The Microwave Oven Thermal Field Uniformity Increasing by Using Powermeter

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***Abstract*— The microwave oven qualities improvement can be achieved, if use a powermeter. Extracting information about the passing power from the sensor signals in the powermeter can be performed by determining the passing power as a geometric mean of the sensor signals. The main advantage of this approach is ease of automation. The limitations of the passing power calculating algorithm as a geometric mean of two sensors signals are that mathematically rigorous expressions. It can be obtained only if two sensor signals are taken at the maximum and minimum of the standing wave. When the sensors was not placed in the maximum and minimum of the standing wave, the error appears. An amendment was made, and the non-excluded residual was estimated.**

Keywords*— *microwave oven, thermal field uniformity, powermeter, passing power, geometric mean, uncertainty

I. INTRODUCTION

The use of microwave energy in microwave ovens due to the possibility of the concentration of high energy in a small volume is very popular and leads to time savings.

The disadvantage of microwave heating is the ununiform distribution of the electromagnetic and thermal fields in the resonator of the microwave oven, which affects not only the cooking quality of food, but also the ununiformity can lead to standing wave ratio of (SWR) much higher than the normal for magnetron, which forces the developer to use additional devices for protection of magnetron, e.g. circulators, relays, etc. The reason for the majority of breakdowns of microwave ovens is the failure of the magnetron generator, which is also the most expensive part of the microwave oven. It is tempting to equip each microwave oven with measuring devices. It will be economically feasible if the cost of the microwave oven with measurement device increases insignificantly as compare without measurement device.

II. MEASUREMENT OF HEATING UNUNIFORMITY IN THE MICROWAVE OVEN

The known methods for measuring the nonuniformity of an electromagnetic field in a resonant chamber of a microwave oven are indirect. Several methods are known for visual observation of the distribution of electromagnetic fields by the thermal effect caused by it. Among them are methods based on the use of thermal photo materials, thermoactive papers, thermoindicators, liquid crystals, phosphors, etc. These methods allow to record the picture of the thermal field distribution only on the surface of microwave absorber, which the thermo-indicator contacts. Thus, the function of the microwave energy absorber and the indication of the thermal relief are distributed. The superficial thermal relief serves only to judge of the electromagnetic field distribution on the surface of product sample. It does not characterize either the distribution of the heat inside product sample or the distribution of the electromagnetic field in the chamber of microwave oven [1].

The standard procedure of the electromagnetic field uniformity measurement in the microwave oven consists in such steps: 5 glasses with 100 gramms of drinking water in each of them is located on the bottom of the resonant chamber of the microwave oven in such manner that one glass in the center and other in the four sides. Than microwave oven is switched on, the water in the glasses is heated during 2 minutes and than microwave oven is switched off. Than the temperature of the water in each glass is measured with thermometer. The thermometer readings are usually different. Than uniformity coefficient is calculated by formula. This is an indirect method of the uniformity of the electromagnetic field distribution in a microwave oven measurement. Its drawback is a large uncertainty in the determination of the uniformity coefficient caused by the difference in water volumes in each glass, the change in the temperature of water in each glass caused by the themperature change during the time from the moment the microwave oven is switched off to the moment when thermometer is immersed in each of five glasses.

The objective of this study is to propose a method for measuring the ununiform distribution of an electromagnetic field in a microwave oven, instead of a undirect complicated measurement temperature the direct measurement of the passing power of the microwave generator is proposed. It allows reduce the measurement uncertainty and simplify the measurement method and the device that implements it.

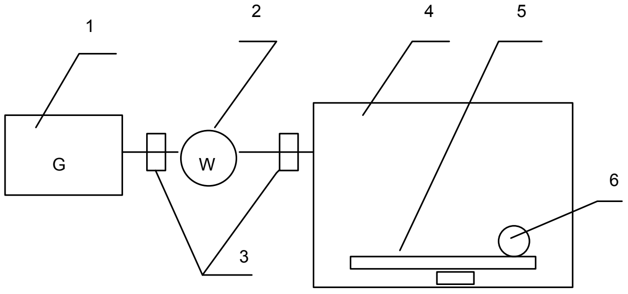

Fig. 1. Microwave oven with powermeter of passing power

III. DEVICE FOR MICROWAVE HEATING UNIFORMITY IMPROVING

To improve the heating uniformity of the microwave oven, it is supplemented with a powermeter (Fig. 1), the plant consists of a microwave generator 1, a powermeter of passing power 2, a resonator chamber of the microwave oven 4, a rotating try with a rotator 5, test body 6.

In the resonant chamber of the microwave oven 4, a test body 6 is mounted on a rotating try 5. The microwave generator 1, radiating the incident power P_{inc} of the electromagnetic field, through the waveguide 3, on which the powermeter 2 sensors are installed, is connected to the chamber of the microwave oven 4. The passing power that is absorbed by the test body is equal to

$$P = P_{inc} \cdot \left(1 - \Gamma^2\right), \qquad (1)$$

where Γ is the test body reflection coefficient modulus from. Γ depends on test body placement in microwave oven chamber.

When the test body 6 is displaced from the center of the rotating try, a new value of the passing power is obtained. The try with test body moves until a complete picture of the distribution of the non-uniformity of the electromagnetic field in the chamber of the microwave oven 4 is obtained. Such a method can be carried out, positioning the try at three points located at an angle of 120 degrees from the axis of rotation [2].

Fig. 2 shows a picture of an improved device for increasing the uniformity of heating in a microwave oven. A device for improving the uniformity of heating in a microwave oven consists of a microwave generator 1, a powermeter of passing power 2, a resonator chamber of a microwave oven 3, a. block 4 positioning the try at three points at an angle of 120 degrees from the axis of rotation, a storage unit of the previous measured signal 5. The previous and current values signal are compared, the comparement result determines the direction of rotation of the try 7. The powermeter 2 performs measurements of power values at two positions of the try located under 120 degrees. There are three different ratio between the current and previous measured signals: the value is the same or the first value is greater or the second value is greater. The first case corresponds to uniform heating, then the try can be stopped. In the second case, it is recommended to change the direction of rotation to the opposite. In the third case, continue rotation at the same direction.

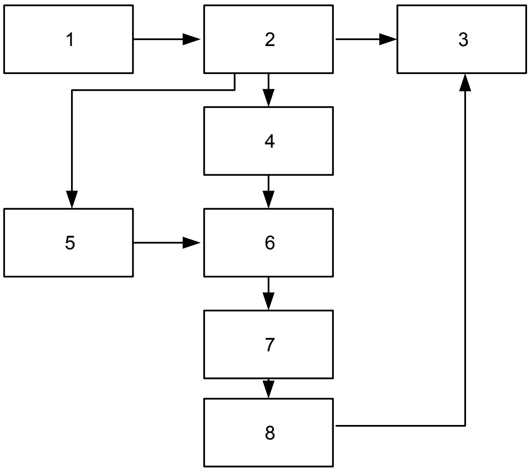

Fig 2 Device for increasing of microwave oven heating uniformity

IV. ALGORITHM FOR PASSING POWER CALCULATION

The principle of operation of the powermeter in the microwave oven is based on a multiprobe method [3-5]. The multiprobe method involves extracting information about the parameters of signals and tract from sensor signals, which is an indirect measurement. In the microwave tract between the generator and the termination a standing wave exist. The standing wave amplitude depends on tract mismatch. The multiprobe method uses the signal of a certain number of sensors in the microwave tract to calculate pasiing incident and reflected power, reflection coefficient modulus and phase. Algorithms play a special role in the multiprobe method. The algorithms for multiprobe devices could be classified on analytical and graphical. The graphical models mainly based on impedance representation by complex number and therefore the plotting of impedance on the complex plane, for example, Smith chart. Due to connection between impedance and reflection coefficient was used graphical representation in the the six-port network analyzer [6]. According to it the sensors signals in this model are circles. The circles centers correspond to sensors location between generator and termination, circle radii are proportional to sensor signal readings. The complex reflection coefficient of the termination is found as a intersection point of the circles, which corresponds to the solution of the system of equations, where each equation corresponds to a sensor.

The sensor signals in analytical methods are

$$P_1 = P_{inc}(1 + \Gamma^2 + 2 \cdot \Gamma \cdot \cos(\varphi)), \qquad (2)$$

$$P_2 = P_{inc}(1 + \Gamma^2 + 2 \cdot \Gamma \cdot \cos(\varphi + \beta)), \qquad (3)$$

where Γ is reflection coefficient modulus, φ is reflection coefficient phase, β is phase distance between adjacent sensors, P_{inc} is incident power. $\beta = 4 \pi l/\lambda_w$, where λ_w is wavelength in the waveguide, l is geometric distance between adjacent sensors.

We propose graphical interpretation of the problem from the article [4] different than traditional in the six-port reflectometer. To prevent further confusion we right away explain that our interpretation based on Pythagorean mean picture and the right-angle triangle. According to it the sensor signals (Fig.3) put along the horizontal axis one after another. The sum of the sensors signals is taken as a diameter of the circle. The radius of the circle is equal to the half sum of the sensor signals.

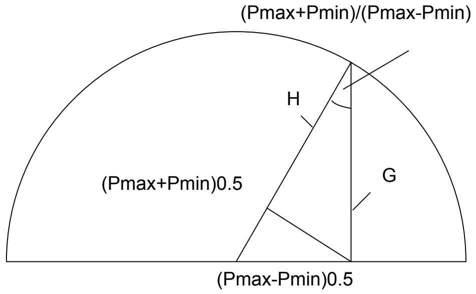

Fig.3 Sensor signal processing algorithm as geometric mean explanation

Suppose there are two sensor signals are represented by the maximum and minimum of the standing wave in the tract between the generator and the termination. If signal is maximum so cosine is 1 and if signal is minimum cosine is - 1. Lets substitute it into expressions (2) and (3)

$$P_{\max} = P_{inc}(1+\Gamma^2+2\cdot\Gamma\cdot\cos(\varphi)), \quad (4)$$

$$P_{\min} = P_{inc}(1+\Gamma^2-2\cdot\Gamma\cdot\cos(\varphi)), \quad (5)$$

Consider right-angle triangle with hypotenuse equal to $(P_{\max} + P_{\min})/2$ and opposite equal to $(P_{\max} - P_{\min})/2$.

$$P_{\max} + P_{\min} = 2\cdot P_{inc}\cdot\left(1+\Gamma^2\right), \quad (6)$$

$$P_{\max} - P_{\min} = 4\cdot P_{inc}\cdot\Gamma, \quad (7)$$

Corresponding to definition sinus is ratio opposite to hypotenuse $(P_{\max} - P_{\min})/(P_{\max} + P_{\min})$.

$$\sin(\alpha) = \frac{P_{\max} - P_{\min}}{P_{\max} + P_{\min}} = \frac{2\cdot\Gamma}{1+\Gamma^2}, \quad (8)$$

The geometric mean of two sensor signals equal to passing power will be proved in the next expression

$$\begin{aligned} G &= 0.5\cdot\left(P_{\max}+P_{\min}\right)\cdot\cos(\alpha) = \\ &= 0.5\cdot\left(P_{\max}+P_{\min}\right)\cdot\sqrt{1-\sin(\alpha)^2} = \\ &= P_{inc}\cdot\left(1+\Gamma^2\right)\cdot\sqrt{1-\left(\frac{2\cdot\Gamma}{1+\Gamma^2}\right)^2} = \\ &= P_{inc}\cdot\left(1+\Gamma^2\right)\cdot\frac{1-\Gamma^2}{1+\Gamma^2} = P_{pass}, \end{aligned} \quad (9)$$

As known sinus and cosinus connected through that sum of their squares equal to 1. The triangle adjacent G is product hypotenuse and angle cosine.

The definition of geometric mean is square root of the sensor signals product. It is shown in fig.3 as the height drawn from the junction point of sections that are the sensor signals

$$\begin{aligned} P_{pass} &= \sqrt{P_{\max}\cdot P_{\min}} = P_{inc}\cdot\sqrt{\left(1+\Gamma^2+2\cdot\Gamma\right)\cdot\left(1+\Gamma^2-2\cdot\Gamma\right)} = \\ &= P_{inc}\cdot\sqrt{\left(1+\Gamma^2\right)^2-\left(2\cdot\Gamma\right)^2} = P_{inc}\cdot\left(1-\Gamma^2\right) = P_{pass}, \end{aligned} \quad (10)$$

For more general case

$$\begin{aligned} P_{pass} &= \sqrt{P_1\cdot P_2} = \\ &= P_{inc}\cdot\sqrt{\left(1+\Gamma^2+2\cdot\Gamma\cdot\cos(\varphi)\right)\cdot\left(1+\Gamma^2+2\cdot\Gamma\cdot\cos(\varphi+\beta)\right)}, \end{aligned} \quad (11)$$

Reflection coefficient for arbitrary sensor signal

$$\Gamma = \frac{P_1+P_2-2\cdot\sqrt{P_1\cdot P_2}}{P_1-P_2}, \quad (12)$$

The reflection coefficient phase φ value can be calculated from expression (2) or (3) after substitution into it Γ from expression (12). So the reflection coefficient phase φ from (2) is

$$\varphi = \arccos\left(\frac{P_1-P_{inc}\left(1+\Gamma^2\right)}{2\cdot\Gamma\cdot P_{inc}}\right), \quad (13)$$

The reflection coefficient phase φ from (3) is

$$\varphi = \arccos\left(\frac{P_2-P_{inc}\left(1+\Gamma^2\right)}{2\cdot\Gamma\cdot P_{inc}}\right)-\beta, \quad (14)$$

If the two sensor signals are represented by the maximum and minimum values is the ideal case. Otherwise uncertainty should be considered.

V. UNCERTAINTY OF PASSING POWER CALCULATION

There was chosen two sensor distance one from another along waveguide equal to a quarter of the wavelength, the reflection coefficient of termination $\Gamma = 0.1$ for simulation. $\Gamma = 0.1$ corresponds to the slightly mismatched tract. Fig. 4 shows the sensor signals and passing power dependance from reflection coefficient phase. When the signal of the first sensor is at a minimum, and the signal of the second sensor is at a maximum, the value of the signal geometrical mean is closest to its theoretical value of passing power, which confirms the theory the geometrical mean applicability for calculating the passing power.

Real calculations, in contrast to ideal algorithms, are accompanied by errors. The dependence of the error on the reflection coefficient phase is called the mismatch error. We calculated its value by the expression

$$\delta = \left(\frac{P_{pass}}{P_{inc}(1-\Gamma^2)}-1\right)\cdot 100, \quad (15)$$

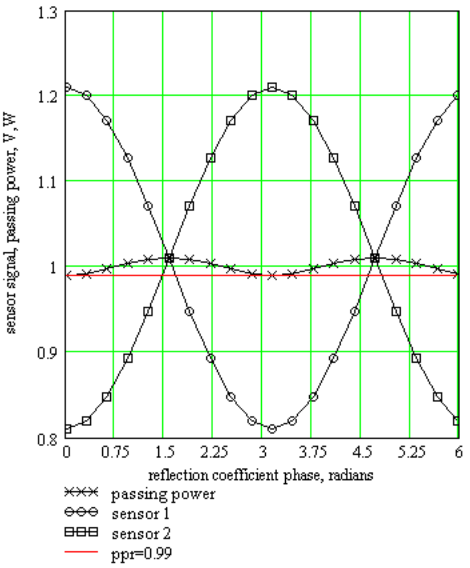

Fig.4 Sensor signals and passing power dependence from reflection coefficient phase

The mismatch error correction factor is entered into the sensor signals. The correction factor is expressed

$$c = \frac{1}{1+\delta}, \tag{16}$$

To correctly apply passing power correction factor the reflection coefficient modulus Γ can be find from expressions given in (12). Despite the correction factor, the non excluded systematic error θ is determined by the expression

$$\theta = \sqrt{\left(\frac{\partial\delta}{\partial\Gamma}\right)^2 \cdot (\Delta\Gamma)^2 + \left(\frac{\partial\delta}{\partial\varphi}\right)^2 \cdot (\Delta\varphi)^2}, \tag{17}$$

Standard uncertainty of B type u_B for value depends on a priori information on value variability. If value is non-excluded systematic error with boundaries then its uncertainty is calculated by the formula [7]

$$u_B = \theta / \sqrt{2}, \tag{18}$$

where $\sqrt{2}$ is coefficient corresponding to the U-shaped law distribution within the boundaries of the non excluded systematic error.

VI. Circuit Design for the Implementation of the Algorithm

To implement the algorithm, two sensors are needed, then it is possible to implement such a computing device on operational amplifiers, which will calculate the power as the geometric mean. The realization price will be minimal and the performance speed will be great.

VII. Conclusion

There was proposed improvement of consumer qualities of the microwave oven. The effect is achieved by add into it a powermeter. It will be economically feasible if the cost of the microwave oven with measurement device increases insignificantly as compare without measurement device. There was chosen the simpest processing algorithm such as geometric mean of two sensor signals to obtain minimal price of its implementation. The limitations of the algorithm for calculating the passing power as two sensors signals geometric mean were investigated. The mathematically rigorous solution can be obtained only if two sensor signals are taken at the maximum and minimum of the standing wave. The standing wave is moving as termination changes but the sensors are fixed. So sensor signals not always in the maximum and minimum of the standing wave. It explains why the error appears. We propose expression for sensor signals correction factor. Finally the non-excluded remains of error was estimated. The device implementing this algorithm fast, cheap and not increasing the cost of a microwave oven.

References

[1] Pat. 31918A, Ukraina MPK G01R 21/08 (2006.01). Method for measurement of nonuniform electromagnetic field distribution in the microwave oven and device for it realisation Vodotovka V.I., Hura K.H., Mkheyan M.F., Repa F.M. opubl 15.12.2000.

[2] Pat. 126877, Ukraina MPK G01R 21/00, G01R 21/08 (2018.01). Device for increasing heating uniformity in the microwave oven Miroshnyk M.A., Zaychenko O.B. opubl.10.07.2018.

[3] M.V. Andreev, O.O. Drobakhin, and D.Y. Saltykov ”Complex reflection coefficient determination via digital spectral analysis of multiprobe re-flectometer output signals,” 2017 IEEE First Ukraine Conference on Electrical and Computer Engineering (UKRCON), IEEE, 2017, pp. 170-175.

[4] A.I. Mekhannikov, and V.A. Perepelkin ”Microwave multimeter and its oper-ating algorithms,” Measurement techniques, 1994, Vol.37, 3, pp. 330-337.

[5] O.B. Zaichenko, I.I. Klyuchnik, M.A. Miroshnik, and R.I. Tzekhmistro ”The comparative analysis of a multiprobe microwave multimeter with involve-ment of processing by the Kalman filtering and least-squares methods with regard for re-reflection of probes,” Telecommunications and Radio Engineering, 2015, vol. 74, pp. 79–86.

[6] G.F. Engen ”The six-port refectometer: An alternative network analyzer,” IEEE Transactions on Microwave Theory and Techniques, 1977, Vol. 25, 12, pp. 1075-1080.

[7] I.P. Zakharov, S.V. Vodotyka, K.A. Klimova, and N.S. Shevchenko ”Some examples of the evaluation of measurement uncertainty,” Measurement Techniques, 2013, Vol.56, Issue 6, pp.591-598.

[8] N. Semezhev, A. Lvov, A. Askarova, S.Ivzhenko, N. Vagarina, and E. Umnova ”Mathematical Modeling and Calibration Procedure of Combined Multiport Correlator,” Conference on Information Technologies, Springer, Cham., 2019, February, pp. 705-719.

[9] F.M. Ghannouchi, and A. Mohammadi ”The six-port technique with mi-crowave and wireless applications”, Artech House, 2009, 245 p.

[10] A.A. L’vov, R.V. Geranin, N. V. Semezhev, A.A. Solopekina, and P.A. L’vov ”A novel parameter estimation technique for software defined radio system based on broadband multi-port receiver,” 2015 International Siberian Conference on Control and Communications (SIBCON), 2015, May, pp. 1-5.