Optical Controls Application for Diagnostics Corrosion Condition of Reinforced Concrete Structures

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Abstract. The increase in the efficiency of methods for non-destructive diagnostics of reinforced concrete structures is explained by a decrease in the labor intensity of the diagnostic process or an increase in the accuracy of assessing the state of the research object. The development of methods that simultaneously reduce labor costs and increase the accuracy of research is of particular interest. The paper proposes the use of video endoscopes and special devices for examining the inner surface of reinforced concrete structures in limited access conditions. The features of using diagnostic equipment are described, an algorithm for examining the contact network supports is developed, and a scheme of a sampling device for spectral diagnostics is presented.

1. Introduction

Technical endoscopy is one of the modern methods of non-destructive testing. Endoscopy allows visual inspection of surfaces in places inaccessible for external examination by conventional methods. In addition to visual inspection, the diagnostic process can be accompanied by additional tasks – measuring or influencing the research object.

Currently, technical endoscopy is widely used in the diagnosis of the state of automobile [1], aircraft engines, drilling, and gas turbine installations. One of the main goals of diagnostic measures is to examine hard-to-reach places for the presence of corrosion damage.

Also, video endoscopy is used in the examination of housing and communal services facilities. Here the relevance of its application is explained by the need to study extended hollow structures, for example, such as ventilation ducts.

The opportunities that open up when using technical endoscopy are relevant when examining hollow reinforced concrete structures. For example, it can be the supports of the railway transport contact network. Corrosion damage to them poses a serious threat to traffic safety and leads to significant economic losses. Currently, there are many ways to diagnose overhead contact network supports, but most of them are associated with labor-intensive sagging of the support to the depth of the survey, since it is in the underground part that the corrosion processes are most intense. For ultrasonic methods, after the support has been excavated to the required depth, the task of drying the surface arises, which creates additional difficulties.

The efficiency of using endoscopes for examining the corrosion state of reinforced concrete supports is due to the presence of ventilation holes on the supports. This makes it possible to exclude...
the laborious process of excavating the support and to judge its corrosive state based on the results of the analysis of the inner surface of the support using a technical video endoscope and related devices.

2. Methodology

To determine the corrosion state of the inner surface of a reinforced concrete support, a method based on determining the quantitative content of corrosion products on the surface of a reinforced concrete structure can be applied. This method makes it possible to make a decision about the corrosion state of the research object based on direct instrumental measurements [2-7]. To process the measurement results, mobile spectrum analyzers should be used, for example, based on laser induced breakdown spectrometry (LIBS) [8-15]. However, the use of such tools in hard-to-reach areas of reinforced concrete structures is difficult primarily due to the lack of visual control of the place where the analysis is performed. For these purposes, it is necessary to use a video endoscope. Consider the features of the use of technical endoscopes in hollow reinforced concrete structures.

To select a suitable model used as a device for sampling and visual inspection of the inner surface of the support, existing optical medical and electronic technical endoscopes from leading manufacturers were considered. Technical characteristics of such endoscopes are given in table 1. The main selection criteria when choosing an endoscope: the length of the immersed part, the outer diameter and the diameter of the instrument channel. The technical video endoscope jProbe VE 2-60-300H possesses the most suitable characteristics, which it was decided to use in further research.

| Parameter                        | jProbe VE 2-60-300H | Olympus CF-HQ190L/I | Pentax 38LV | Aohua VME-90 |
|----------------------------------|---------------------|---------------------|-------------|--------------|
| Overall length, mm              | 3000                | 2005                | 1700        | 1500         |
| Outer diameter, mm              | 6,0                 | 13,2                | 13,4        | 7,9          |
| Instrument channel diameter, mm | 3,7                 | 3,8                 | 2,0         |              |
| Angle of field of view, degrees | 70                  | 160-170             | 120         | 140          |
| Top 100                         | Top 180             | Top 180             | Top 210     |              |
| Down 100                        | Down 180            | Down 180            | Down 90     |              |
| Bending angles of the working part, degrees | Right 160 | Right 160 | Right 160 | Right 100 |
| Top 100                         | Top 180             | Top 180             | Top 210     |              |
| Down 100                        | Down 180            | Down 180            | Down 90     |              |
| Video system                    | CMOS 350kpx         | Olympus CV-190      | Defina 3000 | EPK-Aohua VME- |
| Manufacturer country             | Japan               | China               | China       |              |

3. Research

Most modern technical endoscopy probes are made in a metal or plastic sheath and are resistant to water, oil and corrosive environments. In conditions of concrete structures, the use of probes in a metal sheath is desirable due to the increased resistance to abrasion.

The video endoscope, equipped with the function of displaying the measuring grid, makes it possible to draw conclusions about the size of certain corrosion manifestations or defects on the surface of the structure under study. However, the most important aspect of video endoscopy is the illumination of the surface to be examined.

A technical endoscope allows you to obtain a video image of the inner surface of a reinforced concrete structure in low light conditions, as shown in figure 1. In this case, the problem of exposure of the investigated surface is especially urgent. To solve this problem, both software methods of image processing (figure 2) and schematic solutions can be used. Software methods include image sharpening, adjusting exposure, brightness levels, and adjusting the image histogram. An example of a
successful circuit design is the use of the Hyperion side and forward alternating illumination system in jProbe endoscopes.

The use of not optical, but electronic video endoscopes makes it possible to instantly acquire a digital image and process it. If necessary, adjustments to the image acquisition conditions can be instantly corrected. For example, the histogram of the image can be used to judge the presence of light or dark spots in the image, which will require adjusting the lighting system.

Determination of corrosion manifestations on the surface of the material can also be performed in an automated mode. For example, based on the processing of RGB-histograms of the image.

Electrochemical corrosion of reinforcement is mostly caused by leakage currents, as well as stray currents from the electric rolling stock of railways. For studies of electrocorrosion, samples were made, which were placed in an aqueous electrolyte solution with different NaCl concentrations and connected to an external power supply.

A positive potential was connected to the steel reinforcement, which served as the anode. Iron oxidation occurs at the anode. In concrete, which performs the function of an electrolyte with the saturation of various ions, electrolysis will take place with a uniform distribution of corrosion products in its volume.

Reinforced concrete samples were placed in an aqueous solution of sodium chloride in accordance with the scheme shown in figure 3. The anode was steel reinforcement, and the cathode was a copper electrode. The samples were connected to a constant voltage source. In the experiment, four samples were tested in different environments.
Samples 1, 2, and 3 were placed in one, two and three percent sodium chloride solutions; sample 4 was also placed in a three percent solution, but had a porous concrete structure. The voltage applied to all four samples was the same and amounted to 5 V, and the current was different (from 0.03 to 0.7 A), which is explained by the different concentration of electrolyte solutions and the porosity of concrete. The electrolysis lasted for 30 hours, since this time was sufficient for the release of corrosion products to the concrete surface and the formation of "ochre spots".

As a result of the experiment performed, the samples shown in figure 4.

Upon completion of the electrolysis, traces of corrosion were found on the concrete surface, which indicates the decomposition of steel reinforcement rods [16]. The samples obtained were analyzed for the presence of iron released to the concrete surface from steel reinforcement using a portable spectrometer SciApps Z300 [17].

4. Discussion of results
In figure 5 shows an example of an image of a section of a reinforced concrete surface with traces of corrosion destruction, which was obtained on the reinforced concrete samples described above. The figure shows, firstly, that the image histogram is balanced: it is located in the center of the brightness levels, which means that there are no areas with lost data in the image. When the image is decomposed into RGB channels, it can be seen that the red channel in this image is more pronounced, and the blue, on the contrary, is muted. On average, in corrosive areas, the red component of the color exceeds the green by 50%, and the blue component is 30% less than the green. In areas free from corrosion products on the surface, the red component practically coincides with the green one (exceeds it by 5%), and the blue component turns out to be 15% less than the green one on average.

With digital image processing, based on the information received, it is possible to automatically determine the surface areas on which the concentration of corrosion products is most pronounced. A further decision on the need for spectral analysis should be made by the operator.

For sampling from the inner surface of concrete, a device was developed based on a technical video endoscope equipped with a drill and a fine fraction catcher. Diagnostics of the corrosion state of the internal surfaces of reinforced concrete structures was subsequently carried out by assessing the concentration of iron-based compounds in the selected area [18-20].

The design of the sampling device consist a flexible shell, which is immersed in the inner cavity of the reinforced concrete support for sampling in the form of fine powder from its surface. The control part consists of a video image block (video endoscope input), an instrumental channel (input), into which the flexible axis of the drill is inserted, control handles (up / down and left / right), with which the direction of movement of the distal head is carried out, an intake fan and a reservoir for collecting the sampled sample. There are also elements of manual control, a fan and a drill on the body.

In figure 6 shows a diagram of the arrangement of the sampling device inside the contact network support. The immersed part is placed inside the support through the technological hole.
After the immersed part is located inside the support, the inner surface of the concrete is inspected. The greatest practical interest relates to the inner surface located at a distance of one meter above and below ground level. When traces of corrosion are detected, using the tube control handles, the distal head of the video system (VS) is aimed at the middle of a pronounced area with the presence of corrosion products. Then the drill is turned on and the fan is turned on to collect the sample (CS). The sample obtained is pressed into tablets using a hand press. Such tablets are easily spectral analysis. The amount of powder for analysis does not exceed 2 g. The powder is pressed into a tablet with a diameter of 10 mm for analysis by means of LSES spectrometry. As an instrumental part of spectrometers, it is recommended to use portable LSES installations or LIBS analyzers, such as SciApps Z300.

5. Conclusions
The result of the studies performed was the sampling procedure algorithm for automation devices. Application of the presented algorithm together with technical means of sampling and portable instruments of spectral analysis makes it possible to efficiently determine the corrosion state of hollow reinforced concrete supports of the contact network of direct current railways in the field.

6. References
[1] Ageev E V, Shcherbakov A V, Alekhin Y G, Grashkov S A 2018 Increasing the information content of the process of diagnosing car engines through technical endoscopy News of the Southwest State University Vol 22 1(76) 18-26
[2] Kremers D, Radziemski L 2009 Laser-spark emission spectroscopy (Moscow: Technosphere) 360
[3] Lin Liu, Qiang Wang, Kai Guo 2014 Research on Evaluation Method of Ultrasonic Testing for Inspection of Concrete Jointing Surface Quality Applied Mechanics and Materials Vol 501-504 877-880 DOI: https://doi.org/10.4028/www.scientific.net/AMM.501-504.877
[4] Zhi Yong Ai, Jin Yang Jiang, Sun Wei, Han Ma, Jian Chun Zhang, Dan Song 2016 Passive Behaviour of New Alloy Corrosion Resistant Steel Cr10Mo1 in Simulating Concrete Pore Solutions with Different Chloride Contents Key Engineering Materials Vol 711 1053-1060 DOI: https://doi.org/10.4028/www.scientific.net/KEM.711.1053
[5] Xiang Yun, Jie Xiao 2012 Research Progress of Concrete Corrosion in Acid Environment Advanced Materials Research Vol 598 647-654 DOI: https://doi.org/10.4028/www.scientific.net/AMR.598.647

[6] Musab Alhawat, Amir Khan, Ashraf, Ashour Evaluation of Steel Corrosion in Concrete Structures Using Impact-Echo Method Advanced Materials Research Vol 1158 147-164 DOI: https://doi.org/10.4028/www.scientific.net/AMR.1158.147

[7] Sanad A M, Moussa M A, Hassan H A 2013 Finite Element Modelling of Steel Corrosion in Reinforced Concrete Cylinders, Advanced Materials Research Vol 785-786 273-278 DOI: https://doi.org/10.4028/www.scientific.net/AMR.785-786.273

[8] Weritz F, Ryahi S, Schaurich D, Taffe A, Wilsch G 2005 Quantitative determination of sulfur content in concrete with laser-induced breakdown spectroscopy Spectrochimica Acta Part B 1121-1131

[9] Jian Min Du, Rui Min Jiao, Ying Shu Yuan, Xiao Meng Zhu 2011 Research on the Anti-Sulfate and Chlorine Corrosion Property of Concrete Advanced Materials Research Vol 243-249 5727-5732 DOI: https://doi.org/10.4028/www.scientific.net/AMR.243-249.5727

[10] Singh J K, Singh D N 2012 The nature of rusts and corrosion characteristics of low alloy and plain carbon steels in three kinds of concrete pore solution with salinity and different pH. Corrosion Science 56 129–142

[11] Fan Zhang, Jinshan Pan, Changjian Lin 2009 Localized corrosion behaviour of reinforcement steel in simulated concrete pore solution Corrosion Science 51 2130–2138

[12] Glass G K, Yang R, Dickhaus T, Buenfeld N R 2001 Backscattered electron imaging of the steel-concrete interface Corrosion Science 43 605-610

[13] Ahmad S and Bhattacharjee B 1995 A Simple Arrangement and Procedure for InSitu Measurement of Corrosion Rate of Rebar Embedded in Concrete Corrosion Science Vol 37 5 781-791

[14] Chunhua Lu, Weiliang Jin, Ronggui Liu 2011 Reinforcement corrosion-induced cover cracking and its time prediction for reinforced concrete structures Corrosion Science 53 1337–1347

[15] Ueli Angst, Anders Ronquist, Bernhard Elsener, Claus K Larsen 2011 Oystein Vennesland a Probabilistic considerations on the effect of specimen size on the critical chloride content in reinforced concrete Corrosion Science 53 177–187

[16] Ngoc Anh Vu, Arnaud Castel 2009 Raoul Francois Effect of stress corrosion cracking on stress–strain response of steel wires used in prestressed concrete beams Corrosion Science 51 1453–1459

[17] Elsener B 2005 Corrosion rate of steel in concrete - Measurements beyond the Tafel law Corrosion Science 47 3019–3033

[18] Kandaev V A, Kuznetsov A A, Ponomarev A V, Buchelnikova O S 2017 Patent No. 167680 Russia A device for determining the quantitative composition of products of corrosion of reinforcement on hard-to-reaching surfaces of reinforced concrete products declared 01/29/2016 publ. 10.01.2017 Bul 1

[19] Kuznetsov A A, Bryukhova A S 2018 Determination of the quantitative content of corrosion products on the surface of reinforced concrete products Omsk Scientific Bulletin 6(162) 160 - 164

[20] Kuznetsov A A, Bryukhova A S, Demin Yu V 2019 Positioning system of the optical probe for the study of internal surfaces of hollow reinforced concrete structures Izvestiya vuzov. Instrumentation Vol 62 3 157 - 166