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Approach for Efficiency Enhancement of Microwave Ovens

Ankur Singhal[1], Parag Nijhawan[2], Amrita Sinha[3], Kamlesh Rai[4]
[1]M.E., Electrical and Instrumentation Engineering Department, Thapar Institute of Engineering and Technology Patiala, 147004, India, ankursinghal2010@gmail.com
[2]Faculty, Electrical and Instrumentation Engineering Department, Thapar Institute of Engineering and Technology Patiala, 147004, India, parag@thapar.edu
[3]Faculty, Electrical and Instrumentation Engineering Department, Thapar Institute of Engineering and Technology Patiala, 147004, India, amrita.sinha@thapar.edu
[4]Manager, LG Electronics India Pvt Ltd, Greater Noida Uttar Pradesh, 201306, India, global.rai@gmail.com

ABSTRACT

Nowadays, due to the concern regarding the environment, energy-efficiency performance in microwave ovens are required. This paper presents the output performance enhancement of domestic microwave oven. The power output and efficiency of the oven is calculated by using the test procedure discussed in the IEC 60705. The main component for the efficiency enhancement of oven are vanes type continuous wave magnetron and the high voltage circuit. As per the literature, 3-D particle in cell modelling in CST studio suite software is used for the modelling of the magnetron to examine the performance of the magnetron. The geometrical parameters of the magnetron are changes to achieve the desired efficiency for the oven. Further, modelling of the π quadruple model of non-linear transformer with doubler circuit has been done in MATLAB Simulink environment. The simulated and the experimental data has been collected and compared. It is found that there is approximately less than 5% variation in the simulated and the experimental results. Also, the performance of the oven has been enhanced approximately by 4.5%.

Key words : Microwave oven, Magnetron, High voltage circuit, MATLAB-Simulink, Efficiency.

1. INTRODUCTION

The research works that has been done previously regarding the microwave ovens (MWO) efficiencyincluding its main components such as magnetron (MGT) and the high voltage circuitry which includes high voltage transformer (HVT) with magnetic shunt and the doubler circuit are rare. The areas such as microwave ovens, radar, and heating system used high power microwaves. These waves are generated by the MGT oscillator. Because of the automated manufacturing techniques and Mass production, MGT become unbeatable among other microwave generators specially in case of domestic MWO. Continuous wave (CW) and pulsed are two mode of operation for the MGT.

The efficiencyη of the magnetron is given by

$$\eta = \eta_c\left(1-\frac{mv^2}{2eV}\right) \cong \eta_c\left(1-\frac{r_a+r_c}{r_a-r_c}\frac{\omega}{{neB}/{m-\omega}}\right) \qquad (1)$$

Wherer_c and r_a are the cathode and anode radius, η_c is the efficiency of the circuit, *v, e and m are the* velocity, charge and mass of electron, *V* is the anode voltage, n is the resonator number, $\omega$is the angular frequency and magnetic field is represented by B. Different power rating of MGT are there such as 1–30 kW at 2.45 GHz and 1 to 100 kW at 915 MHz . MGT with higherefficiency and power output are required in scientific [1], industrial [2] and energy sectors [3]. Steps has been taken for the development of such MGT's. Along with these steps, for rising the efficiency of MGT it is required to reduce the velocity of electron refer to (1). Also, the count of anode resonators should increase, narrowed action space size and condensate the magnetic field. It is difficult to analyse and design the MGT because of the nonlinear interaction of the wave. But due to the technological advancement in the recent years some powerful software's are available that helps to analyse [4], [5] the charge and electromagnetic simulation with their interaction in the MGT. Many publications on PIC simulation for oven magnetrons are available [6], [7], [8], [9]. Further, there is another part in the microwave oven i.e. high voltage circuit. Modelling and simulation of the high voltage circuit has been done using MATLAB Simulink environment. Theory for the shunt transformer are completely different than the conventional one. Various literature for the modelling of conventional transformer are available [10], [11], [12], [13], [14] but for shunt transformer are rare. Doubler circuit composed of a diode and capacitor supplied by the phase leakage flux transformer are the main compontnes of the high voltage circuit [15], [16], [17]. The function of the doubler circuit is to stabilize the current and double the voltage that are coming from the transformer side. To summarize, the paper is organized as follows. Section 2 briefly describe the methodology that has been used for making of more efficient MWO. It includes the mechanism for the interaction of electron with the traveling wave. Section 3 describe the approach to increase the efficiency of the oven. The influence of the vane length and other parameters has been discussed briefly. Modelling of high voltage supply for MGT using MATLAB Simulink environment has been disused. The influence on the high voltage supply by change in MGT parameters are studies in section 4. Finally, the conclusion has been drawn in section 5.

2. METHODOLOGY

Efficiency and power output of the oven is calculated according to the IEC60705 standard [18]. This standard describes the test procedure for the same.

The microwave power output and efficiency are calculated refer to (2) & (3)

$$P = \frac{4.187 \times m_w(T_1 - T_0) + 0.55 \times m_c(T_1 - T_A)}{t} \quad (2)$$

$$\eta = 100\frac{P \times t}{W_{in}} \quad (3)$$

Where, P is the microwave power output (W), η is the efficiency, T_0 is the initial temperature of water (°C), T_A is the ambient temperature (°C), T_1 is the final temperature of water (°C), m_c is the mass of the container (g), m_w is the mass of the water (g), t is the heating time (s), excluding the heating up time required by magnetron filament, W_{in} is input power including the heating of magnetron filament. Therefore, the major factor that influence the efficiency of MWO are 'P' and 'W_{in}'. Ratio of 'P' and 'W_{in}' has to be increased for the more efficiency. This could be possible by increasing the penetration of microwaves inside the load. The penetration of the waves can be increased by increasing the number of waves. This can be achieved by the interaction of electron with the RF wave as shown in Figure 1. In this figure traveling wave and electrons are experience constant electric field in azimuthal direction. In the accelerating electric field, electron moves toward the cathode side whereas opposite in deaccelerating field [19]. Electron that give energy to the wave is known as favourable-phase electrons whereas those take energy from the wave are known as unfavourable phase electron.

For high conversion of energy, most of the potential energy present in the electron should give to the microwave fields during gap crossing. Equation (4) shows the rough criteria for the same.

$$\frac{m_e v_d^2/2}{eV_o} = \left(\frac{B_H}{B_o}\right)^2 \frac{\left[1-\left({}^{r_c}/_{r_a}\right)^2\right]^2}{16\left[ln\left({}^{r_a}/_{r_c}\right)\right]^2} \quad (4)$$

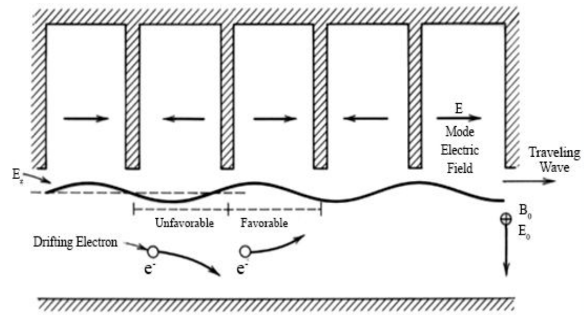


Figure 1: Traveling wave and drifting electron interaction inside the magnetron.

As MGT generally operated well above the Hull cut off condition. Therefore, the factor present in the bracket is low in nature.

3. APPROACH TO THE HIGH EFFICIENCY OF THE MICROWAVE OVEN

The above mention literature is used to achieve the rise in efficiency of the system. The details are given below. In order to achieve high efficiency and low noise, it is best to make the actual magnetic field close to the uniform magnetic field and increase in the favourable electron, after reducing the electron motion space. Hence the length of the vane is changed while keeping other parameters constant as shown in Figure 2. The initial magnetron is named as M1 and the parameter changed magnetron is named as M2.

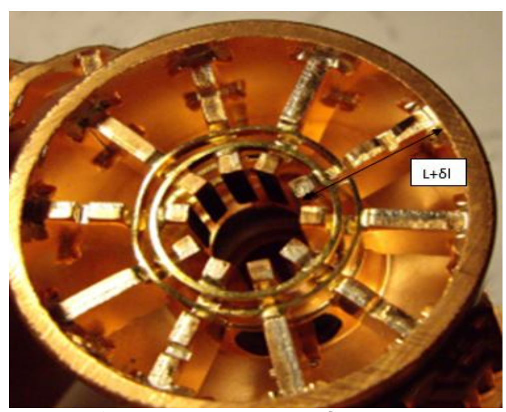


Figure 2: Magnetron Anode Vane

It is also note that, by doing these changes there is adverse effect on the motion of electron. To maintain the Lorentz force and synchronization of electron with RF wave there is need of intense magnetic field. Sr Ferrite magnet is used for the generation of that amount of field. An additional advantage of this is, achievement more uniform magnetic field inside the interaction space. Hence noise in system reduces that enhances the power output of the magnetron.

3.1 Modelling of High Voltage Supply for Magnetron

The modelling of the high voltage part is done to check the inputs to the magnetron. These parameters should lie within the rated capacity of the magnetron. The high voltage supply model has been made by using a Simulink software “MATLAB R2017a”. The Simulink model and the subsystems are shown in Figure 3, Figure 4, Figure 5 respectively.

Figure 3 shows the electrical equivalent circuit of the microwave oven, which includes voltage doubler circuit as shown in Figure 4 and single-phase leakage flux transformer with nonlinear inductances as shown in Figure 5. Nonlinear inductance cell composed of capacitance and diode. A voltage source is used to give supply to the π quadruple model of non-linear transformer or single-phase leakage flux transformer. The nonlinear inductance of the magnetic circuit is the function of the reluctance are shown in Figure 5.

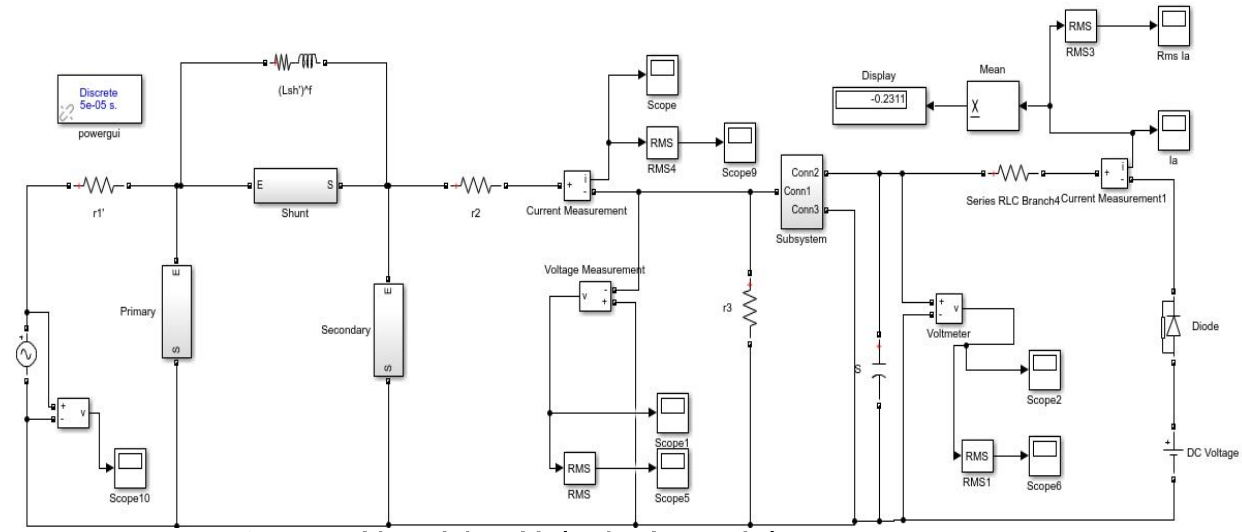


Figure 3: Matlab Simulink Model of High Voltage supply for Magnetron

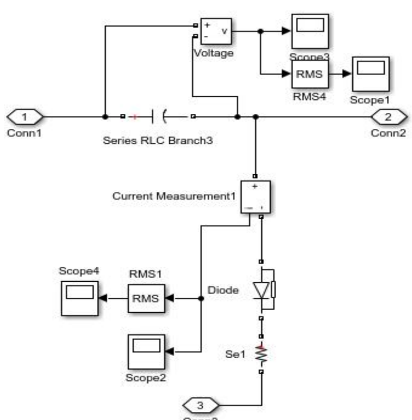


Figure 4: Matlab Simulation Circuit of Voltage doubler cell

Equation (5) and Equation (6) has been used to calculate the nonlinear element of the circuit [20], [21], [22], [23].

$$n_2 * \phi = n_2 * B * S \qquad (5)$$

$$i = {(H * l)}/{n_2} \qquad (6)$$

Where, l = Average portion’s lengths, n_2= Number of turns in secondary coil, S= Unbound core section, ϕ = flux by turn, B= Magnetic field, H= Magnetic flux density.

Using transformer geometrical parameters and B-H curve data, one can calculate flux and current relation as shown in Figure 6 and Figure 7. 100 data values of ϕ and I have been used for the look up table. These values further used in look up table.

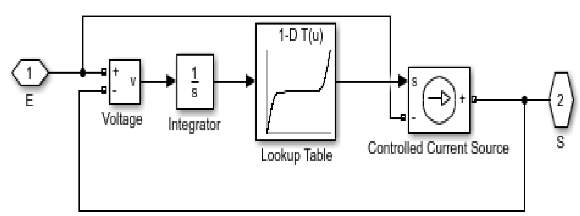


Figure 5: Matlab Simulink Circuit of Nonlinear Inductance

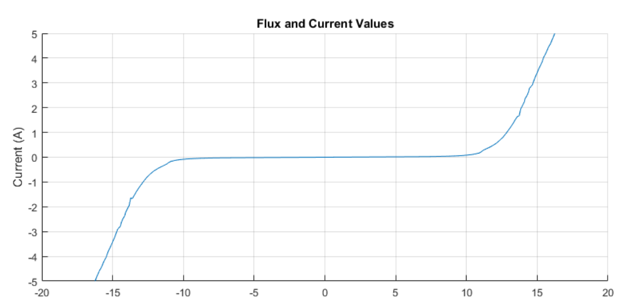


Figure 6: Flux Vs Current Curve of primary and secondary side

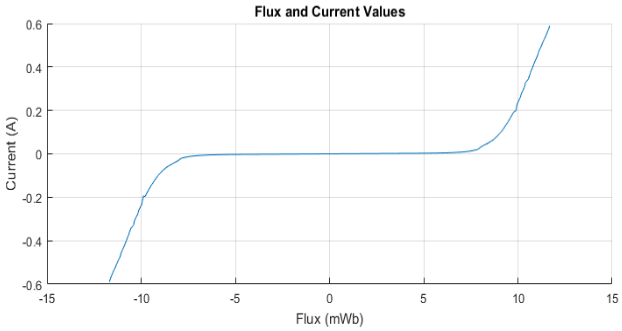


Figure 7: Flux Vs Current Curve of Shunt in HVT

The output of the voltage doubler further moves to the magnetron. To achieve the desired electrical parameters for the magnetron, changes has been done in High voltage circuit. Two different HVT are used. One with the secondary voltage rating of 2285±30V named as T1 and other with 2150±30 V named as T2 are used. Along with this different capacitor having rating 0.86 and 1 microfarad further named as C1 and C2 respectively has been used.

4. RESULTS AND DISCUSSION

The output of the microwave oven is found experimentally using the IEC 60705 standard. Further for high voltage supply lie in the rated capacity range, simulation outputs are checked and verified experimentally as given in table (1). Experimental arrangement for the system is shown in Figure 8.

Figure 9 represent the simulated and experiment waveform of the anode voltage for the desired case.

The experimental and simulated results for the inputs parameters to the magnetron are in good relation. After analysis it is found that, the deviation in the simulated and experimental result are lie in the range of 0-5%.

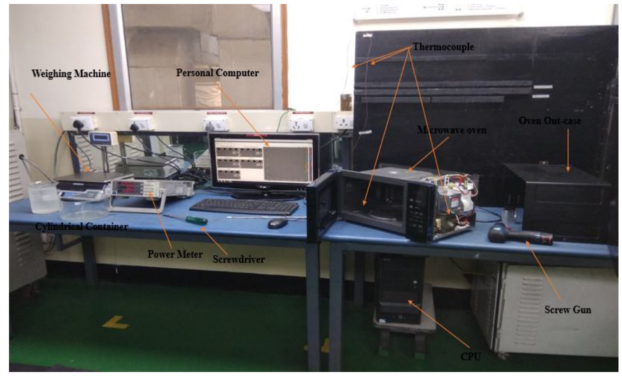
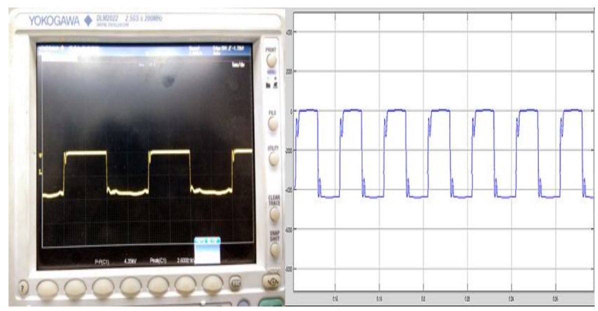


Figure 8: Experimental arrangement for the testing of microwave oven



(a) (b)

Figure 9: (a) Experiment waveform of Anode voltage; (b) Simulink waveform of Anode voltage

Table 1 MGT Input Parameters Values

S.no.	HVT	Capacitor	MGT	Practical Values		Simulated values		(%) Error	
				Anode Voltage (V)	Anode Current (mA)	Anode Voltage (V)	Anode Current (mA)	Anode Voltage (V)	Anode Current (mA)
1	T1	C1	M1	3900	272	4010	273	2.82	0.368
2	T1	C1	M2	3910	270	4093	269.1	4.68	0.333
3	T1	C2	M2	4106	295	4153	305.2	1.14	3.46
4	T2	C1	M2	4250	250	4210	241.8	0.94	3.28
5	T2	C2	M2	4350	280	4260	282.5	2.06	0.893

The performance of the oven with the magnetron and high voltage circuit are shown in the table (2).

From table (2), the temperature rises in the desired case i.e. with M2 and T2 and C2 in oven is more as compared to other cases.

The operating time condition for all the cases are same i.e. 55 sec. Three second are required by magnetron to start. Hence the actual time will be 52 second. Also, the efficiency of the desired system is 57.9% which is approximately 4.5% more than the running case.

5. CONCLUSION

In previous literatures, MAGIC-3-D codes and CST studio environment has been used to study and design the CW vane type magnetrons. It is found that the interaction of particles with the wave can be increased by intensify the field and by reducing the interaction gap. This is because of the formation of uniform field in between cathode and anode gap in which the particles interact with the waves and transfer the energy known as microwave energy.
It is found that there is 10 degree rise in temperature in the same operating time for the microwave oven.
This is because of the more penetration of waves inside the water present in the cavity of the oven. Also, there is rise in the efficiency of the microwave oven by approximately 4.5%.

The modelling and simulation of high voltage supply to the magnetron has been implemented in the MATLAB Simulink environment.
It reveals that the input parameters to the magnetron are within the limit and the values are verified experimentally. After verification it is found that there is 0-5% deviation in the simulated and the experimental values.

Table 2 Performance of the MWO with Different Cases

S.no.	HVT	Capacitor	MGT	Power input (Watt)	Initial water temp. (^oC)	Final water temp. (^oC)	Power output (Watt)	Efficiency (%)
1	T1	C1	M1	1275	10.9	19.5	682	53.4
2	T1	C1	M2	1318	9.9	19	719	54.6
3	T1	C2	M2	1510	10.1	20.3	813	53.8
4	T2	C1	M2	1190	10.3	18.3	628.5	52.8
5	T2	C2	M2	1370	9.9	19.9	794	57.9

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