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Technical and metrological aspects of non-destructive tests of selected elements of rope transport installations

Abstract: The paper highlights the engineering and metrological aspects of non-destructive testing of selected components of cableway installations and ski-lifts. The example of clamping systems in cableaways is recalled and the main point raised is whether the areas subjected to highest stress could be identified by the FEM approach. Other issues include the aspects involved in removal of the outer layers of the materials to account for possible increment or decrement of readouts, in accordance with the standard PN-EN 10228-1 and limited sensitivity of magnetic powder tests done through anti-corrosion coating.

Keywords: diagnostic, non-destructive testing, ropeways

Introduction

The article deals with problems connected with the engineering and metrological examination of the non-destructive elements of the KL cableways and the WN ski lifts. Ordinance of the Minister of Transport of 1 June 2006 on technical issues concerning the design, manufacture, operation, repair and modernization of rope transport equipment (Dz. U. Nr 106, poz.717), operated at least 15 years from the time of the first installation, imposes on exploiting KL and WN obligation to carry out non-destructive testing (control) specialized components subjected to the process of fatigue as a result of the operation [10]. Taking into consideration the above mentioned aspects of the non-destructive testing of selected structural elements on the example of the cableway clamping system, aspects related to the increase or disappearance of the indications as a result of removing the surface layer of native material (removal of defects according to PN-EN 10228-1) [2] and aspects related to the sensitivity of MT testing of structural elements by anti-corrosion coatings.

These issues are the result of many years of experience, observations, analyzes of technical conditions, specifications and norms in the field of NDT research conducted by the personnel of the Research Center for Transport and Materials Research at the Department of Cable Transport AGH in Krakow (current PCA Accreditation No. AB 771).

PCA Zakres akredytacji Nr AB 771

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Kod identyfikacji dziedziny/przedmiotu badań	Dziedzina/przedmiot badań:
J/8; J/21 L/8 N/8	Badania mechaniczne wyrobów i materiałów konstrukcyjnych oraz wyrobów gumowych Badania nieniszczące wyrobów i materiałów konstrukcyjnych Badania właściwości fizycznych wyrobów i materiałów konstrukcyjnych

Wersja strony: A

1. PCA accreditation of the Laboratory of Technical Transport and Materials at KTL AGH in Cracow.

The laboratory has equipment and qualified testing personnel for NDT (MT2, PT2, UT2, MTR3) according to PN-EN ISO 9712: 2012 - Non-destructive testing - Qualification and certification of non-destructive testing personnel (previously PN-EN 473) [8][4]. The Laboratory conducts research covered by the scope of accreditation according to accepted research procedures and standards. There are also other diagnostic and scientific researches outside the scope of accreditation, e.g. : research using thermovision (Flir P640 camera).

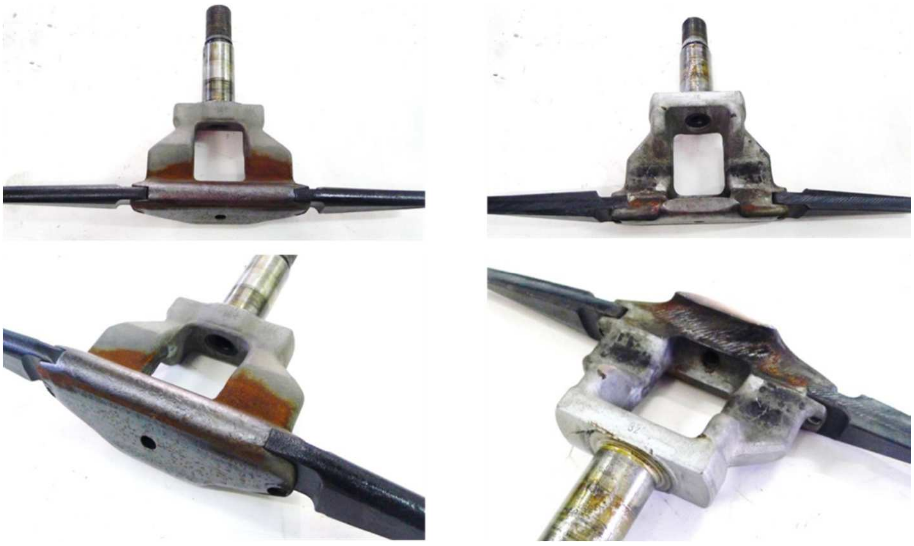
Non-destructive testing areas of selected structural components on the example of the cableway installations.

The essence of NDT is to assess the technical condition of the facility and to ensure its continued operation. An indispensable element of each certified non-destructive method according to PN-EN ISO 9712 also includes costs related to i.a. : time of testing, cost and consumption of diagnostic equipment, research resources and materials, availability of facilities, etc. In the study of a selected population of representative elements on an object, these factors do not play such an important role, but in the case of surveys of the whole population of elements e.g.: 200 pieces of cableway clamping systems consisting of, e.g.: movable jaw, fixed jaw, clamping mandrel, package and tray spring, etc. the importance of costs and factors affecting them begins to increase. The question therefore is whether, in all cases, the scope of the test area for construction elements should cover 100% of the volume or 100% of the area. The authors propose a typology of elements for the research and the scope of their area based on the synergy of the open catalog of proposed criteria, i.e.:

- Experiences from similar / identical construction works on other technical objects
- Documentation overview and identification of the most heavily loaded components and the most intensive components,
- The number of hours worked
- Endurance Analysis using Finite Element Method (FEM)
    - Identify areas of tension concentration and the nature thereof, defining dangerous sections,
    - Validation of test method selection depending on the nature of the tension - surface (VT / MT / PT) or volume (UT / RT)
- Explanation of conditions of operation and recorded emergency events in UTL service (noise, vibration, impact, overloading, etc.)
- Visual assessment of VT (corrosion, abrasion, deformation, etc.)

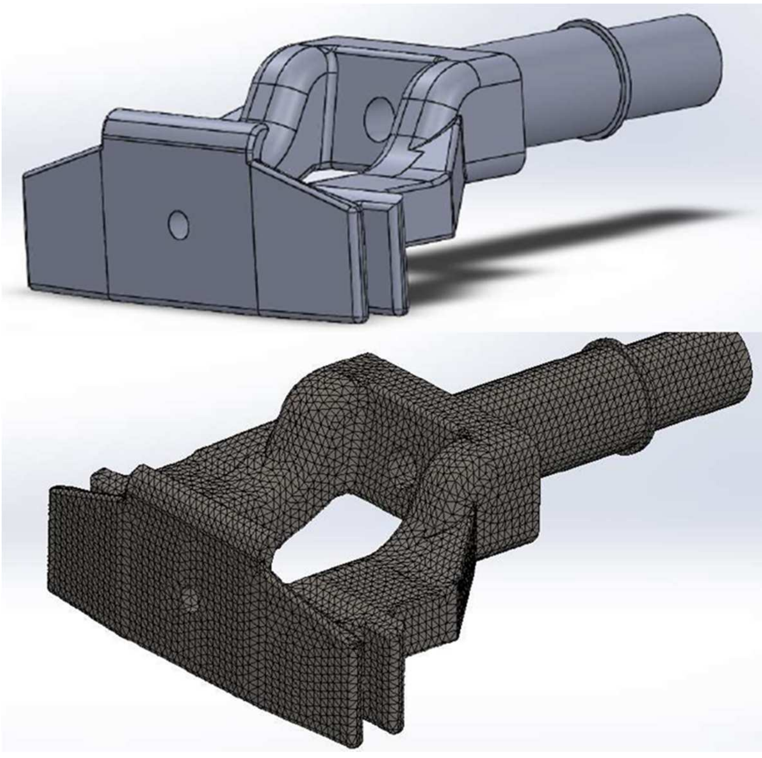
Analysis of the structure according to the above criteria leads to the selection of the most strenuous areas of the examined element, geometric notched places and places with intensive processes.

It is true that endurance numerical analysis with MES also requires time, experience and expensive and advanced software, and given the number of technical facilities (UTLs, cableways and ski-lifts) in Poland or across Europe for which NDT testing is required, fears of additional time and costs. However, there are two main aspects to look at. The first is that in the case of Poland there are three bodies (institutions) involved in UTL special research in recognition and trust in research results. All three sites have a wealth of experience and knowledge in UTL. The second aspect is that there are only a few prominent manufacturers in the European and global markets who have dominated the market with their products such as Doppelmayr Garaventa Group, LEITNER ropeways, TATRAPOMA etc. Given the fact that the vast majority of these units have the same functionality, the same structural and material structure, the same load and restraint scheme, the number of MES analyzes necessary to perform (as one of the factors for cross-sectioning and hazardous areas)) is severely limited. Differences that may occur in structural analysis are the values of the loads resulting e.g.: for KL clutches from the vehicle type (chair / gondola), number of passengers, maximum angle of inclination of the rope between the supports, etc. It will affect the true solutions, except for the most important NDT collisions, which for structural geometry and load diagrams are analogous without reference to input load entrence values.



2. The fixed jaw of inseparable clamping system attached to the inseparable 2-person KL of Doppelmayr.

This article presents the results of an example numerical strength analysis of fixed jaw couplings (Fig. 2) of Doppelamyr double rope railway. Calculations were performed in two independent computing environments, SolidWorks and ANSYS Workbench. Material properties corresponding to the material used in real object - material 34CrMo4 acc. DIN (Table 1).

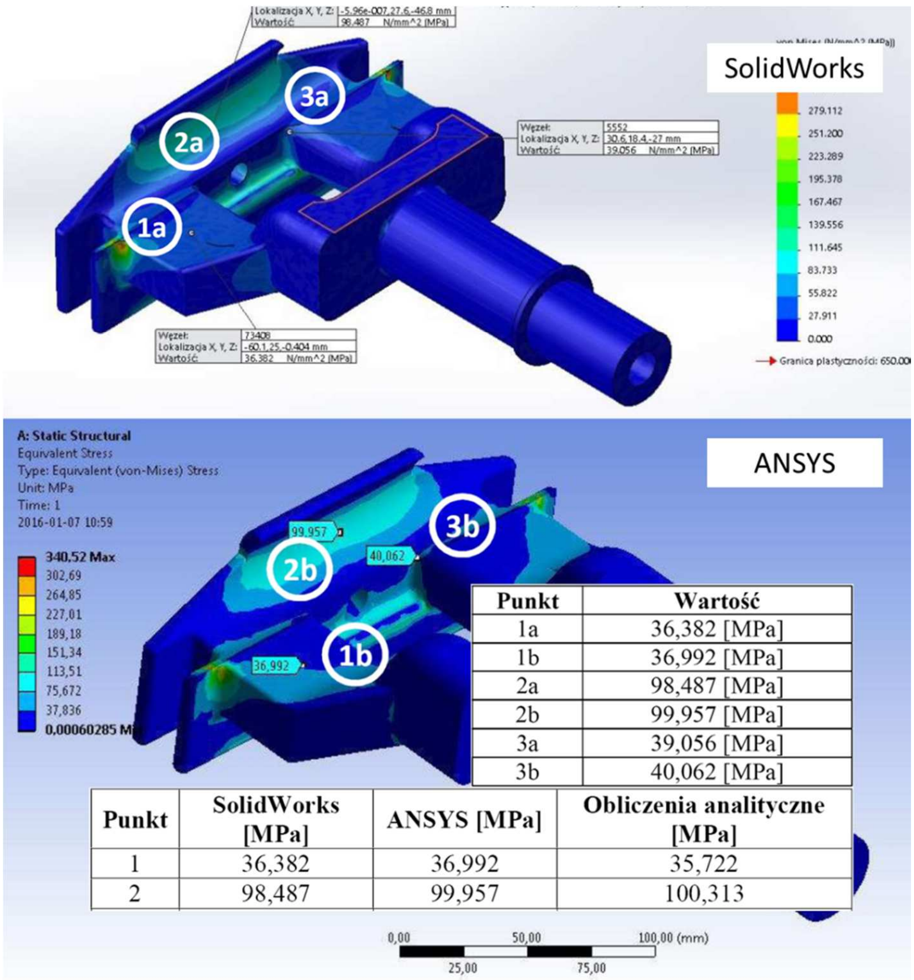


3. 3D solid model and discrete model of the analyzed structure.

The 3D solid model developed by the actual dimensional inventory was clamped and it was discretized (Fig.3). The model was loaded according to the RW conditions - the load on the car's slider head and the load acting on the tongue of the bark from the package of springs passed by the pin, the jaw and the rope. Selected results of numerical analyzes on reduced stresses acc. Huber's hypothesis - Mises was presented in Figures 4 ÷ 6. Numerical results are consistent between both independent counting systems (SolidWorks and ANSYS).

Tab.1. Material properties accepted for numerical analysis MES - Material 34CrMo4 (DIN)

Właściwość	**Wartość**	**Jednostka**
Współczynnik sprężystości	210000	MPa
Współczynnik Poissona	0.28	n.d.
Współczynnik naprężenia ścinającego	79000	MPa
Masa właściwa	7800	kg/m^3
Wytrzymałość na rozciąganie	800	MPa
Wytrzymałość na ściskanie	800	MPa
Granica plastyczności	590,59	MPa
Współczynnik rozszerzalności cieplnej	1.1e-005	/K
Współczynnik przewodzenia ciepła	14	W/(m·K)
Ciepło właściwe	440	J/(kg·K)

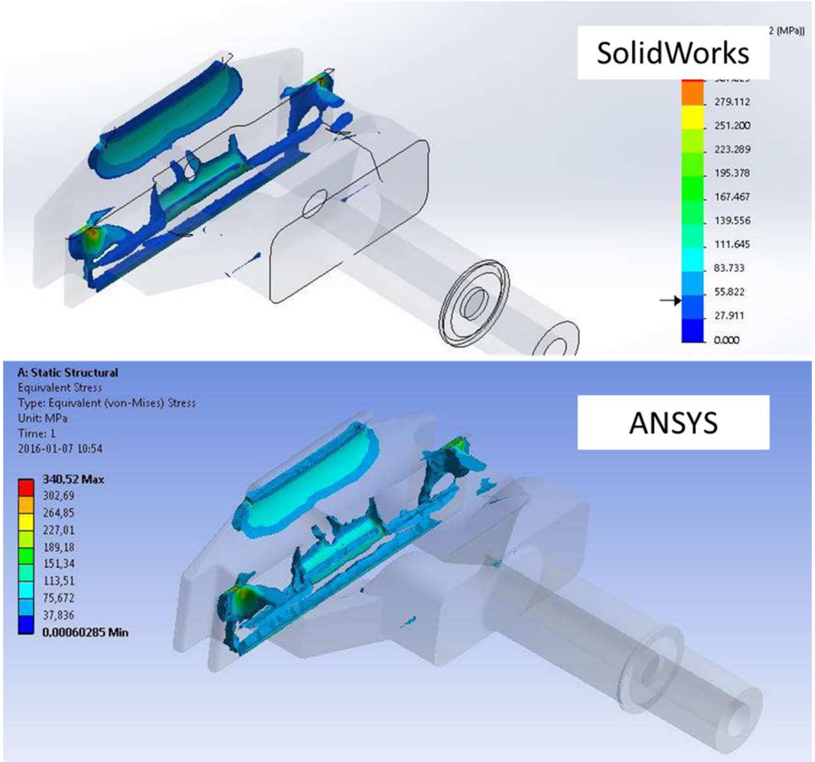


Punkt	Wartość
1a	36,382 [MPa]
1b	36,992 [MPa]
2a	98,487 [MPa]
2b	99,957 [MPa]
3a	39,056 [MPa]
3b	40,062 [MPa]

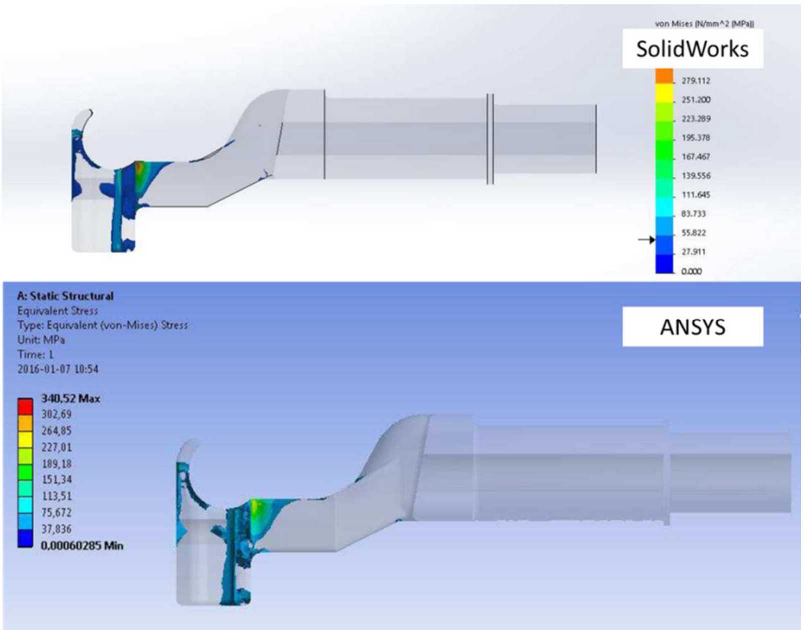
Punkt	SolidWorks [MPa]	ANSYS [MPa]	Obliczenia analityczne [MPa]
1	36,382	36,992	35,722
2	98,487	99,957	100,313

4. Results of reduced stresses

In addition, two analytical calculations were carried out on the basis of the concentration of stresses, which also confirmed the correctness of numerical calculations. The iso-volume graphs (Fig. 5-6) show the areas of the analyzed structure in which the stress values exceeded 50 MPa. You can clearly see the surface here and the subsurface nature of stress concentrations, which additionally confirms the correctness of the selection of MT (magnetic-powder) test method for this type of construction - forgings.



5. Results of reduced stresses - iso-volume diagram above 50MPa



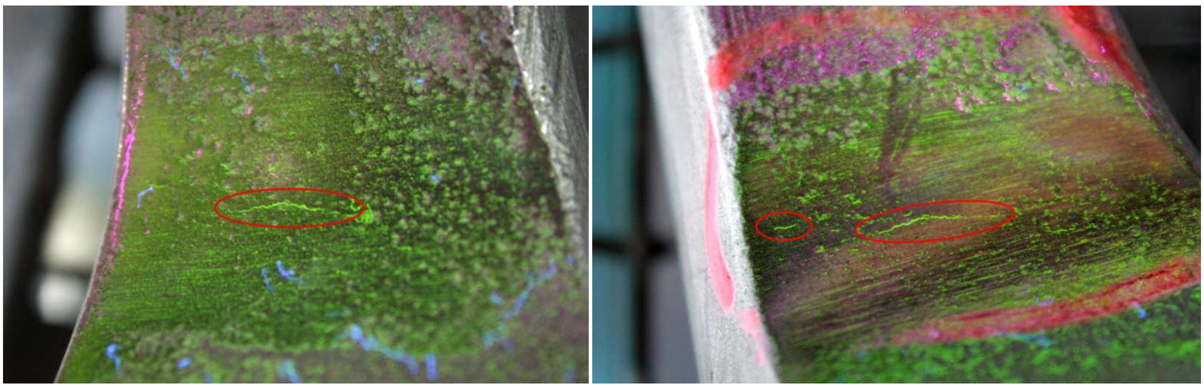
6. Results of reduced stresses - iso-volume diagram above 50MPa

7. Magnetic powder test results of clutch

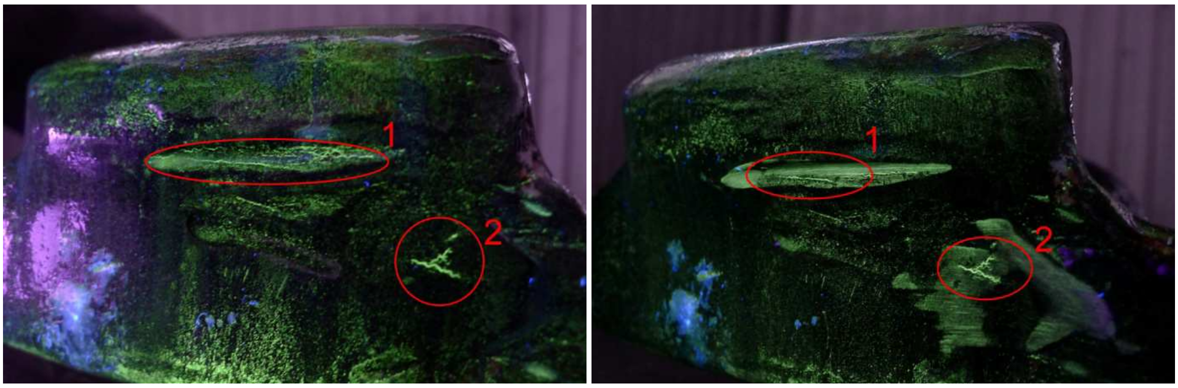
Mechanical removal of indications according to PN-EN 10228-1

The analyses discussed in the previous section show that the damages occurring in the joints are mainly surface or subsurface, and it is recommended to use the magnetic-powder method. One of the stages of the study using this method should be to remove the top layer of the material of the examined element. This action is intended to improve the quality of the surface, eliminating the recognition of all types of scratches, and other surface damage, determining the increase or disappearance of the test material or the possible removal of defects. Standard PN-EN 10228-1 Non-destructive testing of steel forgings Part 1: Magnetic-powder testing recommended: "Indications that do not meet acceptance criteria should be considered defects. Once the defects have been removed, a magnetic-powder test must be carried out again. Disadvantages should be removed by grinding and mechanical treatment, provided that the forgings dimensions remain within the tolerance limit. Grinding to remove the defect should be made in the direction perpendicular to it and so that the resulting recess has a smooth transition to the surface.”

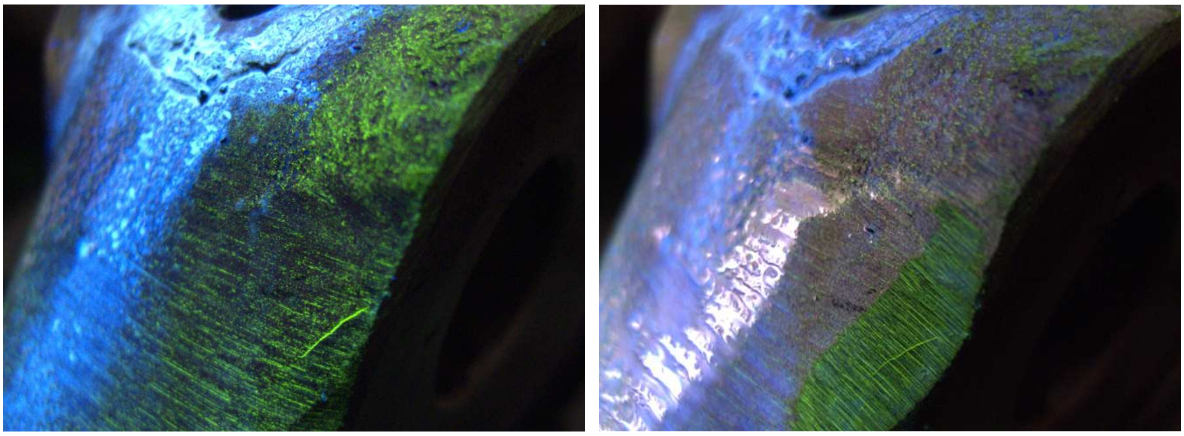
Figure 8 shows the case where the display after the top layer has been removed, Figures 9 and 10 show the disappearance of the display along with the removal of the top layer of the material. In many cases, the previous indications are removed.



8. Display length 7mm (before grinding), indication of length 2mm and 12mm qualify as an indication related to the length of 22mm (after grinding).



9. Indications about the length of about 28.4 mm (marked No. 1) and 6.8 mm and 3.8 mm (marked No. 2) before removing the top layer of the material, indicating the length of about 18.4 mm (marked No. 1) and 5.7 mm and 3.3 mm (marked No. 2) after removal of the surface layer of the material.



10. Display length 5.7mm (before grinding) / 5.2mm (after grinding)

Therefore, the question is about the limits of dimensional tolerances of the tested elements. The documentation of the cableways examined and in particular, the ski lifts in most cases do not contain information on the dimensional tolerances of the tested elements. Picture of the top layer at the point of occurrence of the indications often causes the defect to be removed, and there is no indication in the re-examination. From the operational point of view, this action is good because it can reduce the number of decommissioned items because they do not meet the accepted acceptance criteria.

In the case of couplings, the rating is based on the quality class 4 according to PN-EN 10228-1 [2]. The standard states that "classes shall not apply to areas where a machining allowance of more than 1 mm per side is provided." Accordingly, it can be assumed that in the absence of information in the documentation, sanding to a maximum depth of 1 mm is acceptable.

Testing of structural components by anticorrosion coatings

One of the items to be tested for UTL specialties is their supports and components and above all welded joints and SWC (heat affected zone). These structures are most commonly factory coated with corrosion protection in the form of zinc or other coatings. This leaves some confusion as to the applicability of the magnetic-powdered MT method without interference in the anti-corrosion layer. Standard PN-EN ISO 9934-1: 2015-11 - Non-destructive testing - Powder magnetic tests - Part 1: General principles, informs about preparation of test surfaces *"(...) Non-ferromagnetic coatings up to about 50 μm thick, such as unbroken, closely adhered* *paint coatings, usually do not reduce the sensitivity with which discontinuities are detected. Thicker coats reduce sensitivity. In such cases, the sensitivity should be checked. (...)* "[9]

In the hot dip galvanizing process, coatings with a mean thickness of 70 to 150 microns are obtained (Figure 12-13). This thickness is sufficient to protect the steel against corrosion for decades. The average lifetime of the zinc coating is 30-50 years. The thickness of the zinc coating is measured after calibrating the measuring device (fig. 11) in micrometers or the mass of the coating in g / m2. Minimum coating thickness recommended depending on material thickness, zinc-plated elements are defined by the PN-EN ISO 1461 standard [6].

According to PN-EN ISO 1461, the local thickness of the zinc coating (minimum value) is [6]:

- 45 µm for material up to 1.5 mm thick
- 55 µm for a material with a thickness of 1.5 to 3 mm
- 70 µm for 3 to 6 mm thick material

Over the years, the thickness of the galvanized layer is partially degraded.Table 2 shows the values of galvanic losses depending on the environmental corrosion category. For cableway supports, the category C2 to C4 can be adopted [5].

Tab.2. Atmospheric corrosion categories and examples of typical environments.

Corrosivity category	**Defects µm/year**	**Examples of environments typical for temperate climates** (tylko informacyjnie)	
		Outside	**Inside**
C1 very small	<0,1	-	Heated buildings with a clean atmosphere, e.g. offices, shops, schools, hotels.
C2 small	>0,1 to 0,7	Atmospheres slightly polluted. Mostly rural areas.	Non-heated buildings in which condensation may occur, e.g. magazines, sports halls.
C3 average	>0,7 to 2,1	Urban and industrial atmospheres, medium sulfur oxide (IV) pollution. Coastal areas with low salinity.	Production areas with high humidity and some air pollution, e.g. foodstuffs, laundries, breweries, dairies.
C4 big	>2,1 to 4,2	Industrial areas and coastal areas with medium salinity.	Chemical plants, swimming pools, ship repair yards and boats.
C5-I very big (industrial)	>4,2 to 8,4	Industrial areas with high humidity and aggressive atmosphere.	Buildings or areas with almost continuous condensation and high pollution.
C5-M very big (marine)	>4,2 to 8,4	Coastal areas and away from the shore deep into the sea with high salinity	Buildings or areas with almost continuous condensation and high pollution.

It is, therefore attempt to measure the layer of zinc in the context of records

It is stated that for a thickness of up to 50 microns (according to ISO 9934), it is possible to conduct a study by a protective layer closely adjacent to the surface. For thicker layers, the sensitivity of the MT method may change. This will not necessarily remove the protective layer, which will provide an anti-corrosion protection for the surface originally secured by the support. Many years of experience have shown that the average values of galvanized steel are within the range of 50 to 150 microns. For 30 years and older, this value is often less than 50 microns.

11. Calibration of the anti-corrosion coating thickness gauge
(Left pattern, the right pattern + spacer film having a thickness of 49.5 ± 1 μm)

12. Sample measurements on the support head in the native material.

The thickness of the zinc coating should be measured using a magnetic thickness gauge according to PN-EN ISO 1461 "Zinc coating applied to steel and cast iron products by immersion method - Requirements and test methods" [6]. Measure at least three places as uniformly as possible throughout the product. In order to determine the thickness of the coating in one place, at least 5 measurements on the surface of approx. 10 cm2 should be made and the arithmetic mean of the measurements shall be the local thickness of the coating. The arithmetic mean of the measured local thicknesses is the mean value of the thickness of the coating on the object being examined [1]. Figure 13 shows sample galvanic measurements in the native material, on the weld and in the area of the magnetizing area. It is important that during the MT test the magnetic flux of the yoke must be free to reach the material to be tested, and any discontinuity field from the discontinuity must penetrate the surface through the corrosion layer to form an indication of the magnetic powder.

13. Sample pole measurements of the support:
a) native material, b) weld c) SWC + magnetized area MT.

PN-EN ISO 17638 Non-destructive testing of welds - Magnetic-powder test [7] (previously PN-EN 1290) states that the dimension of the current and magnetic flux in the test material should be greater than or equal to the sum of weld width, SWC and additionally a distance of 50mm. An additional distance of 50mm is due to the fact that at approximately 25mm from each pole of the magnetizing yoke there is a too strong magnetic field that can cause detection of discontinuities, if any. The correct magnetic field strength in the test area should be in the range of 2-6 kA/m [3][7]

Summary

Correct non-destructive testing requires a number of factors, including the way in which the equipment is used and the operating conditions of the equipment being tested, as well as the results obtained and the appropriate test procedure. The article focuses on selected aspects of technical and metrological non-destructive testing. On the example of cableway couplings, the possibility of typing - using the numerical analysis of FEM - the most intensified areas of tested elements was discussed. Attention was drawn to the possibility of removing the obtained indications by grinding the test surface and the associated constraints associated with the dimensional tolerance of the individual components. The necessity of proper preparation of components for in-service research was also discussed, paying attention to the problem of removing non-magnetic layers influencing the sensitivity of magnetic-powder testing, while at the same time securing the structure from corrosive conditions in subsequent years of operation.

Source materials

[1] Materiały firmy FAM Cynkowanie Ogniowe S.A. http://famgk.pl/wp-content/uploads/2015/06/WTO-Cynkowni-02-2015.pdf
[2] PN-EN 10228-1 Badania nieniszczące odkuwek stalowych - Część 1: Badanie magnetyczno-proszkowe
[3] PN-EN 1290 Badania nieniszczące złączy spawanych - Badania magnetyczno-proszkowe złączy spawanych
[4] PN-EN 473 Kwalifikacja i certyfikacja personelu badań nieniszczących - Zasady ogólne
[5] PN-EN ISO 12944-2 Farby i lakiery - Ochrona przed korozją konstrukcji stalowych za pomocą ochronnych systemów malarskich - Część 2: Klasyfikacja środowisk
[6] PN-EN ISO 1461 Powłoki cynkowe nanoszone na wyroby stalowe i żeliwne metodą zanurzeniową - Wymagania i metody badań
[7] PN-EN ISO 17638 Badanie nieniszczące spoin - Badanie magnetyczno-proszkowe
[8] PN-EN ISO 9712 Badania nieniszczące - Kwalifikacja i certyfikacja personelu badań nieniszczących

[9] PN-EN ISO 9934-1 Badania nieniszczące - Badania magnetyczne proszkowe - Część 1: Zasady ogólne

[10] Rozporządzenie Ministra Transportu z dnia 1 czerwca 2006 r. w sprawie warunków technicznych dozoru technicznego w zakresie projektowania, wytwarzania, eksploatacji, naprawy i modernizacji urządzeń transportu linowego (Dz. U. Nr 106, poz.717)