Applying visual optical methods of non-destructive testing while diagnosing metal structures of mine hoisting plants

M V Korniakov, Y O Gurkov, A N Shevchenko and S Y Krasnoshtanov

Irkutsk National Research Technical University, Russia
E-mail: kornikov@istu.edu, shan@istu.edu, sk@istu.edu

Abstract: Research to determine the rational parameters in the development of design and engineering solutions and hardware and software package in order to efficiently conduct microscopic studies of objects and materials has been conducted by the project team at the laboratories and centers of the Irkutsk National Research Technical University since 2013. During this period, the team has completed and registered one know-how, has developed a laboratory model of a microvisor and a test version of a computer program allowing identification of fake signatures, and is currently preparing an application for a utility model patent. We have studied the processes of optimal controlled magnification up to 200 times the size of the object surface image in the reflected light (in the visible, ultraviolet and infrared spectrum). We have developed a new concept of a hardware and software package that allows for the rapid microscopic examination of objects and materials, followed by quick software processing and recording of photos and videos.

1. Introduction
When examining industrial safety of mine hoisting plants, non-destructive testing methods are necessarily used. This is necessary to fully and accurately analyze the technical condition of metal structures and steel ropes. The use of one or another non-destructive testing method depends on the type of technical device and the nature of the damage.

Hoisting structures mainly consist of rolled metal elements of various thickness, which are connected by welding and fasteners. Hoisting technical devices are subject, in the course of operation, to cyclic loads, which lead to the occurrence of the following defects:
1. Fatigue cracks in the welds (masked, through, and surface cracks);
2. delamination of metal;
3. mechanical and corrosive wear.

From a large number of known non-destructive testing methods, technical diagnostics of metal structures of hoisting equipment uses the following ones [7, 8, 9, 12]:
1. visual;
2. visual optical;
3. ultrasonic;
4. eddy-current;
5. magnetic particle;
6. capillary;
7. radiographic;
8. radioscopic.
2. Visual optical method

Let us consider in detail the visual optical method for assessing the state of steel structures and products during non-destructive testing activities.

Visual and dimensional test is carried out in order to identify defects that may be made in the manufacture of equipment or occur both during operation and during transportation and installation of metal structures. All available welded joints are to be inspected in order to identify the following defects: cracks, blowholes, porosity of seams; undercuts, rolls, burn-throughs, unwelded craters; displacement and drift of the edges of the joined elements above the limit; inconsistencies of seam shapes and sizes with technical documentation requirements; surface deformations [1]. Visual inspection is also mandatory when monitoring the condition of the mine hoisting ropes.

External visual inspection is applied, as a rule, with respect to sufficiently large welded structures to detect all possible defects and malfunctions. For this purpose, special optical devices are used which increase the efficiency of the object's examination. In modern practice, it can be such devices as endoscopes, microscopes, lenses, various magnifiers, etc.

The use of optics for visual inspection is necessary, first of all, in the following cases:
- detection of masked defects in the structure under examination and their analysis by means of periscopic type flaw detectors, video monitoring systems, endoscopes and borescopes;
- testing of an object located at a distance of more than 25 cm from the specialist performing the diagnostics. The following devices are used for this: spotting telescopes, telescopic magnifiers and binoculars;
- testing of an object located at a distance of less than 25 cm from the specialist performing the diagnostics. In this case, microscopes and magnifiers are applied.

The use of optical tools can significantly expand the limits of the natural possibilities of human vision: make measurements with higher accuracy, detect smaller defects, carry out control in closed structures inaccessible to humans. Depending on the magnification, the resolution can reach 1...5 μm.

Low magnification magnifiers, such as reading glasses, have a long focal distance, a large field of view, and can be used for binocular observation. In this case, inspection is performed with two eyes, which increases the reliability of the testing. For example, BL-1 and BL-2 binocular head magnifiers with magnification of 1.25×...2× are used as viewing magnifiers. Due to stereoscopy, these magnifiers make it possible to view objects volumetrically, which is impossible when looking through a monocular magnifier.

Measuring magnifiers with magnification up to 8×...20× are used to test small areas and assess the nature and size of detected defects. In order to achieve chromatic correction (exclusion of color bordering), magnifiers with such magnification are made composite. They are usually glued together from two or three lenses made from different grades of optical glass. Many models of modern magnifiers are additionally supplied with illuminators powered from batteries of size AA or AAA.

A microscope is a sophisticated optical multi-lens device for observing elements that are not visible to the naked eye. A microscope has an adjustment of optical properties and makes it possible to obtain a high-quality image with magnification up to 2000×. As a rule, microscopes with high magnification are stationary. For diagnostic purposes during the visual optical testing, portable microscopes are used, which have a simplified design and are installed directly on the object to be tested.

3. Portable microvisor

Specialists of the Department of Mining Machines and Electromechanical Systems of the Irkutsk National Research Technical University conducted an analysis of the consumer market and a detailed study of the structures of existing portable digital microvisors [3, 10, 11]. The work carried out made it possible to formulate the concept of a microvisor, conduct development work, and produce a prototype microvisor designed to quickly obtain and record high-quality surface images with adjustable magnification in the range from 45 to 200 times equipped for microscopic studies in reflected light (visible, ultraviolet, polarized and infrared spectra), measurements and quantitative assessments of the objects under study.
Currently, there is a significant demand for portable microvisors that allow for the rapid microscopic examination of objects and materials, followed by quick software processing and recording of photos and videos.

In particular, these devices are in demand for various kinds of experts in the implementation of their activities such as:

- Assessment and recording of the state of steel structures and products at industrial enterprises during non-destructive testing activities;
- Assessment and recording of physical evidence and materials in the analysis of emergency situations;
- Assessment and recording of materials and samples during metallographic studies, etc.

The common drawbacks of portable microvisors used today are that they do not allow experts to simultaneously examine objects in visible, ultraviolet, infrared and polarized light, and also have poor image quality due to possible parasitic reflections and glare from the object under study.

The examination process can be carried out at a qualitatively higher level by providing experts with modern microvisors simultaneously possessing a full functional set of properties-the ability to get high-quality digital surface images with magnification in the range from 45 to 200 times, provide photo and video recording of research materials, illuminate objects under study in the visible, infrared, ultraviolet spectrum, the presence of built-in contrast and polarization optical filters, if necessary, to transfer the recorded materials via the Internet.

There is a portable microvisor [3] which contains an optical system placed coaxially inside the housing, as well as an object plate made of transparent material. It is characterized in that it additionally contains an element made in the form of a glass with a hole in the bottom on which the object plate is firmly fixed. The object plate completely blocks the hole in the bottom, and the side wall of the glass is connected to the housing with the possibility of axial movement.

However, this microvisor requires placing the object under study on a special object plate, which is a component part of the device. This significantly reduces the functionality in terms of the size and dimensions of the objects under study, moreover, this microvisor does not have the functions of examining objects in the ultraviolet, polarized and infrared spectra, and also has no option of getting an image in a digital code with its subsequent transfer to various digital devices.

A device closest in technical essence to the proposed one is a portable digital microscope [5] consisting of a tripod and a replaceable optical electronic module. Its housing sequentially, along the optical axis, contains a lens and photoelectronic image receiver, as well as an electronic power supply and control circuit, the upper illuminator module and the first group of electrical contacts, the tripod of which consists of a base and a rack with an optical electronic module holder and includes a focusing mechanism, the lower illuminator module and the second group of electrical contacts. The lens is designed to move along the optical axis, the optical electronic module holder is kinematically connected to the focusing mechanism, and the lower illuminator module is located at the base of the tripod. The upper illuminator module is located on the lens housing.

This design solution provides a reduction in overall dimensions and weight of the device.

Improving the performance of a portable digital microscope.

The drawback of this device is that it has insufficient image quality for experts if there are parasitic reflections and glare during the study of objects. In addition, it allows for studying objects only in the visible range and does not give experts the ability to additionally conduct studies in the ultraviolet, polarized and infrared spectra, and also has low image quality due to possible parasitic reflections and glare from the object under study.

The developed portable digital microvisor allows for improving the quality of the image obtained through the use of an analyzer filter having enhanced functionality due to the use of additional illuminators (in the ultraviolet, polarized and infrared spectra).

The technical result consists in the improvement of the resulting image quality and enhancement of the microvisor functionality through the use of special filters and illuminators, as well as their unique layout pattern [6].
This is achieved by the fact that the portable digital microvisor, including a housing, a visible range illuminator, a lens, a focusing mechanism, a photoelectronic image receiver, a power supply and control circuit, is additionally equipped with infrared (IR) and ultraviolet (UV) illuminators, a replaceable contrast filter, polarizer filter and analyzer filter, and an analog-to-digital converter. Component parts are fixed in the microvisor housing along the optical axis sequentially in the following order: replaceable contrast filter, illuminators (of visible, IR and UV ranges), polarizer filter, lens, analyzer filter, photoelectric image receiver, power and control circuit, analog-to-digital converter, while the illuminators and the replaceable contrast filter are made in the form of a ring not overlapping the optical axis of the device, and the analyzer filter can rotate around the optical axis by 360° (Figure 1).

Introduction to the device of the infrared (IR) and ultraviolet (UV) range illuminators, as well as the polarizer filter, allows experts to carry out studies of objects in various spectra and obtain more advanced information about their state. The use of the replaceable contrast filter is necessary to improve the image quality in the study in ultraviolet light. It is installed in the optical and illumination path and transmits a narrow spectrum of excited radiation, cutting off UV radiation. The analyzer filter allows filtering of parasitic reflections and glare from the object under study.

![Figure 1. Portable digital microvisor: 1 – housing, 2 – group of illuminators (of visible, IR and UV ranges), 3 – replaceable contrast filter, 4 – polarizer filter, 5 – lens, 6 – analyzer filter, 7 – photoelectric image receiver, 8 – power and control circuit.](image)

The device works as follows. Light from the group of illuminators (of visible, IR and UV ranges) 2 passes through a replaceable contrast filter 3 and illuminates the object under study. The light reflected from the object under study passes through the polarizer filter 4 into the lens 5, in which it is concentrated, and through the analyzer filter 6 focuses on the photoelectric image receiver 7, where it is converted into an electronic signal for further transmission to various electronic devices.
The analyzer filter 6 constantly present in the optical path is a plate of circular polarization with a variable angle and is designed to filter out parasitic reflections and glare from the object under study, and is also used as an analyzer in the study in polarized light in conjunction with the replaceable polarizer filter 4 installed in the illumination path. Replaceable contrast filters 3 are installed in the illumination path and are used in the visible range of illumination. The replaceable analyzer filter 6 is used in the study in ultraviolet light. It is installed in the optical and illumination path and transmits a narrow spectrum of excited radiation, cutting off UV radiation.

Thus, the image quality of the object under study is improved and the functionality of the portable digital microvisor is expanded.

4. Conclusion
Compared with foreign and Russian analogues, the developed unit is unique in that it is portable, simple and convenient to operate, suitable for carrying out efficient examinations of various levels that require microscopic studies of objects, their recording and digital processing. In contrast to analogues, the developed device allows for the illumination of objects with the ultraviolet and infrared spectrum, as well as for conducting studies in polarized light.

The design of the unit is unique in that it is compatible with any devices for collecting, storing and processing data that have a hardware USB port.

References
[1] Visual and dimensional inspection of welds and joints in metal structures [Electronic resource] https://1cert.ru/statyi/visualno-izmeritelnoe-obledovanie-svarnykh-shvov-i-soedinenny-v-metallicheskikh-konstruktsiyakh (access date: 01.06.2019)
[2] Visual optical and dimensional testing [Electronic resource] https://megalektssi.ru/s1560525.html (access date: 01.08.2019)
[3] Patent No 2108607 Russian Federation MPK6 G02B21/00 Portable microscope E V Mironov, V S Bezugly (EXPOTEKS, Scientific Production Center) LLC 4 p 1
[4] Patent No 167811 Russian Federation MPK8 G02B21/06 Portable digital microvisor / Y.O. Gurkov, A.N. Shevchenko, S.Yu. Krasnoshtanov, M.V. Kornyakov; applicant and patent holder: Irkutsk National Research Technical University 1 p 1
[5] Patent No 69269, Russian Federation, MPK6 G02B21/00 Portable digital microscope / N R Belashenkov, D M Gordeev; applicant and patent holder: LOMO OJSC, NV START LLC 34 p 1
[6] Freeman D 2000 Computer Microvision for MEMS Microscopy Today 8(5) pp 32–35
[7] Kustov A I, Migel I A 2010 The search of strength as one of the base criterion of limit state of materials with acoustomicroscope defectoscopy methods // Bulletin of Russian universities. Mathematics 3-In [Electronic resource] https://cyberleninka.ru/article/n/prochnost-kak-odin-iz-bazovyh-kriteriev-predelnogo-sostoyaniya-materialov-i-eyo-opredelenie-metodomikustomikroskopichesky (access date: 01.08.2019)
[8] Markov A P, Sergeyev S S, Starovoytov A G, Marukovich E I, Patuk E M 2014 Highly sensitive videendoscopy of the geometric bodies surfaces Foundry Production and Metallurgy 2 54–56
[9] Porter A M, Bukatyi S A, Leshin D P, Vasilchuk M V, Galickyi A A 2012 Defectoscopy of the fatigue cracks in the gas turbine parts by means of eddy-current method Bulletin of Samara state aerospace University 3-1(34) pp 196–202
[10] Mohammed A S, Mukha E V, Stsiapanau A A, Pasyankov A V, Smirnov A G 2014 Hard/software functional control method of microdisplay modules for personal video-projection systems Doklady BGUR 3 pp 85–89
[11] Selyaev V P, Nizina T A 2008 Computer technologies for analysis of structure and properties of building materials and products Vestnik of MSU 4 [Electronic resource] https://cyberleninka.ru/article/n/kompyuternye-tehnologii-dlya-analiza-struktury-i-svoystv-stroitelnih-materialov-i-izdeliy (access date: 01.08.2019)
[12] Katsura A V, Lavrenov V A, Ryabin A A 2011 Usage of NDT (nondestructive test) methods for diagnostics of corrosion damage of airframe structure // Siberian journal of science and technology 1 (34) [Electronic resource] http://elibrary.ru/item.asp?id=16340547 (access date: 01.08.2019)

[13] Kovalev V A, Horeshok A A, Herike B L, Kuznetsov V V, Muhortikov S G, Drozdenko U V 2013 Operation of heading machine at the mines of «SUEK-Kuzbass» Vestnik KuzGTU 2 [Electronic resource] https://cyberleninka.ru/article/n/ekspluatatsiya-prohodcheskih-kombaynov-na-shahtah-oao-suek-kuzbass (access date: 01.08.2019)