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THERMAL HARDENING OF PARABOLIC POLYMER COMPOSITE ANTENNAS WITH THE USE OF MICROWAVE RADIATION

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Keywords: *microwave technology, electrodynamic system, source of microwave energy, the temperature distribution, composite material.*

Theoretical results of curing antennas made of composite materials using electromagnetic field of super high frequencies as a source of heat energy are presented. The advantages of microwave heat treatment of the antenna made of carbon fiber with epoxy binder in comparison with traditional methods are presented. Results of theoretical studies on the accelerated curing of antennas made of composite materials in microwave radiation type installation in the periodic mode are presented.
A radial type setup for the polymerization of antennas made of composite materials with a diameter of 1200mm, a thickness of 3mm at a temperature of +180°with the electromagnetic field frequency oscillations of 2450MHz and a power output of 4.8kW was developed. A set allows to reduce the energy consumption for the technological process of accelerated curing of an antenna made of composite material, increase productivity and improve working conditions of staff.
The essential expressions and calculation results of the temperature distribution along the thickness of the antenna made of composite material are presented. The heating duration of the antenna from the temperature of +20°C to a temperature of +200°C, weight 5,4kg, is 160 seconds. The temperature deviation from the nominal value of the temperature on the surface of the antenna is absent, and through the thickness of the antenna does not exceed 2°C.
As a result, the research shows the prospects of using microwave radiation for the production processes associated with accelerated curing of parabolic antennas made of composite materials. Currently work is underway to study the strength characteristics of polymer antennas, assuming that the uniform heating of the antenna leads to the absence of internal stresses and other defects of the material structure of the antenna.

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I. Introduction

At the present time in various industries increasingly used materials based on carbon fiber as cladding material for stealth aircraft, for the manufacture of space antennas, engine parts, as well as for the production of reinforcement of concrete slabs. Composite materials based on carbon fibers are characterized by high values of technical characteristics such as strength, stiffness and low specific gravity.

In connection with the need for the use of telecommunication satellite systems and satellite repeaters interest in the antenna reflectors working in open space is growing [1].

The basic requirements for such a design of the antenna, in addition to radio technical, are: high precision of manufacturing of the antenna, the thermal stability of the antenna structure, thermo mechanical stability and thermal properties of a material, light weight with high rigidity and strength of its design.

The combination of these characteristics allows the greatest use of polymer composite material based on carbon fiber and heat-resistant epoxy binder for the manufacture of the antenna. The operating temperature of the working antenna is in the range of minus 160 °C to plus 140 °C.

Traditional methods of curing antennas made of polymer composite materials are related to the solution of the following processes:

– heating of the antennas made of composite materials to the desired temperature with the use of electric heating elements;

– maintaining the predetermined temperature of the material of the antenna for the time needed to cure the polymeric composite material taking into account the heater radiation into the environment.

Traditional processes of polymeric composite antennas' heating are associated with the account of thermal conductivity and is accompanied by a large expenditure of energy and time.

Low speed curing of antennas made of polymer composite materials is associated with the process of heating the outer layers of the antenna material and the heat transfer to the inner layers of the antenna due to the low thermal conductivity of the composite material. During the heating, internal stresses between the outer and inner layers of the composite antenna polymeric material arise, which can then lead to various defects of the material structure and can reduce the strength characteristics of the antenna.

Microwave method [2-5], compared to traditional methods of the polymeric composite antenna's thermal curing has the following advantages:

– microwave radiation immediately penetrates deep into the material to be treated and accelerates the flow of the polymerization reaction;

– technological processes are accelerated several times due to the nature of the volumetric heating of the polymeric composite antenna;

– volumetric nature of the composite antenna heating does not depend on its thermal conductivity and doesn't lead to internal stresses and other mechanical defects in the internal structure of the product;

– technological process of polymeric composite antennas' heat treatment does not have inertia, which allows to regulate it precisely enough;

– microwave radiation does not heat the surrounding space - air, which allows to save energy costs;

– if the processed material is located in a mandrel made of a radio transparent and thermal insulating material, such as polytetrafluorethylene, it is possible to ignore the heat transfer to the surrounding space, which significantly leads to energy costs saving due to the thermos effect at maintaining the material of the antenna to a predetermined temperature before its solidification.

Thus, the use of microwave radiation allows to intensify the process of heat treatment of products made of polymer composite materials, reduce the area occupied by the heating plants and improve process economics.

II. Main part

The beam-type microwave unit is proposed for curing the antenna polymer composite structure.

The working chamber of the periodic operational microwave unit has the following dimensions: diameter of the microwave installation 1500mm, 1200mm diameter of the antenna, the antenna thickness 3 mm, height of the working chamber 600mm. The antenna is made of carbon fiber with epoxy heat-resistant binder.

Composite material parameters are: the real part of the relative dielectric constant of antenna dielectric material is ε=4,5 at the temperature of +180°C,the imaginary part of the relative permittivity is ε=0,28 at the temperature of +180°C, antenna material density is 1600kg/m^3, the heat capacity of the material is 0,90kJ/(kg·°K), antenna weight is 5,4kg, the power needed to heat a composite antenna material from the temperature of + 20°C to + 180°C corresponds to the value of the processing time of 160 seconds at 4,8kW of power. The antenna is located at a distance of 300mm from the upper lid of the working chamber.

To implement the technological process 6 sources of microwave energy were located on the working chamber. Maximum power output of each source of microwave energy was 0,8kW.

The of the polymer composite antenna was placed in a fluoroplastic mandrel which rotated at a specific angular speed around its axis. The material of mandrel is radio transparent and thermal insulating to ignore the heat leakage into the environment and maintain the desired temperature for the complete curing of the antenna material.

Microwave chamber consists of two parts: the upper part of the chamber includes a lateral cylindrical surface and the top cover with microwave energy sources. Lower portion includes a stand, the bottom of the working chamber with the motor and the rack for supporting the mandrel with the antenna. At the bottom of the working chamber is a spring metal braid that when connecting it to the upper part of the working chamber prevents microwaves leakage from the installation for the safety of staff. Curing of the antenna goes on at + 180°C over a time of 60 seconds.

The source of microwave energy had a weight of 12kg and overall dimensions: length – 400 mm; width – 200 mm; height – 200 mm. Output from the source of microwave energy was carried out by using a waveguide with cross-section of (72 × 34) mm working on the main wave type H_{10}, and the waveguide aperture is used as a radiating antenna.

When calculating the radiation pattern of the aperture of a rectangular waveguide Huygens – Kirchhoff's method was used. Microwave energy sources were located on the top cover of the working chamber so as to ensure the formation of a uniform temperature distribution over the antenna's surface during its movement. The total surface area of the antenna was 1,13m^2; three sources arranged at an angle of 120° provided the uniform heating of the antenna area of 0,57m^2, two sources of microwave energy, located at 180°C ensured the uniform heating of the antenna area of 0,38m^2 and one source provided the uniform heating area of 0,19 m^2 of antenna. Thus the power of microwave radiation per one square meter area of the antenna was 4210W/ m^2.

Fig.1 shows the location of microwave energy sources on the top cover of the microwave beam-type chamber. Such location created the uniform heating of the antenna on its entire area.

The level of spurious emissions from the microwave installation did not exceed 10μW/cm^2, which provided the necessary security health standards for the staff.

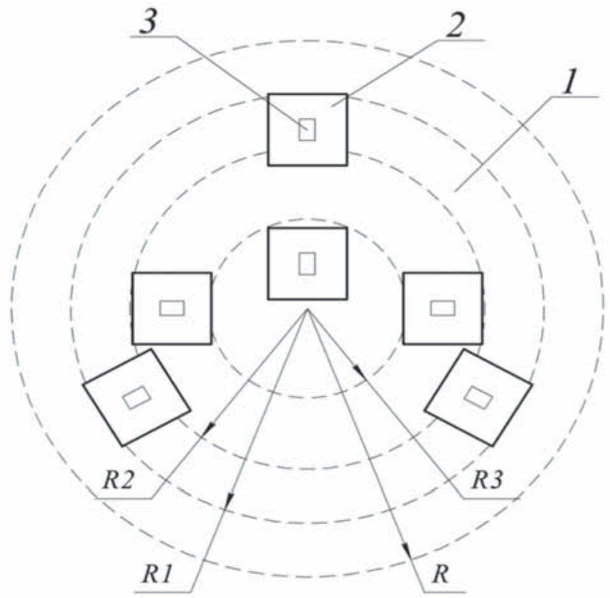

Fig.1. Location of the microwave energy sources on the top surface of the working chamber: 1 – top cover of the working chamber; 2 – source of microwave energy; 3 – rectangular waveguide as an output of microwave energy, R – 750mm, R1 – 600mm, R2 – 425mm, R3 – 245mm

Fig.2 shows a cross-sectional view of the microwave beam-type installation.

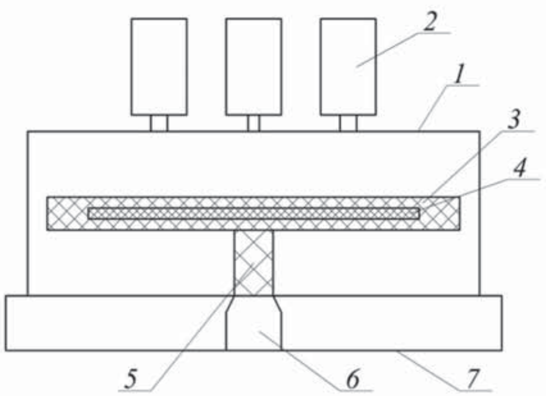

Fig. 2. Cross section of the beam-type microwave installation for polymeric composite antenna curing: 1 – cylindrical chamber, 2 – a source of microwave energy, 3 - PTFE mandrel, 4 – polymeric composite antenna, 5 – stand mandrel of PTFE, 6 – motor, 7 – stand

The temperature distribution through the thickness of the material of the polymeric antenna can be calculated by the formula [6-7]:

$$T(z)=T(0)\cdot e^{-2\alpha\cdot z}, \quad (1)$$

where: $T(z)$ – the temperature of the antenna material at a distance z from its surface; $T(0)$ – temperature at the surface of the antenna (+180°C); α – the electric field attenuation amplitude decay constant, which in a first approximation is given by the expression [6-8]:

$$\alpha=\frac{\pi}{\lambda}\cdot\frac{\varepsilon''}{\sqrt{\varepsilon'}}. \quad (2)$$

Method of placement of the microwave energy on the top cover of the working chamber is that the reaching the source reflected power was minimal and did not affect the operation of the microwave energy source.

Let's carry out an estimate of the reflected microwave power coming to the input of microwave energy source.

The area of the microwave energy source output has a cross section of the waveguide (72 × 34) mm. it corresponds to 0,0024 m^2, and the total area of six microwave energy sources is 0,0144 m^2.

The total area of the irradiated surface is 1,13 m^2, while the surface area of the radiating waveguides is 1,27%. In this case, the reflected power per input of microwave energy source is 0,01 kW and cannot have a significant effect on the microwave installation operation.

The temperature deviation from the nominal value of +180°C on the surface of the antenna material was absent, and in the thickness of the antenna material did not exceed 4°C without taking into account the reflected power (+176,4°C).

With the taking into account the reflected power from the bottom of the working chamber the unevenness of heating in the thickness of the antenna material does not exceed 2°C.

Heat treatment of the composite antenna should be performed prior to full curing. The full curing of the antenna material can be achieved during its exposure at the set temperature of +180°C in the working chamber of the microwave setup within 60 seconds.

III. Conclusion

A microwave beam-type installation for curing the polymer composite antenna with a diameter of 1200mm and a thickness of 3mm at a frequency of the electromagnetic field oscillations of 2450MHz and power output 4,8kW was worked out.

Microwave unit can reduce power consumption for technological polymer composite antenna polymerization process, and improve the working conditions for the staff.

The deviation from the nominal temperature values of +180°C on the surface of the antenna is absent, and in the thickness of the antenna material does not exceed 2°C when it is heated to a temperature of +180°C.

The level of spurious radiation from a microwave-type installation does not exceed 10mkW/cm^2, which ensures the safe sanitary standards for staff.

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ОТВЕРЖДЕНИЕ ПАРАБОЛИЧЕСКИХ АНТЕНН ИЗ ПОЛИМЕРНЫХ КОМПОЗИЦИОННЫХ МАТЕРИАЛОВ С ИСПОЛЬЗОВАНИЕМ МИКРОВОЛНОВОГО ИЗЛУЧЕНИЯ

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Аннотация

Представлены теоретические результаты отверждения параболической антенны из полимерных композиционных материалов с использованием в качестве источника тепла энергии электромагнитного поля сверхвысоких частот. Показаны преимущества микроволнового метода тепловой обработки антенн из углеродного волокна с эпоксидным термоотверждающимся связующим по сравнению с традиционными методами. Приведены результатытеоретических исследований по ускоренному отверждению антенн из полимерных композиционных материалов в микроволновой установке лучевого типа в периодическом режиме. Разработана микроволновая установка лучевого типа для полимеризации антенн из композиционных материалов, диаметром 1200 мм, толщиной 3мм при температуре +180°С на частоте колебаний электромагнитного поля 2450 МГц и выходной микроволновой мощностью 4,8 кВт. Микроволновая установка позволяет сократить энергетические затраты на технологический процесс ускоренного отверждения антенны из полимерного композиционного материала, увеличить производительность и улучшить условия труда обслуживающего персонала. Представлены основные выражения и результаты расчёта распределения температуры по толщине антенны из полимерного композиционного материала. Длительность нагрева антенны от температуры +20°С до температуры +200°С, весом 5,4 кг, составляет 160 секунд. Отклонение температуры от номинального значения температуры по поверхности антенны отсутствует, а по толщине антенны не превышает 2°С. В результате проведенных исследований показана перспективность использования микроволнового излучения для технологических процессов, связанных с ускоренным отверждением параболических антенн из полимерных композиционных материалов. В настоящее время ведутся работы по исследованию прочностных характеристик полимерных антенн, предполагая, что равномерный нагрев антенн по объёму ведёт к отсутствию внутренних напряжений и других дефектов структуры материала антенны.

Ключевые слова: *микроволновая технология, электродинамическая система, источник СВЧ-энергии, распределение температуры, композиционный материал.*

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