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**INDUCTION HEATING IN HISTORY AND DEVELOPMENT.
APPLICATION IN MODERN TRANSPORT REPAIRING TECHNOLOGIES**

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***Abstract.** The technologies used in repair of vehicles were analyzed in the given paper. The shortcomings of the mechanical repair methods in question can be solved by using induction heating. Analysis of the stages of development and implementation of induction heating in industries showed effective performance of this technology and its opportunities for further improvement. An alternative repair technique, which consists in using induction heating, was proposed.*

***Key words:** induction heating, flattening, inductor, metal melting, eddy currents, electromagnetic induction.*

**ИНДУКЦИОННЫЙ НАГРЕВ В ИСТОРИИ И В РАЗВИТИИ. ИСПОЛЬЗОВАНИЕ
В РЕМОНТНЫХ ТЕХНОЛОГИЯХ СОВРЕМЕННОГО ТРАНСПОРТА**

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***Аннотация.** Проведен анализ существующих ремонтных технологий транспортных средств и автомобилей, в частности, с точки зрения недостатков, которые решаются внедрением в технологию ремонта индукционного нагрева.*

***Ключевые слова:** индукционный нагрев, выпрямление вмятин, индуктор, металлообработка, токи Фуко, технология ремонта.*

**ІНДУКЦІЙНИЙ НАГРІВ В ІСТОРІЇ ТА У РОЗВИТКУ. ВИКОРИСТАННЯ
В РЕМОНТНИХ ТЕХНОЛОГІЯХ СУЧАСНОГО ТРАНСПОРТУ**

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***Анотація.** Проведено аналіз існуючих ремонтних технологій транспортних засобів та автомобілів, зокрема, з точки зору недоліків, які вирішуються впровадженням у технологію ремонту індукційного нагріву.*

***Ключові слова:** індукційний нагрів, вирівнювання вм'ятин, індуктор, металообробка, струми Фуко, технологія ремонту.*

Introduction

Recently, the interest towards induction heating in household instrument making and repair technologies of motor transport has sharply increased. First of all, it is necessary to define the

induction heating process – this is heating of metal objects, called blanks by electric currents. Those are induced by the alternating magnetic field of the inductor (a single-turn or multi-turn solenoid). Relevant proposals of compact multi-functional equipment have taken place on the

websites of foreign and native companies. Thus, to remove small dents on the vehicle body covering surface, a contemporary straightening method is proposed. It is realized by metal shrinking when the residual internal stresses are removed due to heat release during the action of eddy currents. Also, the induction heating here described above is effective enough for disconnecting threaded connections due to their expansion and the contact corrosion layer destruction.

Analysis of publications

The eddy currents flowing is accompanied by the Lenz-Joule heat generation, which leads to the metal object heating [1]. This effect has found wide application in the industry for performing a huge number of production operations, for example, hardening of metal parts surfaces, contactless liquids heating, the metals levitation melting, etc. [2, 3]. In addition, it has found application at service operations like stickers removing, dismantling of the back and front glass in the modern cars that are also carried out by the help of induced Foucault currents, the thermal energy of which destroys the adhesive layers [4, 5].

Nevertheless, the existing traditional methods of the nodal connections repairing in vehicle designs suggest the open fire sources use [6]. At the same time, it should be noted that the modern methods of repair using induction heating have appeared recently as the market offer. Namely, there appeared such information in the Internet – not earlier than 2009–2010, concerning the repair equipment of European manufacturers [4]. Ukrainian electrotechnical companies presented their designs only in 2014–2015 [5]. At the same time, information about the author's developments of induction heating systems for vehicles repair appeared on the site of the Laboratory of Electromagnetic Technologies of Kharkiv National Automobile and Highway University [7].

It should be noted that induction heating systems advertisement of American companies appeared somewhat earlier. For example, the «induction heating system» had been presenting its developments in the Internet for 15 years [8, 9]. However, it cannot be used as devices designed for vehicle repair technology. The goal-oriented nature of these proposals could be generalized to the restoration of the element base of vehicles only after substantial constructive processing. The repair specialization of the American manu-

facturers equipment for induction heating as appeared much later [10].

The origins of the induction heating include great discoveries in the area of electrical engineering. This is M. Faraday's (1791–1867) electromagnetic induction discovery. «When a conductor moves in the field of a magnet, the EMF is induced in it, or that is the same when the magnet moves around the conductor contour. This current is called induced. Moreover, if a magnet is entered into the circuit, the one direction current is induced in it, and if the magnet is got out the, current of the other direction appears. The discovery of Faraday led to new scientific results in the area of electrical engineering [11]. The final theoretical substantiation of interaction of the electromagnetic field was given by JC Maxwell (1831–1879) [12]. The ideas of Maxwell and Faraday were confirmed by the works of G. Oersted, who discovered a conductor with a current and magnetic field around in 1820. And also A. Ampere, who discovered the effect of mechanical attraction and repulsion of conductors with a current flow. G.S. Ohm gave a description of the relation between the electric current and the resistance of conductor, obtaining all known Physics laws. The mathematical relation between the currents value and the resistance of the conductor was formulated by J. Joule (1818–1889) in 1840 (Law of Joule) [12]. Relying on these laws, V. Siemens in 1867 justified the principle of electric generator and engine and initiated electromechanical construction [13]. A bit later, N. Tesla (1856–1943) discovered the phenomena of a running rotating electromagnetic field and proposed the idea of the first generator of two-phase current in 1882. He came close to the designs of multiphase AC, developed the first transformer and received a high voltage source at high frequency, which subsequently led to the appearance of powerful alternating current generators and ensured the development of electromagnetic heating [14].

The purpose and problem statement

The aim and main problem of the article consist in comparative analysis of the effectiveness of existing vehicles repair technologies using the technologies based on induction heating. In addition, induction heating is presented as an alternative method that contributes to improving the quality of repair operations.

Existing vehicle repair technology

Before proceeding to describe directly the car units repair, it is necessary to define a diagnosis and determine which type of damage the damage in question relates to. Traditionally, such defects of body structures are:

- mechanical (dents, protuberances, bends, etc.) damage;
- corrosion;
- changing of geometry;
- destruction of welds;
- cracks, etc.

Correction of such defects acquired provides for work on leveling, drawing, knocking out and extruding the sections of the structure been deformed, as well as welding operations.

The complex of such activity for straightening requires a large number of devices. For example, small dents outside on the car body surface can be straightened by mechanical tools using (lever and screw mechanisms for moving the pull rod). But, on the other hand, this method does not guarantee the complete safety of the part repaired, since the rod is fixed either by electric welding or by glue. In both cases, the integrity of the top paint layer is under question. Also, straightening can be carried out with the help of reverse vacuum or pneumatic hammers, or manually. In such cases, the quality and efficiency of the straightening work depends entirely on the master skills. Rust damages of the car parts can be removed not only by mechanical cleaning, but with the help of metal patches applied to the parts with such a defect by welding. Significant geometry changes of the surface cannot be corrected without the use of special tools and stands robotized.

Thus, the main disadvantage of traditional repair methods consists in the open fire tools using. The objects to be repaired are heated by an open external flame, after which, as a result of thermal expansion, the bonds between semidetached structural components are weakened. Here are mentioned threaded joints with pressed components, etc. There is also a straightening technique of small dents with the help of heating the corresponding parts of the cover surface with its rapid subsequent cooling. The temperature differences excited lead to the appearance of internal mechanical stresses. Under special conditions, its action leads to the dents removing and the leveling of the metal surface of the vehicle.

That process becomes extremely fire hazardous, since there appears harmful evaporation; there is a high probability of damage of the repair unit or the body element, as well as the entire vehicle. There is a need for a large number of different expensive equipment conditioned by the lack of universality of such technologies use. In addition, the human factor is also a significant disadvantage.

Induction heating technology in modern repair techniques

As an alternative to the technologies described above, it is possible to propose a method that is carried out with tools based on induction heating. Heating with the help of eddy currents of Foucault allows to concentrate heat processes efficiently in the area defined with a minimum deviation out of its boundaries. Dissipation of thermal energy is small enough, which allows to implement a sufficiently rapid heating of the object of electromagnetic influence. The main condition required for the appearance of induction currents is the presence of closed loops for its flow. The implementation of this requirement must be provided by the proper inductor placing with respect to the conductive elements of the heated object.

The induction heating tool is an inductor that takes the form of is a flat circular or extended cylindrical solenoid. The tool with its working surface is laid on the heating element. It is also possible to place it in the internal cavity of the instrument.

Physically, the «inductor-heated metal» system is a current transformer whose primary winding is the inductor winding, the secondary winding is the metal heated. The first and most significant advantage of repair technologies with the induction heating use is the absolute absence of open fire. First of all, this circumstance completely excludes possible ignition with on going consequences, as well as also emphasizes all disadvantages of the traditional methods of repair that can be solved by induction heating. Effective realization of induction heating according to practical performance of this operation means the maximum possible heating within a minimum period of time. The efficiency in this case is the maximum heating rate achievement of the object processed. Consequently, the heating efficiency being distracted from the geometric and electrophysical charac-

teristics of the processing object is carried out by a maximum of the current transformation coefficient or by a sufficiently high level of electromagnetic coupling between the components of the «inductor-heated metal» system. It seems that a priori, from phenomenological considerations, it is possible to increase the intensity of the currents induced if the metal heated is placed in the internal cavity of the inductor, where the magnetic field excited is concentrated, or if a ferromagnetic is introduced into the inductor structure. Both proposals ultimately lead to an increase of the level of electromagnetic coupling between the source of the field and the processed object metal.

Conclusions

The existing problems of repair technologies was analyzed. Analysis of the existing technologies disadvantages shows that the induction heating tools application solves it with minimal cost and maximum efficiency for this type of repair work. To implement such operations as dent straightening on the car body, dismantling of pipe joints or a connector of rusty screwed connections, the induction heating system is required and a set of tools in the form of inductor systems. In addition, the proposed improvement of repair technologies is safe for the environment, saves material and energy resources.

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