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ELECTROMAGNETIC PROCESSES RESEARCH IN THE WORKING CHAMBER WALLS OF ELECTROMECHANICAL DISINTEGRATOR

N. N. Zablodskiy[1], **V. Yu. Gritsyuk**[2], **O. A. Timofeeva**[2]
[1]*National University of Life and Environmental Sciences of Ukraine*
[2]*Volodymyr Dahl East Ukrainian National University*

Annotation. *The results of numerical calculation of the eddy current distribution and electromagnetic forces in the working electroconductive chamber walls of the electromechanical disintegrator are obtained. The results are agreement with the experimental data, which makes it possible to use the model to improve the design of electromechanical disintegrator.*

Key words: *electromechanical disintegrator, working chamber, numerical simulation, eddy currents, distribution of electromagnetic forces.*

Introduction

Today the processes of crushing and grinding of solid materials for enrichment, allocation of a useful part, and increase of rheological activity, increase of contact surface and intensification of a number of physicochemical processes are the most common technological operations of industrial production of various materials. One of the methods allowing to carry out various technological processes of thin and ultrafine grinding, homogeneous mixing of liquid and solid powder substances (preparation of emulsions, suspensions), acceleration of some chemical Reactions, is the application of a fundamentally new class of electromechanical converters of energy – electromechanical disintegrators (EMD) of multifactor action [1, 2].

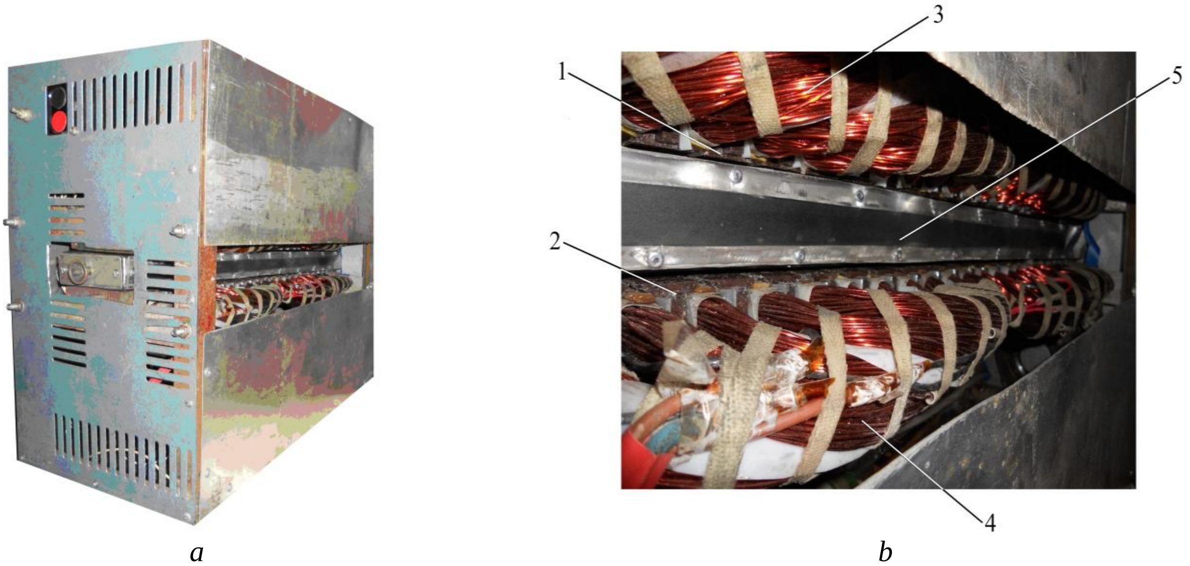
The topical direction of application of such devices can be processing of wastes of human activity, neutralization and utilization of industrial, household and agricultural waste. Existing traditional technologies of neutralization and utilization of industrial and domestic effluents are technically imperfect, consume large amounts of energy, occupy huge areas and are environmentally dangerous [3]. Despite the fact that the devices with the vortex layer have already found application in various industries, the complex physical and mechanical-chemical phenomena occurring in the vortex layer, remain poorly studied. In addition, the existing papers [3-6] deal with the efforts and moments arising in devices whose vortex layer is created by a rotating magnetic field, and some works [7, 8] are devoted to disintegrators created on the basis of axial induction motors with massive rotor that is also a working body.

Fig. 1, *a* shows the general view of the experimental sample of EMD, manufactured in Donbass State Technical University. EMD consists of the upper 1 and the lower 2 flat inductors with three-phase windings 3 and 4, which form the running magnetic fields with the opposite order of alternation of phases, and working chamber 5 with ferromagnetic working bodies (FWB) which is located in the interinductors gap (fig. 1, *b*). Technical data of the experimental sample EMD are given in table 1. Counter running fields form within each pole division of the inductor local zones with intensive vortex movement of FWB (for example, needle type), with the use of which the treatment of the original substance occurs. The vortex layer of FWB can be created both at pressure, and in vacuum, in liquid, gaseous or heterogeneous environment. In addition to the direct mechanical impact of FWB and the electromagnetic field, the processed substance also has a number of concomitant effects: heating, mechanical activation, electrization, a wide range of local acoustic pressures and under certain conditions also cavitation and electrolysis (for liquid materials).

An important issue in the design of EMD is the qualitative and quantitative assessment of the distribution of eddy currents and electromagnetic forces in the walls of the working chamber.

The nature of the distribution of the eddy currents determines the value of the active resistance of the secondary part, which plays an important role in the formation of the working properties and the character of the thermal regime of the EMD. At the same time, the degree of deformation of the working electromotive chamber EMD is determined by the magnitude and duration of the action of electromagnetic forces on its walls.

The goal of the paper is to investigate the distribution of eddy currents and electromagnetic forces in the walls of a working electroconductive chamber of an electromechanical disintegrator of multifactor action.



a *b*

Fig. 1. Experimental sample of EMD:
1, 2 – inductors of running field; 3, 4 – three-phase windings; 5 – working chamber.

Table 1

Technical data of EMD

Parameter name	Value
Source of power	AC network
Supply voltage	380 V
Frequency	50 Hz
Number of phases	3
Active power	4 kW
Consumption current	26,5 A
Consumption current (work without FWB)	27,1 A
Power factor	0,23
Volume of the active zone of electromagnetic	2,82 dm^3
The volume of the working chamber	2,68 dm^3
Operating mode	Short-time
Maximum start-up time followed by a pause for	7 min
Cooling	Forced air

Mathematical model

Calculation of the real distribution of eddy currents and electromagnetic forces in the walls of a working electroconductive chamber is possible when using a three-dimensional mathematical model that takes into account the features of geometry and the factor of finite length. FWB in the vortex layer perform complex motion – translational with a frequent and abrupt change in speed and direction and rotational with a variable angular velocity. The nature of the FWB movement, a large number of factors that significantly affect the processing of material, complicate the theoretical consideration of this issue. Accounting for the presence of FWB in the working chamber without taking into account their complex trajectory and the nature of the motion does not make sense. However, a sufficiently small mass of working bodies in relation to the occupied volume of the EMD electromagnetic interference zone causes a very slight change in the current consumption (1,9-2,3 %) when the FWB is extracted from the working chamber. Taking this into account, we can assume that the pattern of the distribution of the electromagnetic field in the EMD does not change significantly.

In general, the non-linear differential equation of the electromagnetic field in private derivatives relative to vector magnetic potential *A* can be represented as

$$rot(\frac{1}{\mu}rotA)-\gamma\frac{\partial A}{\partial t}-\gamma(v\times rotA)=-J_{ext},$$

where μ – absolute magnetic permeability;

γ – specific conductivity;

v – vector velocity of the electroconductive medium relative to the magnetic field source;

J_{ext} – density extraneous current.

Algorithm of numerical calculation of electromagnetic field EMD, physical properties of calculation parts, as well as boundary conditions similar to those considered in the work [9].

The material of the working chamber is non-magnetic stainless steel with specific electrical conductivity – $1,1\cdot10^7$ S/m. To reduce the estimated time of the model and the amount of hardware resources required, the three-dimensional calculation of the electromagnetic field was performed for the bipolar variant of the EMD.

To create a three-dimensional finite-element model was used software complex Comsol Multiphysics. Fig. 2, 3 shows the three-dimensional geometry and the finite element grid of the model, respectively.

The presentation of the material and its results

When analyzing electromagnetic processes with the use of three-dimensional finite element models, the requirements to the accuracy of the solution essentially increase.

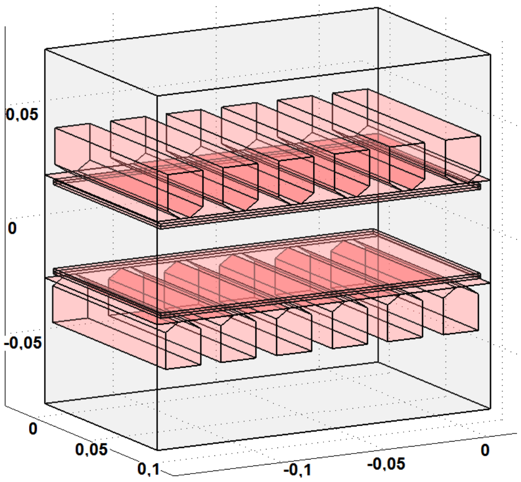


Fig. 2. Three-dimensional geometry of model

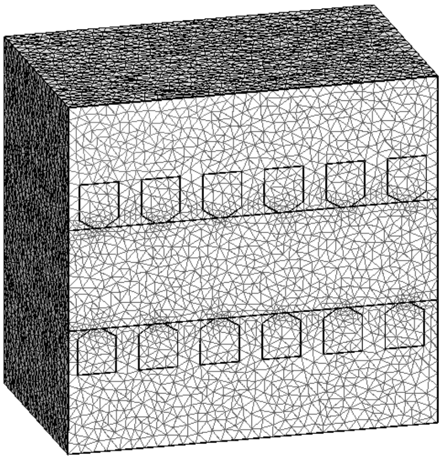


Fig. 3. Finite-element mesh of model

Therefore, at the first stage of the research, the measurement of magnetic induction in the gap of the experimental sample of EMD and subsequent comparison with the numerical calculation of induction for a three-dimensional model were performed. For experimental determination of local values of induction, we used measuring coils made in accordance with the recommendations of [10]. A general view of one of the coils is shown in fig. 4.

Fig. 4. General view of the measuring coil

The number of turns of the measuring coil is 120, the external diameter is 14 mm, the inner diameter is 9 mm. The magnitude and shape of the measured EMF were recorded using a digital oscilloscope RIGOL DS5062M. Based on the results of measurements of the local values of magnetic induction in the middle of the gap in the pole division of the EMD, the largest induction value was 0,11 T. The induction value near the inductor (at a distance of 1,5-2 mm) reaches a value of 0,14 T.

The motion of working bodies begins at a magnetic induction of 0,06 T. When the induction reaches 0,08...0,1 T, practically in the entire working volume of the EMD the regime of intensive movement of the FWB begins.

The spatial graph of distribution of the magnetic induction in the EMD gap, obtained from the calculation of the finite-element model, is shown in fig. 5. The greatest local values of magnetic induction (on the graph are shown in dark-red color) correspond to the gap points, which are as close as possible to the narrowest parts of the crowns of the inductor teeth. The character of the induction distribution in the middle of the EMD gap in the pole division showed good agreement with the data of the physical experiment (fig. 6).

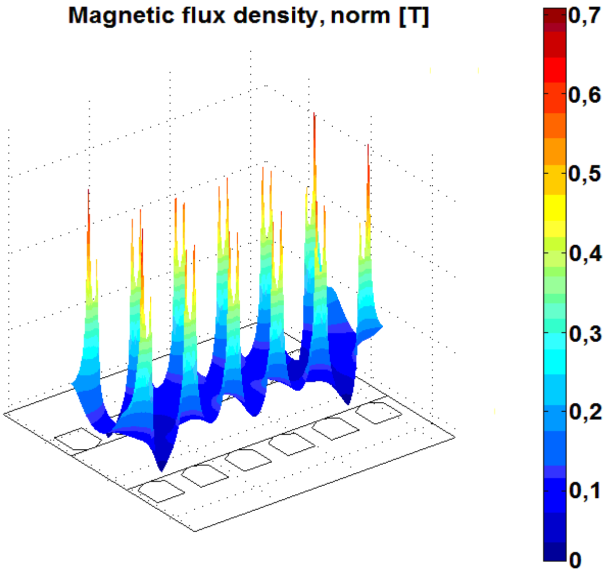


Fig. 5. Spatial graph of distribution magnetic induction in the air gap of the EMD

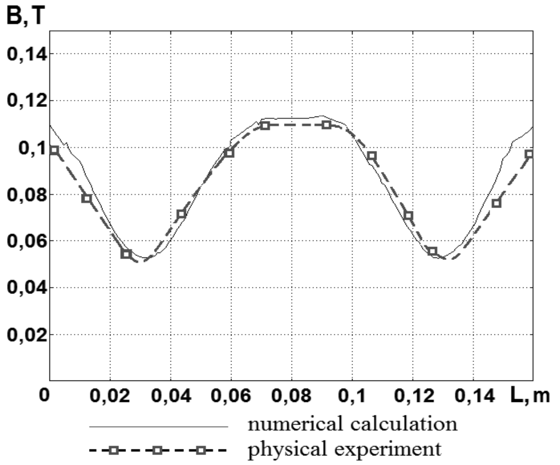


Fig. 6. Magnetic induction distribution in the middle of the EMD gap in the pole division

Calculation of eddy currents in the walls of the working electroconductive chamber EMD is shown in the form of a picture of the instantaneous distribution of the z-component of the current density (fig. 7), and also in the form of streamlines (fig. 8) corresponding to the classical "contours" of eddy currents.

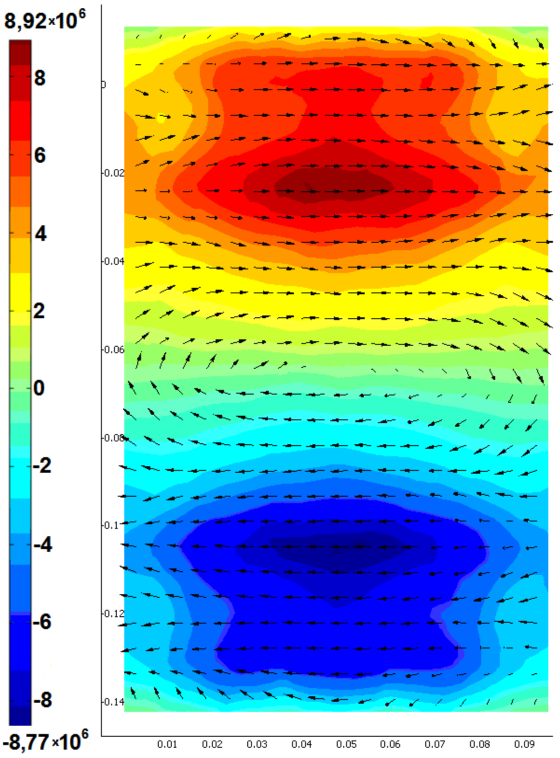


Fig. 7. Distribution of eddy currents in the wall of the chamber in the form of a picture of the instantaneous distribution of the z-component of the current density

The result of interaction of running magnetic fields of inductors and eddy currents flowing in the walls of the working chamber (adjacent to the inductors) is the appearance of characteristic flexure of the walls of the working chamber on each pole division (fig. 9). Fig. 10 shows curves representing the distribution of the deflection depth along the length of one of the walls working chamber after 10, 15, and 20 minutes of EMD operation. The figure shows that after 20 minutes of work disintegrator depth of deflection, at the thickness of the wall of the camera 0,8 mm, reaches 10 mm.

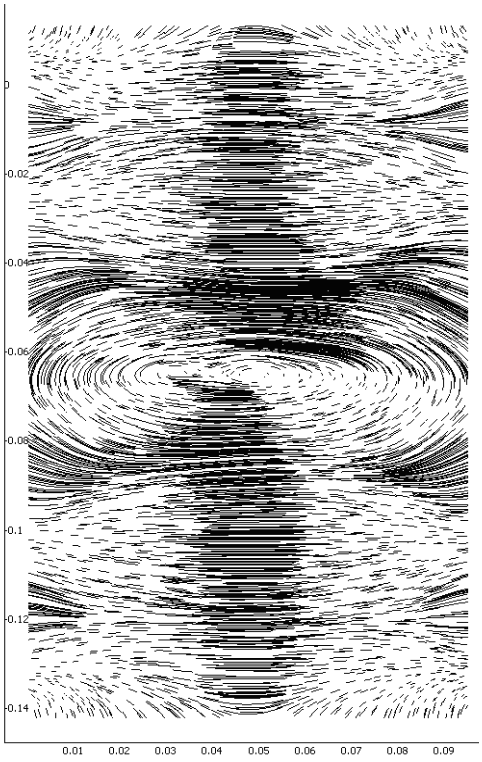


Fig. 8. Distribution of eddy currents in the wall of the chamber in the form of streamlines (contours)

Fig. 9. Deformation of the working chamber EMD

The curves of the distribution of the depth of deflection along the length of the wall of the EMD working chamber, constructed from the results of experimental measurements and the character of the distribution of electromagnetic forces obtained by solving the three-dimensional field problem by the finite element method (fig. 11), qualitatively agree and confirm the presence of localization of the acting forces on the chamber walls on the pole division of inducers.

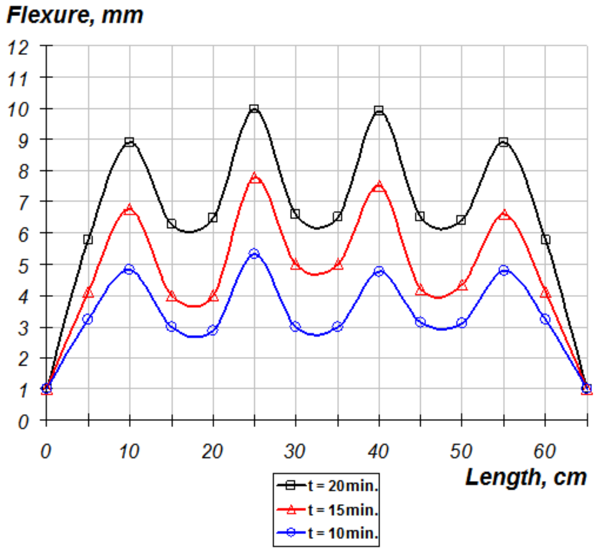


Fig. 10. Distribution of the deflection depth along the length of the walls working chamber

Numerical calculation shows that in the limits of pole division into a nonmagnetic electrically conducting chamber, distributed forces operate, the value of which reaches a value of 25 N.

The software package Comsol Multiphysics allows to define the resulting force which acts on the working conductive chamber by integration of elementary forces on volume, and to separate spatial components of efforts which we interested most.

Deformation of the working chamber EMD is caused, first of all, efforts which are directed normally to a surface of a chamber wall. The use of a working chamber with an increased wall thickness will lead to a significant decrease in the magnetic induction in the active part of the EMD due to an increase in the screening coefficient, and may also lead to overheating of the device due to an increase of the eddy current density in the walls of the chamber.

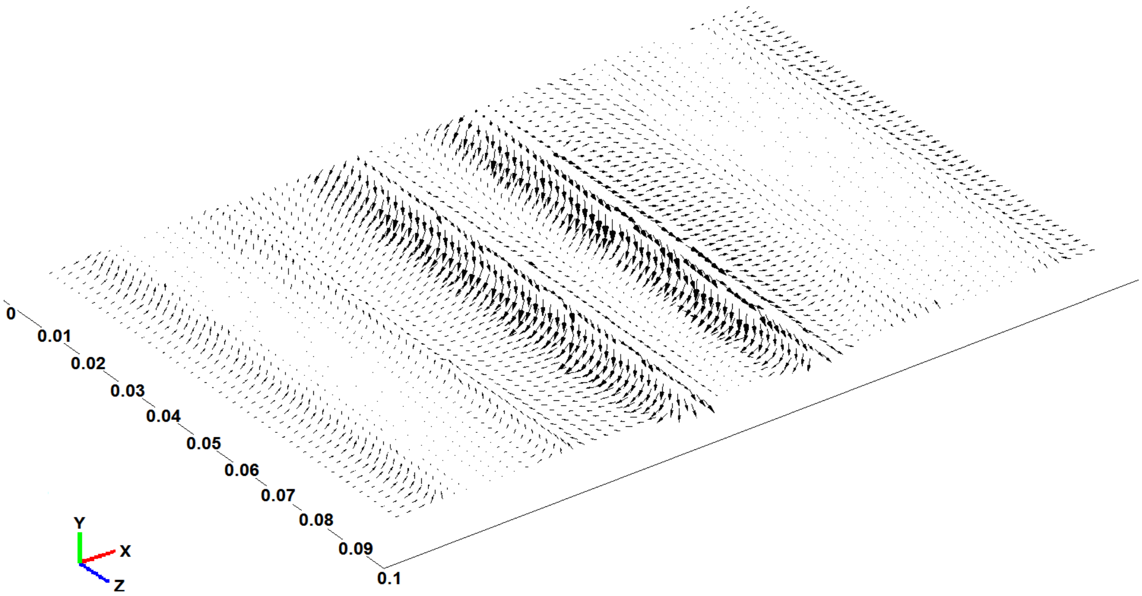


Fig. 11. Three-dimensional distribution of electromagnetic forces in the wall of the EMD working chamber

Conclusions

The results of a numerical calculation of the eddy current distribution and electromagnetic forces in the walls of the working electroconductive chamber of the electromechanical disintegrator are obtained. Calculation confirms the presence of localization of the acting electromagnetic forces in the walls of the electroconductive chamber on the pole division of the inductors. Taking into account the impulsive nature of these forces and shock loads, it is recommended that a working chamber be made of a non-magnetic material with walls having increased rigidity. The results obtained using the numerical model is agreement with the experimental data, which makes it possible to use the model to improve the design of the electromechanical disintegrator.

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ДОСЛІДЖЕННЯ ЕЛЕКТРОМАГНІТНИХ ПРОЦЕСІВ У СТІНКАХ РОБОЧОЇ КАМЕРИ ЕЛЕКТРОМЕХАНІЧНОГО ДЕЗІНТЕГРАТОРА

М. М. Заблодський[1], В. Ю. Грицюк[2], О. О. Тимофєєва[2]
[1]Національний університет біоресурсів і природокористування України
[2]Східноукраїнський національний університет імені Володимира Даля

Анотація. *Одним із способів, що дозволяють здійснювати різні технологічні процеси тонкого і надтонкого подрібнення, перемішування рідких і твердих порошкових речовин, прискорення хімічних реакцій, є застосування електромеханічних дезінтеграторів. Актуальним напрямом застосування таких пристроїв може бути переробка відходів діяльності людини, нейтралізація та утилізація промислових і сільськогосподарських відходів. Розподіл вихрових струмів у стінках робочої камери визначає активний опір вторинної частини електромеханічного дезінтегратора. Ступінь деформації робочої електропровідної камери визначається величиною і тривалістю дії електромагнітних зусиль на її стінки. Застосовано математичне моделювання електромагнітного поля з використанням методу скінченних елементів рішення нелінійних рівнянь в приватних похідних у тривимірному формулюванні, що враховує особливості геометрії та фактор кінцевої довжини. Як інструмент для польового аналізу використано програмний комплекс Comsol Multiphysics. Отримано результати чисельного розрахунку розподілу вихрових струмів та електромагнітних зусиль в стінках робочої електропровідної камери електромеханічного дезінтегратора. Розрахунок підтверджує наявність локалізації діючих електромагнітних зусиль на стінки електропровідної камери в межах полюсного поділу індукторів. Враховуючи імпульсний характер дії зусиль і ударних навантажень, рекомендується виготовлення робочої камери з немагнітного матеріалу зі стінками, що мають підвищену жорсткість. Отримані результати узгоджуються з даними фізичного експерименту, що дозволяє застосовувати модель для вдосконалення конструкції електромеханічного дезінтегратора.*

Ключові слова: *електромеханічний дезінтегратор, робоча камера, чисельне моделювання, вихрові струми, розподіл електромагнітних зусиль.*

ИССЛЕДОВАНИЕ ЭЛЕКТРОМАГНИТНЫХ ПРОЦЕССОВ В СТЕНКАХ РАБОЧЕЙ КАМЕРЫ ЭЛЕКТРОМЕХАНИЧЕСКОГО ДЕЗИНТЕГРАТОРА

Н. Н. Заблодский[1], В. Ю. Грицюк[2], О. А. Тимофеева[2]
[1]*Национальный университет биоресурсов и природопользования Украины*
[2]*Восточноукраинский национальный университет имени Владимира Даля*

Аннотация. *Получены результаты численного расчета распределения вихревых токов и электромагнитных усилий в стенках рабочей электропроводящей камеры электромеханического дезинтегратора. Расчет подтверждает наличие локализации действующих электромагнитных усилий на стенки электропроводящей камеры в пределах полюсного деления индукторов. Полученные результаты согласуются с данными физического эксперимента, что позволяет применять модель для совершенствования конструкции электромеханического дезинтегратора.*

Ключевые слова: *электромеханический дезинтегратор, рабочая камера, численное моделирование, вихревые токи, распределение электромагнитных усилий.*

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Nykolay Zablodskiy, Dr. of Science, Professor of the department of electrical machines and maintenance of electric equipment, University of Life and Environmental Sciences, Heroyiv Oborony st., 15, Kiev, Ukraine, E-mail: zablodskiynn@gmail.com, tel. +38-050-686-99-56

Заблодський Микола Миколайович, доктор технічних наук, професор кафедри електричних машин і експлуатації електрообладнання Національного університету біоресурсів і природокористування України. Вул. Героїв Оборони, 15, Київ, Україна, E-mail: zablodskiynn@gmail.com, тел. +38-050-686-99-56

ORCID ID: 0000-0001-8889-8158

Volodymyr Gritsyuk, Ph.D., Associate Professor of the department of electrical engineering, Volodymyr Dahl East Ukrainian National University, Central ave., 59-a, Severodonetsk, Ukraine, E-mail: gritsyukvy@gmail.com, tel. +38-099-948-54-33

Грицюк Володимир Юрійович, кандидат технічних наук, доцент кафедри електричної інженерії Східноукраїнського національного університету імені Володимира Даля. Просп. Центральний, 59-а, м. Сєвєродонецьк, Україна, E-mail: gritsyukvy@gmail.com, тел. +38-099-948-54-33

ORCID ID: 0000-0003-0156-7589

Olga Tymofieieva, Ph.D-student, Volodymyr Dahl East Ukrainian National University, Central ave., 59-a, Severodonetsk, Ukraine**,** E-mail: o.a.tymofieieva@gmail.com, tel. +38-050-178-46-74

Тимофєєва Ольга Олександрівна, аспірант Східноукраїнського національного університету імені Володимира Даля. Просп. Центральний, 59-а, м. Сєвєродонецьк, Україна, E-mail: o.a.tymofieieva@gmail.com, тел. +38-050-178-46-74

ORCID ID: 0000-0002-6302-4427