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Research Article

Comparative Studies of Electrical Functioning of Magnetron Power Supply for One Magnetron

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Abstract

In this article we will evaluate a new validation approach of electrical functioning of a microwave generators powering one magnetron. This new energetic validation of π quadruple model with MATLAB-SIMULINK code will lead to validate the nominal functioning of the power supply for one magnetron by compares the signals obtained by simulation with those obtained experimentally. From this model, we will establish the energy balance of power supply for one magnetron and compare the obtained performances with that found by the experiment. Based on the fluxes found by simulation which is in good agreement with that experimentally, we checked the law of fluxes conservation.

Keywords: magnetron, magnetic flux, energy balance, modeling, Matlab-Simulink.

1. Introduction

The research works that exists in literature dealing the modeling of special high voltage transformer with magnetic shunt for magnetron are rare, unlike to conventional transformer, this special transformer with shunt has additional leakage flux which protects the magnetron against any eventual voltage variation.

In the first part, we will establish the study of energy balance for power supply powering one magnetron, but before we are forced to present in this paper, the equivalent model [1],[2], [3],[4],[5],[6] retained for the transformer which will be integrated into the overall scheme of the power supply that will be adapted at the modeling of the entire system using a powerful tool for numerical calculation of electrical circuits such as Matlab-Simulink. The first experimental setup discussed in this article will allow to find the different waves of currents and voltage that exist in the whole system of power supply. From the obtained curves we will establish the energy balance and compare the experiment performance with that obtained by simulation with Matlab-Simulink.

In the second part we will study the magnetic functioning of the transformer with shunts. The both identical shunts [7], [8], consisting of a number of stacked sheets are interposed between the two winding of the central core. The second experimental setup discussed in this article will allow to determine the electromotive forces during the load operation of the transformer with shunts, the electromotive forces obtained will permit to determine the various flux by turn, this with the help of an analog electronic card. From the three fluxes (primary, secondary and shunts) we will check the law of fluxes conservation which will be close to that found by simulation under Matlab-Simulink code.

2. Modeling of Single-Phase Power Supply for Magnetron

2.1 Described of the transformer with shunts

(Fig. 1) shows the armored structure of the transformer used in the industrials applications using in the traditional HV power supply for one magnetron. The magnetic shunts are used to deviate an important part of flux circulating between the primary and secondary windings [9]. Taking into account the size of the residual air-gaps and saturation state of materials, the magnetic fluxes in the air can be considered negligible compared to the flux through the shunts. The geometry of the magnetic circuit is symmetrical compared to the central core, having a double section of that common to each side core and each cylinder head.

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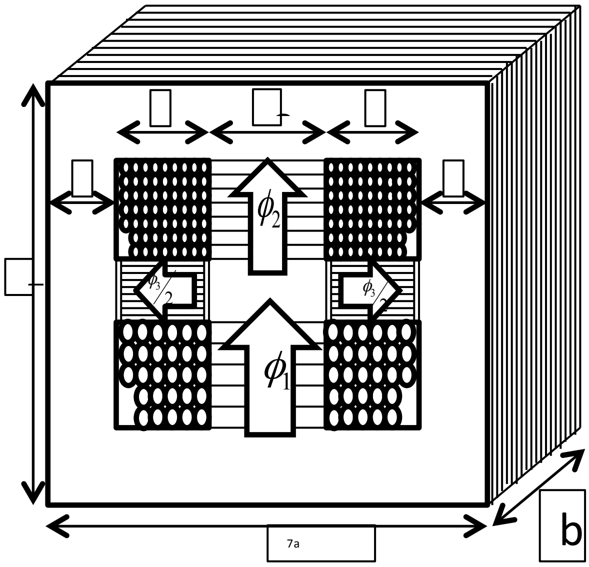

Fig. 1. Section of Cuirassed Transformer with Shunts.

2.2 Modeling of the transformer with shunts

The advantage of the π quadruple model [10] (Fig. 2) is in its equivalent single-phase scheme referred to the secondary, which seems more convenient to study the electrical operation of this transformer using Matlab-Simulink code [11],[12]. This model is qualified as natural because each inductance with iron core is directly related to the reluctance of a precise part of the magnetic circuit. Indeed, the inductances LP and LS are respectively related to the primary reluctance RP and secondary reluctance RS of the magnetic circuit portions. The inductance L'Sh is related to the reluctance of the part in the magnetic circuit including the two identical shunts, each of which has two identical air-gaps of small thickness. The immediate interest of this model is to be able to assign at each nonlinear inductance a "flux-current" relation in the form n2Φ(i), deduced from the geometrical parameters of a specific magnetic circuit portion of the transformer, thus allow us to reflect its real behaviour in nonlinear mode.

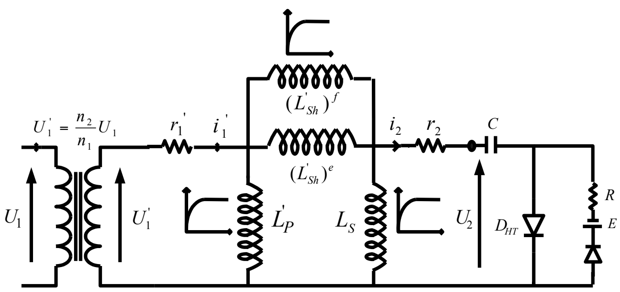

Fig. 2. Global Model of the Power Supply for one Magnetron.

2.**3 Simulation with Matlab - Simulink the Nominal Funtionning of the Power Supply**

To perform this model we have sought to integrate the model of the transformer in the power supply circuit from the source to the magnetron (Fig. 2), where we will represent the microwaves tube by its equivalent circuit deduced from the electrical characteristics which is formally similar to a diode with dynamic resistance R=ΔU/ΔI close to 350 Ω and threshold voltage E ≈3800 volts [13], [14].

The elements of the model including the non linear inductances were determined from the magnetic plate and the geometrical dimensions of the transformer. Each element of storable portion of magnetic circuit, of section S, and medium length l, is represented by its inductance L(i)=(n2Φ(i))/i, which the quantity n2*Φ(i) and its corresponding current can be determined from the B (H) curve of the used material and geometric parameters by the relation .

n2*Φ(i) = n2*B*S and i=(H*l)/ n2.

To validate this model, we performed a tests on a microwaves generators composed of the following elements:

- High voltage transformer with magnetic shunts which possesses the nominal characteristics:
- f=50 Hz, S=1650 VA, U1=220 V, and vacuum U2=2330V (resistance of primary view from secondary r1'=100Ω, secondary resistance r2=65Ω, number of turns in primary n1=224, number of turns in secondary n2 = 2400),
- A condenser of capacity C = 0.9 μF and a high-voltage diode DHT .
- A magnetron designed to operate under a voltage approximately 4000 V.

For its nominal power, it needs a medium intensity Iavg = 300mA, but without exceeding the peak current may destroy the magnetron (Imax<1,2 A).

On the other hand, we do not have analytical expression representing the curve for high values of the magnetic field B(H), we introduced point by point the values of this curve using a linear interpolation between two consecutive points in the iterations of the Simulink code. A specific routine was developed in Matlab-Simulink to deduce the pair of values (i, Φ) from the (H, B) and geometric data for the three inductances [9].

The implemented inductance under Matlab-Simulink code are composed of the following elements:

- Integrator to deduce from the flux Φ(i) the voltage.
- Function (lookup table as a function of current flux) that contains a large number of N points on the flux and currents.
- A source of imposed current.

The figure 3 below illustrates each inductance under Matlab-Simulink Code.

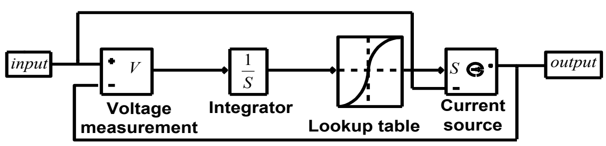

Fig. 3. Diagram Block of one No-linear Inductance.

We compare in the figures 4 and 5, the simulation results obtained by Matlab-Simulink with that obtained experimentally in the same conditions (nominal operation, U1 = 220V and f = 50Hz)).

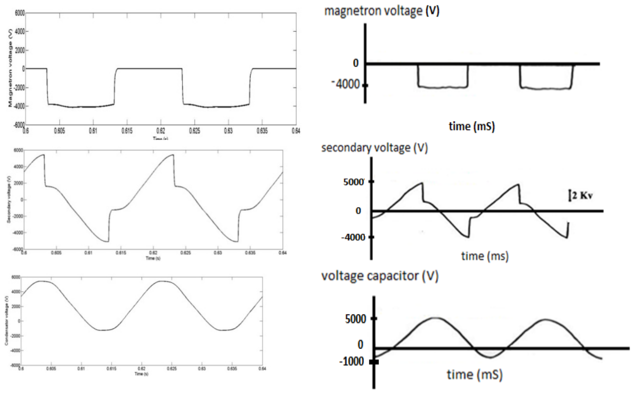

Fig. 4. Simulation with Matlab-Simulink and experiment waveform of voltages (nominal operation)

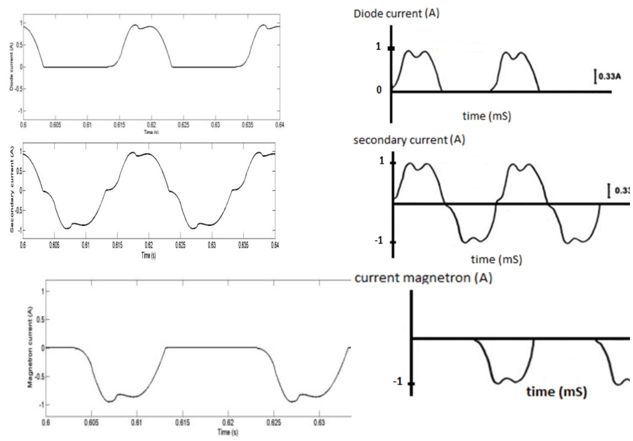

Fig. 5. Simulation with Matlab-Simulink and experiment waveform of currents (nominal operation)

Y1: magnetron voltage,
Y2: secondary voltage,
Y3: condansator voltage,
Y4: diode current,
Y5: secondary current,
Y6: magnetron current,

$$R_1 = 10\,M\Omega.,.R_2 = 10\,K\Omega.,.R_5 = 22\Omega$$

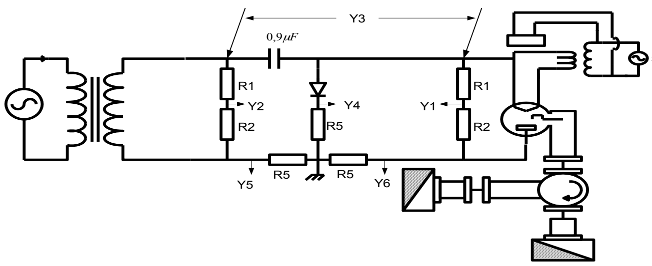

Fig. 6. Experimental Set up for Measuring of the Characteristics: Current and Voltage of the Power Supply HV for Magnetron in Nominal Operation

The results from the simulation by Matlab-Simulink in nominal operation and nonlinear regime, are in accordance with the waveforms recorded under the same experimental conditions (Fig. 6). Indeed, from peak to peak value, the relative differences never exceed 6%. Taking into account to the precision of the various data and acceptable tolerances on the operation of the magnetron, the validity of the model was satisfactory.

The current obtained by simulation with Matlab-Simulink code and that found by the experiment shows that the constraints imposed by the manufacturers are well respected (Imax<1.2A , Iavg≈300mA).

3. Modelling the Power and Computing The Performance of a Microwaves Generator for one Magnetron

Our approach is by exploiting the transformer model and using the Matlab-Simulink code, to perform during simulation, the energy balance of microwaves generator during the nominal operation of its power supply. The statements of voltage curves Um (t) across the magnetron and current Im (t) passing through it will allow to plot the instantaneous power. The sampled data of these two parameters were taken from the output file "To Workspace" containing the results of simulation. From these data, an appropriate program was used to calculate the products Umk * Imk point by point during a period, which will lead to computing the value of the instantaneous power curve. This same curve will allow thereafter to establish the average power curve during a period (Fig.7). The calculation then indicates that the magnetron debits 1237VA useful power [15],[16],[17],[18],[19],[20]. Comparing with that (fig. 8) obtained experimentally 1275VA.

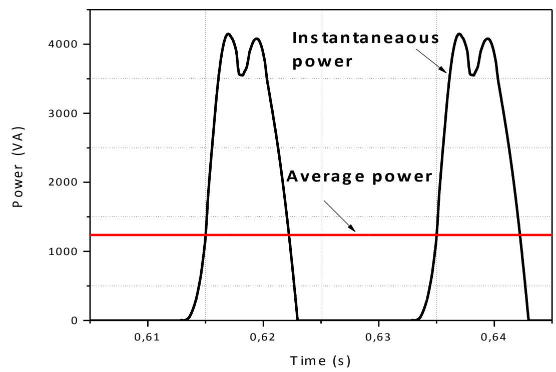

Fig. 7. Average Power and Instantaneous Power Results by Matlab-Simulink

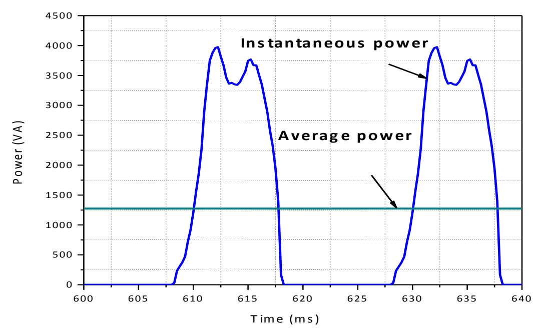

Fig. 8. Average Power and Instantaneous Power Results by Experiment

The nameplate of the HV power supply for the tube microwave indicates an apparent power on the order 1650VA with a factor of apparent power 0,825. We can deduce the performance of this power supply for microwave generators, which is 90% and 93% experimental, either:

$$\eta_{Matlab-simulink} = \frac{1237}{1650 * 0.825} = 90\%$$

$$\eta_{Experimental} = \frac{1275}{1650 * 0.825} = 93\%$$

4. Comparative study of the fluxes in the transformer with shunts

4.1 Experimental study of magnetic flux in the transformer with shunts

The experimental setup shown in the figure 9 was performed in the department of electrical engineering of higher School of Technology in Agadir (Marocco). The tests were performed during nominal operation of the magnetron power supply.

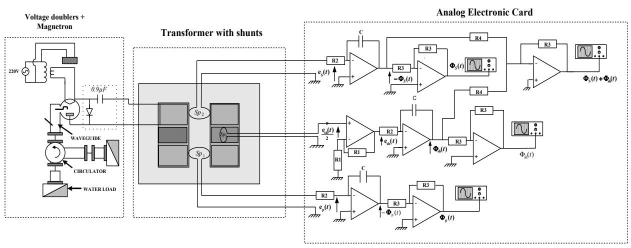

Fig. 9.Experimental setup to measure the magnetic fluxes in the transformer with shunts

The linear integration using an analogue electronic card of the electromotive force curves by turn measured by the circuit presented in the figure 9, allowed to find the corresponding fluxes curves (Faraday's Law) [10]. The total voltage e3(t) of the electromotive force by turn of the two symmetrical shunts is obtained by doubling the voltage e3(t)/2 in terminal of Sp3 enclosing one shunt, this with the help of the amplifier circuit with gain 2. On the other hand, the turns Sp1 and Sp2 give respectively between terminals of primary e1(t) and of secondary e2(t). The integration of three electromotive forces e1(t), e2(t) and e3(t) will lead respectively to the fluxes Φ1(t), Φ2(t) and Φ3(t). Each electromotive force attack the entry of its own assembly ‘’Integrator + reverser’’ of the figure 9 to obtain at its output the image voltage corresponding of the flux.

4.2 Simulation of the fluxes in the transformer with shunts under Matlab-Simulink code

The advantage of Matlab-SIMULINK code is to simulate the nominal operation of the power supply. This will lead to represent simultaneously the primary and secondary fluxes and the flux in the shunts. This was due to the model imposed under Matlab-Simulink code Figure 9.

The equivalent scheme of each inductance contains an integrator which will give the total flux. This latter will be divided by the number of turns to finally obtain the flux by turn represented by the letters a, b and c .

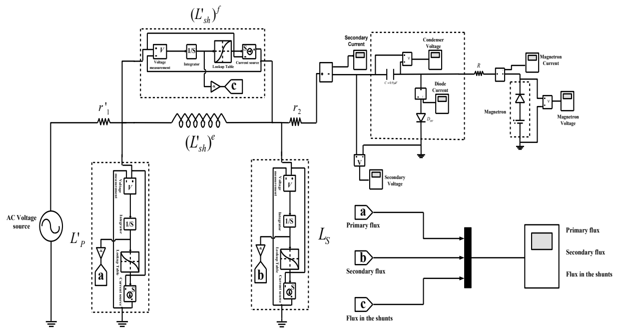

Fig. 9. Theoretical setup under Matlab-Simulink code to determine the flux in the transformer with shunts

4.3 The obtained results

From the figure 10 we see that the results of the flux Φ1(t), Φ2(t) and Φ3(t) outcome of the integration three electromotive forces e1(t),e2(t) and e3(t) are in good agreement with that obtained by simulation figure 10 and figure 11.

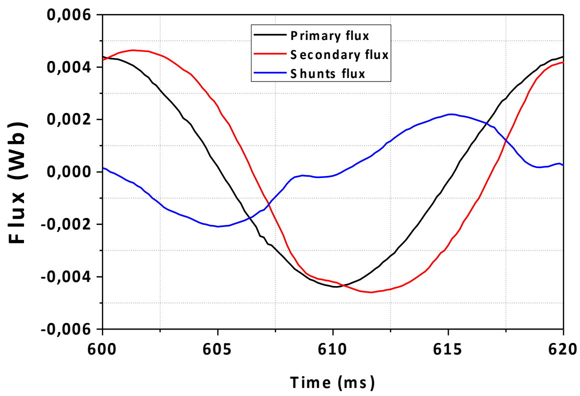

Fig. 10. Representation of three fluxes obtained experimentally

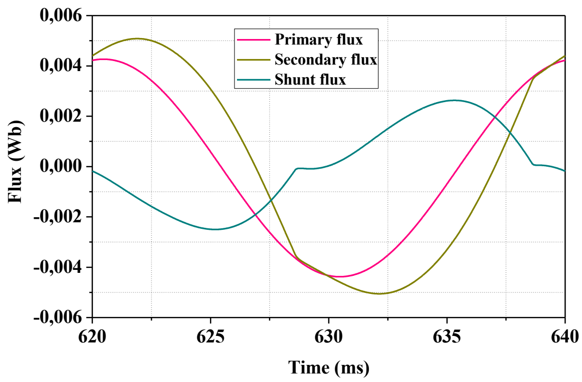

Fig. 11. Representation of three fluxes obtained by simulation under Matlab-Simulink code

To verify the law of flux conservation, it suffices to compare and represent simultaneously the temporal evolution of the flux by turn in the primary Φ1(t) obtained by the assembly of Figure 9, and the sum of secondary flow and the shunts flux Φ2(t)+ Φ3(t) obtained at the output of the circuit ‘summator-reverser ' which receives at its input the two images voltages of the flux -Φ1(t) and – Φ3(t) , the figure shows the results of comparison, shows a good superposition between the two curves. With a relative deviation in order of 5%, But, between peak to peak values, the relative variations do not exceed 8 %.

On the other hand, the values of the flux sum Φ2+Φ3 obtained by simulation is superposed with the values of the curve corresponding to the flux Φ1, because the leakage fluxes in the air are not represented in our model. From the figures 12 and 13, the conservation law of flux, satisfies the equality Φ1= Φ2+2(Φ3/2)= Φ2+ Φ3.

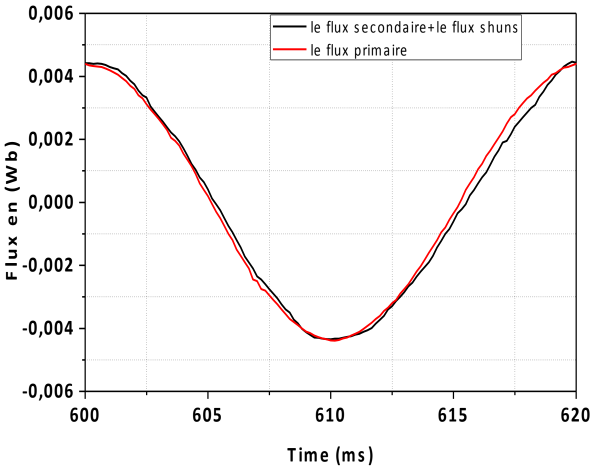

Fig. 12. Experimental verification of the law of flux conservation

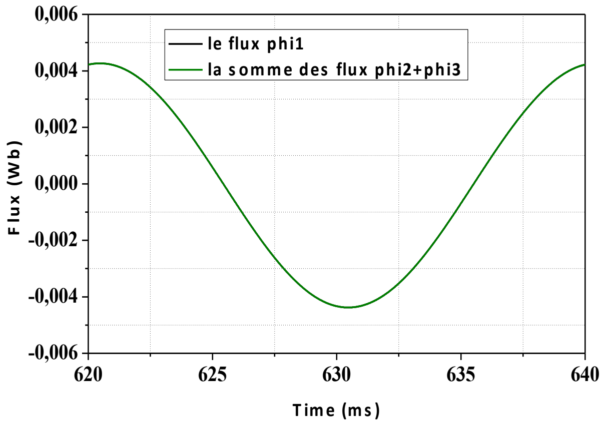

Fig. 13. Verification of the law of flux conservation under Matlab-Simulink code

Conclusion

We successfully validate in this work the nominal functioning of the power supply for one magnetron with Matlab-Simulink software. This latter allow for a comparative study between the results obtained by simulation and that obtained experimentally, this will push us to extended our study to the new six-phase or three-phase power for one or more magnetrons per phase system.

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