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Resonance method of electromagnetic to mechanical energy transformation

Abstract

The ferroelectric is placed in an inhomogeneous electromagnetic field of the microwave and acts on it by a constant electric field. The magnitude and direction of the resonance between the vectors of the electrical moments of the ferroelectric structural particles and the vector of the spatially inhomogeneous electric field strength of the microwave are ensured, than the motion of the chaotically directed electric moments of the domains along it and the direction of its in homogeneity increase. Using the physical modeling method in the zeroth approximation, an algorithm is obtained for calculating the force with which an electromagnetic wave propagating in a rectangular waveguide acts on a ferroelectric ball placed in a constant electric field. The theoretical results of the calculations are compared with the experimental ones.

Keywords: electromagnetic energy, ferroelectric, resonance, transformation, ponderomotive wattmeter

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Martynenko LG,[1] Komarova AL[2]

[1]National University of Trade and Economics, Ukraine
[2]Ukrainian State University of Railway Transport, Ukraine

Correspondence: Martynenko LG, National University of Trade and Economics, Ukraine,
Email leonid.martynenko@gmail.com

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Statement of the problem in general form. Electromagnetic energy of microwave is used in various fields of science and technology: particle accelerators, thermonuclear fusion systems, heating and processing of materials and products in the food industry, radiolocation, telecommunications,[1] medicine,[2] etc..[3] Rational use of microwave energy is impossible without reliable and accurate measuring devices. One of the main parameters of electromagnetic energy, which must be controlled when using it, is power. At present, wattmeters are used to measure the microwave power in industrial conditions, for example: DPM 5000-EX of Bird Electronic Corporation, USA;[4] R & S ® NRP2 from Rohde et al.;[5] M3-56, MKZ-71 of the company "Meridian".[6] The error in measuring the power passing from the generator to the load with these wattmeters is 4-5% (without taking into account the error of the deviation and the error of the additional transitions). Known model ponderomotive wattmeters as close as possible to standards, which have a measurement error, passing from the generator to a load of power equal to 0.2%.[7] The use of these watts in industrial conditions is impossible, since they have a low mechanical strength.

In ponderomotive wattmeters, the suspension system is fixed only on one side. The mechanical energy received by the converter from the electromagnetic wave is not enough to turn the converter under the condition of fixing the suspension system in the wattmeter from both ends. Ponderomotive wattmeters have significant advantages (in terms of measurement accuracy) in comparison with those listed above, namely: power measurement is reduced to measuring the main physical quantities of the SI system-mass, length, and time. Therefore, in our opinion, it is actual to develop methods and means to increase the efficiency of converting electromagnetic energy into mechanical ones to levels at which the wattmeter's suspension system can be fixed on stretches or cores, which will increase the mechanical strength of the ponderomotive wattmeter and use it to measure power in industrial conditions. Analysis of recent research and publications. To improve the method of increasing the efficiency of conversion of electromagnetic energy into mechanical use, the results of the following studies.

In work,[7] the force action of the microwave electromagnetic field on the converter is investigated, which is located in a rectangular waveguide. The converter has a geometric parallelepiped or ellipsoid shape and is made of metal or dielectric. Its linear dimensions are much smaller than the wavelength. An algorithm for calculating the force is developed, the theoretical results of the calculations are compared with the experimental ones. The studies carried out in this paper show that at a microwave power of 1 W, a torque of about 10-11 N · m acts on the transducer. The insignificant force impact of electromagnetic energy on the ponderomotive converter is due to the fact that the electric dipole and magnetic moments of the structural particles of the dielectric or metal, due to thermal motion, are randomly oriented in space. The energy conversion method used in these works does not provide for the coordination of their motion with the motion of an electromagnetic wave. Their motion with the motion of an electromagnetic wave.

In[8] an analytical theory of electromagnetic phenomena in resonant complex spatial systems of small resonance homogeneous isotropic magneto dielectric spheres and located in rectangular metal waveguides was developed. The effect of the resonance phenomenon on the internal and scattered electromagnetic field is investigated. The results of this study show that in the ferrite spheres it is possible to ensure the coordination of the motion of the magnetic moments of domains with the motion of an electromagnetic wave due to the phenomenon of resonance. The effect of ferrimagnetic resonance on the conversion of energy into mechanical resonance was investigated in.[9] The conducted studies confirm an increase in the coefficient of conversion of electromagnetic energy into mechanical energy for ferrimagnetic resonance. The force action of electromagnetic waves on ferroelectrics in the region of electrical resonance (the Stark effect, the electrofield effect) has not been investigated. The purpose of this scientific article is to improve the method of converting microwave electromagnetic energy to mechanical for increasing the efficiency of the converter due to the use of ferroelectrics and the phenomenon of electrical resonance. Statement of the main research material. The physical model of converting microwave electromagnetic energy into mechanical one can be represented as follows. In a rectangular waveguide in which electromagnetic energy is propagated by a H_{10}

wave, a ferroelectric ball is placed and rectangular waveguide, carried out by physical modeling. The axes of a rectangular coordinate system are directed as follows: The x axis is directed along the wide wall of the waveguide, y is along a narrow wall, and z is along the axis of the waveguide. The electromagnetic wave propagates along the z axis. The center of the ferroelectric sphere is located at the point (x=a/4, y=b/2, z=0).

The electric field strength in the waveguide is represented by the following expression:[7]

$$E_y = E_0 \cdot \sin\frac{\pi \cdot x}{a} \cdot e^{i\cdot(\omega\cdot t - \beta\cdot z)}, \tag{1}$$

$$E_0 = \sqrt{\frac{2\cdot Z\cdot P}{a\cdot b\cdot\sqrt{1-\left(\lambda/2\cdot a\right)^2}}}, \tag{2}$$

where a, b - linear dimensions of the walls of a rectangular waveguide; x, y are the coordinates; λ is the length of the electromagnetic wave; ω is the angular frequency; t is the time; β is the propagation constant of the electromagnetic wave in the waveguide; Z is the wave impedance; P is the incident power of the electromagnetic wave; i is the imaginary unit. The strength of the microwave electric field inside the ferroelectric sphere is calculated by the method of integral equations of macroscopic electrodynamics:[8]

$$E_c = E + \frac{1}{4\pi}\left(\mathrm{graddiv} + k^2\right)\int_V \frac{e^{-i\cdot k\cdot|r-r'|}}{|r-r'|}\cdot\chi\cdot E_c\, dV, \tag{3}$$

Where

i. E_c is the electric field strength vector of the electromagnetic field in the ferroelectric sphere;

ii. E is the electric field strength vector of the electromagnetic field in the waveguide;

iii. k is the wave vector;

iv. r - coordinate of the observation point;

v. r′ is the coordinate of the integration point;

vi. V is the volume of the ferroelectric sphere;

vii. χ is the electric susceptibility of a ferroelectric.

The integral equation (1) under the condition that the size of the ferroelectric sphere is much smaller than the length of the electromagnetic wave in its middle (R<<λs) in the zeroth approximation can be represented in the following form:

$$E_c = E + \frac{1}{4\pi}\left(\mathrm{graddiv}\right)\int_V \frac{1}{|r-r'|}\times \chi\cdot E_c\, dV, \tag{4}$$

The solution of equation (4) is known:[7]

$$E_c = \frac{E}{1+3\cdot\chi}, \tag{5}$$

In accordance with the principle of superposition for the vector of electric field strength, vector E_c can berepresented by a sum of two vectors that rotate in opposite directions:

$$E_c = E_{c1} + E_{c2}, \tag{6}$$

$$E_{c1} = E\cdot\left[y_o\cdot\sin\left(\omega\cdot t-\beta\cdot z\right) + z_o\cdot\cos\omega\cdot t-\beta\cdot z\right], \tag{7}$$

$$E_{c2} = E\cdot\left[y_o\cdot\sin\left(\omega\cdot t-\beta\cdot z\right) - z_o\cdot\cos\left(\omega\cdot t-\beta\cdot z\right)\right], \tag{8}$$

$$E = \frac{E_0}{2\cdot\left(1+3\cdot\chi\right)}\cdot\sin\frac{\pi\cdot x}{a}, \tag{9}$$

de y_o, and z_0 are the unit orthes directed along the axes y and z. If the vector of a constant electric field is directed along the x axis, then in this case the vector E_1 and the vector of the electric moments of the domains (p_i) rotate in one direction with one angular frequency ω_0, and the vector E_2 and the vector (p_i) rotate in opposite directions. In the rotating electromagnetic field, the electrical moments of the domains (p_i) acquire potential energy. The average potential energy for a period can be represented by the following equations:

$$U_{1c} = -\frac{1}{T}\int_0^T p_i\cdot E_1\cdot\cos\phi\cdot dt = -p_i\cdot E_1\cdot\cos\phi \tag{10}$$

$$U_{2c} = -\frac{1}{T}\int_0^T p_i\cdot E_2\cos\phi\cdot dt = 0 \tag{11}$$

where φ is the angle between the direction of the vector of the electric moment of the domain (p_i) and the vector of the electric field strength (E_{c1}). Under the condition of thermodynamic equilibrium, in accordance with the Boltzmann distribution, the number of domains that have angles φ in the range from φ to φ + dφ can be calculated by the following expression:

$$dN = D\cdot e^{\frac{p\cdot E_{c1}\cdot\cos\phi}{k\cdot T}}\cdot d\phi, \tag{12}$$

Where

i. k is the Boltzmann constant;

ii. T is the temperature.

The proportionality factor D can be calculated under the condition that the total number of domains per unit volume should be N:

$$D = \frac{N}{\int_0^\pi e^{\frac{p\cdot E_{c1}\cdot\cos\phi}{k\cdot T}}\cdot d\phi}, \tag{13}$$

The total electric moment dN of domains having angles φ in the range from φ to φ + dφ is p · dN, and the projection of this moment on the direction of the vector E_1 is p · dN · cosφ. Polarization of a ferroelectric in an electric field can be calculated using the following equation:

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$$Đ = \frac{N \cdot p \cdot \int_0^{\pi} e^{\frac{p \cdot E_{ñ1} \cdot \cos\phi}{k \cdot T}} \cdot \cos\phi \cdot d\phi}{\int_0^{\pi} e^{\frac{p \cdot E_{ñ1} \cdot \cos\phi}{k \cdot T}} \cdot d\phi}, \quad (14)$$

The potential energy that a ferroelectric ball receives in an electromagnetic field can be calculated using equation:

$$U=-P \times E_{ñ1} \times V, \quad (15)$$

The force with which the electromagnetic field of the microwave acts on the ferroelectric sphere placed in a constant electric field field can be calculated using the following equation:

$$F = gradU, \quad (16)$$

Unknown quantities that are used in the quantitative analysis of the force action of an inhomogeneous electromagnetic wave on a ferroelectric sphere: the number of domains per unit volume N and the electric moment of the domain p were obtained from an analysis of the hysteresis loop for barium titanite constructed by experiment. A numerical analysis of the force F is made for a ball made of barium titanite and having a diameter of 3 mm. Counting parameters: the cross-section of the waveguide is 10 · 23 мм^2; the power of the electromagnetic wave is 10 W; wavelength of 3.2 cm; the number of domains per unit volume - 1.0 · 1018 cm3; the electric moment of the domain is 1.4 · 10^{-23} An experienced laboratory device for measuring the strength with which an electromagnetic wave acts on a ferroelectric ball consists of a source of stabilized voltage, a magnetron generator, a ferrite valve, an attenuator. a section of a rectangular waveguide, a microwave power meter, an analytical balance, and a mobile system for fixing a ferroelectric ball in a waveguide. The mobile system consists of a thin quartz thread on which a ferroelectric ball is fixed. One end of the thread is attached to the prism located on the end of the beam of the analytical balance. At the second end of the quartz thread, a metal cone is fixed, which is immersed in liquid for mechanical stabilization of the mobile system. The wide wall of the waveguide section is placed vertically in space.

A quartz filament with a fixed ball is passed through two holes in the narrow walls of the waveguide. The ferroelectric ball can move freely along the wide wall of the waveguide. The results of measuring the magnitude of the force acting on a ball made of barium titanite and placed in a rectangular waveguide in which an electromagnetic wave propagates, confirm its resonant increase. With an electromagnetic wave power equal to 10 W, which propagates in waveguides with a cross section of 10 · 23 mm2 on a ferroelectric ball having a diameter of 3 mm, the force acts as (2±2)·10-6 N. Putting the ball at a distance of 10 mm from the axis of rotation, we obtain a force moment equal to 2 · 10-8 N · m, which is 200 times greater than the moment of force achieved in.[7]

Conclusion

The use of ferroelectrics placed in a constant electric field for the manufacture of converters of electromagnetic energy into mechanical allows: increasing the moment of force and the sensitivity of the meter as a measuring device; to obtain a sufficient amount of mechanical energy for the rotation of the wattmeters suspension system fixed at both ends by means of stretches or cores. This allows the development of microwave watmeters with sufficient mechanical strength and reliability for industrial applications.

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Conflict of interest

The author declares no conflict of interest.

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