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Application of the nondestructive and destructive research to disclose identification marks on vehicles

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ABSTRACT

Disclosure of removed or illegible identification marks occurs when the need arises to establish the origin of the object or attempt to alter the original designation. In order to make it difficult to identify the subject, the offender removes all the marks characterizing the subject while applying a new mark. In addition to the most primitive character removal methods, there are those that make it difficult to evaluate the removal of the original mark. The publication presents selected methods of destructive and non-destructive testing which are used in forensic vehicle identification. The results of research on the detection of forgeries of vehicle identification numbers obtained using the methods discussed are presented in the publication. The presented results illustrate how easy it is to detect the attempts to process car numbers. As a result of the performed tests, the forgeries of a VIN (vehicle identification number) were revealed using the chemical method in a Hyundai Tucson car and the magnetic method in a Nissan car. In addition, using the thermal method, a forgery of the engine number of a Daewoo Matiz car was revealed. In turn, in an Audi A6 car, an attempt was made to counterfeit the VIN using the permanent magnetic method, and the method of replicas was disclosed.

Keywords: vehicles, identification marks, non-destructive methods, magnetic methods, electrochemical methods, chemical methods.

INTRODUCTION

Identification numbers are usually given in mass-produced items such as weapons, cars, motorcycles, televisions, radio receivers, electric motors, measuring devices, watches, etc. Disclosure of deleted and illegible identification signs occurs when the need arises to determine the origin of the object or suspicion of attempting to change the original sign.

Car theft is common in Europe [1]. Its consequences are attempts to give vehicles a new identity. In addition to forgery of documents, the most common form is forgery of vehicle identification numbers or even transfer of parts from the wrecked vehicle to the stolen vehicle [2].

Nowadays, cars can store a lot of information, divided into public and non-public [3]. Public identifiers include, e.g. VIN or registration plates. They are arranged for easy access and are visible. Public IDs are common in public administration, police, courts, and commerce and are therefore standardized nationally and/or internationally. However, public identifiers (e.g. VIN) can sometimes be hidden [4]. The purpose of this action is to make it difficult for potential counterfeiters to access the data (Fig. 1).

On the other hand, non-public identifiers include manufacturers' markings identifying parts

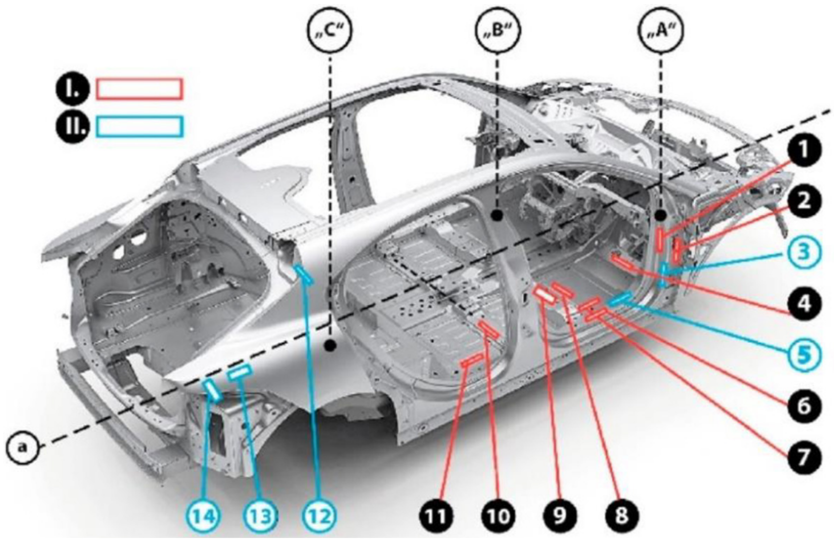

Figure 1. Examples of locations for VIN on the vehicle. Author: Rak [3]

or subassemblies, the date and place of their production, as well as production and/or maintenance services [5]. These identifiers are not intended for public use or processing and therefore are not usually standardized. Non-public identifiers are very useful for forensic purposes, as they very presciently identify a vehicle the public identifiers of which have been intentionally damaged or destroyed.

Since car theft is a common practice nowadays (Fig. 2), the methods of revealing falsified signs are mainly used in forensic science. Both destructive and non-destructive tests can be widely used to reveal the original identification of motor vehicles [6–8].

In the last decade, the number of car thefts in Poland has been decreasing (Fig. 2) and this trend can be determined using the polynomial approximation which is visible in Figure 2.

However, over 8.000 in Poland have still been lost in the last four years. A large number of cars are still stolen from their owners. Criminals wanting to profit from this practice must give the stolen vehicles a new identification.

The aim of the article was to present the results of public information authentication (VIN, engine number) verification tests using non-destructive testing methods, in addition to the effectiveness of detecting crimes despite the simplicity of methods.

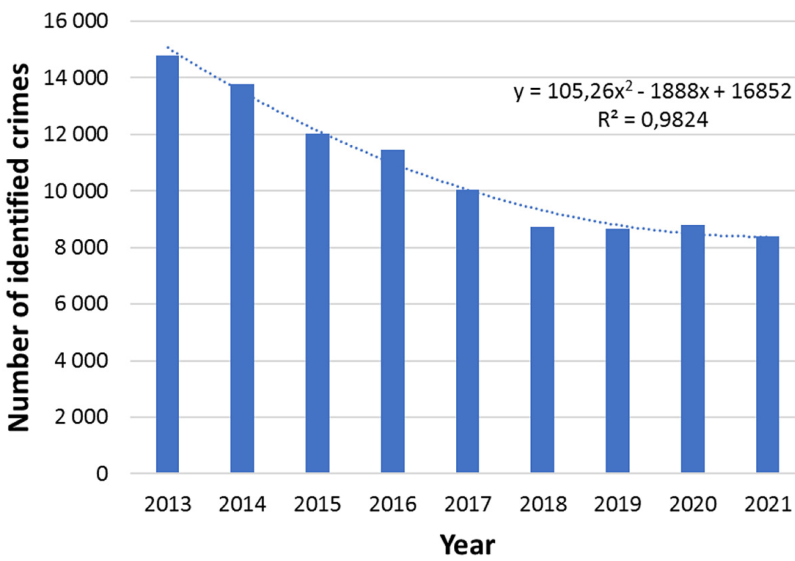

Figure 2. Number of confirmed car thefts in 2013–2021 [9]

Identification numbers applied in cars

The basic vehicle marking, which is a tool for combating car crime, is the original vehicle identification number – VIN. This number is assigned by the manufacturer and placed in specific places on the vehicle. Currently, a VIN consists of 17 characters (digits and letters), excluding the letters I, O and Q. In the European Union, it is assigned according to the ISO-3779 standard [10]. AVIN is divided into three sections (Fig. 3):

- WMI part. WMI, or World Manufacturers Identification – means the so-called global manufacturer's mark, which is made up of three characters of the VIN, where the first letter indicates the country in which the car was manufactured;
- VDS part. VDS, or Vehicle Description Section, is the second part of the vehicle identification number, which consists of six characters and is intended for its description (characteristics of the vehicle's construction, type of body, type of engine and other important features);
- VIS part. VIS, or Vehicle Identification Number, is the so-called section identifying the vehicle, consisting of eight characters, where the last four must be digits (year of production, designation of the factory or assembly plant in which the vehicle was built, consecutive production number of the vehicle).

In Poland, the Road Traffic Law specifies vehicle identification numbers, which are:

- VIN body,
- chassis number,
- and frame number.

Since 21st October 2005, when the Act of 29th July 2005 amending the Road Transport Act and certain other acts (Journal of Laws No. 180, item 1497) came into force, the engine number is no longer a vehicle identification feature, however, on 21st October 2005, the Act of 29 July 2005 came into force.

Destination methods applied in vehicle identification tests

In the process of revealing the signs removed from metal objects are differences in the structure of the places where individual signs were applied to the rest of the area of the number field. A common method to reveal damaged (deleted) determinations is a chemical method consisting in digesting chemical reagent surface of the number field. After digestion, the appearance of the place where the mark can be re-applied to the rest of the field can be stated unevenly. The electrochemical method is a modification of the chemical method. The digestion process in the electrochemical method is accelerated by electric current [6, 8].

Chemical and electrochemical method

The chemical method consists in the action on the surface of the metal with suitable chemical reagents, which are metal substrates. The intensity and chemical composition of the reagent used for digestion varies, depending on the grain size of the metal. The places where the sign (grains crushed, refined, different size from the rest of the substrate) were dissolved faster. If the sign was made as a cladding (the grains of the metal are larger), the place on which it is located is slower to dissolve, and the places beyond the sign dissolve faster. As a result of this varied digestion time, the contours of deleted characters contrast with the ground, allowing the original number to be read out (Fig. 4).

The tested material (sample) should be cleaned, for example, with sandpaper to remove any scratches

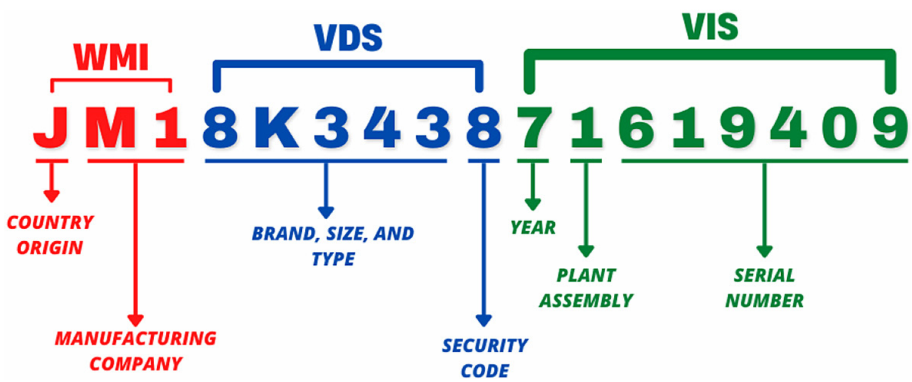

Figure 3. VIN structure [11]

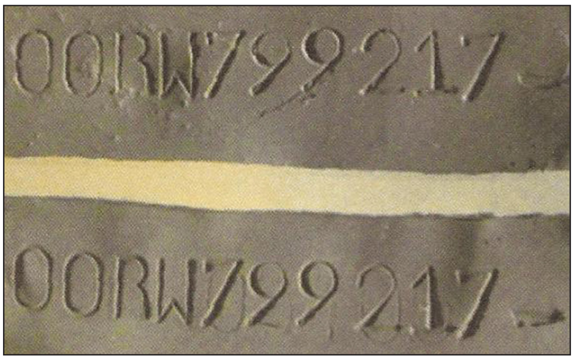

Figure 4. Silicone cast a numerical field made before research and after tests [12]

and other impurities. Then, the tested area should be polished so that the surface has a mirror reflection, if possible. The next step is to wash the surface with benzene or acetone, using cotton wool, to remove grease, paint or other organic impurities. The sample prepared in this way can be etched using a previously prepared chemical agent. The chemical composition of the etching medium depends on the chemical composition of the tested material [13].

The chemical method is a very sensitive method of detecting forgeries. In [14] it was shown that it is possible to restore a marking erased to a depth of 0.04 mm below the engraving depth. In turn, [15] describes the characteristics of restoring erased engraved marks on aluminum surfaces using the etching technique.

The electrochemical method, like the chemical method, uses different dissolution rates of the particles under the influence of chemical reagents and the electrical current that flows through them. The places where the signs were located are digested faster during digestion. As a result of digestion, the contours of deleted characters contrast with the ground, allowing the original character to be read. Disclosure of marks using the electrochemical method takes from several to tens of minutes depending on the etching agent used and the current [6].

Unfortunately, the chemical and electrochemical methods have certain disadvantages. First of all, they are destructive methods – the tests cannot be repeated because this method causes changes (etching) on the surface of the tested material [10]. In the case of a negative test result, another method cannot be used. Another disadvantage of the chemical method is its low effectiveness on cast iron engine blocks. Using these methods during tests for forgeries of body number plates may destroy the bodywork. Since the fumes of the chemical reagents used in this method are very harmful to the respiratory tract and highly corrosive in contact with the skin, these tests can only be performed outdoors [16].

Breaking the sign introduces energy disturbances in a given area, introducing local stresses, strengthening, falling plastic properties, and defects in the crystal lattice that causes the particles to crumble. The area with high surface energy reaches a certain depth in the material. A schematic process of applying changes to the structure of material while striking characters is shown in Figure 5. Depth of change depends on, for example, the strength with which the sign (force applied) and the material from which the number field is made [6]. An impact in the microstructure destroys the original one, wich is ofter obtained by a very sophisticated method of different treatment types, for example can constist of diverse variants of cooling after thermomechanical treatment: cooling in water, natural air-cooling and cooling in water after

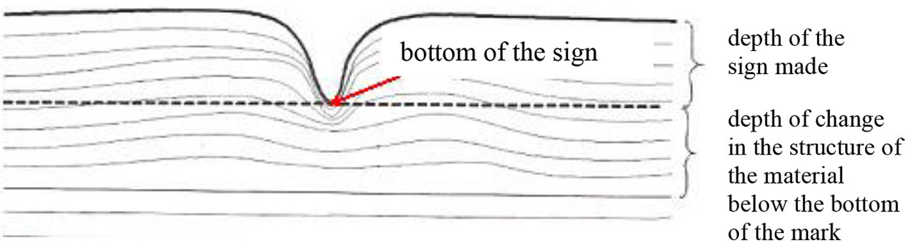

Figure 5. Schematic picture of changes in the structure of the material in the process of punching mark [12]

isothermal holding for 30 s at the temperature of last deformation 850 °C [17].

In the practical application of the thermal method, a surface thermometer is used to heat the surface of the number field to the desired value. Determining the temperature by color of a heated material in a practical application does not produce the desired effects.

Nondestructive methods applied in vehicle identification tests

Magnetic method

The magnetic method, also known as powder magnetic defectoscopy or the magnetic-powder method, was patented in 1920s by W. E. Hoke, and in the 1940s used in industrial research of materials. In the 1970s, this method found its place in forensic investigations in the disclosure of deleted characters on magnetic substrates [18]. The magnetic method of disclosing vehicle identification marks allows for the effective detection of surface defects of ferromagnetic materials.

The secondary effect of the plastic deformation resulting from the identification marking process is the gradual elongation of the grains. This results in the formation of a characteristic fibrous structure and associated anisotropy of property. In the deformed material, there is also a deformation texture, ie the directional orientation of the grain in the polycrystalline material with the distinction of a particular crystallographic direction. The resulting texture reduces the magnetic permeability.

After the number is embossed, the material structure within the stamped symbols is distorted. In the event of a counterfeit, if the original marking is removed, e.g. mechanically, traces of deformation remain in the material. Owing to the analysis of disturbances in the structure of the material by means of changes in the magnetic field in the material, it is possible to reveal a forgery (Fig. 6).

The magnetic method consists in subjecting an element in which hidden defects are sought (e.g. blurry signs) with a strong magnetic field. Before proceeding with disclosure the deleted marks, the place where the mark could be located must be thoroughly cleaned and polished with an abrasive paper of ever-smaller grain thickness. The surface thus prepared must be degreased by rinsing or washing with a solvent (petrol, ethyl ether, acetone, trichlorethylene or chloroform). The tested material, when applied into the magnetic field area sprinkle with magnetic powder or pour a magnetic powder suspension in kerosene, oil or other liquid carrier. Table 1 lists examples of magnetic suspensions used in the magnetic method [20].

The magnetic diffusion field exerts on the particles of the ferromagnetic powder a force

Table 1. Magnetic suspensions used to disclose identification using magnetic methods [7]

Kind of suspension	Description
Contrast lacquer ARDROX 8386W	White contrast lacquer used in magnetic-powder testing processes. Contains dichloromethane (CH_2Cl_2) 1,1,1 – trichloroethane ($C_2H_3Cl_3$)
Black magnetic suspension ARDROX 800/3	Through the cluster of black powder in the field places of the scattering fields, it creates defectograms of defects during the magnetic-powder testing of ferromagnetic materials. Contains hydrocarbon solvent.
Fluorescent magnetic suspension ARDROX 8530	Through the cluster of black powder in the field places of scattering fields creates defectograms of defects during magnetic-powder testing of ferromagnetic materials in ultraviolet light.

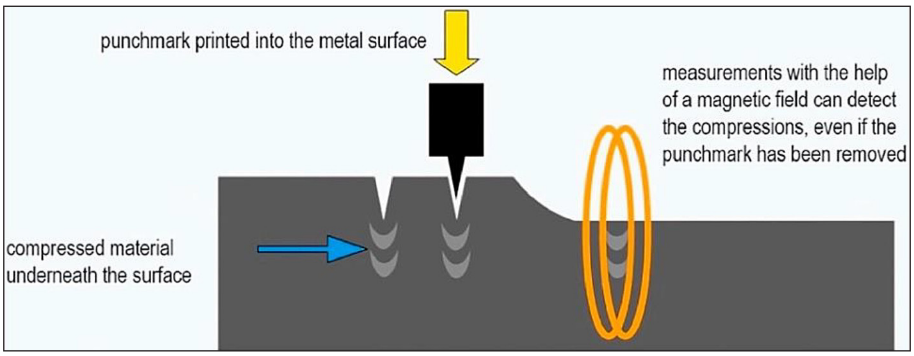

Figure 6. Verification of the counterfeit vehicle number using the magnetic method [19]

directed to the surface of the material to be examined, which causes the particles of powder to accumulate into the masses, which represent the actual shape of the defects or deformations that are the cause of scattering fields. As a result of interaction with the local fields of dispersion, ferromagnetic powder clusters are termed powdered defects (Fig. 7).

The activate of the magnetic field in the material and the search for local magnetic fields of dispersion, which indicate the presence of structural defects, is the basis for the permanent magnetic flaw detection. If solid state ferromagnetic powder is used to detect the local dispersion fields and the magnetic field generator is a permanent magnet, then this method is called permanent magnetic powder method.

The magnetic testing method for counterfeit car numbers and markings has several disadvantages resulting from the nature of its operation. First of all, it can only be used for ferromagnetic materials. For this reason, it cannot be used for testing some aluminum alloys or plastics. The shape and size of the magnets prevent its use in all vehicle models and the obtained results are not always unambiguous, so other methods should be used [12]. Moreover, the magnetic method can only detect surface and subsurface defects, and the detectability of defects depends on their location in relation to the direction of the induced magnetic field [21].

X-Ray method

The X-ray (radiological) method enables the detection of internal and surface discontinuities. This method is rarely used in forensic science because of costly apparatus and limited use – this method cannot be used to test numbers on hard-to-find items. In defectoscopy, the radiological method is used to control elements made of ferromagnetic and non-ferromagnetic metals, conductive and non-conductive materials such as ferritic and austenitic steels, gray and spheroidal cast iron, aluminum and its alloys as well as nonmetals (plastics, ceramics and wood) [22–24].

The research of radiological objects is based on [22–24]:

- exposure of X-ray (X) objects obtained from X-ray tubes or γ-radiation obtained from artificial isotopic sources,
- record shadow images of discontinuity in the form of a radiogram (Fig. 8).

The penetration of ionizing radiation is characterized by its ability to penetrate through matter. The so-called thickness of the half layer characterizes this ability. This is the thickness of the specified material in which the radiation intensity X or γ is reduced to half its initial value. When the radiation is ionized through matter, the radiation energy distribution changes. Less penetrating radiation is absorbed to a greater degree [25].

In radiographic studies, images of discontinuities of objects on radiographs obtained on radiographic membranes are analyzed. The registration of these images is possible due to the different attenuation of radiation for places devoid of discontinuities. Material discontinuities filled with air or material with a lower density than the

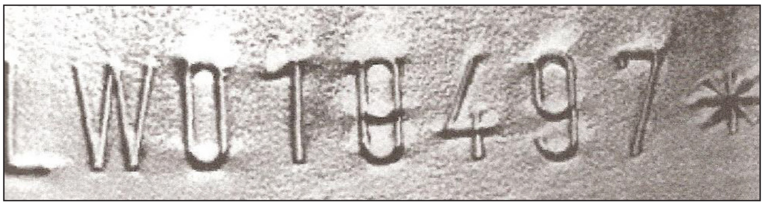

Figure 7. Powder defectogram [12]

Figure 8. Radiograph of Volkswagen's body number field [12]

material of the facility are places where less radiation is attenuated than in the areas without discontinuity [26–29].

The purpose of this paper was to present selected test methods used to disclose identification tags in motor vehicles.

Among the radiological methods, the most important thing to mention is the high costs of conducting tests related to the need to use complicated equipment and consumables. In addition, this method is characterized by poor detectability of flat discontinuities located perpendicular to the direction of radiation propagation and, as a result, the need for access to two opposite surfaces. The testing process itself is complicated and laborious. Also, one cannot forget about the risk associated with radiation [21, 25, 30].

This article presented selected methods of non-destructive and destructive testing used in forensics to reveal removed car identification markings. These methods are among the most frequently used and give the best results. A comparison of the methods used in the research for this publication is presented in Table 2. An important criterion for selecting these methods in the work of experts is also the economic aspect, because the use of the presented methods does not require expensive equipment. The aim of the article was to present the application of selected research methods in forensics, with the help of which it is possible to reveal forgery of car identification number markings. In addition, these methods can be used to reveal forgery of numbers and identification marks of other devices, machines and also collections.

MATERIALS AND METHODOLOGY

The following measuring devices were used to perform the tests:
- SM-1 permanent magnetic flaw detector,
- camera,
- thickness gauge.

In order to prepare the surface of the materials being tested for testing, especially to remove organic and inorganic dirt, the following were used:
- sandpaper with different gradation of abrasive grains: P800, P500, P120;
- soft and hard wire brushes,
- single-sided abrasive sponge type 03808 and 03809;
- acetone or extraction gasoline;
- substances for removing paint coatings that do not react with factory paint – BONDEX, Abbeizer Grüneck M-AB 30, VITAF Afbijtmiddel Decapant;
- reagents for etching steel and cast iron – copper or chromium reagent based on hydrochloric acid, aqua regia, sodium hydroxide NaOH (for aluminum), hydrochloric acid HCl;

Table 2. Comparison of the presented methods of detecting car counterfeits

Chemical methods	Magnetic methods	Radiological method
Very effective method, especially when revealing numbers on the vehicle body.	Relatively high effectiveness.	Poor detectability of flat discontinuities located perpendicular to the direction of radiation propagation.
Very simple and relatively quick operation.	Easy to use - simple principle of powder image formation.	Requires qualified personnel to operate.
No specialist equipment required.	Relatively short test time.	Requires specialist equipment.
It can be carried out anywhere – it does not require laboratory conditions.	The shape and size of the magnets prevent its use in all vehicle models.	The need to prepare the surface of the objects by removing scale, metal splinters, grease, oils, etc.
It is one of the most economical methods.	It is only applicable to ferromagnetic surfaces.	High research costs.
Destructive method – tests cannot be repeated.	Non-destructive method.	Non-destructive method.
Low efficiency on cast iron engine blocks.	Enables reading of ground-down characters even to a considerable depth.	Possibility of detecting flat discontinuities located along the direction of incident radiation.
Possibility of damaging the bodywork.	Not useful in engine number testing.	Possibility of assessing the dimensions of discontinuities in a plane perpendicular to the direction of radiation propagation Possibility of assessing the height of discontinuities in a plane parallel to the direction of radiation propagation.

To perform the magnetic tests, a white primer (white contrast) – MAGNAFLUX WCP-2 and magnetic dust dissolved in kerosene or water – MAGNAFLUX 7HF MPI INK were used.

RESULTS

The chemical method consists of the action on the surface of the metal with suitable chemical reagents that digest the metal substrate. This method reveals an attempt to change the numbered field of the Hyundai Tucson car. The places where the sign (grains crushed, crushed, other than the rest of the substrate) were dissolved faster revealing the original designation (Fig. 9–11).

The magnetic method of vehicle identification marking allows for the effective detection of surface defects of ferromagnetic materials using a permanent magnetic defectoscope processing of the Nissan X-trail vehicle number field (Fig. 12 and Fig. 13).

Magnetic methods of character counterfeit detection, including examining VIN fields and detecting tampering with other number fields, such as engine numbers, are based on registering and analyzing the distribution of own magnetic scattered fields (WMPR). They are formed in products in stress concentration zones (SKN) during the production or stamping of numbers. This diagnostic is based on an irreversible change in magnetization, which reflects the direction of

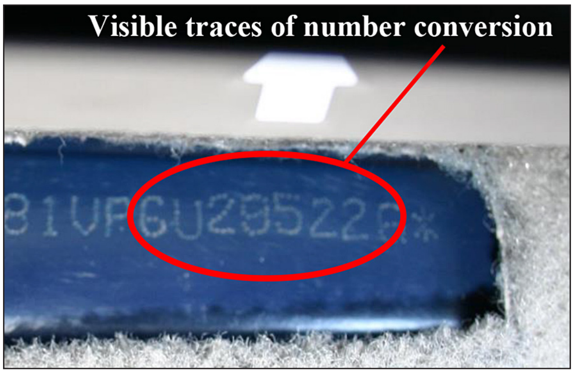

Figure 9. Numeric box made by point punching method with converted markings

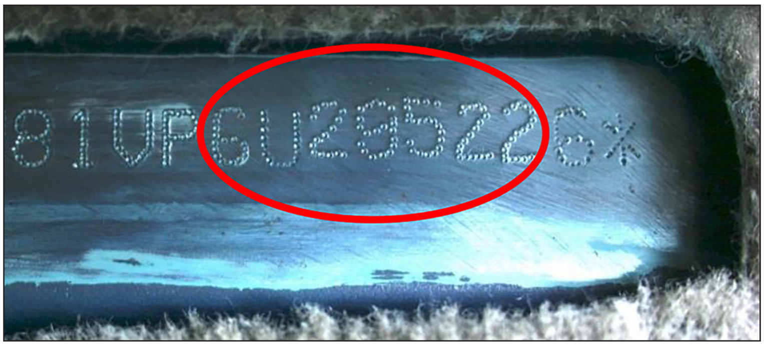

Figure 10. View of the number field after removing lacquer

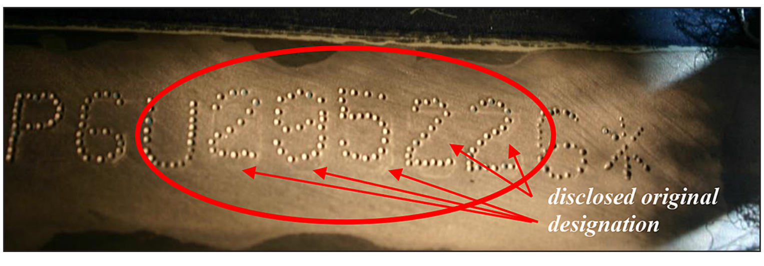

Figure 11. A fragment of a converted number field with the original signage revealed by the chemical method

Figure 12. Numeric box made with punching method without visible changes

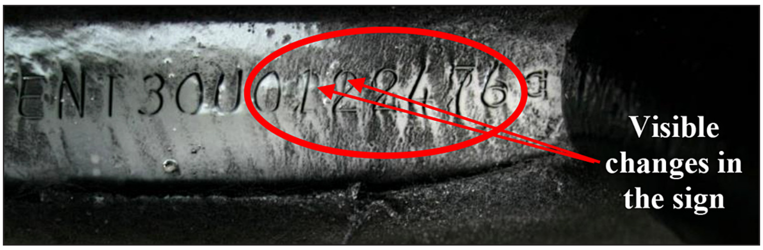

Figure 13. Displays changes in the number field using a constant magnetic flaw detector

the main stresses from working loads, as well as the structural and technological heredity of the metal/alloy, or the weld after their production, and then cooling in the Earth's magnetic field [29, 31]. The magnetic method of detecting forgery of car signs stamped in metal alloys is based on three physical phenomena [32]:

- changing the magnetization of the material under the influence of mechanical stress – the Villari effect (reverse magnetostrictive effect);
- change in the magnetization of the material in the plastic deformation zones, which is caused by the deformation of the material (reverse magnetoplastic effect);
- the leakage effect of the magnetic field intensity vector flux caused by the mechanical and structural inhomogeneities of the material.

Another example of the use of the chemical method to detect forgeries of markings of motor vehicles is shown in Figure 14. The etching reagents were applied to the surface of the field with specially prepared brushes in the form of a stick or a glass rod with a cotton pad wound on it. After the reagents were distributed evenly on the number field, an etching process took place, resulting in the false characters becoming visible (Fig. 15).

Figure 14. Number field after removing varnish and base paint

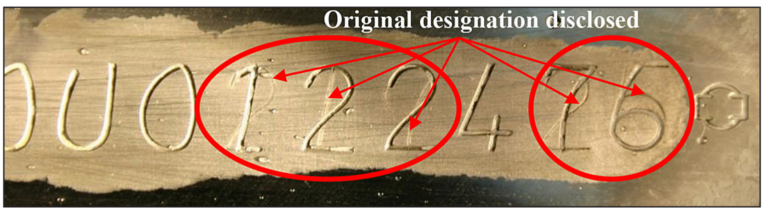

Figure 15. Fragment of a processed number field with the original labelling disclosed by the chemical method

The thermal method is also very useful for detecting falsified car numbers and markings. Breaking the mark causes an energetic disturbance in a given area through the defect of the crystal lattice, resulting in the fragmentation of microstructure grains and material strengthening, thus introducing local stresses and decreasing plastic properties. The area with high surface energy reaches a certain depth in the material [33, 34]. Plastic deformation causes distortions of the crystal structure in the metal, which is accompanied by an increase in the internal energy of the system (stored deformation energy). In the thermal method, the supply of thermal energy causes the gradual disappearance of network defects, and at the same time causes the separation of the stored deformation energy. Figures 16–18 show the engine number field of a Daewoo Matiz car.

Another example of a detected counterfeit is shown in Figures 19–21. Examination of the

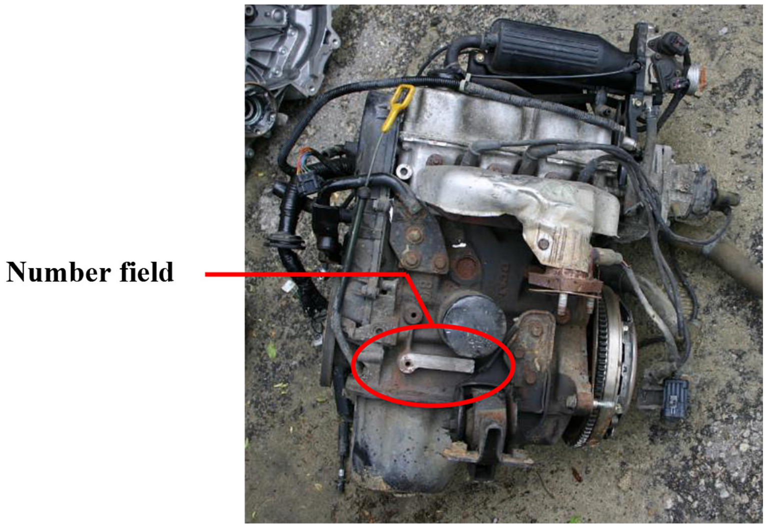

Figure 16. View of the engine with a visible sanded off number field

Figure 17. Number field with sanded off marking

Figure 18. Revealed identification marking using the thermal method

Figure 19. Part of the vehicle number field with visible changes to the marking

Figure 20. Primary VIN Marking Revealed

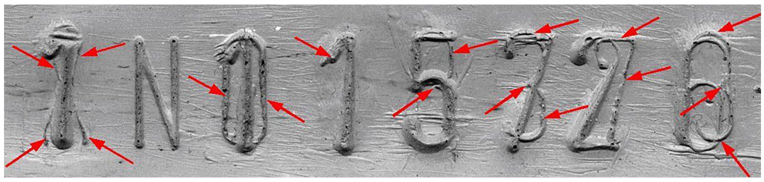

Figure 21. Micro force replica imitating the traces of rework. Arrows indicate the revealed primary characters

marking area of an Audi A6 car body with the use of a permanent magnetic flaw detector showed that within the field mentioned above, there are disturbances in the continuity of the car body sheet structure. The original VIN marking was revealed after removing the paint coating from the car body (within the number field) and the putty layer underneath it.

The forgery was detected owing to the fact that the permanent magnetic flaw detector enables the detection of cracks, sticking, delamination, crimping, rolling and other flat defects protruding to the surface or lying just below it and situated perpendicularly or obliquely to it [35]. The analysis of potential forgeries is also possible in hard-to-reach places in the car (e.g. in the windshield) by means of magnetic-optical visualization. It consists of copying the magnetic structure of the studied area, analyzing it with a magneto-optical head, and visualizing the results on a computer monitor [36].

CONCLUSIONS

Presented examples of destructive and non-destructive tests indicate high vehicle identification number disclosure efficiency. It should be stressed that the expertise and experience of forensic experts is of particular importance in conducting this research. As shown in [37], the appropriate location of X-rays determines the quality of results. The presented research results show that:

- chemical methods make it possible to identify false marks stamped on a metal surface (VIN, car chassis number);
- magnetic methods are primarily used to detect fraudulent VIN;
- thermal methods can be successfully used to identify car engine numbers.

The presented methods are among the most commonly used and best performing in forensics. An important criterion for choosing these methods in the work of experts is also the economic aspect, because the application of the presented methods requires no expensive apparatus.

The work does not include the latest research methods, which have not yet become a permanent fixture in police laboratories. This is often due to the fact that some of them are still at the development stage and are laboratory-based. The following should be mentioned in particular:

- verification methods using laser technology, and in particular LIBS – Laser-Induced Breakdown Spectroscopy, which enables non-contact surface testing, is a very useful tool due to its ability to create maps and profiles of elements, and also enables testing of surfaces and deeper layers of multilayer materials. The LIBS technique can be used to test multilayer organic and inorganic materials, as well as materials subject to diffusion-controlled processes, such as corrosion [38, 39];

- 3D imaging for structural analysis of materials; techniques such as micro-computed tomography are becoming more widely used and, in addition to visualizing the actual structure, they also enable quantitative description of the structure elements [40], are also non-destructive methods, and enable combining 3D structural characteristics with real-time in situ perturbations [41];
- machine learning for analyzing results (e.g. interpretation of X-ray images), which has been used for several decades to analyze the obtained results [42]. It enables analysis of very large amounts of data and verification (comparative analysis) of this data with previously collected results [43]. Machine learning or artificial intelligence tools, such as artificial neural networks, enable interpretation of results and non-linear analysis of many factors that affect the final effect.

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