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ЭЛЕКТРОМАГНИТНЫЕ ВОЛНЫ КАК СПОСОБ ЗАЩИТЫ ОТ ГОЛОЛЕДА ПРОМЫШЛЕННЫХ ОБЪЕКТОВ

ELECTROMAGNETIC WAVES AS A WAY TO PROTECT AGAINST ICING INDUSTRIAL FACILITIES

Аннотация. Анализируются два способа преобразования электромагнитной энергии в тепло: с помощью бегущей и стоячей волны. Рассматривается применение первого способа для борьбы с гололедом в электросетях, второго – в контактной сети железной дороги.

Ключевые слова: линия электропередачи, гололед, скин-эффект, электромагнитная волна, тепловой нагрев, СВЧ резонатор.

Summary. Two ways to convert electromagnetic energy into heat: with the help of traveling and standing waves are analyzed. The application of the first way to deal with icing in electricity, the second - in the contact network of railways are examined.

Keywords: electric wires, icing, skin-effect, electromagnetic wave, thermal heating, SHF resonator.

Introduction. Icing is a natural phenomenon, brings great damage to industrial facilities open type. In particular this applies to high-voltage transmission lines and contact network of high-speed rail and tram transport.

Icing as thick ice formations, reaching up to 50mm or more deposited on the wires, significantly weigh down their leads to breakage and swinging. The deposition of icing even in the form of a thin layer on the contact wire of railway transport leads to an arc discharges occur with high currents and damage to the graphite current collectors pantographs.

As a particularly devastating impact of ice on electrical networks is called Canada in the Montreal area. There is a consequence of ice broken wires, the destruction and disruption of power supply supports large areas [1]. An example of the negative impact of ice on the contact network is a high-speed railway line Paris-London [2].

There are three basic ways to combat icing: mechanical removal of ice, coating the wire de -icing fluid and ice melting at short-circuit wires and heating above 100^0 C. All three methods related to the suspension of the normal functioning industrial design and therefore often ineffective.

Consider a fundamentally new method of protecting wires from the icing by converting microwave energy electromagnetic waves to heat and heated the wires at + $(15\text{-}20)^0$C, which prevents the formation of icing on them.

On the transformation of the energy of microwave electromagnetic waves into heat.

At the heart of this transformation is the Poynting equation that determines the time variation of the electromagnetic field energy W in the volume V [3,4]:

$$\frac{dW}{dt} = P_G - \int_V \gamma \mathbf{E}^2 \, dV - \int_S \mathbf{EH} \, dS \ , \qquad (1)$$

where **E** –the electric field vector; **H** - magnetic field vector; *S* - surface bounding the volume *V*; γ – the conductivity bodies located within the volume.

The first term on the right side P_G of the equation (1) is the power of third-party sources (generators), its energy in the volume *V*; the second - power electromagnetic energy transferred to heat because the active losses in the amount of *V;* the third - the Poynting vector is determined by **P=E×H**, characterizing the energy radiated beyond the consideration of the volume *V* through the surface *S*.

There are two possible electromagnetic wave energy conversion heat. The first option is associated with a traveling electromagnetic wave propagating along a guide structure, in this case along a two- or three-wire line. Such a wave moving along the elongated structure with active losses, gives her his energy.

The second variant related to the conversion of energy of electromagnetic oscillations into heat in the oscillatory system volumetric resonance mode, whereby in the cavity mode standing wave is established.

The conversion of energy of the traveling wave in the heat. In this case, the power balance equation (1) for an electromagnetic wave propagating along an infinitely long line at a distance x from its origin (Figure 1) takes the form:

$$P(x) = P_G - P_R(x) - P_S(x), \qquad (2)$$

wherein P_G - wave power supplied to the line from an external RF generator; P_R - wave power, passing in heat due to of distributed long line of resistance; P_S - radiation power line.

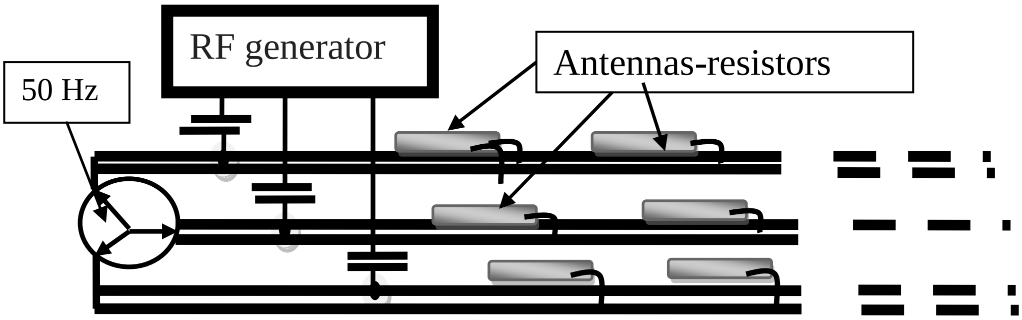

Fig.1

Because the amplitude of the incident wave propagating along the line decreases exponentially, the second term in (2) :

$$P_R(x) = P_G e^{-2\alpha x} \,, \tag{3}$$

where $\alpha = R_f / \rho$ (1 m) – the damping constant; ρ - characteristic impedance of the line; R_f - the resistance per unit length of one of the two identical cables whose value in the microwave range depends on the surface a thin layer of δ virtue of the skin effect, i.e. displacement current to the outer shell conductor [3,4].

Skin depth δ with increasing frequency is reduced to a few millimeters, which determines the sudden increase of two orders of magnitude or more, the wiring resistance as compared with the power frequency at 50Hz, and hence more efficient conversion of electromagnetic energy into heat

With the aid of the following simple method can to pay the conversion into heat and radiation energy. To this end, along the main line (position 1 in Figure 2, a) that governs the electromagnetic wave with a certain step should be to place the short pigtails - vertical vibrators (position 2 in Fig. 2, a), the radiation power of each of them :

$$P_V = 0{,}5\, R_\Sigma\, I^2 \approx 400 \left(l/\lambda\right)^2 I^2 \,, \tag{4}$$

where λ- wavelength, l - the length of the vibrator, R_Σ - radiation resistance of the antenna.

When replacing a piece of wire graffiti - ceramic resistor R>>R_Σ (position 3 in Figure 2, b) most of the signal power is not emitted into the environment, and is dissipated as heat in the resistor temperature is set to T_0. Finally, moving the resistor in a horizontal position and leaned it to the main transmission line (Figure 2,c), to carry out efficient heating line by the radiated power, the total value of which is at a distance x is:

$$P_S(x) = \sum_{i=1}^{N} P_{i\,S} \,, \qquad (5)$$

where N - total number of vibrators at the site of the main line 0 - x (Fig.1).

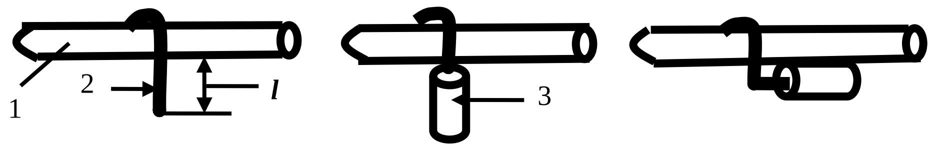

Fig.2 a) b) c)

The general scheme of the experiment to verify this method of heating line corresponds to Figure 1. As a source of energy used by the generator 500 watt frequency of 81.36 MHz is authorized for use for industrial and scientific purposes, according to "Radio Regulations". During the experiment heats two-wire line with stranded aluminum conductors type AC-16 radius r=2.5 mm and a length of 200m. The temperature was measured using thermometers alcohol group attached to the wires, and an infrared pyrometer

When the RF generator heating temperature ceramic transducers which are used as resistance MLT, equal from 50^0 C to 80^0 C at an ambient temperature of 20^0 C, and the surface is heated wires on average ΔT = 15 ... 20^0 C with respect to ambient temperature in a power density RF power costs of about 3 to 4 W/m.

Thus, our experimental studies have confirmed the principle of heating the core wire using high-frequency electromagnetic waves using two physical phenomena: the skin effect and convert radiated energy into heat

The conversion of energy of the standing electromagnetic wave in the heat. In this case, the heated body will be stirred inside the cavity resonator, the resonant frequency is determined by a number of half-waves of standing, stacked along the walls of the latter. The oscillator frequency must coincide with the resonance frequency of the resonator, and a frequency of the dipole moment of the molecules of bodies heated body [5] . At observance the second condition is more rapid and intense electromagnetic wave energy conversion into heat. For example, water has several such resonant frequencies, one of which is equal to 2450 MHz used in household microwave ovens.

There are two main types of cavities: closed and open (Figure 3 a, b).

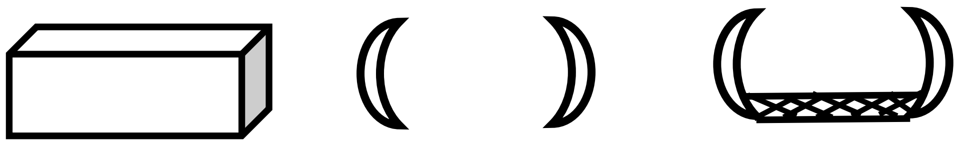

Fig.3 a) b) c)

The resonator is open (Figure 3 b), [6] consisting of spaced at a predetermined distance opposite each other two spherical metallic reflector is used, for example, in lasers. Apart from the two known types of cavities is possible, and a third type in which the space between the reflectors are covered only partially (Figure 3, c). Such a resonator, which is called the half-open, is required, for example, in cases of code need to quickly heated object input and output from the space between the reflectors, i.e, from the region of intense electromagnetic field. The need for such a cavity caused by the fact that it, as shown by experimental studies in the centimeter band can create a strong electromagnetic field than in an open cavity.

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The results of experimental verification of the proposed method of rapid heating of water in the cavity semi-open. Photo laboratory setup is shown in Figure 4.

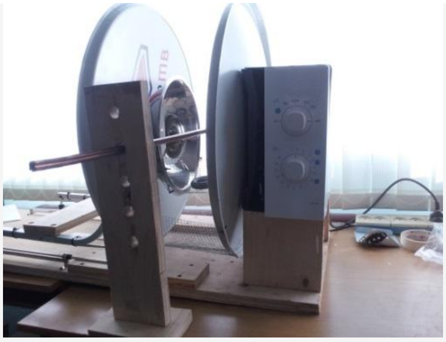

Fig.4

The installation includes a magnetron power of 800 W power supply from a commercially available microwave oven. As the half-open type resonator used two metal reflector diameter 25cm connected to each other by the bottom quarter of the circumference of the metal mesh with small cells. The distance between reflector centers is 31 cm. The temperature is measured with an infrared pyrometer.

As an indicator of the efficiency of heating by microwave radiation used water tank with a mass of 100g, placed in the free space between the reflectors (Figure 4). When magnetron power of 800 watts frequency of 2450 MHz, the water is heated to ΔT = 70^{0}C for 3 minutes. For heating the same amount of water in the microwave oven cavity closed type requires 1.5 minutes

Consequently, the effectiveness ratio of microwave heating in the created laboratory installation with half-open the resonator, approximately, is doubled less, than in similar installation with the resonator of the closed type.

Thus, the principle of heating of water by means of the microwave generator (magnetron) with a frequency of 2450 MHz and the half-open resonator is experimentally confirmed.

The energy of the electromagnetic field associated with the power of the microwave generator function:

$$W_{EM} = P_G \, Q / \pi \, f_P \ , \tag{6}$$

where P_G - power generator, Q - factor of the cavity, taking into account losses in its walls and heated body, f_P - the resonance frequency.

This energy with dipole moment leads to fluctuations of the water molecules with the resonant frequency and the rapid heating of water. The effectiveness of a semi-open cavity twice lower closed because of the energy it "spills" out.

Thus, the experimentally confirmed principle water heating using a microwave generator (magnetron) frequency of 2450 MHz and half-open cavity. The ultimate goal of the experiment: check the possibility of applying this method to destroy the icing even on the contact wire of railway transport (Figure 5).

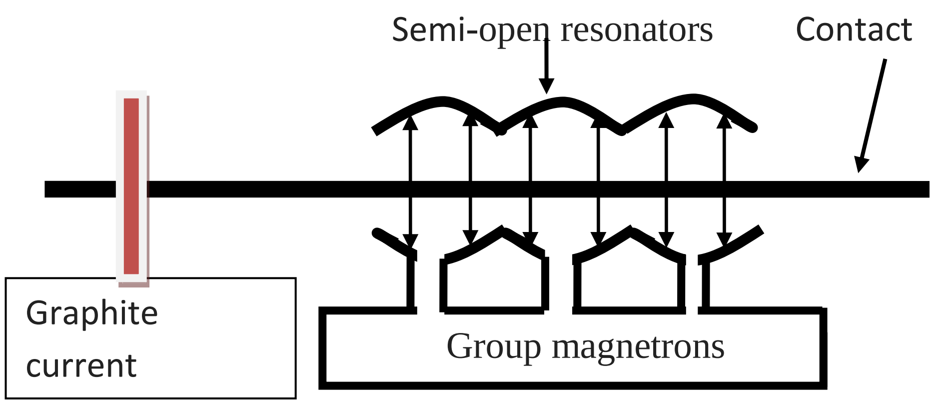

Fig.5

Located in front of a group of microwave pantograph heaters with high power magnetrons each locomotive will, figuratively speaking, to clear the road in front of him, getting rid of the ice on the contact wire.

The two discussed ways to protect industrial facilities from icing are protected by patents of the Russian Federation [7,8].

References:

1. Freezing rain in Canada were left without electricity 400 thousand people. 2013г.Internet.
2. Struggle with icing of contact wires. - CRDM-online-11-2002 .
3.J. D. Jackson. Classical Electrodynamics. - John Willey Sons. Inc. New Yourk, 1962.
4 Ramo, S., Whinnery, J. Fields and Waves in Modern Radio.- NewYork,1944.
5. Dergolts V.F. World of water.- Nedra,1979.
6.Vayshteyn I.A. Open resonators and open waveguides.- M., Sov. Radio, 1961
7. Kaganov V.I. RF patent for the the invention of 20.05.2009, №2356148.
8. Kaganov V.I. RF patent for the the invention of 29.05.2014 № 2014121747