which lower the value of tangential stresses and thus increase their durability. Ropes of this type are very popular nowadays in cableways. A more cylindrical shape compared to non-deformed ropes reduces the vibration of the rope and the mating elements. In most cases, they are used as variants of the 6x25F structure shown in the figure 13.

13. Surface wire joint rope for cableways

The development trends of cableways in the world are going to increase the number of working hours per day and improve passenger comfort. For this purpose, companies producing ropes develop new designs. Ropes have been developed that do not have vibrations caused by movement. This was done by inserting between strands of steel rope inserts or thin plastic cords (strings) as shown in Figure 14. The purpose of making such a construction is to maximally approximate the cross-section of the rope to the circle.

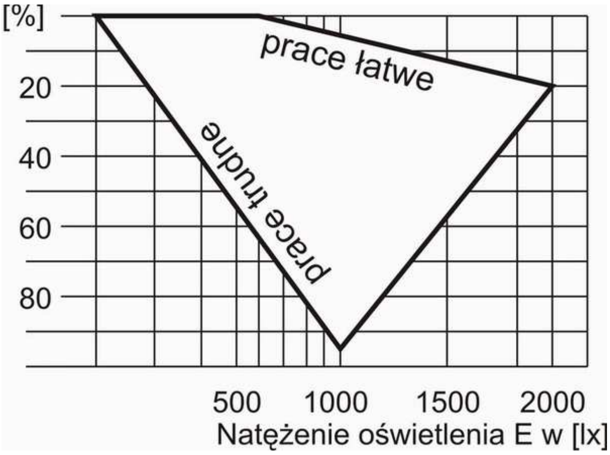
14. Surface wire joint rope with full plastic inserts

Ropes of this type are used in systems with a high number of working hours during the day and wherever vibrations and noise can impair driving comfort, especially in regional ropes and cable cars in urban rope transport systems. In these systems, the vibration problem is more pronounced due to the higher speeds than the classic rope applications. Ropes of this type have several important advantages. It is thanks to the use of inserts with damping properties that the cable running through the discs and wheels has less vibration and produces less noise. The high sectional filling factor affects very small cable lengths during operation. The steel ropes of this construction are much more durable than traditional ropes used for cableways. Plastic inserts reduce friction, which does not require lubrication. Smooth surface reduces wear on discs and linear wheel coverings.

Unfortunately, for all rope constructions despite their advantages and prolonged working time remains the same problem, i.e. the assessment of wear level.

Rope research

Visual inspection of steel ropes is a difficult and somewhat dangerous task. Inspectors working in the immediate vicinity of the running rope are exposed to considerable risk, e.g. injury caused by possible contact with the test rope. The test speed is not high (average 0.5 m / s), but it causes concentration-related effort to detect the least damage on the moving line. Visual research is used in many research methods as an examination to determine changes in detected discontinuities. As a result of visual studies, you can determine the length (dimensions) of the discontinuity. Visual lighting is required to ensure the quality of the visual examination. Visual illumination in most cases is artificial. Therefore, according to the standards of visual examination, the illumination should be at least 350lx and 500lx is recommended. For visual studies, it is important to choose the type of lighting and direction. Improper lighting during research can affect human error. The correlation between the number of possible errors and the illumination is shown in the figure 15.



15. Reduce the number of errors of assessment of objects status by visual methods depending on the intensity of lighting [5]

Visual research is very important for the researcher. The visual method is very often used to assess the technical condition due to the low cost of the test. However, it is a non-objective method due to lack of signal recording. More objectivity can be achieved by measuring geometric parameters (diameter, length of stroke) at selected locations, which in the case of rope testing is even necessary imposed by appropriate legal acts. The visual assessment also includes verification of damage detected during obligatory magnetic tests. During visual inspection various deformations occurring on the lines during operation are detected and, using appropriate instruments, you can look at the "center" of the rope. Rope connections (wagons and fasteners) are mostly visually evaluated in most cases.

The development of methods and apparatus which has been improved during the investigation of cableway ropes in Poland since 1946 [16] has also led to the introduction of magnetic surveys to the mining industry by the 1978 and present mining regulations [13] as a method for periodical control of mining ropes shaft. At present, in the basic areas of rope transport such as: underground mining, open pit mining, drilling, climbing cranes, the magnetic method is the recommended method, and ropes appear to be obligatory in these cables

[10][11][12]. Based on magnetic tests we obtain information in the form of a registered defectogram , on the basis of which we assess the technical condition of the object. A sample printout of this defectogram in paper version showing the inlet on the rope-propulsion cable line shows the figure 16.

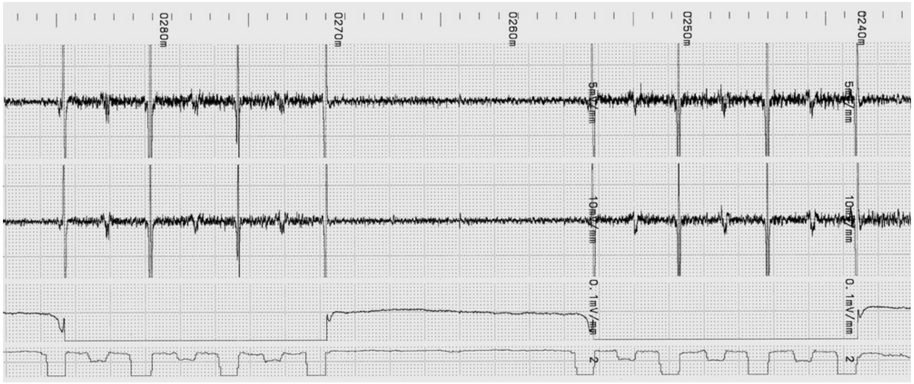
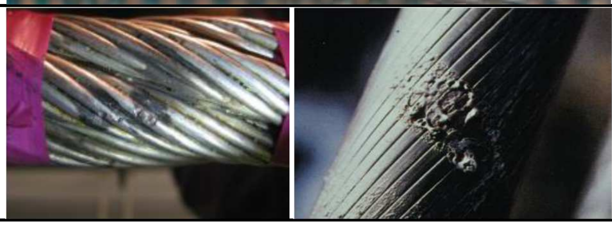


Fig. 16. Sample print registered with MD120 defectogram during the rope test

In the defoctogram record, the amplitude of the signal is interpreted, which gives information about the value of the change in the section of the metallic rope. However, the shape of the signal informs about the nature of the change of the section (loss or oversize), and the width of the pulse indicates the distance between the ends of the damage. Information on the location of damage to the line is also recorded on the tape, which facilitates visual assessment.

The state of the rope always determines the greatest damage, and the presented test methods are used to detect the most dangerous places on the rope to identify the various types of damage. The use of ropes in the form of cracks is the easiest to locate and describe. Determining the cause of the crack is much more difficult. Knowledge about the type of cracks during operation allows you to indicate the cause of cracks. Table 5.1 gives examples of cracks and other damage, based on which the degree of wear can be determined, for example, by magnetic tests.

Tab.1. Types of cracks occurring in ropes

Damage type	The cause	Image of the surface
Wire cracks	Excessive clamping of the rope to the cooperating element	
Wire cracks	Large number of cycles, fatigue wear, stretching	
Wire cracks	Cracks at the place of the knots due to excessive stress	
Damage from atmospheric discharge	Damage caused by the instantaneous flow of high currents	
Mechanical damage	Damage caused by hooking the rope to another cooperating element	

Damage in the form of cracks can be detected during operation, unequivocally determining both their position on the rope as well as the level of wear of the rope. The crack growth rate can be reduced by reducing the stresses in the wires. The easiest way to reduce these stresses is through the use of lining of rope wheels, discs, etc. made of plastic.

Summary

In order to ensure an adequate level of safety of rope transport equipment, a number of maintenance and repair operations must be performed. These include various types of replacement of consumables (grease, bearings, etc.). Ropes in cableways are also components that work to exchange. Determining the time-consuming operation of the equipment is extremely useful for optimizing the maintenance period. This is followed by proven methods and means of technical diagnostics. The effectiveness of the diagnostic process depends on the effectiveness of the diagnostic procedures and the ability to draw correct conclusions from the staff. For building diagnostic procedures, the information content of the signals obtained about the technical condition of the device is extremely important. Diagnostic procedures are extremely important:

- ways of obtaining information,
- descriptions and interpretations of diagnostic signals,
- methods of processing and verification of acquired diagnostic information,
- imaging the information obtained in a user-friendly manner,
- limit values for measurable signals.

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