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OPTIMIZATION OF HIGH VOLTAGE POWER SUPPLY FOR INDUSTRIAL MICROWAVE GENERATORS FOR ONE MAGNETRON

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ABSTRACT

This work treats the optimization of high voltage power supply for microwave generators with a single magnetron. The design of this power supply uses one single-phase HV transformer with magnetic shunts powering a cell doubler of voltage and current stabilizer composed of a capacitor and a diode. The model of the transformer is presented by an equivalent circuit as a quadruple in π. This article treats on the one hand, the modeling of the transformer with magnetic shunts of HV power supply for a magnetron 800Watt-2450MHz, determining the analytical expressions of the non linear saturable inductances, from the magnetization curve B (H) of the material used. The resulting model has been implemented in Matlab-Simulink which is a programming language used to develop the solutions requiring a very high computing power. Using Matlab-Simulink, we have introduced a strategy to optimize this power supply for magnetron, to envisage the possibility to obtain a gains in the section, volume, cost of implementation and maintenance and make this system more economical while respecting the process of regulation of the current in the magnetron (Imax <1.2 A; Imean ≈300 mA).

Keywords: *Magnetron, Matlab-Simulink, Microwave, Modeling, Optimization, Power Supply, High Voltage (HV)*

1. INTRODUCTION

Currently, the single-phase power supply for microwave generators for magnetron 800watt-2450MHz (Fig1) is essentially composed of a HV transformer with magnetic shunts and a cell doubler composed of a capacitor and a diode, which doubles the voltage and stabilizes the current [1], [2], [11], [13]. The modeling of this HV power supply for magnetrons must pass by the modeling and the dimensioning of its own HV transformer, which ensures the stabilization of the current in the magnetron. The treating works of the modeling of this special transformer are rare contrary to the traditional transformers which are frequent [14], [15], [17], [18], [19], [20]. In the first phase, we proposed a model as a quadruple in π of HV power supply for microwave generators with a single magnetron (N =1). This model is based on the determination of the analytical expressions of the nonlinear saturable inductances, from the magnetization curve B (H) of the material used. The resulting model was simulated using Matlab-Simulink. This program enabled us to present the curve B (H) of the material used in the form of mathematical equation or to introduce an unlimited number of points (100 points). This tool is more accurate than the conventional code (EMTP) that forces us to introduce only a limited number of points (17 points). Our objective in this paper is, firstly, to improve the modeling of the current single phase power supply designed to power normally, in nominal mode, one magnetron which is mark Moulinex. On the other hand, to optimize this power supply and calculating the total volume. The paper is organized as follows: Firstly, we treat the modeling of the current power supply for microwave generators with N = 1 magnetron. The treated model is based on the determination of the analytical expressions of the nonlinear inductances from the magnetization curve B (H) of the material used. This model will be

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implemented for the first time in Matlab-Simulink. The results of this model will be compared with those obtained experimentally. Secondly, using Matlab-Simulink, we treat the optimization of HV power supply for magnetron 800 watt-2450MHz (fig1) for microwave generators with single magnetron, which possible to obtain relative to the current device, gains of size, volume, cost of implementation and maintenance, thus reduce the cost of the transformer while ensuring the process of controlling the current in the magnetron.

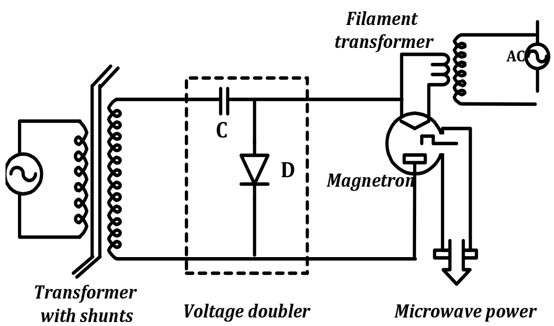

Fig1. Current Power Supply For A Magnetron (Amperex Technology)

2. MODELING OF A SINGLE-PHASE HV POWER SUPPLY FOR ONE MAGNETRON

The modeling already developed [5], [9], [10], [12], [13], [15], [16] of a single-phase HV power supply for a magnetron 800 Watts-2450 MHz (fig1) consist essentially to modeling the HV special transformer with magnetic shunts which ensures the stabilization of the mean anode current in the magnetron. So the equivalent model obtained of this transformer will be integrated into the global scheme of the power supply studied to be adapted at the modeling of the whole device under Matlab-Simulink. The simultaneous resolution of the electric and magnetic equations of the whole system is too complex and the solution can be only numerical (Matlab-Simulink).

The figure 2 shows the integration of the equivalent scheme in π of the transformer with shunts in the power supply extracted from the electrical and magnetic equations of its operation. This model presents an advantage is in its single-phase equivalent scheme referred to the secondary which seems more practical to study the functioning of the transformer under Matlab-Simulink.

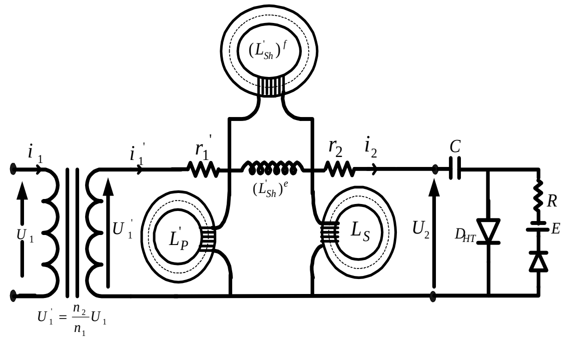

Fig2. Global Model Of The Power Supply Study For A Magnetron

The interest of this model is the ability to assign at each inductance a non linear relation "flow-current" under the form $n_2\Phi(i)$ from the geometrical parameters of a specific portion of the magnetic circuit of the transformer, thus translating into real functioning in non linear regime. To perform this modeling [5], [10] we have introduced the model of the transformer in the power circuit from the source to the magnetron (Fig2.), where we represented this tube microwave by its equivalent scheme deducted from its electrical characteristics which is formally similar at a diode with a resistance dynamic R=350 Ohms and threshold voltage E= 3800 Volts. The non linear inductances L'_P, L_S and $(L'_{sh})^f$ are determined from the magnetic characteristics of the plates and the geometrical dimensions of the transformer. Each element of a saturable portion of the magnetic circuit, with a section S and average length *l* is represented by its inductance $L(i) = \frac{n_2\Phi(i)}{i}$ where the quantity $n_2\Phi(i)$ and its current corresponding i can be determined from the curve B (H) of the material used and the geometrical elements using the relations : $n_2 * \Phi = n_2 * B * S$ and $i = (H * \ell) / n_2$

The curve B (H) of each inductance is represented by a mathematical expression which we use the analytical expressions by separating the curve in two parts:
• The linear part: fitted by the method of a series of non-integer power.
• Part of saturation: approximated by a polynomial representation [23].

The figure 3 shows the simulation of the curve B(H) of the ferromagnetic material used (SF19) obtained under Matlab, using the two analytical expressions and the experimental measurements.

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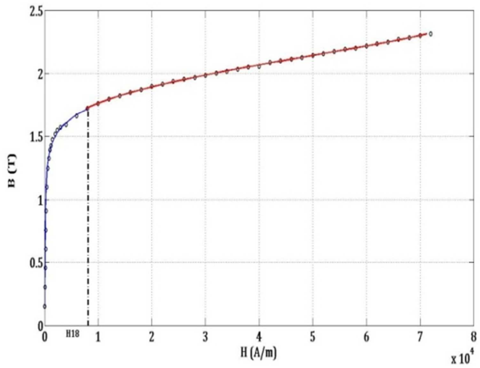

Fig3. The Magnetization Curve B (H): °°° Data Measurements; ____Curve Represented By A Series Of Non-Integer Power; ____Curve Represented By A Polynomial Representation

To validate this model, we have carried out tests on a microwave generator composed of the following elements:

- A HV transformer with magnetic shunts characterized by: f=50 Hz, S=1650 VA, U_1=220 V, and U_2=2330 V(resistance of the primary referred to the secondary r'_1 =100Ω, secondary resistance r_2=65Ω, number of primary turns: n_1=224, number of turns in the secondary n_2 = 2400).
- A condenser with a capacity C=0,9 uF and a high voltage diode DHT.
- A magnetron designed to function under an approximately voltage ≈4000 V.

To obtain its nominal power, it needs an average intensity I_{mean} ≈300 mA, but without exceeding the peak value of its current (I_{peak}<1,2 A). In addition, the data from the manufacturer made it possible to extract the values E = 3800 V and R = 350Ω.

The figures 4 and 5 show that in nominal functioning (U_1 =220 V and f= 50Hz) the results of the simulation by Matlab-Simulink of the device in the non linear regime, are in concordance with the experimental waveforms identified under the same conditions. Indeed, between values peak to peak, the relative differences will never exceed 6 %. Given the accuracy of the various data and the acceptable tolerances on the functioning of the magnetron, the validity of the modeling was considered satisfactory. On the other hand, the stabilizing effect of the current magnetron was verified with respect to variations of the primary voltage with 10% of nominal voltage (±20V).

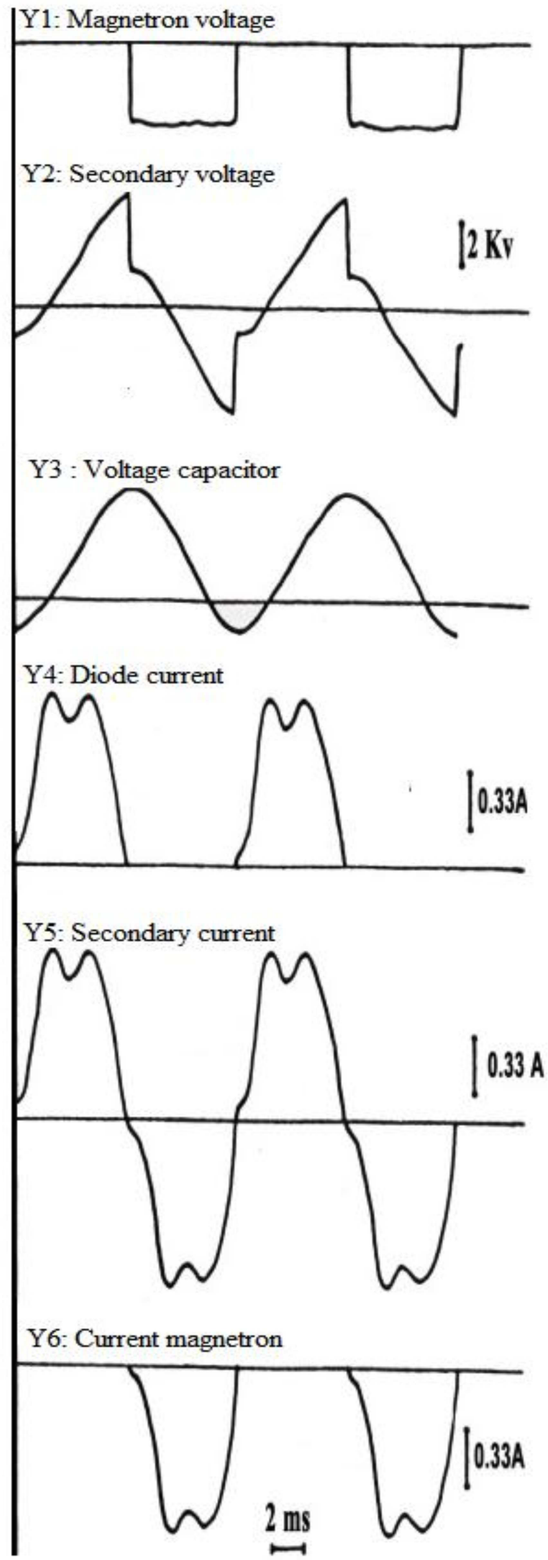

Fig4. Concordance Of The Experimental Waveforms Of Currents And Voltages (Nominal Mode)

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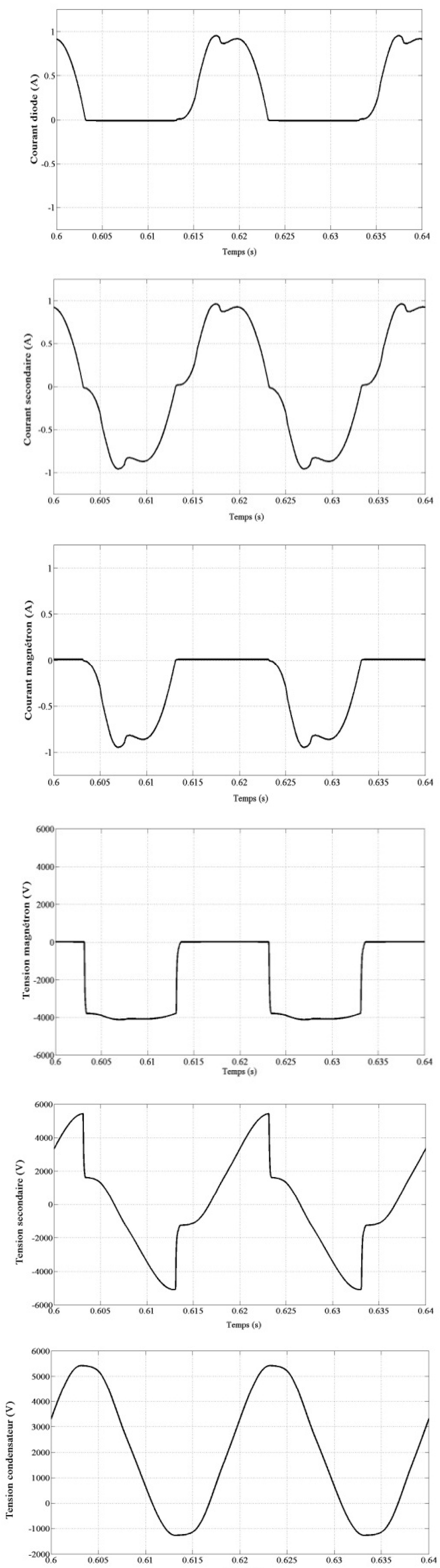

Fig5. Concordance Of The Theoretical Waveforms Of Currents And Voltages (Nominal Mode)

3. OPTIMIZATION OF THE HV POWER SUPPLY FOR A MAGNETRON

3.1. Principle Of Optimization

The principle is based on the exploitation of the model, quadruple in π, of this transformer mentioned above using the Matlab-Simulink code to highlight relative to the reference case (see Appendix), the sensitivity of the electrical functioning of the HV power supply and in particular that of the current magnetron, to any variations of one or more geometric parameters of construction of the transformer.

Our objective in this paper is to envisage an optimization of the parameters of the transformer presenting a minimum volume of iron and copper. To do this, we perform in the first step, a games of simulations by varying only one of the following parameters:

- The size of the magnetic circuit a (mm).
- The number of secondary turns n_2.
- The quality of magnetic plates.
- The size of the shunts materialized by n_3.
- The width of the air gap e (mm).

The second step is to present a strategy that enables the simultaneous variation of the different parameters. This strategy can optimize the high voltage transformer with shunts, and can lead to solutions which answered the criteria recommended by the manufacturer ($I_{max} < 1.2$ A; $I_{mean} \approx 300$mA).

3.2. Study Of The Influence Of Various Parameters Of The Transformer

There is no question that the inductances of the model, quadruple in π, depend on the geometrical parameters of the transformer, so the variation of these parameters completely changes the functioning of the equivalent circuit of the high voltage power supply (fig6.). Therefore, the study of its influence we can to perform a series of optimization in order to achieve our first objective. In each simulation, we observed the waveforms of the different electrical sizes of HV circuit, in particular that giving the curve of the current magnetron, and recording in every time the maximum and mean values. In order to answer the second objective, our approach is based on an iterative method based on the study of the sensitivity of the current magnetron with respect to the variation of these parameters.

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This strategy encourages us to study the simultaneous influence of one or more parameters on the different characteristics of the HV circuit for a magnetron, which leads to several solutions using Matlab function *"fmincon"* as described in paragraph 4. In the following, we introduce examples, not exhaustive, which show the influence of some parameters on the maximum and the mean magnetron current.

3.2. A. Influence of the size of the magnetic circuit of the transformer on the magnetron current

We studied the influence of the size of the magnetic circuit of the transformer by varying only the width "a" of unwound core in a well defined range (between 15 and 25 mm) and maintaining the other parameters constant as indicates the Appendix. This variation modifies the maximum and the averages values of the magnetron current obtained by simulation. During every simulation, by registering these maximal and mean values, we obtain the figure 6 which gives the variations of these values according to "a".

We conclude from this figure that the mean current of the magnetron decreases when "a" decreases and that its maximum value remains below an acceptable limit (Imax≤ 1.2 (A)). We can reduce the volume of magnetic circuit of the transformer by decreasing "a" while respecting the constraints of functioning recommended by the manufacturer.

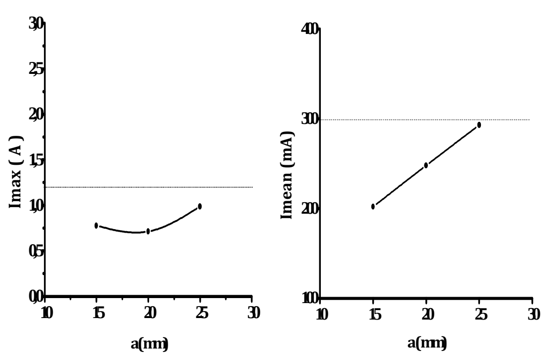

Fig6. Simulation Of The Magnetron Current According To The Size Of The Cuirassed Magnetic Circuit Of The Transformer (Maximum And Mean Values)

3.2. B. Influence of the number of secondary turns on the magnetron current

The unique variation in the number of turns of the secondary winding was done between 2050 and 2750 for all simulations, maintaining the other parameters fixed and adapting in each time the number of turns of the primary winding necessary for the report transformation remains constant (n_2/n_1). The figure 7 shows the results of the survey mean and maximum values of the magnetron current obtained at each simulation for different values of n_2.

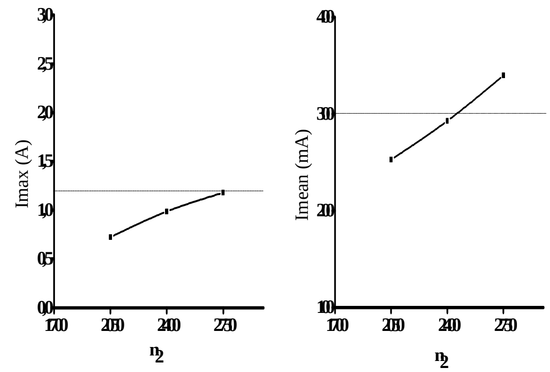

Fig7. Simulation Of The Magnetron Current According To The Number Of Secondary Turns Of The Cuirassed Magnetic Circuit Of The Transformer (Maximum And Mean Values)

We find that the maximum current decreases when the number of secondary turns decreases, as well as the mean value. It is therefore possible to reduce the volume of copper by reducing the number of secondary turns in ways that the magnetron current remains within the range recommended by the manufacturer.

3.2. C. Influence of the magnetic quality on the magnetron current

We have to highlight the influence of the magnetic quality of our transformer plates (Appendix) on the magnetron current. The other parameters remain unchanged. The figure 8 shows the curves of induction depending on the scope of the materials studied.

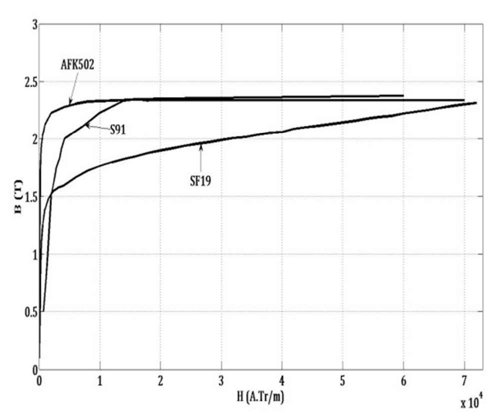

Fig8. The Curves B (H) Of The Plates Used

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Using the Matlab code, we carried out the games of simulation by exploiting the model quadruple in π. The figure 9 gives the maximum and the mean current as a function of “a” for the different qualities of plates.

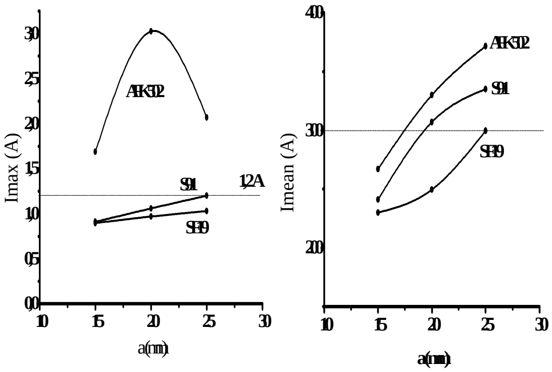

Fig9. Simulation Results Of The Characteristic Of The Magnetron Current Of HV Circuit As A Function Of “A” For Different Types Of Materials

The figure 9 shows that there is a possibility of using the alloy AFK502 by exploiting its superiority in the high inductance on the other magnetic materials, which allows to obtain high gains of section, of size and weight in condition to look the influence of the remaining parameters to ensure compliance with the constraints on the functioning of the magnetron tube without exceeding the peak of his current likely to destroy it.

3.2. D. Influence of the size of the shunts on the magnetron current

At the nominal mode, the electrical functioning of the HV power supply was simulated for different sizes of each shunt of the transformer, the other parameters remained unchanged and identical at those specified in the appendix. The principle consists to vary the number of stacked plates of each shunt between 10 and 18, which changes the overall functioning of the circuit. In each simulation, we withdraw for each size of the shunt the mean and maximum values of the current magnetron, which allows us to plot the results shown in the figure 10.

In this figure, we note that the maximum current of the magnetron declined when the number of plates constituting each shunt increased, while the mean value of the magnetron current remains within acceptable limits. Therefore we have another advantage in the minimization of the size of shunts while respecting the constraints of nominal functioning of the magnetron tube.

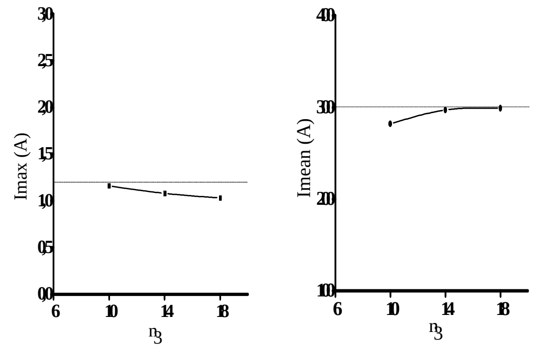

Fig10. Simulation Of The Magnetron Current For Different Sizes Of Magnetic Shunts (Maximum And Mean Values)

3.2. E. Influence of the air gap on the magnetron current

By varying only the thickness of the air gap between 0.45 and 1.05 mm, we carried out a series of repetitive simulations allowing to see the behavior of the electrical functioning of the power supply for a magnetron. The change in thickness of the air gap makes it possible to change the electrical functioning of the high voltage power supply. During each simulation, we note the mean and maximum values depending on the thickness of the air gap, the results obtained are grouped on the figure 11.

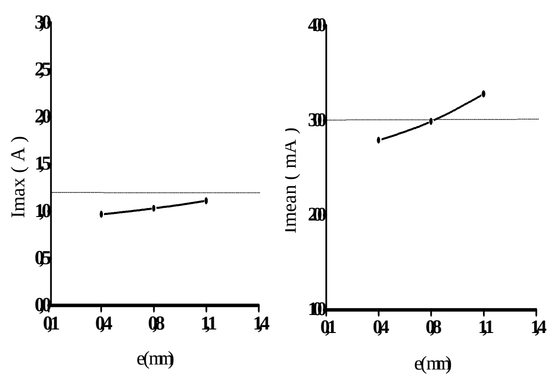

Fig11. Simulation Of The Magnetron Current Depending On The Thickness Of The Air Gap (Maximum And Mean Values)

This figure shows that the maximum current of the magnetron increased when the thickness of the air gap increased, as well as it’s the average values.

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4. STRATEGY OF OPTIMIZING

The results obtained in the above confirm the sensitivity of the current magnetron as function of the variation of each geometrical parameters of the transformer, as well they impel us to define a strategy for the further study of the optimization. This strategy is based on the SQP algorithm and can be used in Matlab by using the function *"fmincon"*, which allows to choose a simultaneous reduction in the window "a", the number of turns n_2 and the number of plates n_3, so to minimize the volume and cost of the transformer. Consequently, this strategy we insist to study the simultaneous influence of more parameters compared to a reference case, the circuit of the HV power supply.

4.1. The Algorithm Used

To optimize the HV transformer of the microwave generator for one magnetron (N= 1), we introduced the method of sequential programming (SQP). The use of this method is successful in optimization of dimensioning and shape optimization. This algorithm is powerful and effective in the non linear programming (NLP), attempts to resolve the program directly instead of transforming it into a sequence problems of minimization without constraints, which makes this algorithm differs compared to other methods (method of optimization without constraints). The advantage of the SQP method is that it can be manipulated in Matlab by using the function "fmincon" in the toolbox of Matlab. This algorithm minimizes a given objective function respecting the constraints determined by the user, where the objective function, defined the total volume of the transformer with shunts, is in the following form:

$$V_{total} = V_{iron} + V_{copper}$$

Or,

$$V_{total}\ (X)= (6*a*5*a*b)+2*(h*a*b) - 2*a*b*(3*(a-h)) +(\pi*(d_1)^2/2) *(2*(a+b))*(cd_1+\sum 4*d_1*j+cd_{1v}) + (\pi*(d_2)^2/2) *(2*(a+b))*(cd_2+\sum 4*d_2*j+cd_{2v}$$

• X is the line vector composed of the geometric parameters of the construction of the transformer:
X = [a, n2, n3, e] with an initial value X_0 = [25 18 2750 0.75] represents the reference value.
• $d_1 = 4*S_1/\pi$: The diameter of the spire at the primary, with $S_1 = I_1/4$ (I_1 =7 A).
• $c_{d1} = [(n_2 / m) * d_1] / f$, represents the number of layer at the primary, with:

- $m=n_2/n_1 = 10.71$ is the report of transformation
- f = (3 * (a-h)) /2 is a window shown on the fig12.

• $c_{d1v} = [c_{d1}\text{-fix}(c_{d1})] * l_{m1}$, where fix ($c_{d1}$) is the integer part of the actual number c_{d1} and l_{m1} define the maximum number of lines in the primary.
• $d_2 = 4*S_2/\pi$: The diameter of the spire at the secondary, with $S_2 = I_2/4$ (I_2 =7 A).
• $c_{d2} = (n_2 * d_2) / f$, represents the number of layers in the secondary.
• $c_{d2v} = [c_{d2}\text{-fix}(c_{d2})] * l_{m2}$, lm2 represents the maximum number of lines in the secondary.

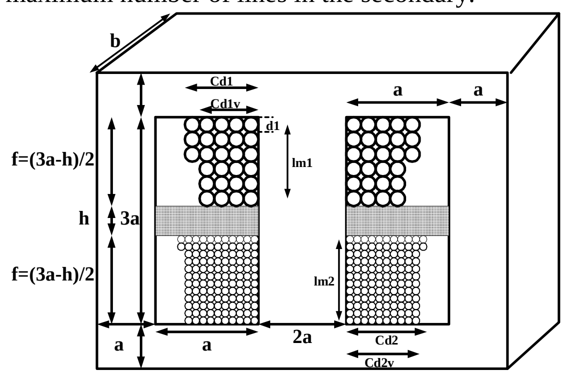

Fig12. Section Of The Cuirassed Transformer With Shunts

Moreover, the constraints in the table 1 were redefined as the inequality constraints ≤ 0.

Table 1. Range Of Variations Of Parameters

Parameter name	Range of variation
a (mm)	$15 \le a \le 25$
n_2	$2050 \le n2 \le 2750$
n_3	$10 \le n3 \le 18$
e (mm)	$0.45 \le e \le 1.05$

We have carried out, for the various possible configurations of parameters of the transformer, the simulations needed to predict the electrical behavior under nominal conditions. Each of these parameters varies within a certain range determined as indicated in the Table 1. For each iteration, we simulated the model of quadruple in π using the Matlab function'' *sim''*, which satisfies the following conditions:

If (the maximum current in the magnetron <1.2A,and its mean ≤ 300 mA):

$\rightarrow I_{max}, I_{mean}, X, V_{total}(X)$

Else (the program moves to the next iteration)

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This method allows us to choose the solution that we interested from the optimal solutions of the problem on the contrary to the methods of evolutionary optimization which can lead to a single optimal solution.
Abbreviation and acronyms should be defined the first time they appear in the text, even after the have already been defined in the abstract. Do not use abbreviations in the title unless they are unavoidable.

4.2. The results obtained

The table 2 presents the selected solutions that can give the best functioning of the magnetron 800W-2450Hz for microwave generators. We have selected the solutions from this table that respect the conditions recommended by the manufacturer: I_{max} <1.2 A and $I_{mean} \leq$ 300 mA.

Table 2. Selected Solutions That Respects The Norms Imposed By Manufactures

Solution	Magnetic quality	a (mm)	n_3	e (mm)	n_2	V_{total} (cm^3)
A (Ref.)	**SF19**	**25**	**18**	**0.75**	**2400**	**1087.6**
B	**ordinary plates**	**24**	**18**	**0.55**	**2750**	**1066.3**
C	**ordinary plates**	**23.5**	**14**	**0.55**	**2650**	**994.4**
D	**SF19**	**22**	**14**	**0.45**	**2500**	**889.6**
E	**ordinary plates**	**20**	**14**	**0.45**	**2325**	**781**
F	**SF19**	**20**	**10**	**0.45**	**2300**	**748.8**

From this table represents the total volume of the active part of the transformer (iron volume + volume of copper), we find that the solution E simultaneously allows the best compromise between gains of section of iron and copper, so the best gain of size and cost of the transformer (I_{peak}=1.009 A and I_{mean} =291 mA). We note that the solution F presents a minimum volume but it does not allow a functioning of the magnetron in plain power (Ipeak =0.7 A and Imean =234 mA).

By using the configuration settings of the transformer of the solution E, we simulated under Matlab the electrical behavior of HV circuit of the power for a magnetron. The waveforms obtained during this simulation are shown in figure 12.

The waveforms obtained shows that these results do not show an oscillations affecting the magnetron tube and meet the criteria recommended by the manufacturer (Imax<1.2 A and Imean ≤ 300 mA.)

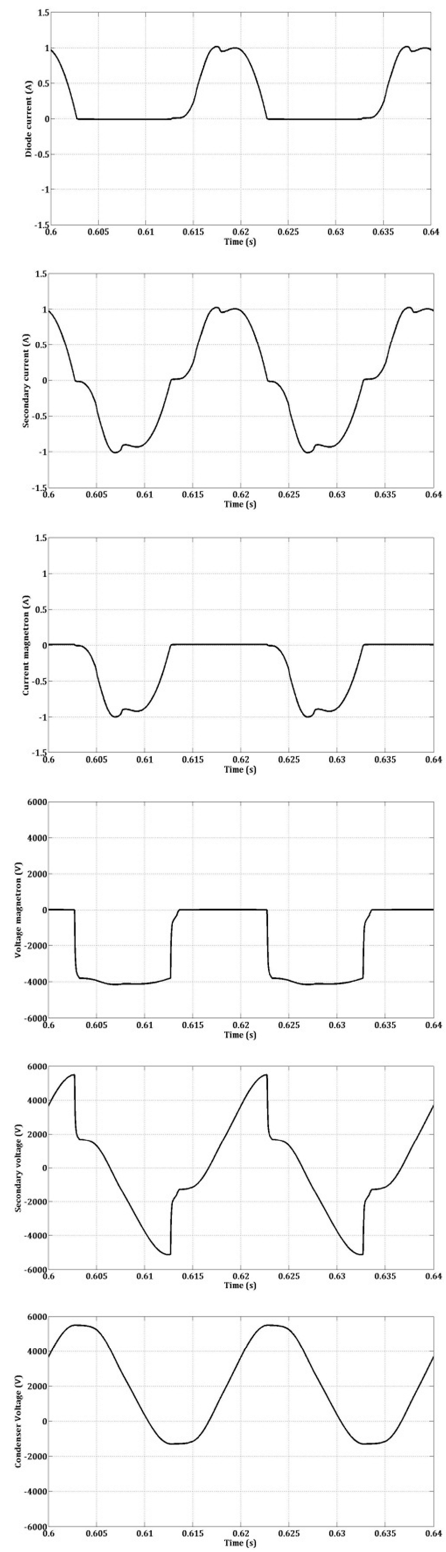

Fig12. Waveforms Of Voltages And Currents Corresponds To E Solution Of The Transformer

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5. CONCLUSION

The optimization of a high voltage power supply for microwave generators with a single magnetron for industrial applications is conclusive.

Based on the reference case (Appendix), we have shown in this paper by simulation using Matlab-Simulink, the influence of the sensitivity of one and several parameters on the nominal functioning of the circuit of the HV power supply. By analyzing the results, we have succeeded in reaching the objective that we set at the start, to define a choice of transformer with shunts presenting a gain in section, of volume and weight while respecting the criteria of control of magnetron current recommended by the load imposed by the manufacturer.

This work can be also done in a similar manner to the case of the same type of HV power supply for one magnetron of useful power 1000 Watts or 1200 Watts at 2450 Mhz for microwave generators used in industrial applications.

6. APPENDIX

During this work, we have taken as reference the following geometrical dimensions of the transformer with shunts:

- The size of the magnetic circuit a=25 mm.
- The width of the magnetic circuit: b = 60 mm
- The size of the shunts materialized by n_3=18
- The number of turns on the primary: n_1 = 224
- The number of secondary turns n_2=2400
- The surface of the central nucleus: S_1 = 2a.b
- The height of the stack of plates of the shunts: h=0.5 .n3
- The surface of each shunt: S_3 = b.h
- The quality of magnetic plates: SF19
- The width of the air gap e=0.75mm.

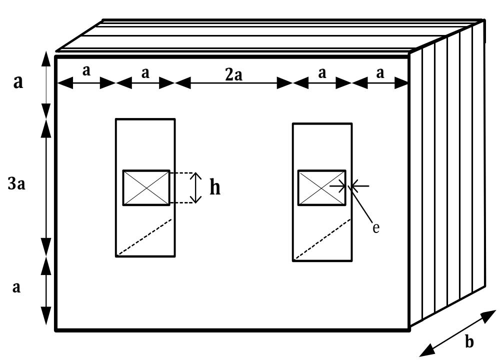

Figure13. The Geometrical Dimensions Of The Transformer With Shunts (Reference Case)

REFRENCES:

[1] Dick E.P., Waston W., “Transformers models for transcient studies based on field measurements”, *IEEE Transactions* (PAS-100, N°1, (1981) 409-419).

[2] Gill, P.E., W. Murray, M.A. Saunders, and M.H. Wright, "Procedures for Optimization Problems with a Mixture of Bounds and General Linear Constraints" *ACM Trans. Math.* (Software, Vol. 10, pp 282-298, 1984).

[3] J. R. Lucas, “representation of magnetization curves over a wide region using a non-integer power series”(*international J. Elect. Enging. Edduc* – vol. 25. pp. 335 – 340. Manchester U.P. 1988. Printed in Great Britais)

[4] David Greene J., Gross C.A., “non linear modelling of transformers”, *IEEE transactions On Industry Applications*, N°3, 24, May/June (1988).

[5] Aguili T & Chraygane M., “Une alimentation originale pour générateurs micro-ondes”, *Revue Générale de l’Electricité - France, RGE* 5 (1990) 49-51.

[6] Gill, P.E., W. Murray, and M.H. Wright, “Numerical Linear Algebra and Optimization”, Vol. 1, Addison Wesley, 1991.

[7] Chan J. H., Vladimirescu A., Gao X. C., Liebmann P., Valainis J., “Non linear transformer model for circuit simulation”, *IEEE Transactions on Computer-Aided*, N°4, 10, April (1991).

[8] Chraygane M, “Modélisation et optimisation du transformateur à shunts d’une alimentation haute tension à magnétron pour générateurs micro-ondes 800W-2450Mhz destinés aux applications industrielles”, *Thèse de doctorat, Université Claude Bernard Lyon I, France*, n° 189 (1993).

[9] Teissier M., Chraygane M., Jammal A. et Masson J.P , “Leakage Flux Transformer Modelling”, *Communication, International Conference on Electric Machines, ICEM’94, Paris*, (1994).

[10] Chraygane M, Teissier M., Jammal A. et Masson J.P, “Modélisation d’un transformateur à shunts utilisé dans l’alimentation H.T d’un générateurs micro-ondes à magnétron, publication”, *journal de physique III, France*, (1994) 2329-2338.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

[11] Guanghao Liu, Xiao-Bang Xu, "Improved Modeling of the Nonlinear B–H Curve and Its Application in Power Cable Analysis", *IEEE Transaction on Magnetics*, vol. 38, NO. 4, July 2002

[12] Chraygane, M. El Khouzaï, M. Ferfra, & B. Hlimi, "Etude analytique de la répartition des flux dans le transformateur à shunts d'une alimentation haute tension pour magnétron 800 Watts à 2450 Mhz", *revue Physical and Chemical News, PCN*, 22 (2005) 65-74.

[13] Chraygane M., ferfra M. & Hlimi B., "Modélisation d'une alimentation haute tension pour générateurs micro-ondes industriels à magnétron", *La Revue 3EI, Paris, France*, vol. 41, 2005, pp. 37-47.

[14] B. Kawkabani, J.-J. Simond, "Improved Modeling of Three-Phase Transformer Analysis Based on Magnetic Equivalent Circuit Diagrams And Taking Into Account Nonlinear B-H Curve", *Journal Electromotion*, Volume 13, Number 1, January-March 2006, pp. 5-10.

[15] M. Chraygane, M. Ferfra, & B. Hlimi, "Etude analytique et expérimentale des flux du transformateur à shunts d'une alimentation pour magnétron 800 Watts à 2450 Mhz", *revue Physical and Chemical News*, PCN, 27, (2006) 31-42.

[16] Satoru Hiwa, Tomoyuki Hiroyasu, Mitsunori Miki. "Hybrid optimization using DIRECT, GA, and SQP for global exploration". *IEEE Congress on Evolutionary Computation'2007*. pp.1709~1716.

[17] A. D. Theocharis · J. Milias-Argitis · Th. Zacharias, "Single-phase transformer model including magnetic hysteresis, and eddy currents", *Electr Eng* vol. 90, 2008, pp. 229–241.

[18] M. Chraygane, M. Ferfra, B. Hlimi, "Détermination analytique des flux et des courants du transformateur à fuites d'une alimentation haute tension à magnétron pour générateurs micro-ondes industriels 800 Watts à 2450 Mhz", *Phys. Chem. News, PCN*, 40 (2008) 51-61.

[19] Jouni Pylvänäinen, Kirsi Nousiainen, Pekka Verho "Studies to Utilise Calculated Condition Information and Measurements for Transformer Condition Assessment". *International Review of Electrical Engineering (I.R.E.E.)*. Vol. 4. n. 4. june.2009. pp. 684-689.

[20] H. Ouaddi, S. Baranowski, Nadir Idir, "High frequency modelling of power transformer: Application to railway substation in scale model", *Przeglad Elektrotechniczny (Electrical Review)*, 2010. pp. 165-169,

[21] M.Ferfra, M.Chraygane, M.Fadel, M.Ould Ahmedou. *Physical and Chemical News 54*, pp. 17-30, 2010.

[22] M.Ould.Ahmedou, M.Chraygane, M.Ferfra, "New π Model Validation Approach to the Leakage Flux Transformer of a High Voltage Power Supply Used for Magnetron for the Industrial Micro-Waves Generators 800 Watts". *International Review of Electrical Engineering (I.R.E.E.)*, Vol. 5. n. 3. May-June.2010. pp. 1003-1011.

[23] M.Ould.Ahmedou, M.Ferfram R.Nouri, M.Chraygane "Improved Model of the Leakage Flux Transformer Used for Magnetrons", *International Conference on Multimedia Computing and Systems, IEEE Conference, Ouarzazat(Morocco) from 07 to 09 April 2011*