Measurements in microwave electrotechnology

S Kalganova¹, E Vasinkina¹, V Alekseev¹, V Lavrentyev¹, S Trigorly¹,
T Dunaeva¹
¹Yuri Gagarin Saratov State Technical University, Saratov, 410054, Russia

Abstract. The classification of measurements in microwave electrical engineering is given, which takes into account all measurements at different stages of creation and operation of both a microwave electrical installation and its individual elements.

Introduction
Intensive and extensive research on the use of electrophysical methods of processing materials and products showed the effectiveness of using for this purpose the energy of microwave electromagnetic oscillations [1,2]. The experience of scientific research in the field of microwave electrotechnology, development and operation of microwave electrotechnological installations, shows the important role of measurements of all at the stages of the life cycle of the installation. Data on measurements and their results are given in many scientific articles [1-3]. However, all this information is fragmentary, not systematized, they do not indicate the problem of measurements in microwave electrotechnology, they do not define a complete list of measured parameters. During scientific research, during the development of microwave installations, during their testing and operation, various measurements are made of the parameters of the installation, its elements and the properties of the treated object. These measurements are specific, substantially different from similar measurements in microwave technology, in materials science, and sometimes have no analogues in related fields. This allows us to consider that a systematic approach to the measurement problem in microwave electrotechnology is very relevant.

Methodology
A variant of the classification of measurements is proposed, which takes into account the different stages of creation and operation of both the microwave electrotechnological unit and its structural elements. A distinctive feature of the developed classification is the presence in its structure of measurements at the stage of scientific research, including measurements of technological properties of the processed object.

The authors do not consider measurements within the framework of specific technologies that are of independent significance.

Results and discussion
With all the diversity of microwave electrothermal installations and the technological processes implemented in them, all these installations have the same structural scheme (Figure 1).

There can be several variants of the technical classification. One of them is classical if we add to it the studies of the physico-mechanical, physico-chemical properties of the processed object:
- measurement of current strength;
- measurement of voltage;
- power measurement;
- frequency measurement;
- measurement of standing wave ratio;
- Measurement of Q-factor of oscillatory systems and attenuation of the lines of the trans-response;
- measurement of electrical properties of materials;
- measurement of field strength;
- research of physical-mechanical, physical-chemical and technological properties of the processed object.

![Figure 1. Structural diagram of microwave electrothermal unit](image)

However, this classification option does not take into account that at different stages of creation and operation of both the microwave electrotechnological unit and its structural elements, different measurements have to be made. This circumstance is taken into account in the classification variant shown in Figure 2.

At the stage of developing the energy source, it is necessary to measure the current intensity I, the voltage at the electrodes U, the power P and frequency f of the magnetron P, and also the full-load characteristic P(KcmU), f(KcmU) and the efficiency of the magnetron η; KcmU max – he maximum permissible value of KcmU, at which the normal operation of the magne-tron is ensured (the parameters specified in its passport are retained); KcmU - standing wave ratio to the magnetron loading tension (process of the module).

For the technological module: T, U, p – temperature, moisture content and vapour pressure in the processed object; To – ambient temperature environment temperature; c, ρ, ε', tg δ - specific heat capacity, density, relative permittivity, the tangent of the dielectric loss angle of the processed object; hе – heat transfer coefficient of evaporation; τ – time of the microwave oven of processing of an object; K11, K12, …, K33 – heat and mass transfer parameters included in the Lykov-Mikhailov equation (heat and mass transfer equation for capillary-porous bodies); υ - the velocity of an object in the working chamber; P_{rad} – the magnitude of the microwave radiation from the installation into the surrounding space.

At scientific researches the following parameters: ξ1, ξ2, ξ3 - point coordinates in volume of the processed object; α - the attenuation coefficient of the electromagnetic wave in the transmission line with the processed object; Vmin – the minimum allowable volume of the object being processed; E – the electric field of the electromagnetic wave in the processed object; P_{micro} - microwave energy scattered in the object; m – mass of object being processed.
As for the measurements related to the determination of physicomechanical, physico-chemical and technological properties of the processed object, they are very diverse and are determined by the aggregate state and purpose of this object. So, for example, solid bodies often measure hardness, strength, ductility, specific electrical resistance, and other specific parameters. In liquid bodies - the coefficient of kinematic viscosity, surface tension, in food - biochemical and microbiological characteristics, etc.

Other variants of classification are possible, but the scheme shown in Figure 2 makes it possible to consider quite often the most frequently occurring measurements in microwave electrotechnology. Measurements in microwave electrotechnology have their own peculiarities. First, they are very diverse: electrical, including such specific ones as microwave measurements; thermal, including mass transfer, as well as measurements related to the determination of the operational properties of the object being treated. Secondly, measurements, as a rule, have to be carried out in a relatively short time, since microwave electrotechnological processes are highly intensive. Third, for measuring in a working microwave camera, traditional measuring means (thermocouples, thermometers) are not suitable, since it affects the distribution of electromagnetic field in the chamber and, consequently, on the processing of the object. Fourth, we have measurements that have no analogues in the areas adjacent to the microwave electro-technology. For example, unlike traditional microwave technology, the coordination of the working chamber and the end load for the magnetron during the heat treatment varies in time. And fifth, to calculate the working chamber and mathematical modeling of the technological process, it is necessary to measure the dependence of the electrophysical and thermophysical parameters of the treated object on temperature and moisture content (humidity).

These features are very significant and as a result we have two consequences:
- it is not very promising to plan and carry out measurements in microwave electrotechnology, only...
in the field of electrical, thermal measurements or in the field of materials science or a specific technology:
- often in microwave electrotechnology, it is not possible to provide the same accuracy as measured by classical measurement methods (for example, as a measurement $\varepsilon'$ and $\tg\delta$ as a function of temperature) when measuring. However, in many cases, such high accuracy is not required. Thus, in measuring $\varepsilon'(T)$ and $\tg\delta(T)$ for solving the problem of synthesis of the working chamber and mathematical modeling of the technological process, the nature of these dependences

**Conclusions**

Measurements in microwave electrotechnology have their own peculiarities, they are very diverse and specific. For example, electrical measurements include measurements at ultra-high frequencies, thermal measurements for mass transfer, and measurements related to determining the properties of the object being treated.

Other variants of classification are possible, but also shown in figure 2 makes it possible to consider quite often the most frequently metered in microwave electronics measurements.

The paper systematically describes the measurement in microwave electronics at both the research stage and during the development and operation of microwave electrotechnological installations.

**References**

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