Вісник Тернопільського національного технічного університету
https://doi.org/10.33108/visnyk_tntu
Scientific Journal of the Ternopil National Technical University
2021, № 4 (104) https://doi.org/10.33108/visnyk_tntu2021.04
ISSN 2522-4433. Web: ***visnyk.tntu.edu.ua***

UDC 531.374

THE PROCESS OF SHELLS FORMATION BY ELECTRIC ARC SPRAYING METHOD AND OPTIMIZATION BY THE CRITERION OF THEIR GEOMETRIC SHAPE ACCURACY

Taras Dubynyak[1]; Roman Dzhydzhora[1]; Oleksandra Manziy[2]; Stanislav Andreichuk[2]

[1]*Ternopil Ivan Puluj National Technical University, Ternopil, Ukraine*
[2]*Lviv Polytechnic National University, Lviv, Lviv, Ukraine*

Summary. *The process of shells formation, finding the position of grid elements after deformation is investigated. Minimization of potential energy is carried out numerically by iterative method. The result is the formation of antenna array by electric arc spraying method.This techonology of manufacturing shells from mesh material can be used for the manufacture of axisymmetric and non-axisymmetric reflectors or individual elements of mirror antennas.*
Key words: *electric arc spraying, grid, potential energy, mirror, axisymmetric antenna.*

https://doi.org/10.33108/visnyk_tntu2021.04.024 *Received 10.12.2021*

The production of antenna systems and the production of reflective surfaces is based on new technological and design ideas, the implementation of which requires appropriate scientific and technical support, and is possible in close cooperation of production with scientific potential. The technology of shells manufacturing from mesh material can be used for the manufacture of axisymmetric and non-axisymmetric reflectors or individual elements of mirror antennas [1].

The following shape-shifting operations of sheet metal stamping are known: hood, rotary hood, embossed molding, upholstery, including rubber, liquid, hydromechanical and explosion hood, electric discharge stamping, electromagnetic stamping, which makes it possible to obtain shell from sheet material (continuous, gas and water-permeable) by pressing it to the matrix or punch by the transfer medium. The shell with certain errors reproduces the profile of the forming element [2]. The main design and technological ideas that are implemented in antenna systems are:

- preservation of the basic principles of aviation technologies in the production of antennas and with the exception of technological processes of the influence of subjective factors on product quality;
- optimization of structures according to the criteria – rigidity – accuracy – mass;
- use without stacking assembly and adjustment of antennas on objects;
- use of vector diffraction methods in optimizing the electrodynamic characteristics of the antenna system at the design stage [3];
- control system of antenna positioning, control of the speeds of it’s movement, diagnostics of condition at operation, self-testing, is carried out on the basis of digital information processing [4].

Operations of forming the reflective surface of a given profile, for example, by casting are known. The closest is the method of making the reflector shield. It lies in the fact that the reflective surface of the reflector is formed on the matrix, then the power frame of the multilayer composite

 Corresponding author: Taras Dubynyak; e-mail: d_taras@ukr.net

type is made, the lower end surface of which repeats the profile of the matrix. After polymerization process of the power frame it is subjected to natural or artificial aging. Then the power frame is glued to the reflective surface without removing it from the matrix and compensating for errors in the profile of the connecting surfaces with different thickness of the adhesive seam. The disadvantage of this method is the low performance, increased overall dimensions of the shell thickness and, accordingly, the weight of the product, unsuitability for the creation of breathable shells that transmit reduced wind load, significant manufacturing costs.

The investigation of the process of shell formation consists of predicting and verifying the deformation of two-dimensional grid. The difficulty of describing the deformation process is that the mesh behaves in deformation qualitatively differently than a sheet of solid material. This is due to its structure, in particular, the ability to rotate mutually perpendicular wires of the grid relative to each other at the nodes.

One of the tasks studied in the formation of the shell is to find the position of the elements of the grid after deformation, which in our case is to find the position of the nodes of the grid after deformation. this problem must be solved for known vectors of displacement of all nodes during deformation.

The energy of the entire grid can be found by calculating of each element and summing the values obtained for all elements. Minimization of potencial energy is carried out by iterative method.

Deformation depends on the effort applied to the ends of the mesh element. The stiffness matrix of the element is located using DIP-FEM package, for which a model of the element is created and at a given unit effort for each direction, the application of the displacement load is calculated [5].

The energy of the entire grid can be found by calculating the energy of each element and summing the values obtained for all elements.

Approbation of the method is performed in the manufacture of axisymmetric mirror antenna. Galvanized steel wire mesh is used as a blank. Spraying is carried out by electric arc sprayer with aluminum wire

The task is to form the shell of the antenna array by electric arc spraying method, the stages of which are presented graphically:

The frame grid is given (Fig. 1 a):

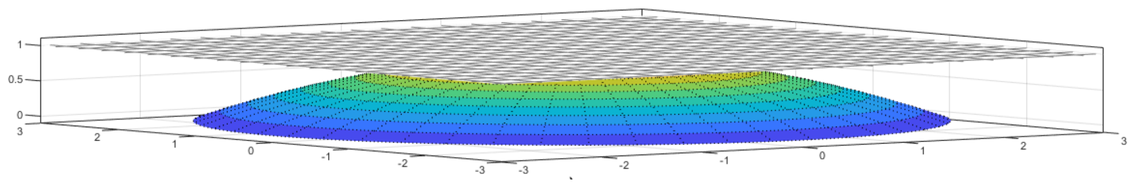


Figure 1 a. Shaping – stage 1

Forming is carried out by means of punch (fig. 1 b)

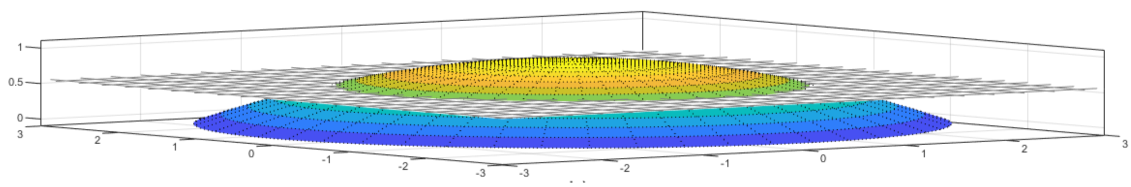


Figure 1 b. Shaping – stage 2

The result of deformation – the formed shell is investigated (fig. 1 with)

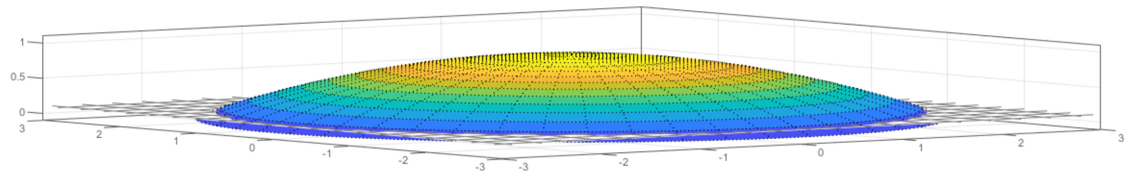
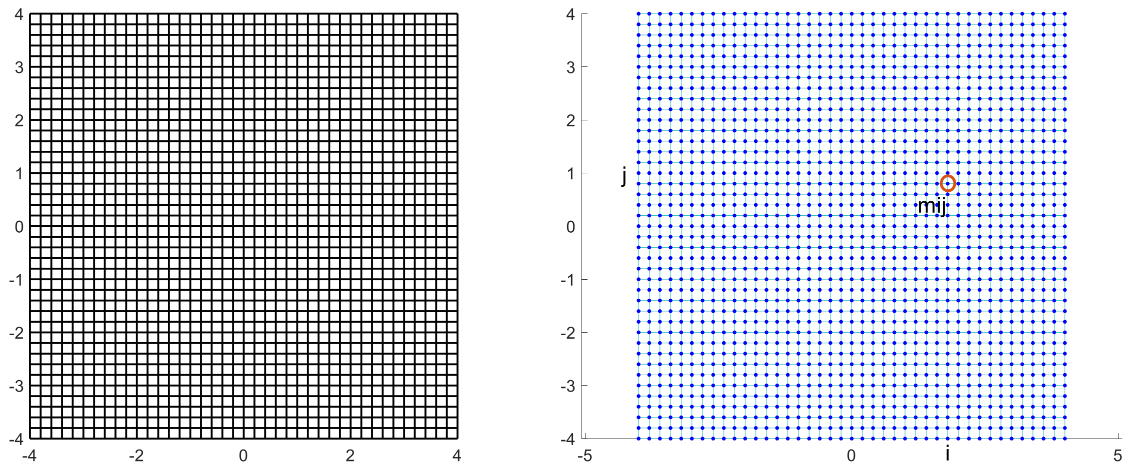


Figure 1 c. The result of shaping

While describing this model of the frame grid deformation, we use cylindrical coordinate system. The grid in the unformed state lies in plane z = 0 (Fig. 2 a). Nodes of the grid are the point of intersection of perpendicular wires of the grid, we assume that only rotation of the wires of the grid relative to each other are acceptable in the nodes, while shifts are not acceptable. In fact, shifts (ambiguous) exist, but in the first approximation they can be neglected [6].



a b

Figure 2. a – Frame mesh; b – Grid nodes

Thus, according to the above mentioned assumptions, the position of the grid will be well known if the positions of its nodes are known. Therefore, the task is to find the position of the grid nodes after deformation. While solving the problem due to symmetry, it is reasonable to consider only that part of the grid which is in the first quadrant. In order to find the position of the nodes of the grid as a whole, it is sufficient to consider that the grid has symmetry about z axis. The grid node is numbered with two numbers i and j (Fig. 2 b).

The problem will be solved if the vectors of displacements of all nodes during deformation are found [2]. Let us denote the displacement vector of the node (i, j) as uij. There are a finite number of such vectors. Along with the vectors uij, we also introduce the vector-mapping function u (x, y). The content of this function is that each point (x, y) of plane z = 0 corresponds to the vector u (x, y) and thus sets the mapping of plane z = 0 on the surface, each point of which is point (x, y) the plane z = 0, shifted by vector u (x, y). We consider the mapping to be mutually unique, and the function u (x, y) itself to be continuously differentiated in the whole domain. We impose another condition on the function u (x, y): if xj and yi are coordinates of the node (i, j) then: u $(x_j, y_i) = u_{ij}$. In other words, let us define the function u (x, y) in such a way that it reflects the grid on the surface:

$$\begin{cases} z = f(\rho) \\ \rho = \sqrt{x^2 + y^2} \end{cases} \quad (1.1)$$

Since the diameter of the wire mesh material is small, and the workpiece provides free sliding of the wires in the nodes, we can assume that it will take the shape of the working surface under its own weight (Fig. 3)

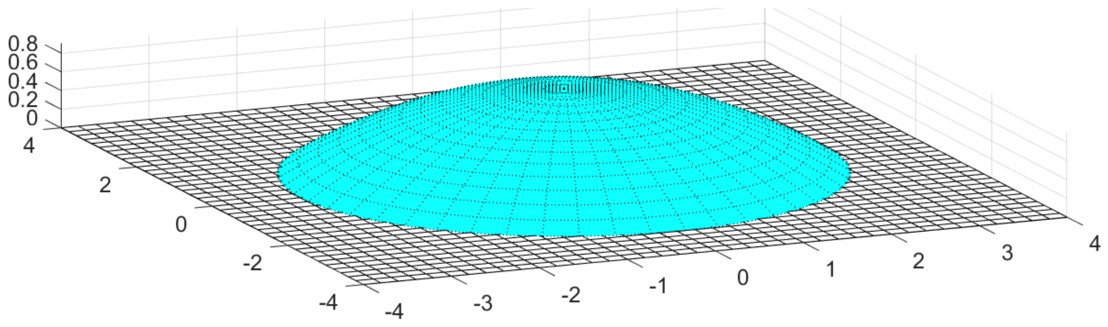


Figure 3. Profiling of the frame grid on the reference surface of the punch in the final version

While calculating the energy, we use the obvious fact that the energy of the element depends only on the deformation of the element itself, and the deformation in turn depends on the effort applied to the ends of the element. It is also obvious that the energy of the whole grid is equal to the sum of the energies of its parts.

The calculation of the grid energy can be represented by its mathematical model with concentrated parameters in the form of a set of masses m_{ij}, localized in nodes $i = 1,2,\dots,n; j = 1,2,\dots l$,as shown in Fig.2 b) [8].

Then the minimum potential energy is as follows:

$$W_{min} = \sum_{i=1}^{n}\sum_{j=1}^{n} m_{ij} g L_{ij} \quad (1.2)$$

where L_{ij} is the distance of the node in the initial position from the reference surface (Fig. 4).

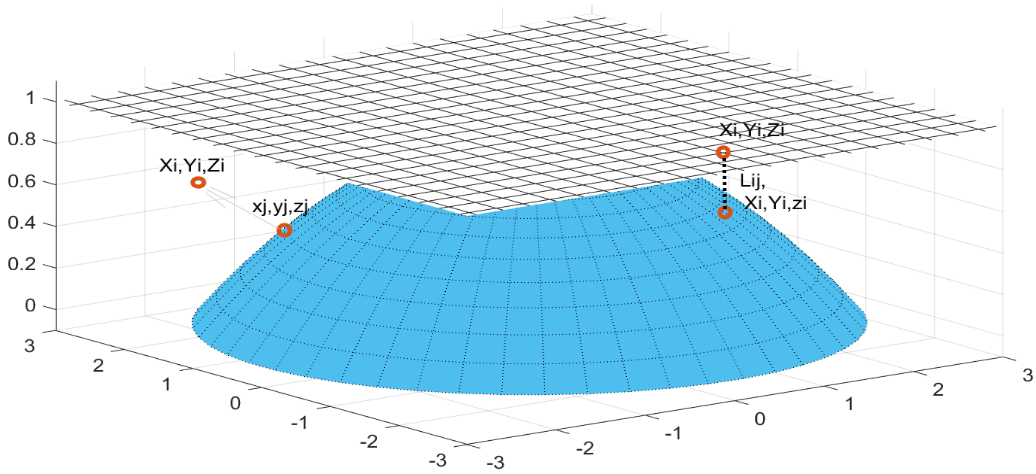


Figure 4. Displacement of nodes in formation

If the surface of the punch in the coordinate system $Oxyz$ is represented by its mathematical model

$$F(x, y, z) = 0 \tag{1.3}$$

Then

$$L_{ij} = Z_{ij} - z_{ij} \tag{1.4}$$

where the value $z_{ij} = q$ is found as the solution of equation $F(X_i, Y_j, q) = 0$.

A detailed description of the deformation calculations of the grid elements is performed in the paper presented in the conference abstracts [9]. Therefore, the most common approach is used to solve the problem, namely the theorem on the minimum potential energy of the system at equilibrium. At the same time friction in the system is neglected; it can be taken into account when improving the developed methodology. Minimization of potential energy is carried out numerically by iterative method. The stiffness matrix of the elements is located using DIP-FEM package.

If the element is alternately applied in such a way that in each case in vector F_i is different from 0 only one component (alternately from the first to the sixth), and this component is equal to 1. According to the relationship between displacements and forces for the element:

$$D_i = \sum_{j=1}^{6} B_{ij} * F_j$$

B_{ij} is equal to D_i when applying a unit force in the «direction» j. Then C_{ij} is located as a matrix inverted to B_{ij}. With a given unit effort for each direction of application, the displacement loads are calculated by the package. Illustrations representing the element deformation element when applying loads are given in the graphic part of the work. The search of inverse matrix is done by the program written in Borland Pascal. The stiffness matrix for the grid with 7.5 mm step made from the steel wire with 0.75 mm. diameter is given below. As expected, it turned out to be symmetrical (accuracy to errors caused by rounding).

Table 1

The stiffness matrix of the grid element

i\j	1	2	3	4	5	6
1	2.582E+05	9.566E-10	1.405E+06	7.845E-13	-4.415E+02	2.163E-14
2	9.612E-10	8.962E+04	5.333E-11	3.361E+02	2.061E-13	-3.361E+01
3	1.405E+06	1.318E-11	1.181E+07	-2.354E-13	-8.395E+02	-2.311E-15
4	8.073E-13	3.361E+02	-3.356E-14	1.694E+00	-3.566E-16	-1.346E-01
5	-4.415E+02	2.092E-13	-8.395E+02	-3.414E-16	1.776E+00	-7.324E-17
6	1.891E-14	-3.361E+01	-2.328E-14	-1.346E-01	-7.048E-17	3.611E-01

Another problems that arise while implementing the spraying technique are positioning, trajectory, linear and angular velocity of the nozzle of the sprayer, which would ensure the uniformity of the coating layer over the entire surface. Without going into technological details of the process, let us consider the condition of the torch orientation, perpendicular to the working surface. The minimum distance of the initial position of the nozzle with coordinates (X_i, Y_j) to the reference surface (Fig. 4) spraying is found as the length of the segment normal to this surface passing through the point with coordinates $(X_i, Y_j, 0)$,and intersects the surface at the point with coordinates$(x_{0i}, y_{0j}, z_{0ij})$: [10].

$$D = \sqrt{(X_i - x_{0i})^2 + \left(Y_j - y_{0j}\right)^2 + \left(z_{0ij}\right)^2} \tag{1.5}$$

The equation of the normal to the surface at point$M_{0ij}(x_{0i}, y_{0j}, z_{0ij})$ is as follows:

$$\frac{X - x_{0i}}{\frac{dF}{dx}(M_{0ij})} = \frac{Y - y_{0j}}{\frac{dF}{dy}(M_{0ij})} = \frac{-z_{0ij}}{\frac{dF}{dz}(M_{0ij})}. \tag{1.6}$$

Based on the system of equations given by relations (1.3–1.4) we can estimate the minimum distance of the node (i, j) of the grid (Fig. 2 a), which is in the initial position (Fig. 1 a), from the reference surface [11].

The change of distance h of the position of the sprayer nozzle end to the workpiece surface changes the temperature in the area of contact of the sprayed particles of material with the workpiece surface and air pressure in this area, which makes it possible to control the process of applying the material. The grid serves as a power frame and provides intensification of the coating process, which enables to form better reflective surface of the shell. Subsequent passages with smaller distance h increase the reliability of grid nodes fixing [12].

Testing of the method was performed in the manufacture of axisymmetric antenna mirrors with 1.5 meterdiameter. Galvanized steel wire mesh with 0.5 mm diameter and mesh size of 5 mm was used as a blank. Spraying was carried out by electric arc sprayer with aluminum wire on industrial installation [14].

The described method of problem solution is implemented for the case when f (p) is the next function (Fig. 5).

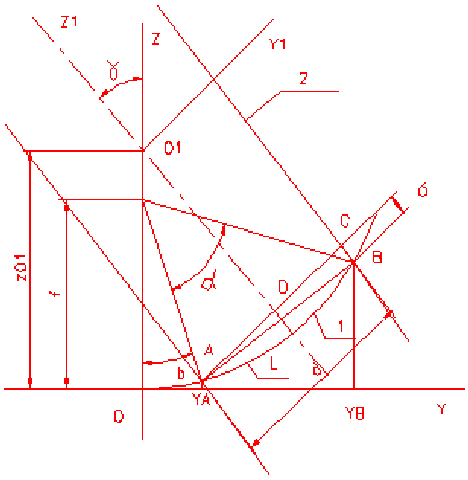


Figure 5. Focal length of the axisymmetric antenna mirror

Figure 6. Mirror axisymmetric antenna with 1.5 meterdiameter

It is evident from Fig. 5, R_0=b+d that if parabola has focal length f [13], then mathematically it is difined in the following way:

$$\begin{cases} d = \dfrac{r * b}{\sqrt{4f^2 + b^2}}, \\ a = \dfrac{b^2}{4f} + r * \left(1 - \dfrac{b}{\sqrt{4f^2 + b^2}}\right); \end{cases} \tag{1.7}$$

The following values of variables are taken in the solution (1.7):

r=12 mm; b=200 mm; f=500 mm.

The grid is taken in the form of the square with mesh size l = 5 mm. The resulting shape of the sprayed grid is shown in Fig. 6. The mirror of the axisymmetric antenna with 1.5 meter diameter is sprayed with electric arc sprayer with aluminum wire on the industrial installation.

Conclusions. In the course of the work the methods of production of antenna systems and production of reflective surfaces based on new technological and design ideas are considered. The process of forming shells from mesh material, which can be used for the manufacture of axisymmetric and non-axisymmetric reflectors or individual elements of mirror antennas, has been studied.

One of the task investigated in the formation of the shell is to find the position of the elements of the grid after deformation, which in our case is to find the position of the elements of the grid after deformation. Finding the position of the elements of the grid after deformation.

Minimization of potential energy was carried out numerically by iterative method. When calculating the energy, the obvious fact is used that the energy of the element depends only on the deformation of the element itself, and the deformation in turn depends on the effort applied to the ends of the element. It is also obvious that the energy of the whole grid is equal to the sum of the energies of its parts.

The grid serves performs the function as a power frame and provides intensification of the coating process, which allows you to form a better reflective surface of the shell. Another problem that arises in the implementation of the spraying technique is the positioning, trajectory, linear and angular velocity of the nozzle of the sprayer, which would ensure the uniformity of the coating layer over the entire surface. This techonology of manufacturing shells from mesh material can be used for the manufacture of axisymmetric and non-axisymmetric reflectors or individual elements of mirror antennas.

References

1. Hansen R. S. 2012. Phased antenna arrays part. Publishing house “Tekhnosfera”. Moscow. 66 p.
2. Rothammel K., Krishke A. 2001. Antennas. Minsk. 416 p.
3. Belyansky P. V., Sergeev B. G. 1980. Control of terrestrial antennas and radio telescopes. Sov. Radio. Moscow.
4. Palamar M., Chaikovskyi A., Pasternak V., Shevchuk V., Yavorska M. The Influence of Antenna Installation Accuracy on Quality of Signal Reception. Proceedings of the 5th IEEE International Symposium on Wireless Systems within the International Conferences on Intelligent Data Acquisition and Advanced Computing Systems (IDAACS-SWS): 17–18 September, 2020, Dortmund, Germany. P. 209–212. ISBN 978-1-7281-9959-7, IEEE Catalog Number: CFP20WSI-USB. (Scopus, WoS).
5. Shulim G. T. 2007. Fundamentals of mathematical theory of thermoelastic equilibrium of deformable solids with thin inclusions. Research and Publishing Center NTSh. Lviv, 715 p.
6. Ovcharenko V. A., Podlesny S. V., Zinchenko S. M. 2008. Fundamentals of the finite element method and its application in engineering calculations. Tutorial. Kramatorsk, 380 p.
7. Karvatsky A. Y. 2015. Finite element method in problems of mechanics of continuous media.- Program implementation and visualization of results [Electronic resource]. 391 p.
8. Tarapov I. E. 2002. Continuum mechanics. Golden pages. Kharkov, 516 p.
9. ADVANCED APPLIED ENERGY and INFORMATION TECHNOLOGIES 2021. Proceedings of the International Conference (Ternopil, 15–17 of December 2021.) / Ministry of Education and Science of Ukraine, Ternopil Ivan Puluj National Technical Universtiy and other. Ternopil: TNTU, Zhytomyr: “Publishing house “Book-Druk”” LLC, 2021. 222 c.
10. Dmitrieva V. F. 2008. Physics. K.: Tehnika, 644 p.

11. Gusev V. G., Gusev Y. M. 1991. Electronics: Textbook for instrument-making specialties of universities. M.: Higher School, 622 p.
12. Zaitsev D. A. 2004. Mathematical Models of Discrete Systems. Primer. Odessa, 40 p.
13. Popovsky V. V., 2006. Mathematical foundations of the theory of telecommunication systems.TOV “Company SMIT”. Kharkiv, 564 p.
14. Duboviy O. M., Yankovets T. A. 2006. Coating spraying technology. Tutorial.
15. Klyuev O. 2008. “Cold” sawing of metal coatings. MTT: World of Engineering and Technology.

Список використаної літератури

1. Хансен Р. С. фазированные антенные решетки. Ч. 1. Москва, изд-во «Техносфера», 2012. 66 с.
2. Ротхаммель К., Кришке А. Антенны. Том 1 / пер с нем. Мн.: ОМО «Наш город», 2001. 416 с.
3. Белянский П. В., Сергеев Б. Г. Управление наземними антеннами и радио-телескопами. Москва: «Сов. Радио», 1980.
4. Palamar M., Chaikovskyi A., Pasternak V., Shevchuk V., Yavorska M. The Influence of Antenna Installation Accuracy on Quality of Signal Reception: Proceedings of the 5th IEEE International Symposium on Wireless Systems within the International Conferences on Intelligent Data Acquisition and Advanced Computing Systems (IDAACS-SWS) (17–18 September, 2020.), Dortmund, Germany. P. 209–212. ISBN 978-1-7281-9959-7, IEEE Catalog Number: CFP20WSI-USB. (Scopus, WoS).
5. Сулим Г. Т. Основи математичної теорії термопружної рівноваги деформівних твердих тіл з тонкими включеннями. Львів: Дослідно-видавничий центр НТШ, 2007. 716 с.
6. Овчаренко В. А., Подлєсний С. В., Зінченко С. М. Основи методу скінчених елементів і його застосування в інженерних розрахунках: навчальний посібник. Краматорськ: ДДМА, 2008. 380 с.
7. Карвацький А. Я. Метод скінченних елементів у задачах механіки суцільних середовищ. Програмна реалізація та візуалізація результатів [Електронний ресурс], 2015.
8. Тарапов І. Є. Прикладна математика та механіка. Харків: Золоті сторінки, 516 с.
9. ADVANCED APPLIED ENERGY and INFORMATION TECHNOLOGIES 2021. Proceedings of the International Conference (Ternopil, 15–17 of December 2021.) / Ministry of Education and Science of Ukraine, Ternopil Ivan Puluj National Technical Universtiy and other. Ternopil: TNTU, Zhytomyr: «Publishing house «Book-Druk»» LLC, 2021. 222 с
10. Дмитрієва В. Ф. Фізика. К.:Техніка, 2008. 644 с.
11. Гусев В. Г., Гусев Ю. М. Электроника: учебное пособие для приборостроительных специальностей вузов. М.: Высшая школа, 1991. 622 с.
12. Зайцев Д. А. Математичні моделі дискретних систем: навчальний посібник. Одеса: ОНАЗ імені О. С. Попова, 2004. 40 с.
13. Математичні основи теорії телекомунікаційних систем: підручник за загальною редакцію В. В. Поповського. Харків: ТОВ «Компанія СМІТ», 2006. 564 с.
14. Дубовий О. М., Янковець Т. А. Технологія напиленняпокриттів: навчальний посібник. 2006.
15. Клюев О., Каширин А. «Холодное» напиление металлических покритий. МТТ: Мир Техники и технологий. 2008. 2 7. 0. 58–61.

УДК 531.374

ДОСЛІДЖЕННЯ ПРОЦЕСУ ТА ЗАДАЧІ, ЩО ВИНИКАЮТЬ ПРИ УТВОРЕННІ ОБОЛОНОК МЕТОДОМ ЕЛЕКТРОДУГОВОГО НАПИЛЕННЯ

Тарас Дубиняк[1]; Роман Джиджора[1]; Олександра Манзій[2]; Станіслав Андрейчук[2]

[1]*Тернопільський національний технічний університет імені Івана Пулюя, Тернопіль, Україна*
[2]*Національний університет «Львівська політехніка», Львів, Україна*

Резюме. *Розглянуто методи виробництва антенних систем та виготовлення відбиваючих поверхонь, що базується на нових технологічних і конструкторських ідеях. Основними напрямками є* *збереження при виробництві антен основних принципів авіаційних технологій і видалення технологічних процесів впливу суб'єктивних негативних факторів. Оптимізація конструкцій за критеріями жорсткість-точність-маса. Використання безстапельного складання і юстування антен на об'єкті. Використання методів векторної дифракції при оптимізації електродинамічних характеристик антенної системи на стадії проектування. Створення систем управління позиціювання антени, управління швидкостями її переміщення, діагностика стану при експлуатації, самотестування, здійснюється на базі цифрового опрацювання інформації.*

Досліджено процес утворення оболонок з сітчастого матеріалу, що може бути використано для виготовлення осесиметричних і неосесиметричних рефлекторів або окремих елементів дзеркальних антен. Однією з задач, які досліджують при формуванні оболонки, є знаходження положення елементів сітки після деформування, що у нашому випадку зводиться до знаходження положення вузлів сітки після деформації, знаходження положення елементів сітки після деформування.

Мінімізація потенціальної енергії здійснено чисельно ітераційним методом. При розрахунку енергії використовується очевидний факт, що енергія елемента залежить лише від деформації самого елемента, а деформація, в свою чергу, залежить від зусиль, прикладених до кінців елемента. Також очевидним є те, що енергія всієї сітки дорівнює сумі енергій її частин. Сітка виконує функцію силового каркасу й забезпечує інтенсифікацію процесу нанесення покриття, що дозволяє сформувати якіснішу відбиваючу поверхню оболонки. Іншою проблемою, яка виникає при реалізації методики напилення, є позиціонування, траєкторія, лінійна й кутова швидкості переміщення сопла напилювача, які б забезпечували рівномірність шару покриття по всій поверхні. Дана технологія виготовлення оболонок із сітчастого матеріалу може бути використана для виготовлення осесиметричних і неосесиметричних рефлекторів або окремих елементів дзеркальних антен.

Ключові слова: *електродугове напилення, сітка, потенціальна енергія, дзеркало, осесиметрична антена.*

https://doi.org/10.33108/visnyk_tntu2021.04.024 *Отримано 10.12.2021*