Research Article

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Increasing reliability of forensic analysis while research on destroyed relief marking with magneto-optical devices

While research on destroyed relief marking of metal objects using the magneto-optical method, visualization of (invisible) fields of internal stress in the VIN plate area is performed and then a forensic analysis of obtained instrumental data is carried out (indirect organoleptic observation of the visualization results); thus, forensic analysis reliability of results directly depends on sensitivity of instruments and informativeness of instrumental data.

The main quantitative characteristic in this case is probability of correct signal recognition (contours of marking signs) against the background of noise (structural noise of investigated surface and the noise of the visualization method itself) determined by the signal-to-noise ratio.

This article presents results of a comparative experimental assessment of signal-to-noise ratio and probability of correct signal recognition while restoring the destroyed relief markings for two complexes of magneto-optical imaging – models of 2006 and 2018.

This article purpose is a quantitative and qualitative comparative assessment of results of visualization of internal stresses in areas of completely removed relief marking of metal objects. The results of successful practical research obtained by forensic experts from different countries make it possible to assess effectiveness and prospects of using the magneto-optical imaging method.

In a new modification of the magneto-optical complex:

- *signal level is 4.35 dB higher (contrast of reconstructed marking signs);*
- *2.71 dB lower noise level (surface relief/texture and magnetic copying noise);*
- *probability of correct character recognition is P> 0.995 (increased by 14.9%).*

The author declares no conflict of interest of relavance to this topic.

Technical improvements in implementation of magneto-optical visualization method made it possible to expand the range of materials for research objects(magnetic and electrically conductive materials were investigated).

The high efficiency of method for restoring marking is illustrated by results of forensic examinations for materials with a low level of residual stresses (aluminum alloy, low-carbon steel) which chemical etching method did not give results for.

The use of new modification allows examining the rust layer, up to cases of corrosion to the entire depth of marks.

Considering non-destructive nature of magneto-optical researches, possibility of their repeated repetition without losing object properties, this method (in accordance with the order of application of types of studies) deserves more attention for application.

Keywords: *relief marking, magneto-optical visualization, data recovery of remote marking, non-destructive methods.*

Formulation of Research Problem. While research on destroyed relief marking, firstly, visualization of (invisible) fields of internal stress in the VIN plate area is performed and then a forensic analysis of obtained instrumental data is carried out (indirect organoleptic observation of visualization results); thus, forensic analysis reliability of results directly depends on sensitivity of instruments and informativeness of instrumental data.

It is known from the signal theory that the probability of correct signal recognition (marking contours) against the background of noise (structural noise of investigated surface and the noise of the visualization method itself) is determined by the signal-to-noise ratio.

The task of this research paper is a comparative experimental assessment of signal-to-noise ratio and probability of correct signal recognition while restoring the destroyed relief markings for two complexes of magneto-optical imaging: models of 2006 and 2018.

Analysis of Essential Researches and Publications. Forensic expert practice of using magneto-optical (hereinafter referred to as MO) devices for the study of relief marking has been initiated recently: the first complexes were introduced in 2000 [1]. Main provisions of application of such techniques in forensic examinations are outlined in the corresponding methodology[2], further integration of theoretical foundations of this method is carried out in the research paper [3].

[1] Спосіб магнітооптичного контролю виробу : пат. 42880 Україна. № 99074257 ; заявл. 22.07.1999 р.; опубл. 15.11.2001 р., Бюл. № 10.

[2] Агалиди Ю. С., Левый С. В., Прохоров-Лукин Г. В. Реализация комплексной методики криминалистических исследований идентификационных номеров автотранспортных средств на программно-аппаратном уровне. *Криминалистика и судебная экспертиза*. 2003. Вып. 51. Р. 24—29.

[3] Агаліді Ю. С. Магнітооптична візуалізація магнітограм рельєфних зображень і структурних неоднорідностей поверхневого шару феромагнітних виробів : дис. … канд. техн. наук. Київ, 2006. 193 р.

Over time, authors of the methodology thoroughly studied technical parameters and tested devices, as well as performed a metrological assessment of their main characteristics[1]. The next stage in the application of the new instrumental method was the study of its potential within the framework of expert researches. Results of the comparison of the experimental assessment of sensitivity for MO, magnetic-powder and electrochemical methods of research on removed relief marking are considered in a number of research papers[2].

The result of these research papers[3] was a conclusion on certain fundamental advantages of the MO method, among which the main ones are high sensitivity and non-destructive nature of researches helping to effectively investigate even such a complex substance as a layer of rust from the surface of the VIN plate area.

The result of successful approbation of MO devices and a corresponding methodology was the introduction of this method in the forensic expert practice of research on vehicle [4] marking.

The next major step in the development of MO equipment for expert researches is the development of eddy current magnetic imaging registered as a national patent of Ukraine and international patents. This technology has significantly increased sensitivity and informativeness of magneto-optical visualization as well as expanded the scope of application of the MO method, having added to the list of studied objects not only magnetic but also electrically conductive materials.

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[1] Агалиди Ю. С., Левый С. В., Мачнев А. М. Экспериментальная оценка чувствительности и достоверности магнитооптической визуализации рельефных трасс. *Вісник НТУУ «КПІ». Серія приладобудування*. 2006. Вип. 32. P. 39—46 ; Ibidem. Методика исследований сигналов и шумов при магнитооптической дефектоскопии. *Учёные записки Таврического национального университета им. В. И. Вернадского. Серия: физика.* 2006. Вып. 19 (58). № 1. P. 23—29.

[2] Ibid. Сравнительный анализ магнитопорошкового и магнитооптического методов визуализации пространственного распределения магнитного поля при исследовании остаточных напряжений. *Вісник НТУУ «КПІ». Серія приладобудування.* 2006. Вип. 31. P. 18—24 ; Про затвердження Інструкції про порядок проведення криміналістичних досліджень транспортних засобів і реєстраційних документів, що їх супроводжують, працівниками Експертної служби МВС України : наказ МВС України від 31.05.2013 р. № 537. URL: https://zakon.rada.gov.ua/laws/show/z1309-13 (date accessed: 22.02.2021) ; Агалиди Ю. С., Левый С. В., Мачнев А. М., Прохоров-Лукин Г. В. Сравнительная оценка чувствительности магнитооптического, магнитопорошкового и электрохимического методов при исследовании удалённой рельефной маркировки. Ч. 1—3. *Криминалистика и судебная экспертиза.* 2008. Вып. 54. P. 80—119.

[3] Агалиди Ю. С., Левый С. В., Мачнев А. М. Сравнительный анализ … ; Агалиди Ю. С., Левый С. В., Мачнев А. М., Прохоров-Лукин Г. В. Сравнительная оценка чувствительности … .

[4] Про затвердження Інструкції про порядок проведення криміналістичних досліджень транспортних засобів … . URL: https://zakon.rada.gov.ua/laws/show/z1309-13 (date accessed: 22.02.2021).

The development of the theory of the magneto-optical visualization method has contributed to the advancement of technical tools implemented in forensic laboratories in more than 40 countries.

The **Article Purpose.** Research papers about technical visualization tools used for expert researches, published predominantly in foreign publications and are little known among Ukrainian experts.

This paper outlines results of the experimental assessment of the signal-to-noise ratio and probability of correct signal recognition while restoring the destroyed relief markings for two complexes of magneto-optical imaging being checked.

New possibilities of MO technology for restoring the destroyed relief marking of metal magnetic and electrically conductive objects are considered.

Results of expert research on restoration of destroyed relief markings on real objects for which obtaining data on primary marking by other methods was inefficient or impossible are presented.

Main Content Presentation. ***Equipment.*** Both comparable complexes are guided by similar physical principles: it can be stressed that they demonstrate the evolution of technical improvement of this type of devices.

The principle of operation of such MO devices is outlined in detail in publications[1], it consists of subsequent performance of a number of operations. Firstly, the magnetic tape (intermediate storage medium) is demagnetized. Then the magnetic tape is placed on the studied surface and with the help of a magnetic scanner, magnetic imaging (magnetography) is performed: record to a magnetic tape the response of the magnetic field from the surface layers of the VIN plate area of a metal research object. The response of the magnetic field reflects the relief and structural inhomogeneities (in particular, the internal tension). Then the obtained magnetogram (magnetic tape with a copy of magnetic properties) is placed in the MO imaging device where it is gradually read out and converted into a visible image using a converter based on the MO Faraday effect.

The compared complexes of the MO equipment differ in structural and design solutions, hardware components, technological sophistication of production, software and algorithm support, what, undoubtedly, impacts main functional characteristics.

Thus, the set of the MO equipment for research on relief marking of the 2006 model (Fig. 1) consisted of *Вій-5А* MO imaging device, high-frequency bias device and a metal magnetic tape for digital recording from ЕП-298 alloy (as a magnetic carrier).

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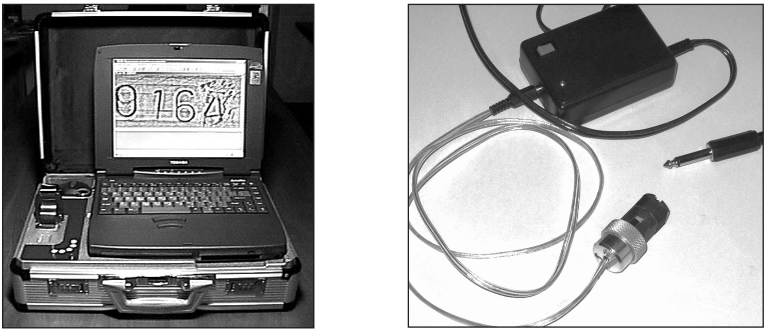
[1] Пат. 42880 Україна ; Агаліді Ю. С. Магнітооптична візуалізація магнітограм … ; Agalidi Yu., Kozhukhar P., Levyi S., Rogozhinsky Yu., Shumsky I. Eddy current fields/magnetic recording/magneto-optic imaging NDI method. *Nondestructive Testing and Evaluation.* 2012. Vol. 27. Is. 2. P. 109—119. DOI: https://doi.org/10.1080/10589759.2011.610453 (date accessed: 22.02.2021).



a) *Вій-5А* MO imaging device b) High-frequency bias device

Fig. 1. Set of MO equipment for research on relief marking (model of 2006)

Вій-5А MO imaging device (Fig. 1) helps to copy the visualized area with dimensions of 150 × 22 mm, the image has a physical size of image point: 37 m. The high-frequency bias device uses a harmonic signal with a frequency of 400 Hz and an amplitude of about 40 kA / m, which allows to increase the sensitivity of magnetography to weak signals of internal stress fields. The type of magnetic carrier used is a metal magnetic tape for ЕП-298 ТУ14-1-375-94 (bandwidth: 25.4 mm) digital recording. This type of magnetic carrier has a high amplitude of the recorded signal, however, also has a high level of structural noise. The set of MO equipment for research on relief marking of the 2018 model (Fig. 2) contains *Регула 7505м* MO visualization device, *Регула 7515м* high-frequency bias device, magnetic carrier: *BASF Sm900* plastic magnetic tape for analogue recording.

a) *Регула 7505м* MO visualization device b) *Регула 7515м* high-frequency bias device

Fig. 2. Set of MO equipment for research on relief marking (model dated 2018)

Регула 7505м MO visualization device (Fig. 2) ensures copying of the visualized area with dimensions of 450 × 18 mm, and the physical size of the image point: 14 m, which is much higher than similar indicators of the previous model.

Регула 7515м high-frequency bias device uses an impulse signal of instantaneous frequency up to 1 MHz with adjustable amplitude, which allows not only to increase the sensitivity of magnetography to weak signals of internal stress fields but also to create eddy currents in the surface layer (skin effect), having added to the magnetic component of the analyzed data also the electric alone. Additionally, the use of high frequency biasing enables to study not only magnetic materials, but also electrically conductive ones (in particular, aluminum alloys) [1].

The type of the used magnetic media carrier is *BASF Sm900* (magnetic tape for polymer-based analog recording, magnetic carrier width: 25.4 mm). This type of magnetic carrier has not only a high amplitude of a recorded signal but also a low level of structural noise, which significantly improves the signal-to-noise ratio for recorded magnetograms.

Experimental researches. The purpose of experimental research was to obtain visualization of latent images of a test object (hereinafter referred to as TO); research was conducted on two sets of MO equipment which were compared. TO is a plate of sheet metal (Steel 45 with the thickness of 1,5 mm) with the primary relief marking: 865 performed by the method of mechanical stress treatment (cold stamping). The size of a mark : font № 6 (characters height is 6 mm), the depth of characters relief is 0.3—0.4 mm. Conditions for changing the VIN number (removal of markings): grinding with the removal of a metal layer of 0.5 mm deep (it is impossible to visually determine contours of initial characters).

The appearance of the TO surface is shown in Fig. 3a, the relief mark in the form of a triangle on the right serves to mark the stressed side of the sample (side with removed signs).

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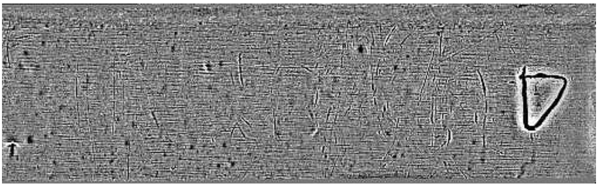
[1] Ibid; Пат. 42880 Україна ; Patent Certificate for Invention (China) № ZL2009801595628, announcement date 30.07.2014 announcement number CN102449470. Inductor of eddy currents for magnetic tape scanning and scanner based thereon. Inventor: Levyi S., Agalidi Yu., Shumsky I. Forwarding letter for the Patent Certificate Y/R: I000364MZ-CN, O/R: PIUA1111850(YFK), filling date 01.07.2009. Patentee: Levyi S., Agalidi Yu., Shumsky I. ; Patent Certificate for Invention (EP) № EP2435822 A1, announcement date 04.04.2018 announcement number 09845325, 09845325.1, 2009845325, EP 2435822 A1, EP 2435822A1, EP-A1-2435822, EP09845325, EP20090845325, EP2435822 A1, EP2435822A1. Inductor of eddy currents for magnetic tape scanning and scanner based thereon. Inventor: Levyi S., Agalidi Yu., Shumsky I. Forwarding letter for the Patent Certificate EP20090845325 filling date 01.07.2009. Patentee: Levyi S., Agalidi Yu., Shumsky I.

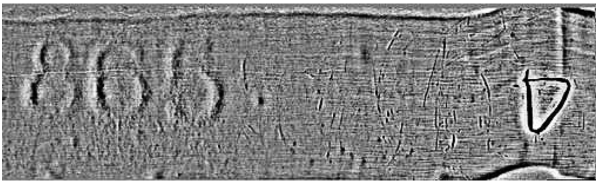
Qualitative assessment of the obtained experimental data (Fig. 3) indicates that there are significant differences in the results of the MO visualization of internal stress conditioned by properties of the compared models of complexes.

Thus, the complex of the magneto-optical model of 2006 (Fig. 3b) makes it possible to visualize the internal stress in the area of removed 865 signs at the level enabling to determine their original value (the image was obtained from the results of an eddy-current scanner). At the same time, the MO image has noticeable magnetic copying noises: black lines from the plane-parallel movement of a scanner mark the boundaries of the width of the magnetic imaging area. Also structural noises of the ЕП-298 metal magnetic tape could be observed: horizontal lines corresponding to the orientation of the domain structure and formed while magnetic tape manufacture (strip roll). Besides, a characteristic feature of high-frequency magnetic imaging is the high sensitivity to surface defects of types of scratches: location of scratches in the optical image (Fig. 3a) and MO image (Fig. 3b) is almost the same. However, in this type of research (restoration of signs of primary marking) such kinds of surface defects are uninformative: in fact, they are noises that prevent the reading of the signal of the internal stress field. In addition, the amplitude of the signal in gradation of brightness (Fig. 3c) looks a bit asymmetrical: the peak brightness of *white* reaches 209, that is +81 for the average level (*gray:* level 128), the peak of *black* is only 87 (or -41 from *gray*).

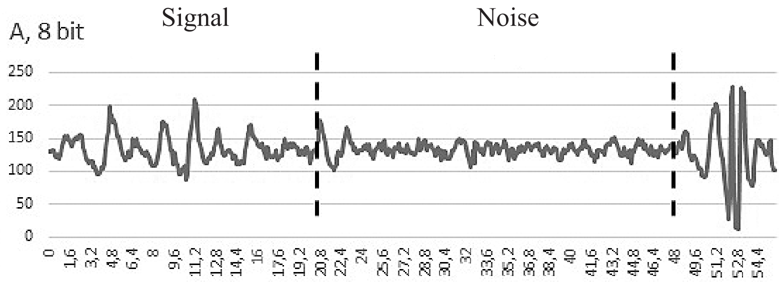
The set of MO model dated 2018 (Fig. 3d) also directly visualizes the internal stress in the area of the removed *865* signs, at the same time the image has a higher quality. The MO image of this complex has no noticeable noises: no traces of the scanner's trajectory are visible during magnetic imaging. The structural noises of the BASF Sm900 polymer magnetic tape are practically invisible, what corresponds to fine graininess size (approximately 0.5 m) and high homogenization of the magnetic substance. What is more, a characteristic feature of eddy current magnetic imaging is low sensitivity to surface defects such as scratches: location of big scratches in the optical image (Fig. 3a) and MO image (Fig. 3d) is identical, but small scratches in MO image are absent: they are filtered thanks to excitation of eddy currents in a deeper subsurface skin layer.



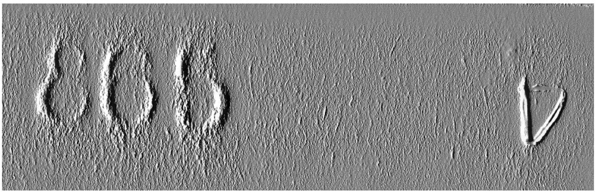
a)



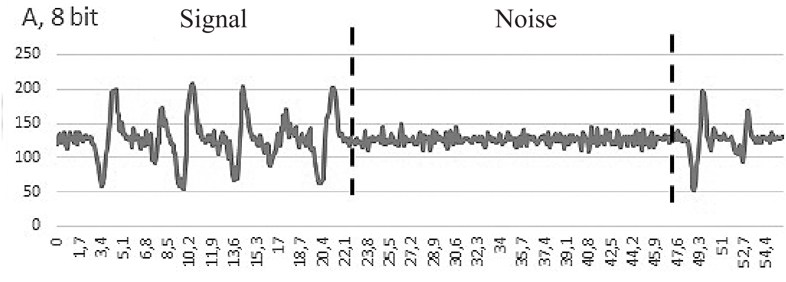
b)



c)



d)



e)

Fig. 3. TO with the internal stress of the metal in the area of destroyed relief marking: a) photo of the surface; b) MO imaging and signal amplitude for the device of 2006 model; c) brightness in the horizontal section for MO image b); d) MO visualization for the device model dated 2018; e) the brightness in the horizontal section for the MO image d)

The above-mentioned skin effect enabled to improve the detailing of MO image of the samples contours due to the superposition of dispersion fields from magnetic and electrical inhomogeneities in the areas of internal stress of the surface layer of a TO. The amplitude of the signal in the gradations of brightness (Fig. 3d) looks symmetrical: the brightness peak of *white* reaches 208, or +80 as to the average level (*gray*: level 128), while the peak of *black* is 55 (or -73).

Thus, the quantitative assessment of graphs and visual assessment of images of Fig. 3 show that the set of MO equipment of the model dated 2018 ensures a higher level of internal stress signal (in the area of destroyed marking) and a lower level of structural noise of a TO (in the area without marking).

Analysis of experimental data. To assess the signal-to-noise ratio and probability of correct signal recognition, a technique[1] based on the study of experimental data for signal and noise distributions was implemented: signal and noise areas are separated by vertical dotted lines (Figs. 3c, 3e).

According to the brightness of these sections, the values of mathematical expectation and standard deviation (for signal and noise respectively) were calculated, and the amplitude values of local brightness extrema calculated as moduli of deviation from the *gray* level were used to assess a signal and a noise.

The boundary value (decision threshold) of the correct recognition of the internal stress signal against the background of noise was taken to be the value at which the probability of erroneous signal detection is equal to the probability of signal omission. The value of the quantile corresponding to the tabular values [2] for the normal distribution with parameters (0, 1) was calculated as follows:

$$u_p = \frac{|M_с - M_ш|}{\delta_с + \delta_ш}$$

where: M, δ — mathematical expectation and standard deviation of a signal (с) and a noise (ш).

The Table 1 shows the values of mathematical expectation and standard deviations for a signal and a noise as well as results of the probability of correct recognition of the contours of primary (Fig. 3) markings.

Table 1

№ s/n	Set of MO equipment	$M_ш$	$\delta_ш$	$M_с$	$\delta_с$	u_p	P
1	Model dated 2006	8,1	5,6	36,5	21,7	1,04	> 0,851
2	Model dated 2018	5,2	4,1	60,2	17,0	2,60	> 0,995

Analysis of data from Table 1 demonstrates the following: the MO equipment set of the 2018 model has significant advantages, as evidenced by a higher level

[1] Агалиди Ю. С., Левый С. В., Мачнев А. М. Методика исследований сигналов и шумов … .

[2] Ивченко Г. И., Медведев Ю. И. Математическая статистика. Москва, 1984. 248 p.

of visualization quality indicators: the signal level increased by 20 lg (60.2 / 36.5) = 4.35 dB, while the noise level decreased by 20 lg (5.6 / 4.1) = 2.71 dB.

The criterion of exceeding the boundary level by the instantaneous value of the signal amplitude provides detection / recognition of symbols of removed relief marking with a probability not worse than:

- 0,995 for the set of MO equipment of the 2018 model;
- 0,851 for the set of MO equipment of the 2006 model.

At the same time, while forensic examinations, a forensic expert assesses results of experimental researches by a number of factors (font style and size, nature of structural surface noise, etc.) that are poorly formalized, i.e. recognition of primary marking by restored markings also depends on individual visual properties, features of psychophysiological processing of visual information and experience of forensic expert practice, etc.

The results of practical research using MO devices: "Регула 7505м" and "Регула 7515м". The unique characteristics of modern magneto-optical devices enabled to implement a number of new types of research previously unavailable or limitedly available for tools of forensic technique.

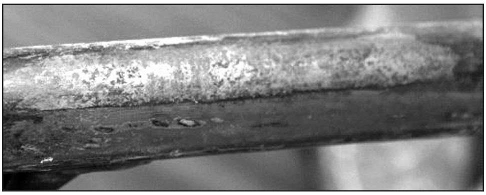
Thus, Fig. 4 demonstrates the result of a practical research on removed relief markings on the motorcycle frame (steel structure). Marking is removed completely, the layer of metal with relief markings is removed to a depth exceeding the depth of relief markings; it is impossible to identify contours of markings visually.

Peculiarities of this research are a shape and condition of the VIN plate area (Fig. 4b): VIN plate that is placed on a cylindrical surface (which is not convenient for most methods of trace evidence analysis); in addition, the surface is rough, with craters from ulcerative corrosion due to previous chemical etching (which was not effective).

Obtained results of MO visualization of internal stress fields in the area of removed marking helped to determine absolutely all signs of primary marking.

In addition, the detailing of the MO image made it possible to specify the method of carrying out primary marking (laser engraving) and the method of its removal:grinding with the use of a hand tool with a small diameter work tool (type: dremel; Fig. 4c).

a) Appearance of an object



b) Enlarged image of the VIN plate area

c) MO visualization of internal stress

Fig. 4. The result of a practical research on removed relief marking on the frame of the motorcycle (ferromagnetic material: steel)

In the following example of a practical research study of remote marking, the research object is also the motorcycle frame (Fig. 5), but the construction material is non-magnetic (aluminum alloy).

The VIN plate area (fig. 5b) is placed on a flat surface and is not considerably rough. Markings are also completely removed, contours of the markings cannot be visually established.

a) Object appearance

b) Enlarged image of the VIN plate area

c) MO visualization of internal stress

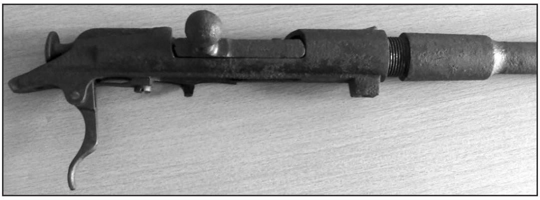
Fig. 5. The result of a practical research
on removed relief marking on the frame of the motorcycle
(aluminum alloy: non-magnetic, electrically conductive)

As was mentioned above, research by the magneto-optical method of internal stresses in non-ferromagnetic electrically conductive materials became possible only in models after 2018 (with the advent of eddy current technology of magnetic copying). The amplitude and depth of internal stress fields for aluminum alloys (due to significant ductility) is smaller than for steel.

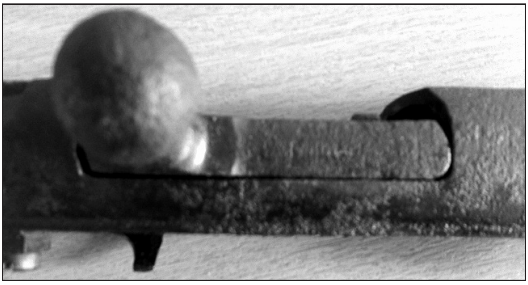
However, even in this case, the result of MO visualization of internal stress fields in the area of removed marking (Fig. 5c) allows to actually restore primary markings. Also, the high detailing of the MO image helps to draw a conclusion regarding the fact that laser engraving is the method of manufacturing primary marking.

Researches which results are provided in Fig. 4 and 5, were held in one of forensic centers of the United States with participation of a specialist from the *Регула* company.

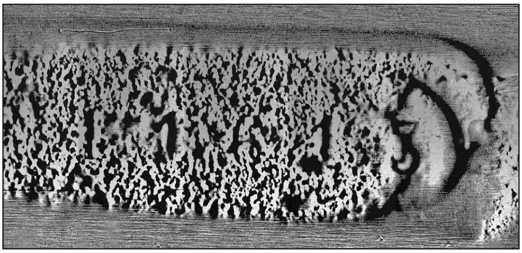
Subsequent researches were performed in the forensic center of Latvia; it is interesting because the marking is damaged as a result of surface corrosion process (Fig. 6).



a) Object appearance



b) Enlarged image of the VIN plate area



c) MO visualization of internal stresses

Fig. 6. The result of a practical research on removed relief marking on bolt-action of the rifle

The VIN area plate is placed on the shutter of the Mosin rifle, which has strong corrosion due to long stay under the ground (Fig. 6a, 6b), markings in the relief surface of the corrosion layer cannot be identified.

The corrosion layer has a heterogeneous structure due uneven corrosion process, in particular due to the dependence of the relief of the corrosion layer on the initial surface relief and on the internal stresses of the surface layer.

As stated above, the corrosion layer is a specific data carrier, and its studies (especially in a non-destructive manner) are now[1] available, as far as we know, only by the MO method.

From forensic expert practice it is known that for cases where corrosion penetrates to a depth greater than the depth of marking, the corrosion layer may be the last available source of information.

According to results of researches, obtained images of the MO visualization of internal stress fields enabled to establish all signs of primary marking (Fig. 6c). Detailing of the MO image is sufficient to determine the method of marking (plastic deformation, branding). There are no signs of primary marking removal.

After, results of a practical study of the removed relief marking on a container made of a thick layer of steel (Fig. 7a) are outlined.

Marking is removed in particular areas of the VIP plate area in order to get rid of important identification information applied by the manufacturer, as well as in the process of maintenance and filling cycles. Markings were completely removed, visible elements of primary marking are absent.

The surface of the container is curved, spherical, as a consequence implementation of marking renewal methods that use liquids is hard to put into practice.

Sizes of the VIP plate area compared to ordinary research objects (transport, weapons) are insignificant, and the number of characters in the VIP plate area reaches several dozen. An example of the VIP plate area is provided in Fig. 7b.

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[1] Агалиди Ю. С., Левый С. В., Троицкий В. А., Посыпайко Ю. Н. Магнитооптическая дефектоскопия приповерхностных слоёв ферромагнитных изделий. *Техническая диагностика и неразрушающий контроль*. 2007. Вып. 4. Р. 16—20.

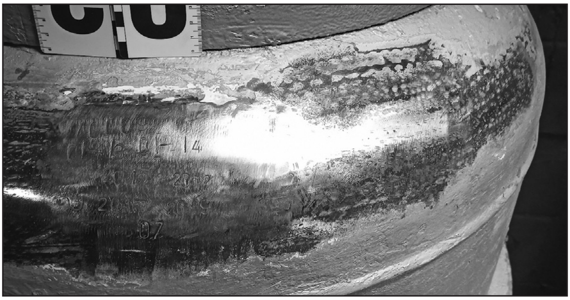
It should be emphasized that the material on which the marking is applied (branding by impacts manually) is low-carbon non-alloy steel with high ductility and low hardness, resulting in low residual internal stresses (this conclusion was drawn by forensic experts based on numerous expert researches on relief marking by impacts in different types of steel: from average carbon to complex alloyed).

The task of restoring marking on the indicated containers is complicated for all methods of marking restoring, as physical fundamentals of processes used in various methods of trace evidence analysis on marking restoring are structural heterogeneities (and, accordingly, residual stresses).

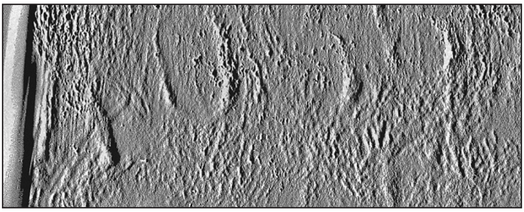
An attempt to use the method of chemical etching turned out to be ineffective for the above reasons: surface curvilinearity, size of the VIN plate area, residual stresses.

As a result of applying magneto-optical method for visualization of the fields of internal residual stresses, data which have identification meaning were restored in areas with destroyed primary relief marking. Examples of restored data are shown in Fig. 7c and 7d.

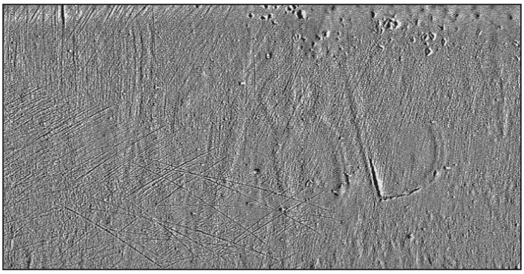
a) Appearance of object



b) Enlarged image of the VIN plate area



c) MO visualization 1



d) MO visualization 2

Fig. 7. The result of research on removed relief marking
on a thick-walled object (material: low-carbon non-alloyed steel)

It should be emphasized that the method of magneto-optical imaging is non-destructive: in all studies, geometry of the objects surface remained unchanged, without changing the residual stress fields. Thus, MO technology helps to repeatedly study the same areas using this method, for example, to clarify the elements of primary markings, ways to remove primary markings.

Researches carried out in indicated research papers[1] on the boundary sensitivity of the magneto-optical method for ferromagnetic alloys show that thanks to application of this method it is possible to restore markings after removing the metal surface layer to a depth of 1.5 mm.

Conclusions. Comparative experimental researches are conducted on the assessment of basic parameters of magneto-optical visualization of internal stresses of destroyed relief marking for two sets of MO complexes: models dated 2006 and 2018.

Quantitative assessment of obtained experimental data allows to provide a numerical assessment of main indicators of image quality for comparable sets of MO complexes. The best indicators of the 2018 model are noted in comparison with similar characteristics of the 2006 model:

[1] Agalidi Yu., Kozhukhar P., Levyi S., Turbin D. Enhanced magneto-optical imaging of internal stresses in the removed surface layer. *Nondestructive Testing and Evaluation*. 2015. Vol. 30. Is. 4. P. 347—355 ; Agalidi Yu., Kozhukhar P., Levyi S., Rogozhinsky Yu., Shumsky I. Eddy current fields/magnetic … . DOI: https://doi.org/10.1080/10589759.2011.610453 (date accessed: 22.02.2021).

- signal level is 4.35 dB higher (contrast of reconstructed marking signs);
- 2.71 dB lower noise level (surface relief/texture and magnetic copying noise);
- probability of correct character recognition is P> 0.995 increased by 14.9% (for the 2006 model, the indicator is P> 0.851).

Qualitative assessment of collected experimental data demonstrates that the complex of 2018 has significant advantages over the model of 2006, which is evidenced by a higher quality of visualization:

- improved detailing of the display of outlines of restored markings as a result of the superposition of the scattering fields of magnetic and electrical inhomogeneities in the area of internal stress (due to the eddy current nature of object magnetization);
- improved distinction / contrast of restored markings against the background of smoothed relief noise of the surface of the VIN plate area, which is one of results of the eddy current nature of magnetization in the subsurface skin layer;
- magnetic copying noise is significantly reduced due to the adaptive design of the flexible emitter of the eddy current scanner and fineness of the working layer of the polymer magnetic tape.

Results of practical researches obtained with the use of modern models of MO equipment by forensic experts from different countries sufficiently prove the effectiveness of MO technology for a wide range of objects with removed marking, in particular, traditionally complex for instrumental researches on plastic aluminum alloys and low-carbon non-alloy steel (with low internal stresses), a thick layer of corrosion on the surface of steel objects (in case of destruction of the initial relief and, most frequently, the subsurface layer of residual stresses).

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Підвищення достовірності експертної оцінки під час дослідження знищеного рельєфного маркування магнітооптичними приладами

Можливість відновлення даних видаленого рельєфного маркування залежить від чутливості інструментальних засобів дослідження та визначається співвідношенням сигнал/шум.

Останнім часом в експертній практиці для дослідження маркувальних даних металевих об'єктів використовують магнітооптичний метод, *реалізацію якого в цій статті представлено на прикладі двох поколінь комплексів, для яких досі не було проведено комплексного порівняльного аналізу.*

Метою статті є кількісна та якісна оцінка результатів візуалізації залишкових полів внутрішніх напружень для комплексів магнітооптичного обладнання моделей 2006 р. і 2018 р., а також презентація практичних результатів досліджень, у яких традиційні методи не мали успіху.

Ключові слова: *рельєфне маркування, магнітооптична візуалізація, відновлення даних видаленого маркування, неруйнівні методи.*

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Повышение достоверности експертной оценки при исследовании уничтоженной рельефной маркировки магнитооптическими приборами

При исследовании уничтоженной рельефной маркировки металлических объектов с помощью магнитооптического метода выполняют визуализацию (невидимых) полей внутреннего напряжения в зоне номерной площадки, а затем проводят экспертную оценку полученных инструментальных данных (непрямое органолептическое наблюдение за результатами визуализации); таким образом, достоверность экспертной оценки результатов непосредственно зависит от чувствительности приборов и информативности инструментальных данных.

Основной количественной характеристикой в данном случае выступает вероятность правильного распознавания сигнала (контуров знаков маркировки) на фоне шума (структурного шума исследуемой поверхности и шумов самого метода визуализации), определяемая соотношением сигнал/шум.

В данной статье представлены результаты сравнительной экспериментальной оценки отношения сигнал/шум и вероятности правильного распознавания сигнала при восстановлении уничтоженной рельефной маркировки для двух комплексов магнитооптической визуализации — моделей 2006 г. и 2018 г.

Целью статьи является количественная и качественная сравнительная оценка результатов визуализации внутренних напряжений на участках полностью удалённой рельефной маркировки металлических объектов. Результаты успешных практических исследований, полученных экспертами разных стран, дают возможность оценить эффективность и перспективность применения метода магнитооптической визуализации.

В новой модификации магнитооптического комплекса:

- *на 4,35 дБ выше уровень сигнала (контраст восстановленных знаков маркировки);*
- *на 2,71 дБ ниже уровень шума (рельеф/фактура поверхности и шумы магнитного копирования);*
- *вероятность правильного распознавания символов составляет Р > 0,995 (возросла на 14,9 %).*

Технические усовершенствования реализации метода магнитооптической визуализации позволили расширить диапазон материалов объектов исследования (исследованы магнитные и электропроводные материалы).

Высокую эффективность метода по восстановлению маркировки проиллюстрировано результатами экспертиз для материалов с низким уровнем остаточных напряжений (алюминиевого сплава, низкоуглеродистой стали), для которых метод химического травления не дал результатов.

Использование новой модификации позволяет исследовать слой ржавчины, вплоть до случаев коррозии на всю глубину знаков.

Учитывая неразрушающий характер магнитооптических исследований, возможность их многократного повторения без потери свойств объекта, этот метод (в соответствии с порядком применения видов исследований) заслуживает большего внимания для применения.

Ключевые слова: *рельефная маркировка, магнитооптическая визуализация, восстановление данных удалённой маркировки, неразрушающие методы.*

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Contributors

The authors contributed solely to the intellectual discussion underlying this paper, case-law exploration, writing and editing, and accept responsibility for the content and interpretation.