MICROWAVE GENERATORS DESIGN USING AN ADJUSTED METHOD

Marghitas O.
Technical University of Cluj-Napoca, Electrical Engineering Department

Abstract. Electrical schemes are employed that act on two main parameters namely: on the magnetic field of the magnetron and on the anode voltage of the magnetron. The magnetic field allows for the adjustment of the output power in microwave by creating in the anode – cathode space of the magnetron of a magnetic induction „B“ perpendicular on the movement direction of the electrons emitted by the cathode. Magnetic field lines modify the trajectory of the electrons emitted by the cathode, and if the magnetic field value is high enough, the electrons do not reach the anode and so the exit power in microwaves becomes zero. The magnetic field that determines the nullification of the power exited in microwave is called critical magnetic field. The adjustment system for the output power in microwaves is presented above; it is employed for magnetrons fitted with electromagnet and maximum output in microwave power of about 5,5 kW. The adjustment scheme consists in the utilisation of thyristors or triacs connected in the primary winding of the transformer of anode voltage and the adjustment of the supply voltage of the primary winding of the transformer through the command of their opening angle.

Keywords: microwave power, microwave equipments, waveguide, magnetron

INTRODUCTION

In order to adjust the output power in the microwaves they use electrical diagrams in which they action especially on the following two parameters: on the magnetic field of the magnetron; on the high voltage of the magnetron.

1.1. The output power adjustment in the microwaves by modulating the magnetic field of the magnetron. In the case of the magnetrons that contain a driving magnet which functions as a magnetic fields source, the adjustment of the output power in the microwaves is realized by modifying the intensity of the electromagnetic field caused by the driving magnet.

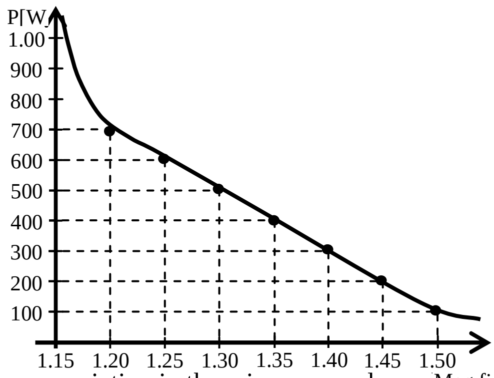

Fig. 1. The output power variation in the microwaves depending on the magnetic field intensity.

The magnetic field allows the adjustment of the output power in the microwaves by creating in the anode – cathode space of the magnetron a magnetic induction B that is perpendicular to the course of the electronic displacement released by the cathode.

The magnetic field lines modify the trajectory of the electrons released by the cathode, and if the magnetic field value is big enough the electrons never reach the anode, so that the output power in the microwaves becomes null. The magnetic field that causes the annihilation of the output power in the microwaves is called critical magnetic field.

The output power variation in the microwaves depending on the magnetic field value is shown in Fig.1. The principal electric diagram used for the output power adjustment in the microwaves by adjusting the magnetic field value of the magnetron is shown in the Fig. 2. From the electrical diagram shown in Fig. 2 it can be seen that the two distinct magnet windings are fed also by a direct current source as by the plate current taken by the magnetron from the anodic potential transformer.

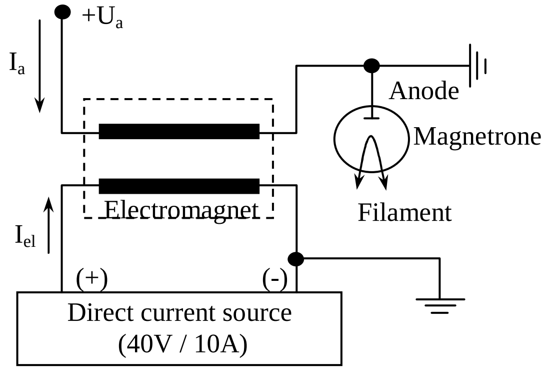

Fig. 2. The electric diagram used for the output power adjustment in the microwaves by adjusting the magnetic field of the magnetron.

This magnetron feeding diagram assures the magnetron stable functioning so that if, from different reasons, there occurs an increase of the anodic current, this one passing through the electron winding, it causes the increase of the magnetic field intensity that, in its turn, diminishes the anodic current until it reaches the initial values [1].

The output power adjusting system in the microwaves is presented above; it is used for the magnetrons that have driving magnet and maximum output powers in the microwaves of about 5,5kW.

1.2. The output power adjustment in the microwaves by adjusting the high voltage of the magnetron.

In this paper a simpler solution will be used to adjust the output power in the microwaves of the generator. The setting form consists in using triacs or thyristors connected in the initial high voltage transformer and in the adjusting power-supply of the high voltage transformer by the opening angle command of them. By using some proper electronic components a continuous and fine adjustment of the high voltage can be obtained and consequently, of the output power in the microwaves of the microwave generating magnetron. The adjustable output power microwave generator will adopt as solution for the adjustment of the output power in the microwaves this type of diagram and the use of some commanded triacs set in the initial high voltage transformer.

2. THE EVALUATION OF THE OUTPUT POWER OF THE MICROWAVE GENERATOR WITH ADJUSTABLE OUTPUT POWER

The dissipated power in the epoxy resin mass is given by the expression:

$$P = \pi \cdot f \cdot \varepsilon_0 \cdot \varepsilon'' \cdot E^2 \quad [W/m^3] \qquad (1)$$

where:

- P – the power density $[W/m^3]$;
- f – the frequency;
- ε_0 – the absolute dielectric permittivity $[F/m]$;
- ε'' – relative loss factors;
- E – the electric field intensity $[V/m]$.

A very important factor that has to be taken into account when evaluating the level of the power supplied by a microwave generator is the maximum power density that has to be injected in the microwave applicator where the electric insulation with epoxy resin is subjected to the polymerization process.

This maximum power level injected in the applicator must satisfy the necessities of the desired chemical transformations (the epoxy resin polymerization) while obeying these two restraints:

– there should not appear the electric breakdown in air or gas in the applicator which is caused by the mixture of volatiles from the epoxy resin;
– the destructive effect in the dielectric insulation due to the mechanic stress caused by the thermocontractable bands used for the electric insulations should be minimum.

The second condition depends clearly on the behavior of the resin in a microwave field, on the values of the real and imaginary side, respectively, of the complex dielectric constant (dielectric permittivity ε' and loss factor ε'') and on their variation together with the temperature during the polymerization process. The medium value of the electric field intensity in the microwave oven where the epoxy resin polymerizing takes place corresponds to the value of the medium level of needs supplied by the microwave generator. This medium value of the electric field intensity is given by the expression:

$$\frac{E_{max}}{H_{max}} = \sqrt{\frac{\mu}{\varepsilon_0}} \qquad (2)$$

that leads to:

$$E_{max} = \sqrt{\frac{\frac{P}{V_c} \cdot Q_0}{2 \cdot \pi \cdot f \cdot \varepsilon_0 \cdot 10^6}} \qquad (3)$$

where:

- P – the power in microwaves;
- V_c – the bulk of the applicator;
- Q_0 – the quality factor of the applicator;
- f – frequency;
- ε_0 – the relative permittivity of the clear opening.

3. THE LIMITED POWER AND THE POWER TRANSMITTED THROUGH THE OUTPUT WAVEGUIDE OF THE MICROWAVE GENERATOR

The power transmitted through the microwave generator waveguide depends on its cross sizes. The active power is transmitted through the output waveguide of the microwave generator towards the applicator, only when the latter is in running wave state. The medium power transmitted trough the output waveguide is given by the relation:

$$P_\varepsilon = \frac{1}{4} \cdot \frac{E^2}{Z_{TE}} \cdot ab \qquad (4)$$

where:

- E – the electric field intensity;
- a, b – the cross sizes of the waveguide;
- Z_{TR} – the waveguide impedance.

The maximum value of the power transmitted through the cross sized output waveguide (a,b) given at a frequency of $2{,}45\,GHz$ depends on the value of the electric field E. At normal pressure and in normal insulation conditions the admissible maximum point where the discharges begin to take place is of $30 kV/cm$. In practice the adaptation is not perfect. Some values of the standing wave factor SWF of about $1{,}1 \div 1{,}2$ are accepted. In this case, there exists in the guide, beside the forward wave (direct power), the backward wave (reflected power) [2]. The active power absorbed by the charge is given by the difference between the transmitted (direct) power and the reflected one. In the case when the power is measured with a common probe that has no directional characteristic a line with longitudinal slot is usually used; it allows the minimums and the maximums to be found.

The graphic in the Fig. 3 shows how the presence of some backward waves, even of low power, on a waveguide may lead to great power variations received by a probe inserted in the waveguide.

Thus, for instance, a backward wave which represents only 1% of the incident power causes some great backward waves, which means that a probe of common design size placed near a maximum will show power values with 50% higher than in the case when it would be placed near a minimum.

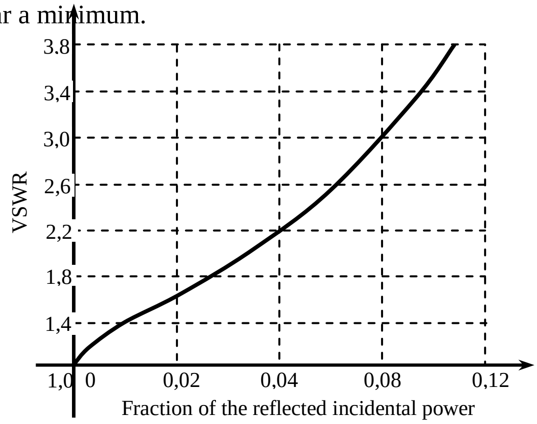

Fig. 3. The influence of the incident power reflexions on the measured power

If a directional divider is used, the reflexion of 1% of the incident power will lead to a measurement error of 1%. The power measurements in the microwaves demand to take off a small part of the incident (direct) power that is transmitted to the load on the waveguide. This taking off of the power demands to know the relative power distribution in the frequency band of the microwaves.

If a non-directional common probe is used, the results will be unsatisfactory because they will be influenced by the positions of the minimums and of the maximums; the probe may be either on a minimum or on a maximum of the standing wave. The directional coupler may be used to measure the direct and the reflected power without altering the indicated values. If the directional coupler is thus conceived that it can measure only the reflected power the charge impedance may be adjusted so that the released reflexions to be minimum.

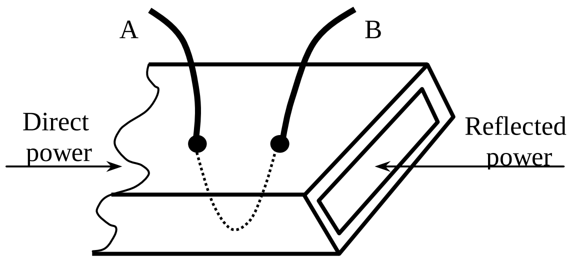

Fig. 4. The currents in the cable „A" are determined by the wave that spreads on the transmission line from left towards right (transmitted power) and the currents in the cable „B" are determined by the wave that spreads from right towards left

The couplers don't measure directly the power on the waveguide. They take off some power, thus allowing determining the total direct power that spreads from the generator towards the charge or the reflected power that spreads from the charge towards the generator. The capacitive directional coupler is used in order to measure the power reflected on the waveguides where the microwave energy spreads towards the applicator. It is conceived from the waveguide WR430 or WR340, inside of which a measure line of impedance 50Ω is connected; this line is so conceived that its input impedance is resistive [3].

The capacitive directional coupler is schematically presented in the Fig. 4.

The following conditions should be obeyed in order to obtain satisfactory properties

– the sizes of the cables A and B in the waveguide should be less than $tg4$;
– the input choke of the cables in the waveguide, determined by its inductance, should be less than the wave impedance of the waveguide
– the form of the cables in the waveguide should be adequate

both ends of the cables should be charged with an unit power factor impedance (for instance a loss coaxial rod).

The equivalent diagram and the vectorial diagram of the currents induced by the magnetic field are shown in the Fig. 5.

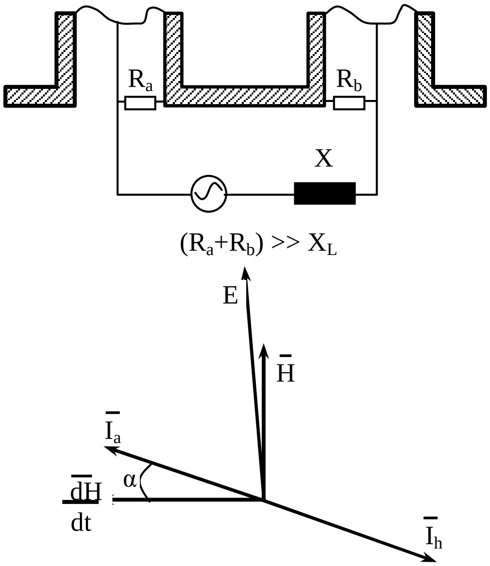

Fig. 5. The equivalent diagram and the vectorial diagram of the currents induced by the magnetic field.

Having seen the capacity between the horizontal side of the cable and the horizontal walls of the leads to the fact that, in the vertical walls of the cables, appear phasic currents, beside the usual antiphasic currents (I_a and I_b) [4]. Due to the system's linearity the equivalent diagrams and their corresponding electromotive forces can be distinctly studied and then the results can be compared. The diagram in the Fig. 3 contains a generator of an electromotive force proportional to $\left(\frac{dH}{dt}\right)$ and the source impedance X_L is determined by the inductance of the cable.

The resistances R_a and R_b represent the wave impedance of the two cables series connected in the above diagram. The main impedance in this diagram is resistive, determined by the loss cables, and the currents are almost in phase with the electromotive force of the generator and they are dephased with 90° before the electric field „$\vec{E}$" from the inside of the waveguide. The angle α is the result of the cable inductance. The equivalent diagram for the phasic currents is shown in the Fig. 4. In this case the generator's voltage is proportional to the electric field in the waveguide. The capacities between the cables and the corresponding horizontal walls of the waveguide are marked with C_1 and C_2. In the equivalent diagram in the Fig. 6 the resistances R_a and R_b are paralleled.

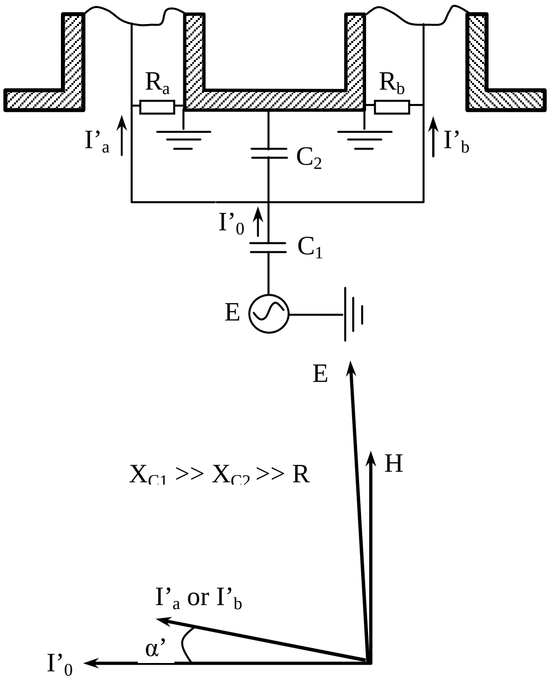

Fig. 6. The equivalent diagram and the vectorial diagram for the currents inducted by the electric current.

As the choke of C_1 is much more than the other chokes in the diagram of the Fig. 4, the current $I_0^{'}$ will be moved with about $90°$ before the electromotive force of the generator. The angle between $I_0^{'}$ and $I_a^{'}$ appears due to the leak effect of the capacity C_2. It can be seen from these two vectorial diagrams how the currents in R_a, produced by the two generators, will be almost in phase or in antiphase, depending on the direction of the wave in the waveguide. The same thing happens to the currents in R_b. Thus, it can be concluded that in the case of a wave that spreads in the waveguide the currents in a cable will compensate if their amplitudes are equal and the phases opposed. The relative amplitudes of the currents can be adjusted by varying the surface or the form of the cable or the thickness of the wire. The angles α and α' may be equal if the capacity C_2 is properly chosen. The above presented coupler will function satisfactorily as long as the proportion of the transversal components of the vectors $\vec{E}$ and $\vec{H}$ doesn't change. If the coupler is used on a standard rectangular waveguide the width of the band is limited due to the wave impedance variation of the waveguide. The latter has a strong variation near the critical frequency but at frequencies other than the critical one it has an almost constant value.

The critical frequency may be reduced with about $1/3$ of the normal value by means of some longitudinal beaks inside the waveguide. If the beak has a key with a variable section that widen to null and if the sizes of the key are correctly chosen, the reflexions due to the beak will be not major. In a waveguide with beaks the wavelength and its wave impedance have the same values as in clear opening and it varies in an important frequency band. The cables and their probes, which penetrate the waveguide, should not be put exactly in the middle of the horizontal wall of the waveguide; it can be put near the edge. The condition that X_{C_1} should be large compared to the equivalent impedance of the two paralleled cables is not hard to obey, as X_{C_1} will be of 3000Ω order while by shunt connection of R_a and R_b we will obtain 25Ω.

In the Fig. 5 the angle α will be:

$$\alpha = arctg \frac{\omega \cdot L}{R_a + R_b} \qquad (5)$$

and in the figure 6 the angle α' will be:

$$\alpha' = arctg \frac{R_a \cdot C_2 \cdot \omega}{2} \qquad (6)$$

and both of them increase depending on the frequency, at the same speed. The same dependence is valid as against the amplitudes of the values because the electromotive force of the generator increases in the same time with the frequency at the same speed and the compensation conditions are thus obeyed [5].

The dielectric properties of the coupler do not vary with the frequency but its output voltage is variable. In several cases it doesn't matter but when the damping of a loss cable is measured, the voltage may be adjusted so that it compensates the variation of the output voltage of the probe. In this case the voltage at the end of the cable can't vary with more than $\pm 0{,}25 dB$ in a frequency band of $2{,}2 \div 2{,}5 GHz$.

In the case of the directional coupler with two slots, one measuring the direct power and the other the reflected one, which is conceived from an auxiliary waveguide coupled to the main one by means of two slots put at a distance of $\lambda_g / 4$ one from another, the field which spreads in the main waveguide excites through these slots the auxiliary waveguide. In the auxiliary waveguide the waves spread in the same direction as in the main one, as it can be seen in the Fig. 7.

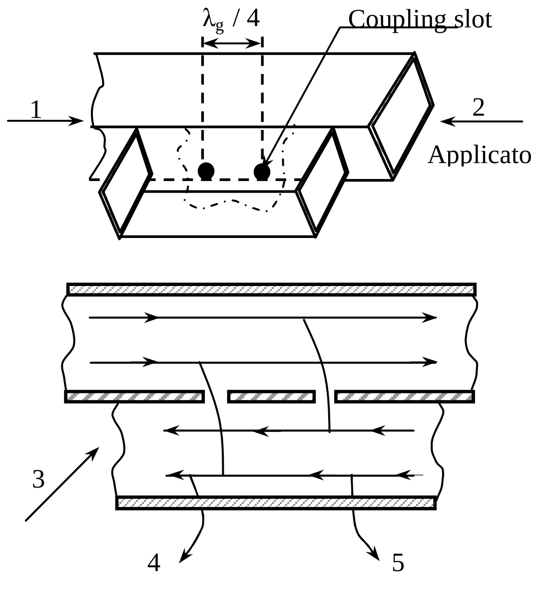

Fig. 7. Directional coupler with two slots:
1 – the propagation direction of the microwave energy from the generator, 2 – the propagation direction of the microwave energy towards the source; 3 – the auxiliary waveguide; 4 – antiphasic waves that mutually compensate; 5 – phasic waves that sum up

Most often the measurement systems of the two sizes (P_d and P_r) are connected to the auxiliary waveguide. In this case the waveguide should have a charge equivalent to its capacitive impedance in order to avoid the reflected waves that alter both the coupler's diversity and the measured values.

The above presented coupler functions satisfactorily with three or more slots; the power taken off by the auxiliary waveguide must be lower with $18 \div 20 dB$ at least than the power from the main waveguide. While functioning the main waveguide behaves like a transmission line on which the microwave power spreads towards the charge. The auxiliary waveguide is electrically coupled to the main one by means of the slots put at a distance of $\lambda_g / 4$ one from another (see Fig. 7). When a wave spreads through the main waveguide a very small part of it passes in the auxiliary waveguide, exciting it, and its oscillations will spread in reverse direction. For instance, we assume that a running wave spreads in the main waveguide from the microwaves generator (direction 1 – Fig. 7) towards the charge, the coupling between the main and the auxiliary waveguide is made by means of the longitudinal and the cross components of the magnetic field vector, each of them exciting waves that spread in reverse direction in the auxiliary waveguide. If the values of the coupling that results from these combinations are properly chosen the amplitudes of these waves will be equivalent. Although they may show that the waves that spread (towards left) will be phasic and will be arithmetically summed and the waves that spread towards right will be antiphasic and will be mutually summed [6]. In order to avoid the reflexions an absorber charge can be put at the end of the auxiliary waveguide; it that can be realized from strong microwave absorbers.

4. TECHNICAL DATA FOR THE WAVEGUIDES WITH RECTANGULAR SECTION

The waveguides used to spread microwaves at a frequency of $2{,}45 GHz$ are shown in the table from below. The first three types of waveguide are standard. The last two represents aluminium profiles that can be found on the market and that can be used as waveguides only under certain conditions. That is why they are not recommended in the activities of conceiving some laboratory equipments for research and experiment activities.

Table 1

Some technical data for the waveguides

No.	The type of the waveguide	Inner sizes (mm)	Wavelength in the waveguide at 2,45GHz (mm)
1.	WR 430 – RG 104	109,22 x 54,61	147,65
2.	WR 340 – RG 112	86,36 x 43,18	173,30
3.	WR 284 – RG 48	72,14 x 34,04	230,89
4.	A1	96,0 x 46,0	158,98
5.	A2	76,0 x 36,0	206,68

CONCLUSIONS

By employing some appropriate electronic components we can assure a continuous and fine adjustment of the anode voltage and implicitly of the output in microwave power of the microwave magnetron generator. The microwave generator with adjustable output power will adopt as a solution for adjusting the output in microwave power this kind of scheme namely the employment of certain commanded triacs fitted in the primary winding of the anode voltage transformer.

REFERENCES

1. Metaxas A.C., Meredith, R.J. : Industrial Microwave Heating, 2000, p.5 – 23.
2. Thuery I.: Les micro ondes et leur effet sur la matiere, Ed. Technique et Documentation - Lavoisier, 2001, p.72 – 92.
3. Hippel A : Dielectric materials and applications, Cambridge MIT Press, 1983.
4. Tinga W., Nelson, S. : Dielectric properties of materials for microwave processing - tabulated, T. Microwave Power, 8, N°1, 1989, p.23 – 65.
5. Bengetsson N., Risman, P. : Dielectrics properties of foods at 3 GHz as determined by a cavity perturbation technique, T. Microwave power, 6, N°2, 2003, p. 107 – 123.
6. Rulea G.: Tehnica microundelor, Buc., Ed. Didactică şi Pedagogică, 1981, p. 56 – 67.