ABSTRACT

Strelnikova V. A. Improving the efficiency of electromagnetic technologies of automobile transport repair. – Qualification scholarly paper: a manuscript.

Thesis submitted for obtaining the Doctor of Philosophy degree in Transport, Specialty 274 – Automobile transport. – Kharkiv National Automobile and Highway University, Kharkiv, 2021.

The work was accomplished at the Physics Chair of Kharkiv National Automobile and Highway University of the Ministry of Education and Science of Ukraine

The object of study is electromagnetic processes in the electromagnetic technologies tools of automobile transport repair: induction heating systems with ferromagnetic cores and systems of magnetic-pulse attraction of thin-walled metals with "direct current passage".

The subject of study is methods to increase the efficiency of electromagnetic tools for automobile transport repair, based on the introduction of ferromagnetic cores in induction heating devices and the use of Ampere's law in magnetic-pulse attraction systems with "direct current passage".

This thesis is devoted to further development of progressive technologies of automobile transport repair, from base elements of aggregates to body panels, using the energy of electromagnetic fields increasing the effect intensiveness on metal region caused by adding into repair-tool construction ferromagnetic cores, and also implementing of magnetic-pulsed attraction with “direct current passage” through the processing object.

Practical interest to electromagnetic repair methods is driven by their effectiveness in solving difficult technological tasks, such as flattering of vehicle bodies without any damage to their polish layer or its direct disassembly, which is higher than traditional way to manage same processes. Nowadays induction heating has not only industrial usage, but it is also production technology with many advantages under sustainable attention of

researchers. Development of new effective tools based on interaction between electromagnetic fields of source and processing object, analysis of processes in equal systems and search of ways to optimize the technology, all this and even more present the scientific novelty of the given thesis.

In the presented dissertation has been conducted analysis of induction heating technology and tools for its realization which allows indicating the real opportunity for increasing magnitude of induced currents and velocity of processing operation at the same level of energy by additional ferromagnetic cores in tools construction. Physically, such solution helps to decrease the dissipation of electromagnetic fields and concentrate them in local direction on processing metal region.

There has been investigated the effect of magnetic properties of inductor-tool inner space filling on electromagnetic processes in working metal object – massive billet and thin sheet metal, which were considered in two totally opposite physical idealizations: “transparency” for electromagnetic fields and superconductivity. The real problem of metal processing by electromagnetic effect is between them. In case of massive metal object, it is possible to reach “perfect” conductivity because it is corresponding rather high frequencies mode when an abrupt skin-effect takes place. But at the same time metal “transparency” depends on strict fulfillment of at least one of two conditions. The first is metal unit electrical conductivity that is tending to zero ($\gamma_1 \to 0$) which rather corresponds not to a conductor, but to a dielectric. Or the second one is exciting signal frequency that is tending to zero ($\omega \to 0$) which rather corresponds to direct current in the inductor winding, when any induction effects are not possible. However, the idealization of "transparency" is interesting for practical reasons because, though qualitatively, it sets possible benchmarks for the implementation of induction heating of massive and poorly conductive objects.

It has been determined that the dependence on magnetic properties of the selected media, inductor and metal being processed is determined by the factor $\beta = \frac{\mu_{r2}}{\left(\left(\frac{\mu_{r2}}{\mu_{r1}}\right)+1\right)}$.

Its value establishes the effect of magnetization on the excitation process of induced current in the metal sample.

The issue of thin-walled metal processing is a bit opposite than of massive one; some kind of “transparency” can be reached in the assumption of its rather low conductivity, due to the real values of unit electrical conductivity it is super low frequencies mode.

The analytical conclusion of the tool design with ferromagnetic core effectiveness, determination of the proportionality factor between the maximum densities of excitation and induced currents, which value defines the energy transformation in the investigating system “inductor – processing metal”, also corresponding experimental researches are testify to achievement of the set purpose of the dissertation thesis.

A separate part of the dissertation research is the magnetic-pulse attraction of sheet metals with “direct current passage” through the object of processing. Currently, there is not much information about research on this topic.

Analysis of magnetic-pulse methods of force, based on the attraction of specified areas of sheet metals, showed the demand for electromagnetic technologies for the restoration of vehicles and the need for their further development through the introduction of new tool designs.

Analysis of the effectiveness of non-contact magnetic pulse attraction tools based on the manifestation of magnetic properties of processed metals or on the force interaction of induced currents, showed the need to create new tools where attraction can be done by "direct current passage" through a given section of sheet metal.

The scientific novelty of the dissertation research is in the following statements.

1. For the first time, it is proposed to use of ferromagnetic cores in induction heating tools for the repair of automobile transport has been proposed, which leads to increased amplitudes of excited fields, increased intensity of thermal processes and reduced heating time of processing objects.

2. For the first time, it is proposed to use magnetic-pulse attraction with "direct current passage" through the treatment object to remove dents instead of mechanical analogues with a lever system for removing damaged areas of sheet metal, which significantly simplifies repair technology, reduce time and cost.

3. The theory of electromagnetic and thermal processes in massive and thin-walled sheet metals in the presence of a ferromagnetic core in the design of induction heating tools was further developed, which allows performing numerical estimates necessary for designing real effective repair tools.

4. Analytical approaches to theoretical models of electromagnetic processes in the working areas of tools with "direct current passage" have been further developed, which allows the performance of numerical estimates necessary for the design of real effective car body straightening tools.

5. Experimental models of the developed samples of electromagnetic technologies tools are successfully tested for automobile transport repair, both induction heating, and attraction with "direct current passage" that successfully allows to carry out reliable calculations of tools designs parameters for performance of real production operations.

The results of the dissertation research were used at Kharkiv National Automobile and Highway University in the framework of research work on the state budget topic “Universal tools of non-alternative electromagnetic technologies for repairing steel and aluminum elements of vehicle structures (inductor systems with attracting screen)” (the state registration number **№** 0117U002402, 2017-2018).

The developed systems of induction heating and magnetic-pulse processing have been tested at the enterprise “AVTODOM KHARKIV LLC”. The technical novelty of the developments is confirmed by 2 patents of Ukraine.

Also, the results of the dissertation are used in the educational process of Kharkiv National Automobile and Highway University in teaching the disciplines “Fundamentals of technology of production and repair of automobiles” and “Electric machines”.

Key words: automobile transport, effective repair technologies, induction heating, magnetic-pulsed attraction, “direct current passage”, electrical engineering

LIST OF APPLICANT’S PUBLICATIONS

The main scientific results of the dissertation

Articles in scientific specialized editions of Ukraine:

1. Batygin YV, Sabokar OS, Strelnikova VA. Induction heating. History and development. Application in modern transport repairing technologies. Automobile transport. 2017;40:75-9.

(*Personal contribution of the applicant*: an analysis of existing repair technologies of automobile transport, a proposal to use induction heating as a modern technology that eliminates the disadvantages of traditional repair equipment)

2. Batygin YV, Strelnikova VA. Induction heating and magnetic-pulsed attraction for modern production technologies. Kharkiv: Leader; 2019. 162 p. ISBN 978-617-7476-29-9

(*Personal contribution of the applicant*: a formulation of topics, collection and processing of theoretical material, design of the publication)

Articles in scientific publications of EU countries:

3. Strelnikova V. Experimental research of induction heating in inner hollow of cylindrical solenoid. European Journal of Engineering Research and Science. 2020;5(8):986-9. doi: 10.24018/ejers.2020.5.8.2053

Published works for approbation purpose:

4. Strelnikova VA, Voronova YM. Electromagnetic metal forming. The relevance and prospects for the use in industry. In: Integration processes and innovative technologies. Achievements and prospects of engineering sciences; 2017 Mar 22; Kharkiv. Kharkiv: KhNAHU; 2017, 7(2), p. 205-7.

(*Personal contribution of the applicant*: a prospects definition of application of electromagnetic metal forming for repair technologies of automobile transport)

5. Lavinsky DV, Konkin VM, Strelnikova VA. Numerical estimates of temperature field inside the elements of power equipment including electromagnetic field affection. In: Energy and thermal engineering processes and equipment; 2019 Apr 25-26; Kharkiv. Kharkiv: NTU “KhPI”, “Leader”; 2019, p. 66-7.

(*Personal contribution of the applicant*: a participation in the development of an effective method of analysis of a non-stationary temperature field arising in conductive materials under the influence of an electromagnetic field)

6. Strelnikova VA. Modern technologies of automobile repair using electromagnetic metal forming. In: Energy resources saving problems in production area. Science and practice; 2017 May 11-12; Mariupol. Mariupol: Priazovsky STU, 2017 p. 70-2.

7. Strelnikova VA. Induction heating of metals process modeling using finite-element analysis program package ANSYS. In: Mathematical training in a multilevel system of higher education: the view of students and young scientists; 2017 Apr 13-14; Kharkiv. Kharkiv: KhNAHU; 2017, p. 412–4.

Articles in scientific professional editions of Ukraine, whichadditionally reflect the results of the dissertation

Articles in scientific professional editions of Ukraine, which are included in international science-computer databases (Web of Science):

8. Batygin YV, Chaplygin EA, Shinderuk SA, Strelnikova VA. The main inventions for technologies of the magnetic-pulsed attraction of the sheet metals. A brief

review. Electrical Engineering & Electromechanics. 2018;3:43-52. doi: 10.20998/2074-272X.2018.3.06.

(*Personal contribution of the applicant:* a theoretical review of the existing magnetic-pulsed technologies of sheet metal attraction, comparative analysis of attraction tools for production operations)

9. Batygin YV, Chaplygin EA, Shinderuk SA, Strelnikova VA. Numerical estimates of currents and forces in linear tools of the magnetic-pulse attraction of metals. Part 1: Low electrical conductance metals. Electrical Engineering & Electromechanics. 2019;5:40-4. doi: 10.20998/2074-272X.2019.5.07.

(*Personal contribution of the applicant:* a definition of magnitude-time dependences of currents and electrodynamic forces in linear magnetic-pulsed tools for processing metals with low electrical conductivity)

10. Batygin YV, Chaplygin EA, Shinderuk SA, Strelnikova VA. Numerical estimates of currents and forces in linear tools of the magnetic-pulse attraction of metals. Part 2: High electrical conductance metals. Electrical Engineering & Electromechanics. 2019;6:39-43. doi: 10.20998/2074-272X.2019.6.05

(*Personal contribution of the applicant:* a definition of amplitude-time dependences of currents and electrodynamic forces in linear magnetic-pulsed tools for processing metals with high electrical conductivity)

11. Batygin YV, Chaplygin YO, Sabokar OS, Strelnikova VA. Analysis of electromagnetic processes in the system “cylindrical solenoid – massive conductor” Electrical Engineering & Electromechanics. 2018;1:54-8. doi: 10.20998/2074-272X.2018.1.08

(*Personal contribution of the applicant*: a determination of multi-turn cylindrical solenoid parameters as an instrument of induction heating, influencing the magnitudes of excited eddy currents in a massive conductor)

Articles in scientific specialized editions of Ukraine:

12. Batygin YV, Sabokar OS, Strelnikova VA. Equipment for practical induction heating implementation in modern technology engineering. Visnyk of Vinnytsia Polytechnical Institute. 2017;4(133):70-4.

(*Personal contribution of the applicant:* an analysis of production methods for metal heating, a description of alternative induction heating system for solving problems of repair and maintenance of automobile transport)

13. Batygin YV, Sabokar OS, Strelnikova VA. Induction heating of thin ferromagnetic plate by the field of plane solenoid. Visnyk of Vinnytsia Polytechnical Institute. 2017;6:135-140.

(*Personal contribution of the applicant*: a solution of the physical and mathematical problem for the inductor-thin ferromagnetic plate system, an analysis of the obtained results)

14. Strelnikova VA. Features of induction heating of a massive metal billets by inductors with ferromagnetic cores. Bulletin of NTU "KhPI" series "Problems of Electrical Machines and Apparatus Perfection. The Theory and Practice". 2018;32(1308):99-104. doi: 10.20998/2079-3944.2018.32.17

15. Batygin YV, Yeryomina EF, Chaplygin YA, Strelnikova VA. Electrodynamic processes in instruments of magnetic-pulse attraction at direct current passing through the handled metal. Bulletin of the NTU "KhPI" series "Mathematical modeling in engineering and technologies". 2019;8(1333):207-13.

(*Personal contribution of the applicant*: obtaining analytical dependences that allow to calculate the current distributions in the cross section of the sheet metal under the action of the tool of magnetic-pulsed attraction by direct current passing through the processed metal)

16. Batygin YV, Yeryomina OF, Shinderuk SO, Strelnikova VA, Chaplygin YO. Magnetic-pulsed attraction of sheet billets with "direct passage of current". Bulletin of the

NTU “KhPI” series “New solutions in modern technology”. 2020;4(6):3-13. doi:10.20998/2413-4295.2020.04.01.

(*Personal contribution of the applicant*: a theoretical substantiation of the efficiency of a method of magnetic-pulsed attraction of metals with “direct current passing” through the processed object, the solution of boundary electrodynamic problem for obtaining of phase dependences of currents in experimental system and excited forces of attraction of processing object)

17. Batygin YV, Chaplygin YO, Sabokar OS, Strelnikova VA. Induction heating in the inner cavity of the cylindrical solenoid. Running processes main relationships. Herald of Khmelnytskyi national university. 2017;6(255):32-6.

(*Personal contribution of the applicant*: a development of a model of induction heating of toothed cylindrical blanks and solution of an electrodynamic problem for the presented model)

18. Batygin YV, Serikov GS, Shinderuk SO, Strelnikova VA. Resonant reactive power amplifier. Analysis of electromagnetic processes. Electrical Engineering and Power Engineering. 2019;2:34-42.

(*Personal contribution of the applicant*: a formulation of recommendations for further development of circuit elements of power supplies for magnetic-pulsed attraction of metals)

Patents:

19. Batygin YV, Chaplygin YA, Sabokar OS, Strelnikova VA, inventors; KhNAHU, assignee. Method of processing sheet metals by concentrated energy sources of magnetic fields with preheating. Patent of Ukraine № 121597. 2017 Dec 11.

(*Personal contribution of the applicant*: a development of the formula of the utility model and the description of its functioning)

20. Batygin YV, Sabokar OS, Strelnikova VA, Shinderuk SA, Chaplygin YA, inventors; KhNAHU, assignee. Induction heating device with magnetic concentrator. Patent of Ukraine № 122800. 2018 Jan 25.

(*Personal contribution of the applicant*: development of a utility model formula and preparation of patent application documentation)

International Internships:

«Uczciwość akademicka»: 14–25 października 2019 r. – 120 god. Uniwersytet Kardynała Stefana Wyszyńskiego w Warszawie (Poland) and Foundation Institute for International Scientific and Academic Cooperation. Certificate KW-102019/010; 25.10.2019

"ENGR2000X: A Hands-on Introduction to Engineering Simulations" of Cornell University. Valid Certificate ID f154360b025140b5b870c1fb0e8f92d0 Verified Certificate Issued January 12, 2020