International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

June 2016 | Issue 27 | Volume 8 | Number 2 | Pages 13-17

# CALCULATION OF ELECTRICAL CONDUCTIVITY OF ENERGY SAVING NANOSTRUCTURED COMPOSITE ELECTRIC HEATERS

**A.B. Dorosh [1] T.M. Khalina [1] M.V. Khalin [1] S.A. Huseynova [2]**

*1. Polzunov Altay State Technical University, Barnaul, Russia, temf@yandex.ru*
*2. Institute of Physics, Azerbaijan National Academy of Sciences, Baku, Azerbaijan, sabish1977@rambler.ru*

**Abstract-** This scientific paper provides for analysis of the designed models used for determination of electric conductivity of the plate-type electric heaters with two or three lead electrodes. A method of determination of electric conductivity according to the set design parameters has been proposed. This method allows for calculation of the transcendent equations with the required precision that simulate a composite electric heater. An algorithm of calculation of electric conductivity has been proposed based on use of NumPy, SciPy, Mpmath libraries that allow for design of various types of nanostructured electric heaters within the wide range of the design parameters.

**Keywords:** Energy-Saving Nanostructured Composite Electric Heater, Design Model, Electrical Conduction, Electric and Design Parameters.

## I. INTRODUCTION

Nowadays development of energy-saving technologies and instruments of local heating in various economic sectors, considering steady increase in energy resources costs, becomes a particularly urgent issue. The choice of an efficient local heating system for a specific facility is a complex scientific and technical challenge covering such issues as energy balance of heated area, analysis of conditions and methods of heat transfer, instruments used, feasibility study of the selected method of heating, etc. [1, 2].

So far, development of energy-saving technologies of local heating using the surface distributed heating systems based on nanostructured multi-electrode composite electric heaters (MECEH) is still a deficient issue. Due to this fact, the challenge of the directional design of the energy-saving electric heaters with a pre-set surface temperature remains a crucial task and still requires solution.

## II. DESIGN OF MULTI-ELECTRODE COMPOSITE ELECTRIC HEATER

The proposed multi-electrode nanostructured composite butyl rubber-based plate-type electric heater features a system that converts electric energy into heat energy thus ensuring achievement of the set surface temperature (300-400 K), and the relevant electrical, thermic, physical and mechanical properties (Figure 1) [3].

The general layout of such a heater displays the resistive layer 3 placed between the insulation layer 1 and 2 with the inserted electrodes and electrode system 4 and input leads 5.

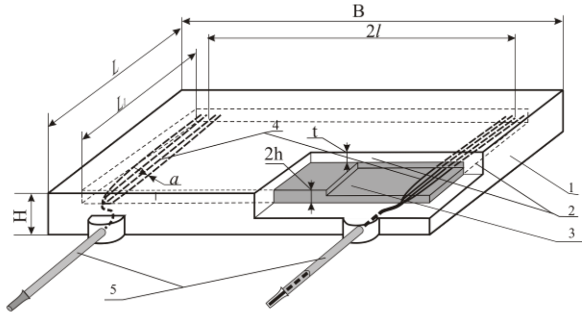


Figure 1. Nanostructured composite plate-type electric heater (general layout); 1,2 - insulation layers; 3 - electrically conductive layer; 4 - electrodes; 5- input leads; V, $L$, $L_1$, $h$, $l$, $t$, $a$, - MECEH dimensions

## III. METHOD OF DETERMINATION OF ELECTRICAL CONDUCTIVITY OF MULTI-ELECTRODE COMPOSITE ELECTRIC HEATER

In order to achieve the required design characteristics of MECEH which ensure achievement of the set surface temperature and compliance with the operational requirements, including self-regulated energy-saving operational mode, MECEH condition shall be evaluated including determination of electrical conductivity based on the analysis of the design features of the electrical field in quasi-homogenious medium.

The general evaluation procedure of various MECEH options is based on the obtained correlation of the coordinates of the initial Z-axis and the imaged projection $\zeta$, use of electric intensity formulae within the imaged projection and established correlations based on the conformal images and direct determination of field intensity $E$ considering for mathematical analogy of electrostatic field and stationary electrical field [4, 5].

The analysis of the designed models used in the quoted scientific papers shows that only a system with impermeable boundaries may be partially used to determine electrical conductivity of the electric heater; the other designed models either do no provide for such the boundaries, or provide for the boundaries with an infinitely high conductivity value. Additionally, electrical conductivity may be determined for a limited range of the electric heater dimensions.

Thus, the prior art solutions may not be applied to determine electrical conductivity $G_{эL1}$ of MECEH at its various dimensional correlations.

By now, electrical conductivity per length unit of the multi-electrode system may be determined by the following formulae [5, 6]:

For double-electrode systems

$$\frac{G_{эL1}}{\gamma}=\frac{I_7-I_5+\dfrac{I_1}{I_2}(I_6-I_8)}{\dfrac{I_1I_4}{I_2}-I_3} \tag{1}$$

For triple-electrode systems

$$\frac{G_{эL1}}{\gamma}=\frac{I_{10}-I_{13}+I_{16}-\left(c_{01}^2+c_{02}^2\right)\left(I_{11}-I_{14}+I_{17}\right)}{I_7-\left(c_{01}^2+c_{02}^2\right)I_8+c_{01}^2c_{02}^2I_9}+ \\ +\frac{c_{01}^2c_{02}^2\left(I_{12}-I_{15}+I_{18}\right)}{I_7-\left(c_{01}^2+c_{02}^2\right)I_8+c_{01}^2c_{02}^2I_9} \tag{2}$$

where the specific coordinates of the second kind $c_{01}$ and $c_{02}$ may be calculated using the following formulae:

$$c_{01}^2=\frac{I_1-c_{02}^2I_2}{I_2-c_{02}^2I_3} \tag{3}$$

$$c_{02}^2=\frac{I_3I_4-I_1I_6}{2\left(I_3I_5-I_2I_6\right)}+\frac{\sqrt{\left(I_1I_6-I_3I_4\right)^2-4\left(I_3I_5-I_2I_6\right)\left(I_2I_4-I_1I_5\right)}}{2\left(I_3I_5-I_2I_6\right)} \tag{4}$$

where, $I_1$-$I_8$, $I_1$-$I_{18}$ are the groups of hyperelliptic integrals, e.g. values of hyperelliptic integrals of triple-electrode systems may be presented by the following formulae:

$$I_1=\int_{a_2}^{a_3}\frac{\xi^4d\xi}{\sqrt{\left(\xi^2-a_1^2\right)\left(\xi^2-a_2^2\right)\left(a_3^2-\xi^2\right)\left(a_4^2-\xi^2\right)\left(a_5^2-\xi^2\right)\left(a_6^2-\xi^2\right)}} \tag{5}$$

$$I_2=\int_{a_2}^{a_3}\frac{\xi^2d\xi}{\sqrt{\left(\xi^2-a_1^2\right)\left(\xi^2-a_2^2\right)\left(a_3^2-\xi^2\right)\left(a_4^2-\xi^2\right)\left(a_5^2-\xi^2\right)\left(a_6^2-\xi^2\right)}} \tag{6}$$

$$I_3=\int_{a_2}^{a_3}\frac{d\xi}{\sqrt{\left(\xi^2-a_1^2\right)\left(\xi^2-a_2^2\right)\left(a_3^2-\xi^2\right)\left(a_4^2-\xi^2\right)\left(a_5^2-\xi^2\right)\left(a_6^2-\xi^2\right)}} \tag{7}$$

$$I_4=\int_{a_4}^{a_5}\frac{\xi^4d\xi}{\sqrt{\left(\xi^2-a_1^2\right)\left(\xi^2-a_2^2\right)\left(\xi^2-a_3^2\right)\left(\xi^2-a_4^2\right)\left(a_5^2-\xi^2\right)\left(a_6^2-\xi^2\right)}} \tag{8}$$

$$I_5=\int_{a_4}^{a_5}\frac{\xi^2d\xi}{\sqrt{\left(\xi^2-a_1^2\right)\left(\xi^2-a_2^2\right)\left(\xi^2-a_3^2\right)\left(\xi^2-a_4^2\right)\left(a_5^2-\xi^2\right)\left(a_6^2-\xi^2\right)}} \tag{9}$$

$$I_6=\int_{a_4}^{a_5}\frac{d\xi}{\sqrt{\left(\xi^2-a_1^2\right)\left(\xi^2-a_2^2\right)\left(\xi^2-a_3^2\right)\left(\xi^2-a_4^2\right)\left(a_5^2-\xi^2\right)\left(a_6^2-\xi^2\right)}} \tag{10}$$

$$I_7=\int_{0}^{a_1}\frac{\xi^4d\xi}{\sqrt{\left(a_1^2-\xi^2\right)\left(a_2^2-\xi^2\right)\left(a_3^2-\xi^2\right)\left(a_4^2-\xi^2\right)\left(a_5^2-\xi^2\right)\left(a_6^2-\xi^2\right)}} \tag{11}$$

$$I_8=\int_{0}^{a_1}\frac{\xi^2d\xi}{\sqrt{\left(a_1^2-\xi^2\right)\left(a_2^2-\xi^2\right)\left(a_3^2-\xi^2\right)\left(a_4^2-\xi^2\right)\left(a_5^2-\xi^2\right)\left(a_6^2-\xi^2\right)}} \tag{12}$$

$$I_9=\int_{0}^{a_1}\frac{d\xi}{\sqrt{\left(a_1^2-\xi^2\right)\left(a_2^2-\xi^2\right)\left(a_3^2-\xi^2\right)\left(a_4^2-\xi^2\right)\left(a_5^2-\xi^2\right)\left(a_6^2-\xi^2\right)}} \tag{13}$$

$$I_{10}=\int_{a_1}^{a_2}\frac{\xi^4d\xi}{\sqrt{\left(\xi^2-a_1^2\right)\left(a_2^2-\xi^2\right)\left(a_3^2-\xi^2\right)\left(a_4^2-\xi^2\right)\left(a_5^2-\xi^2\right)\left(a_6^2-\xi^2\right)}} \tag{14}$$

$$I_{11}=\int_{a_1}^{a_2}\frac{\xi^2d\xi}{\sqrt{\left(\xi^2-a_1^2\right)\left(a_2^2-\xi^2\right)\left(a_3^2-\xi^2\right)\left(a_4^2-\xi^2\right)\left(a_5^2-\xi^2\right)\left(a_6^2-\xi^2\right)}} \tag{15}$$

$$I_{12}=\int_{a_1}^{a_2}\frac{d\xi}{\sqrt{\left(\xi^2-a_1^2\right)\left(a_2^2-\xi^2\right)\left(a_3^2-\xi^2\right)\left(a_4^2-\xi^2\right)\left(a_5^2-\xi^2\right)\left(a_6^2-\xi^2\right)}} \tag{16}$$

$$I_{13}=\int_{a_3}^{a_4}\frac{\xi^4d\xi}{\sqrt{\left(\xi^2-a_1^2\right)\left(\xi^2-a_2^2\right)\left(\xi^2-a_3^2\right)\left(a_4^2-\xi^2\right)\left(a_5^2-\xi^2\right)\left(a_6^2-\xi^2\right)}} \tag{17}$$

$$I_{14}=\int_{a_3}^{a_4}\frac{\xi^2d\xi}{\sqrt{\left(\xi^2-a_1^2\right)\left(\xi^2-a_2^2\right)\left(\xi^2-a_3^2\right)\left(a_4^2-\xi^2\right)\left(a_5^2-\xi^2\right)\left(a_6^2-\xi^2\right)}} \tag{18}$$

$$I_{15}=\int_{a_3}^{a_4}\frac{d\xi}{\sqrt{\left(\xi^2-a_1^2\right)\left(\xi^2-a_2^2\right)\left(\xi^2-a_3^2\right)\left(a_4^2-\xi^2\right)\left(a_5^2-\xi^2\right)\left(a_6^2-\xi^2\right)}} \tag{19}$$

$$I_{16}=\int_{a_5}^{a_6}\frac{\xi^4d\xi}{\sqrt{\left(\xi^2-a_1^2\right)\left(\xi^2-a_2^2\right)\left(\xi^2-a_3^2\right)\left(\xi^2-a_4^2\right)\left(\xi^2-a_5^2\right)\left(a_6^2-\xi^2\right)}} \tag{20}$$

$$I_{17}=\int_{a_5}^{a_6}\frac{\xi^2d\xi}{\sqrt{\left(\xi^2-a_1^2\right)\left(\xi^2-a_2^2\right)\left(\xi^2-a_3^2\right)\left(\xi^2-a_4^2\right)\left(\xi^2-a_5^2\right)\left(a_6^2-\xi^2\right)}} \tag{21}$$

$$I_{18}=\int_{a_5}^{a_6}\frac{d\xi}{\sqrt{\left(\xi^2-a_1^2\right)\left(\xi^2-a_2^2\right)\left(\xi^2-a_3^2\right)\left(\xi^2-a_4^2\right)\left(\xi^2-a_5^2\right)\left(a_6^2-\xi^2\right)}} \tag{22}$$

To determine electrical conductivity of the above systems, numerical values of geometrical factors $a_1 \div a_4$ or $a_1/a_6 - a_5/a_6$ shall be calculated using the set design dimensions $L_1$, $h$, $l$, $t$, $a$ taken from the set of the equations that establish correlation of the initial and the imaged projections; using such the values, the groups of integrals $I_1$-$I_8$ or $I_1$-$I_{18}$, may be calculated, and specific coordinates $c_{01}$ and $c_{02}$ may be determined; further, the electrical conductivity $G_{эL1}$ may be determined using Equation (1) or (2). Applicability of Equations (1)-(4) is limited by range $1/5 < l/h \le 5$ for the simplest systems, or $1/3 < l/h \le 3$ for complex systems, thus making it impossible to determine electrical conductivity of a MECEH that is currently used in the heating systems.

The proposed method of determination of electrical conductivity will allow for elimination of the above limitations and provide for the required range of the design features; usually it makes $5 < l/h \le 30$ per section. This method provides for direct determination of module $k_0$ of elliptic sine of full elliptic integral $k_0$ through the solution to the transcendent equation with the required precision, while the method algorithm provides for its determination with the required precision for further calculations, as well as allows for expansion of application of the calculation formulae for hyperelliptic integrals using Newton-Cotes method due to the best choice of the coordinates for calculation of the sub-integral functions. The structure of the above algorithm of determination of electric conductivity of the composite MECEH with various dimensional ranges $h$, $l$, is shown in in Figure 2.

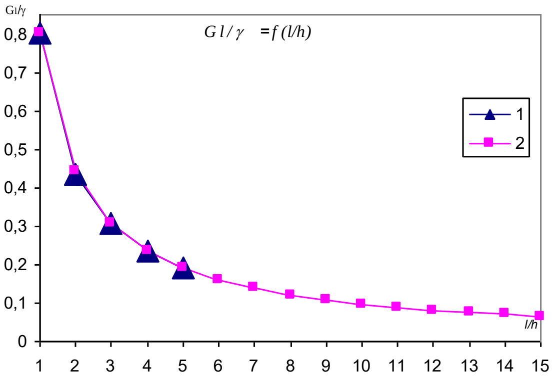


Figure 2. Dependency graph of non-dimensional conductivity $G_l/\gamma$:
1. Calculation was carried out using an approximation formula;
2. Calculation was carried out using the offered method

## IV. ALGORITHM OF DETERMINATION OF ELECTRIC CONDUCTIVITY OF MULTI-ELECTRODE COMPOSITE ELECTRIC HEATER

Based on the foregoing, we may formulate the key features and requirements that shall be considered for algorithm development. The following algorithm code that is responsible for programmatic implementation of the similar feature using Pascal language, has been adopted as a prototype.

The requirements to the algorithm structure are as follows:

- Due to the user-defined build and design of the electrical heaters, determination procedure shall consider for as simple introduction of various calculation methods into the program and their modifications as possible;
- The algorithm code shall be simple, well recorded, and as close as possible to the most frequently used programming languages;
- The program responsible for implementation of the algorithm shall not have any limitations on the number of decimals, and provide for high-precision calculations;
- The algorithm shall be easily integrated in any most popular operating system (Windows, Linux, MacOS).
- The source code shall be universal enough, and depend on the least possible number of the additional libraries and extensions, as well as allow for use of the current language versions, be susceptible to the language core updates, including the libraries and extensions used in it. Figure 3 features the flow chart of the algorithm.

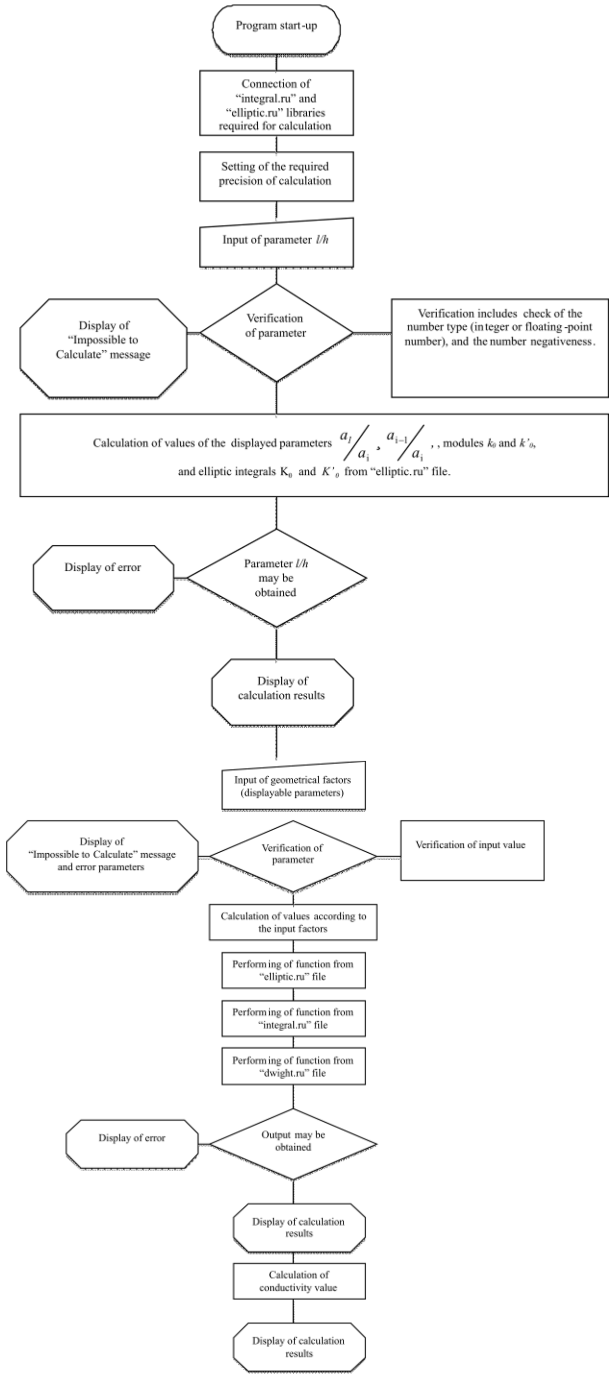


Figure 3. Flow chart of algorithm of determination of MECEH electric conductivity

The overall program implementation procedure includes a few basic operations: program start-up, entering of parameters $l/h$, calculation of the displayable parameters, input of the factors, determination of conductivity. The program is launched by Python script in the command line. Given the fact that code language is Python 3, the run script in the most UNIX systems will be implemented as "%python3/address/to/file/launcher.ru".

Further, the parameters required for calculation of ratio *l*/*h* shall by entered and confirmed by pressing ENTER button.

After display of calculation results, the factor values shall be entered. Entering of each parameter shall be confirmed by pressing ENTER button. Since the program that implements the algorithm is not a server-based application, and offers no features that may harm the operational system, no verification of availability of the input values is required, and use of the integrated language error analyzer is enough. As such, the main objective of verification of the entered input values is verification of their type aimed at obtaining of correct calculation results. Based on the basic program algorithm, we may formulate the basic program architecture.

The program will be launched by "launcher.ru" file with all the basic configuration and settings required to prepare the language core to calculations. All the libraries required for calculations, setting of calculation accuracy, any additional files required for further program run, including some auxiliary functions, will be connected to.

Given the fact that the method of calculation implies calculation of the first-kind elliptic integrals, and that the required functionality within NumPy, SciPy, MPmath libraries is missing, the required function shall be integrated into the program script. "integral.ru" file will calculate the elliptic integral of the first kind. As these libraries cannot calculate the elliptic sine, a special function shall be integrated into the program and implemented as "lliptic.ru" file. Based on the available calculations, values may be calculated for a large number of heater types. As such, we advise to locate the calculation formulae into a separate "dwight.ru" file in the program. Further input of the factors will be similar to input of *l*/*h* values followed by performance of all the required calculations.

## V. CONCLUSION

The proposed algorithm of calculation using the required functionally within NumPy, SciPy, MPmath libraries, and methods of calculation of the elliptic integrals of first kind and values of the elliptic sine will allow for calculation of various types of nanostructured electric heaters within the wide range of the design parameters.

## REFERENCES

[1] A.B. Dorosh, T.M. Khalina, "Energy-Saving Nanostructured Composite Electric Heaters for Agro-Industrial Complex", The Polzunov Bulletin, Printing House of Polzunov, PolzunovAltay State Technical University, Barnaul, Russia, No. 4.1, pp. 131-135, 2014.

[2] M.V. Khalin, E.I. Vostrikov, S.A. Guseinova, D.G. Chasovschikov, "Energy-Saving System with Grain Heating Self-Regulation", The Polzunov Bulletin, Printing House, Polzunov Altay State Technical University, Barnaul, Russia, No. 4.2, pp. 20-23, 2014.

[3] T.M. Khalina, M.V. Khalin, A.B. Dorosh, Russian Federation Patent No. 2476033, IPC No. H05B3/28, Art of Manufacture of Composite Electric Heaters, Bulletin No. 5, pp. 9, Russia, 20 February 2013.

[4] T.M. Khalina, M.V. Khalin, S.A. Huseinova "A Heating System Based on Nanostructured Multi-Electrode Composite Electric Heaters", 9th International Conference on Technical and Physical Problems of Electrical Engineering (ICTPE-2013), pp. 471-473, Istanbul, Turkey, 9-11 September 2013.

[5] Yu.Ya. Yossel, E.S. Kochanov, M.G. Strusinov, "Determination of Heat Capacity", Energoatomizdat, Leningrad, Russia, pp. 288, 1981.

[6] T.M. Khalina, "Multi-Electrode Systems of Low-Temperature Composite Electric Heaters for Agro-Industrial Complex", Thesis Work of Doc. Tech. Sci., p. 445, Barnaul, Russia, 2005.

[7] T.M. Khalina, M.V Khalin, A.B. Dorosh, M.N. Strokov, E.I. Vostrikov, M.Yu. Zybtsev, "Development of the Engineering Design Documentation for Manufacturing of the Units and Plants Based on the Multi-Electrode Composite Electric Heaters", Report on the Research and Advanced Developments, Energo Effect Tekhnologia, State Reg. No. 02200953368, State Contract No. 5922p/6815, p. 178, Barnaul, Russia, 2009.

## BIOGRAPHIES

**Aleksandr B. Dorosh** graduated from the Energy Department of Altay State Technical University, Barnaul, Russia in 2002. Currently, he is an Engineer at the General Electrical Technology Department of the same university. His scientific interest is energy saving technologies.

**Tatyana M. Khalina** graduated from the Energy Department of Altay Polytechnic Institute, Barnaul, Russia in 1975. Currently, she is Doct. Tech. Sci., Professor, and Head of the General Electrical Technology Department of Polzunov Altay State Technical University, Barnaul, Russia. Her scientific interests are electro physics, electric power, and energy saving technologies.

**Mikhail V. Khalin** graduated from the Energy Department of Altay Polytechnic Institute, Barnaul, Russia in 1975. Currently, he is Doct. Tech. Sci., Professor at the General Electrical Technology Department of Polzunov Altay State Technical University, Barnaul, Russia. His scientific interests are electro physics, electric power, and energy saving technologies.

**Sabina A. Huseynova** was born in Baku, Azerbaijan, on July 24, 1977. She received the B.Sc. and the M.Sc. degrees from the Azerbaijan State Oil Academy (Baku, Azerbaijan) all in, in 1998, 2002 respectively. Currently, she is a scientific researcher at the Laboratory of High-Voltage Physics and Engineering, Institute of Physics, Azerbaijan National Academy of Sciences (Baku, Azerbaijan). Her areas of expertise are various types of heaters, including industrial carbon, butyl rubber, and electric heater.