Methods for measuring the reflection coefficient of radio waves

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Abstract. Methods for measuring the reflection coefficient of non-ionized electromagnetic radiation from sheet materials are considered. Horn antennas with square apertures were used for measurements. The maximum dimensions of the irradiation spot are determined depending on the distance to the irradiating horn antenna for different frequency ranges. Two methods of measuring the reflection coefficient of radio waves from sheet materials are described. The first method is based on the use of two antennas for irradiating the material and for receiving the reflected signal. The second method is based on the use of a measuring line. In this case, one antenna is used. A measuring installation was made.

1. Introduction
At present, high-frequency (HF) and ultra-high-frequency (microwave) installations of high power are widely used for induction heating of ferrous and non-ferrous metals and in the production of various plastics. Various methods are used to protect personnel from powerful non-ionizing radiation. Often for these purposes, metal screens are used that reflect electromagnetic waves, as well as absorbing coatings with a low reflection coefficient and a high absorption coefficient.

When choosing absorbent materials, it is important to ensure that the material has sufficient absorption or low reflectance. It is technically easier to measure the reflection of radio waves rather than the energy absorbed by the material and converted into heat. If an industrial plant operates at different frequencies, then measurements must be carried out at these frequencies, which requires not only different generator and measuring equipment, but also different measurement techniques.

Powerful RF and microwave installations almost always require shielding of the entire volume of the emitting installation in order to exclude possible re-reflection of radio waves from local objects. The waves reflected from the metal screens affect the technological process and can lead to distortion of the operating parameters of the emitting installations [1]. The application of sheet absorbing coatings to metal screens solves this problem, since the coating absorbs the main energy of non-ionizing radiation, converting it into heat. In this case, waves reflected from the metal screen pass through the absorbing coating again and are further attenuated. In this case, the metal screen acts as a radiator, radiating heat into the surrounding space [2-4].

2. Materials and methods
Radio reflectance measurements can be performed in a variety of ways. The most commonly used measurement method is based on the use of two antennas [3,5]. One antenna is used to irradiate the
material under study with radio waves, and the other antenna receives signals reflected from the material, as shown in figure 1.

Let us consider the features of the process of irradiation with a microwave field. Typical standard devices with an output power of 1-3 mW can be used as microwave generators. The generator must be matched with the emitting antenna [5-8]. It is necessary that the horn antennas be located in such a way that only the plate of the measured material is irradiated and the irradiating microwave field does not go beyond the dimensions of the material whose absorption coefficient is measured. Therefore, it is necessary to determine how the dimensions of the microwave irradiation spot change depending on the height of the horn antennas relative to the measured sheet of material.

Figure 1. Installation for measuring the reflection coefficient of non-ionizing radiation (F1, F2 - connecting feeders, MS - metal sheet, MM - measured material, A1, A2 - transmitting and receiving antennas, DS - detector section).

The geometric dimensions of the pyramidal horns \((l_E, l_H, \text{horn aperture size}, K, \text{horn length})\) for different wavelengths, on the basis of which the measuring stand is implemented, can be selected in accordance with table 1.

| λ, cm | 2.0 | 3.0 | 10 | 24 |
|-------|-----|-----|----|----|
| \(l_E, l_H, \text{mm}\) | 50 | 75 | 255 | 350 |
| K, mm | 195 | 295 | 500 | 700 |

Horn antennas can be kept at a distance of more than 5-8 wavelengths from the measured material [8]. In this case, the plane of irradiation of the measured material will be in the far zone and the irradiation spot will have the shape of an ellipse with dimensions \(l_E\) and \(l_H\), as shown in figure 2.

Figure 2. A platform irradiated with a pyramidal horn from the far zone of the microwave field formation.

Horn antennas for wavelengths over 10 cm have to be placed at distances from the measured plate not exceeding 1-3 wavelengths [9]. Therefore, for these waves, the plane of irradiation of the radio-
absorbing plate is in the near zone. In this case, the illumination spot represents approximately the projection of the horn opening onto the irradiation plane and has the form of a square with side l equal to the horn opening side.

The width of the directional diagram of the horns in the E and H planes is calculated by the formulas

$$\theta_E = \frac{2\lambda}{l_E}, \text{rad}; \quad \theta_H = \frac{3\lambda}{l_H}, \text{rad},$$

(1)

where $\lambda$ is the length of the irradiating wave.

The irradiation spot of the material should not exceed the dimensions of the sheet of the measured material and the dimensions of the irradiation ellipse are calculated by the formula

$$l_{E,H} = 2h \sin \frac{\theta_{E,H}}{2},$$

(2)

where $h$ is the height of the horn suspension.

From expressions (1) and (2), it is not difficult to determine the height of the suspension of the horn antennas $h$, above the measured material. Since $l_H > l_E$ for horn antennas, when calculating the distance between the horn antenna and the measured material, we proceed from the value of $l_H$. The results of calculating the size of the irradiation spots from the height of the horn suspension are shown in Table 2 for different wavelengths.

| $h$, mm | $\lambda$, cm | $l_{E}$, mm | $l_{H}$, mm | $l$, mm | $l$, mm |
|---------|---------------|--------------|--------------|---------|---------|
| 50      | 2.0           | 56.4         | 59.7         | 280.5   | 375     |
| 250     | 3.0           | 282.1        | 298.4        | 382.5   | 475     |
| 500     | 24.0          | 564.2        | 596.9        | 510     | 600     |

Figure 3 shows the calculated value of the relationship between the maximum spot size of the microwave field irradiation with the measured material from the height $h$ of the horn antenna aperture above the material for different wavelengths.

![Figure 3. Relationship of the height of the horn antenna with maximum irradiation spot size.](image)

Placing a clean sheet of metal under the horn, we take the reflection of radio waves from the metal sheet as 100% reflection, or as a reflection coefficient equal to 1. If a power of no more than 1-3 mW is applied to the irradiating antenna (A1 in figure 1) and the level of the microwave signal is recorded, at which the reflection from the metal sheet was taken as 100%, then placing the measured material on top
of the metal sheet, taking into account the quadratic characteristic of the detector at low signal levels, the indicator will immediately show the reflection coefficient of radio waves from the sheet material in percent. This method of measuring the reflection coefficient is very convenient, since it does not require additional calculations and measurements are made quickly [10].

However, with radio wavelengths greater than 10 cm, the dimensions of the horns become large (for example, at $\lambda = 20$ cm, the height of the horn is 0.7 m, and the opening has a size of 0.35 m by 0.35 m). In this case, the dimensions of the measuring unit can increase significantly. At frequencies from 1 to 5 GHz, it is more convenient to measure the reflectance from materials using a single antenna and a measurement line operating in this range, as shown in figure 4.

![Figure 4. Installation for measuring the reflection coefficient of non-ionizing radiation using a measuring line.](image)

In the measuring line, the direct and reflected waves are summed up and the resulting wave has the form shown in figure 5. Since the detector in the line is square-law, the indicator shows the power and the graph of the total signal is given in power units. In this case, all measurements are made in power units, since signals with a level of 1-3 mW fall on the quadratic section of the detector characteristic.

![Figure 5. Aggregate signal when moving the measuring line carriage.](image)

To determine the reflection coefficient using the measuring line, it is necessary to measure the maximum $U_{\text{max}}$ and minimum $U_{\text{min}}$ of the sum of the voltages of the direct and reflected waves and calculate the reflection coefficient. Since the reference is the reflection from the metal sheet, it is necessary to determine a correction factor that indicates the reflection coefficient from the metal sheet when measured with a measuring line. For this, by moving the detector section along the measuring line, the reflection from the metal sheet $P_{\text{max}}$ met, $P_{\text{min}}$ met is measured and the correction factor $K_n$ is calculated in accordance with the expression. The power reflection coefficient is determined by placing
the material to be measured under the horn, measuring P_{max} and P_{min} and calculating in accordance with the expression.

\[ K_n = \left( \frac{\sqrt{P_{\text{max, met}}}}{\sqrt{P_{\text{max, met}}} + \sqrt{P_{\text{min, met}}}} \right)^2 \] (3)

The power reflection coefficient (PRC) is determined by placing the material to be measured under the horn, measuring P_{max} and P_{min} and calculating in accordance with the expression

\[ PRC_n = \frac{1}{K_n} \left( \frac{\sqrt{P_{\text{max}}}}{\sqrt{P_{\text{max}}} + \sqrt{P_{\text{min}}}} \right)^2 \] (4)

3. Results

In accordance with the described technique, a measuring stand has been implemented, which makes it possible to measure the reflection coefficient of non-ionization radio wave radiation from sheet materials in different frequency ranges. The appearance of the constructed stand is shown in figure 6.

![Figure 6. Appearance of the measuring stand.](image)

References

[1] Panyshrin A N, Panushrin N N and Samoylov A G 2019 Effective thickness of a flat screen. *Design and technology of electronic tools* 4 38-41
[2] Koryakin-Chrnjak S L, Partala O N and Shustov M A 2014 *Electrotechnical reference book* (Moscow: Science and Technology) 592
[3] Polushin P A and Samoylov A G 1993 An Impedance Gage for Gas Discharge Lasers Excited by High-Frequency Signals *Instruments and experimental technique* 36(5) 90-3
[4] Sazonov D M, Gridin A N and Mishustin M A 1981 Microwave devices Moscow Hign school 295
[5] Polushin P A, Samoylov A G and Samoylov S A 2000 Adaptive high frequency generators for biomedical purposes *Medical technology* 4 26-32
[6] Ryabokon AV and Samoilov A G 2008 Design of matching circuits for high-power generators with external excitation *Design and technology of electronic tools* 1 7-12
[7] Collin R E 2001 *Foundations for microwave engineering* (John Wiley & Sons, Inc Hoboken, New Jersey) p 924
[8] Polushin P A and Samoylov A G 1993 Impedance meter for an RF - pumped gas - discharge laser *Instruments and Experimental Techniques* 36(5) 716-18
[9] Rizzi P A 1988 *Microwave engineering Passive circuits* (Prentice-Hall. Inc. London)

[10] Polushin P A and Samoilov A G 1995 An adaptive pump generator for waveguide lasers
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