A HIGH EFFIECIENCY ELECTRO – THERMAL CONVERTERS

Cezar POPA, Radu PENTIUC
"Stefan cel Mare" University of Suceava
str.Universitatii nr.1 , RO-5800 Suceava
cezarp@eed.usv.ro, radup@eed.usv.ro

Petru LEONTE
"Gheorghe Asachi" Technical University of Iaşi
B-dul Carol I nr. 11, RO-6600 Iaşi

Abstract *Magnetic field modelling for electro - thermal energy converter is essential in calculation of total losses and to estimate warm developed in massif windings. Knowlegement of local magnetic field intensity give the possibility to evaluate local current density and volume distribution of electrical power in material.*

Introduction

To evaluate the components of a bidimensional magnetic field, for proposed electro – thermal converter, who is essentially a iron core with two concentrically windings, we can represent a winding section as a rectangular current distribution (curvature ignored) and use complex potential method in association with the method of images. If material depth, when electromagnetic energy flow to a single part, is bigger than 2.5÷3 δ (depth of penetration of excitation wave), can suppose that is equivalent to infinitely semi space with plane surface. In a bidimensional magnetic field, the magnetic vector potential $\boldsymbol{A}$, has a single component about z co-ordinate [1]. The magnetic field intensity components H_x, H_y are real functions, in hypothesis to a field without vertices and sources [2].

Method of images to calculate the stray magnetic field in transformer

In case of transformer with concentrically windings and symmetrical core is sufficient to analyse only a half from magnetic circuit. Applying images method in case when magnetic materials are only present to one of the four winding window boundaries, we obtaining geometrical configuration presented in figure 2. The significance for elements presented is: $\underline{r}$ - distance between element dy to point $P_{(X,\ jY)}$, where is calculate magnetic field; $J = \frac{N \cdot i}{h}$ - linear current density; N - number of turns coil. i - current in coil; h – height of coil; $dI = J \cdot dy$ - current into elementary element dy; μ_0 - vide magnetic relative permeability; μ_{r1} - magnetic core relative permeability. Finite permeability of the core is being catered for, by adjusting the weight of images equivalent current, with a factor [3], as indicated:

$$k_1 = \frac{\mu_{r1} - 1}{\mu_{r1}} \tag{1}$$

To calculate magnetic field in an aleatory point is necessary to sum all components about x and y co-ordinate of applied and images field. About this steep is possible to evaluate power developed in secondary massif windings by using a *Poynting* vector formula. The position vectors, in complex plane, which corresponds to windings respectively to their images, are:

$$\begin{aligned}
\underline{r_1} &= (X - g_{a1} - g_1) + j\cdot(Y - y) = \mathrm{Re}_1 + j\cdot \mathrm{Im}_1 \\
\underline{r_2} &= (X - g_{a1} - g_1 - g_a - g_2) + j\cdot(Y - y) = \mathrm{Re}_2 + j\cdot \mathrm{Im}_1 \\
\underline{r_1}' &= (X + g_{a1} + g_1) + j\cdot(Y - y) = \mathrm{Re}_9 + j\cdot \mathrm{Im}_1 \\
\underline{r_2}' &= (X + g_{a1} + g_1 + g_a + g_2) + j\cdot(Y - y) = \mathrm{Re}_{10} + j\cdot \mathrm{Im}_1
\end{aligned} \tag{2}$$

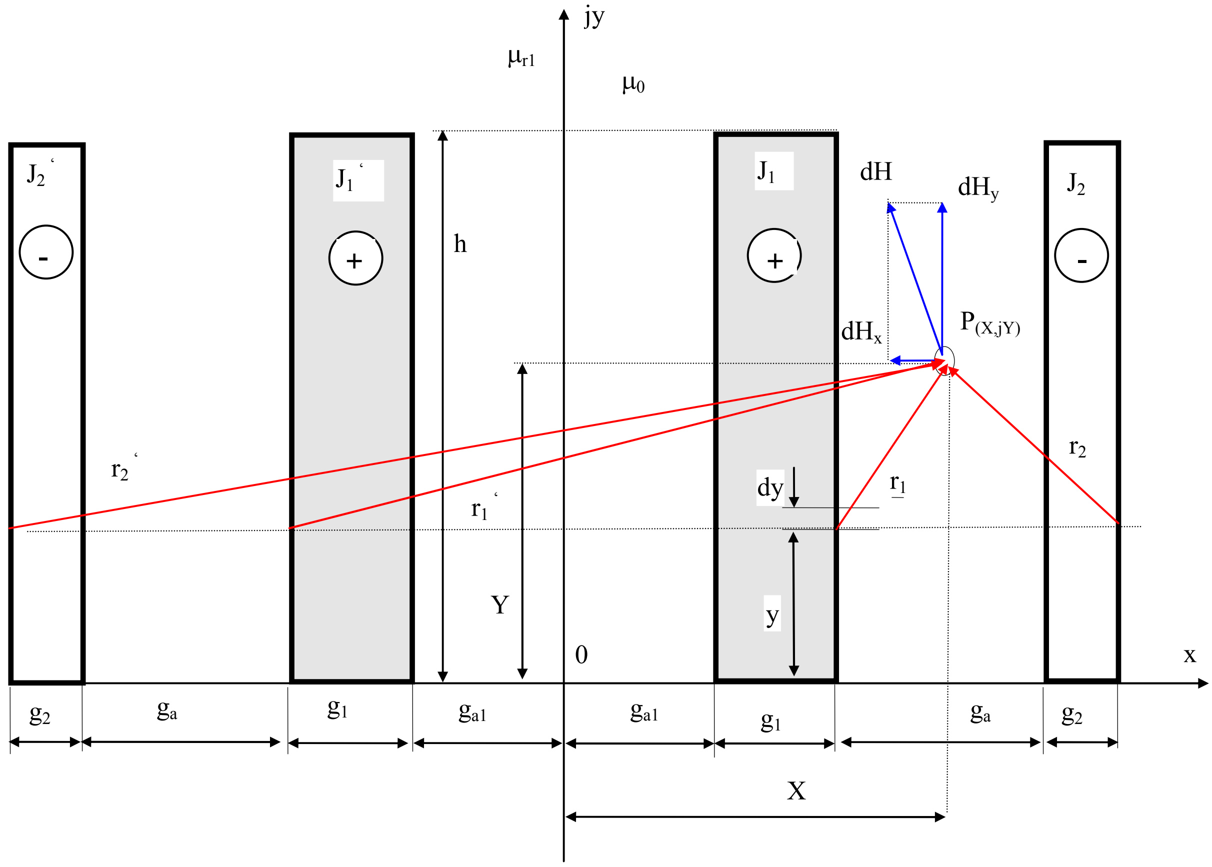


Figure 1. Magnetic model of an electro-thermal converter type transformer with massif secondary coil

Linearly current density taking account to current sign and correction factor is:

$$J_1 = \frac{N_1 \cdot i_1}{h}$$
$$J_2 = -\frac{N_2 \cdot i_2}{h} \tag{3}$$
$$J_1^{'} = k_1 \cdot \frac{N_1 \cdot i_1}{h}$$
$$J_2^{'} = -k_1 \cdot \frac{N_2 \cdot i_2}{h}$$

In accord to equations (7; 8) the components of magnetic field generated by every windings and images are [4]:

$$\begin{cases} H_x^{(1)} = -\frac{J_1}{4 \cdot \pi} \ln \frac{\mathrm{Re}_1^{\,2} + A_1^2}{\mathrm{Re}_1^{\,2} + A_2^2} \\ H_y^{(1)} = \frac{J_1}{2 \cdot \pi} \left[arctg \frac{A_1}{\mathrm{Re}_1} - arctg \frac{A_2}{\mathrm{Re}_1} \right] \end{cases} \tag{4}$$

$$\begin{cases} H_x^{(2)} = -\frac{J_2}{4 \cdot \pi} \ln \frac{\mathrm{Re}_2^{\,2} + A_1^2}{\mathrm{Re}_2^{\,2} + A_2^2} \\ H_y^{(2)} = \frac{J_2}{2 \cdot \pi} \left[arctg \frac{A_1}{\mathrm{Re}_2} - arctg \frac{A_2}{\mathrm{Re}_2} \right] \end{cases} \tag{5}$$

$$\begin{cases} H_x^{(1')} = -\frac{J_1^{'}}{4 \cdot \pi} \ln \frac{\mathrm{Re}_9^{\,2} + A_1^2}{\mathrm{Re}_9^{\,2} + A_2^2} \\ H_y^{(1')} = \frac{J_1^{'}}{2 \cdot \pi} \left[arctg \frac{A_1}{\mathrm{Re}_9} - arctg \frac{A_2}{\mathrm{Re}_9} \right] \end{cases} \tag{6}$$

$$\begin{cases} H_x^{(2')} = -\frac{J_2^{'}}{4 \cdot \pi} \ln \frac{\mathrm{Re}_{10}^{\,2} + A_1^2}{\mathrm{Re}_{10}^{\,2} + A_2^2} \\ H_y^{(2')} = \frac{J_2^{'}}{2 \cdot \pi} \left[arctg \frac{A_1}{\mathrm{Re}_{10}} - arctg \frac{A_2}{\mathrm{Re}_{10}} \right] \end{cases} \tag{7}$$

with:

$$A_1 = Y - h$$
$$A_2 = Y \tag{8}$$

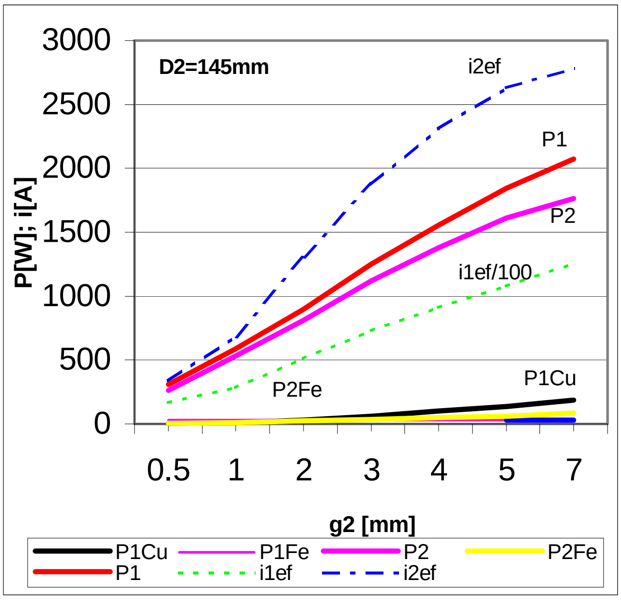
The final components of magnetic field intensity are:

$$\begin{cases} H_{x(X,Y)} = H_x^{(1)} + H_x^{(2)} + H_x^{(1')} + H_x^{(2')} \\ H_{y(X,Y)} = H_y^{(1)} + H_y^{(2)} + H_y^{(1')} + H_y^{(2')} \end{cases} \quad (9)$$

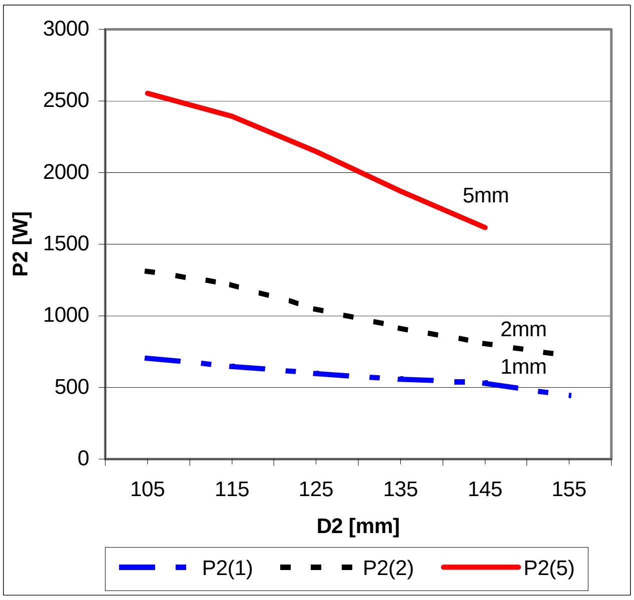
$$|H| = \sqrt{H_x^2 + H_y^2}$$
$$tg\theta = \frac{H_y}{H_x} \quad (10)$$

Converter analysis in case of system geometry variation

Geometry and the position of the inductor and of the secondary have a significant influence on the transfer of the electromagnetic energy.
Because it is essential to obtain for every type of electro-thermal converter a very high electric efficiency, is necessary in the design stage an available model that mirrors as correctly as possible the way in which the change of some parameters influences the converter's performances. As the electric efficiency depends on a large number of interchangeable parameters and with various ratios, identifying the best geometry is significantly simplified if there are used numerical models for design. In order to validate the calculus model of the heating sources in the event of geometry variation, there have been carried out experimental determinations and the adequate simulations for various geometrical configurations of the massive secondary circuit made of steel or aluminium [5]. Hi order to analyse the way in which it may be increased the power P_2 developed in the secondary circuit, under the conditions of maintaining a satisfactory electric efficiency, it has been modified the secondary's thickness g_2, under the conditions of maintaining the inner diameter constant at $D2$ = 145 mm.



a.

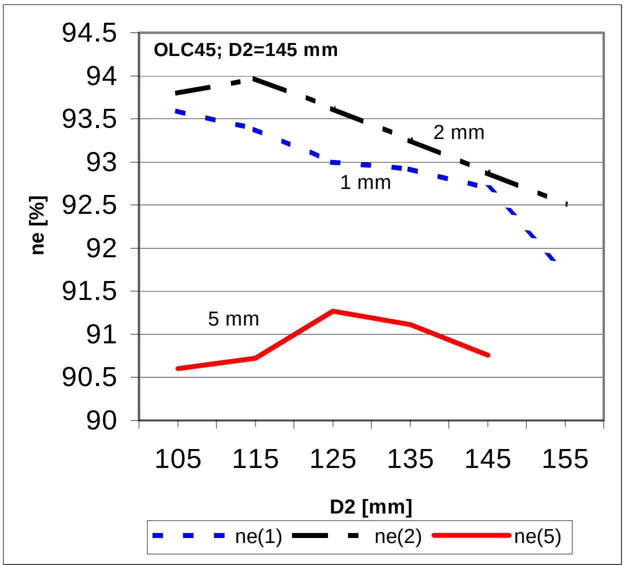


b.

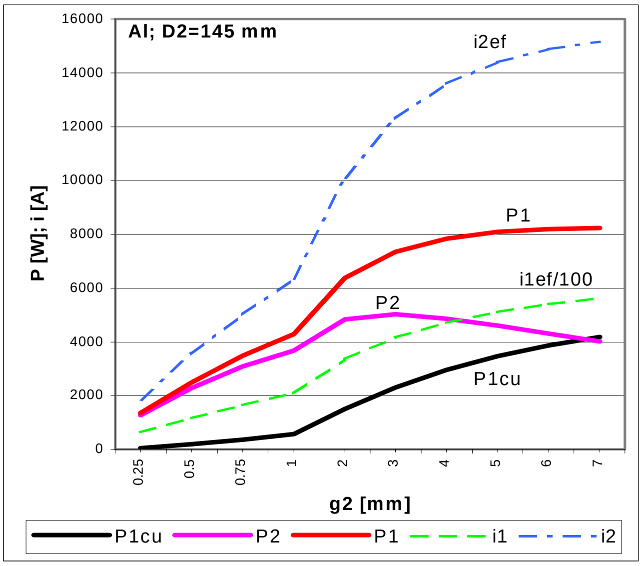
Figure 2. The variation of the main electric parameters (simulation), massive steel secondary, for: a. modification of the second's thickness; b. modification of the primary-secondary magnetic-clutch U_1 = 220V, δ = 0.1 mm, $\theta_{secondary}$ = 25 °C.

The results of the simulations in figure 2.a show that for the established geometry of the electro-thermal converter with secondary made of steel, the best thickness is around the value of 5 mm. After this value is surpassed, there can be noticed a drop in the increase of the secondary power simultaneously with the increase of the losses inside the primary circuit and the drop of efficiency. The increase of the secondary power, for a given thickness of the secondary circuit, may be realized through the increase of the clutch factor between the primary circuit and the secondary one. When exploiting this possibility in practice, we have to take into consideration the fact that the diminution of the inner diameter *D2* of the secondary can not be done without taking into account the necessary thickness and the nature of the thermal insulating layer of the primary circuit. This restrictive condition imposes, according to figure 2.b., the choice of a very large thickness for the secondary, in order to benefit by a very important variation of the secondary power when modifying the inner diameter in a limited way.

The simultaneous modification of the thickness, respectively diameter, of the inner secondary, by using the numerical program for modelisation the electro-thermal converter, points out the possibility of improving the geometry of the system in order to maximize the value of the electric efficiency, figure 3.a.



a.



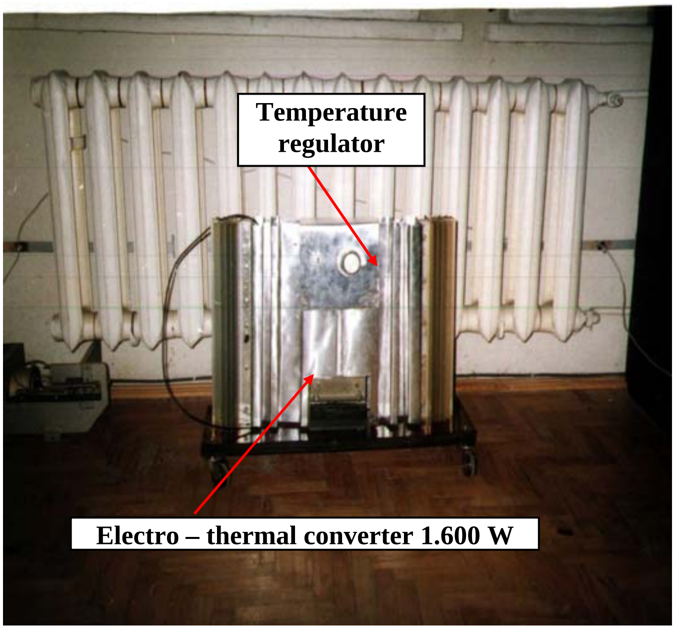
b.

Figure 3. Optimisation graphics for electrical parameters function of system geometry: a. electrical efficiency; b. secondary power, $U_1 = 220V$, $\delta = 0.1$ mm, $\theta_{secondary} = 25$ °C.

Observing the same analysis criteria, in figure 3.b. it is shown the influence of the variation of the geometric dimensions in the case of the electro-thermal converter equipped with massive aluminium secondary. It has been pointed out the existence of the best value for the secondary's thickness for a given inner diameter. Surpassing this value determines the decrease in the transfer of power to the secondary circuit, the decrease in the converter's efficiency and unjustified thermal stress of the primary circuit. Comparatively to the steel secondary, it is established that for the same geometry, under the same conditions, the secondary power P_2 developed by the electro-thermal converter equipped with aluminium secondary is on average approximately 2...7 higher, while the losses in the primary circuit increase 10. .25 times.

Induction electric heating equipment

On the basis of the working principle of the electro-thermal converter, type electric transformer with massive secondary circuit, there have been made and tested three variants of induction heating equipment with maximum powers between 600…1.600 W. In figure 4 it is presented the option of heating equipment with maximum power of 1.600W, devised for heating the dwelling spaces, with the possibility of integration in an automatic thermal system.



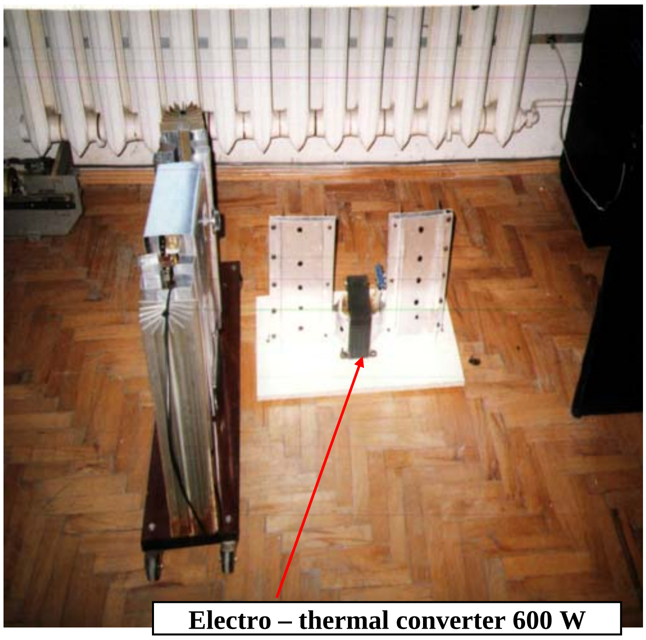


Figure 4. Variants for electro – thermal converters.

Compared to the electric heaters with resistance immersed in oil, or those with open flame, the induction heating equipment has a few advantages that may impose it in making the heating installations:

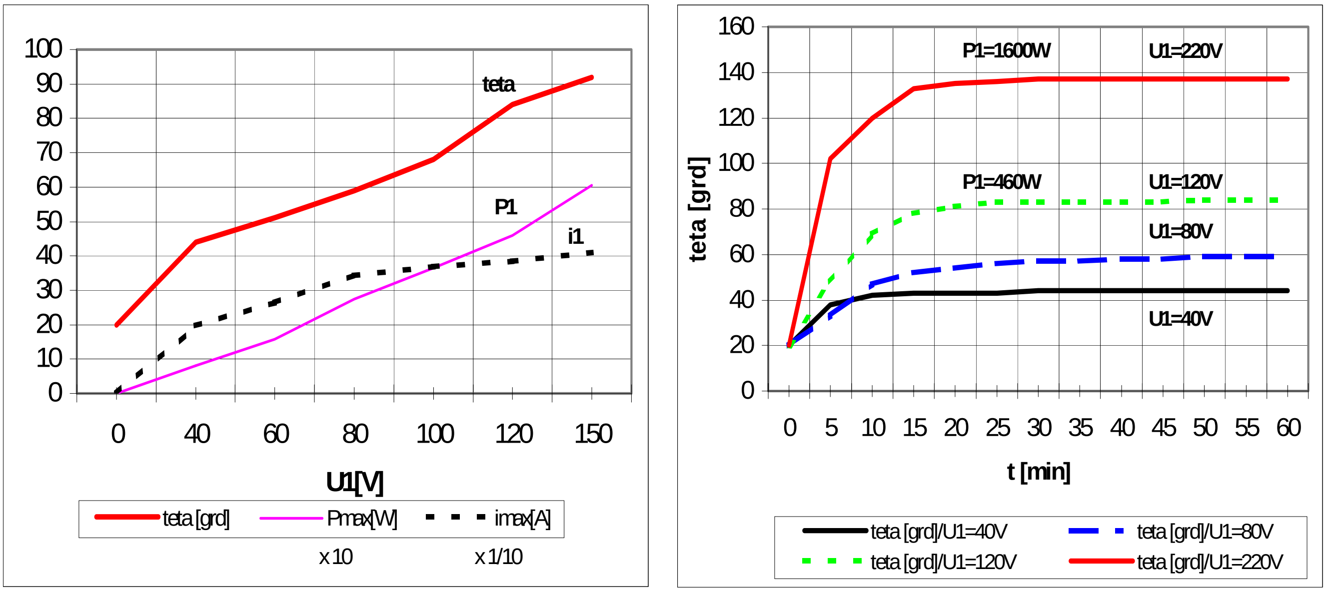
- it is not dangerous when overheated, because: the limitation of the control angle of the variable voltage regulator and the sizing of the radiating surface so that the maximum working temperature does not exceed 85-90 °C, at a surrounding temperature of 20 °C;
- it does not present any explosion and fire hazard if the variable voltage regulator breaks (heater with electric resistance immersed in oil) or any gas leak hazard (heater with open flame);
- it does not modify the oxygen content in the room where it is mounted (the heater with open flame);
- the developed power/size-weight ratio is very good;
- the total exploitation duration is compared to that of the steel heating equipment used in the district heating networks, but at a reduced price for the same radiated power;
- it does not present any electric shock danger through direct touch of the secondary radiant surface;
- the maintenance costs are insignificant, as there are necessary only periodic general overhauls.

Experimental results

The experimental determinations were carried out for three types of induction heating equipment:

- with electrical power P_1 = 600 W, U_{1max} = 110 V, radiant surface S_r = 0,2 m^2, θmax = 200 °C, without temperature regulator;
- with electrical power 1.600 W, U_{1max} = 220 V, radiant surface S_r = 1,2 m^2, θ_{max} = 140 °C, with temperature regulator and control of top temperature;
- with maximum electrical power limited in automatic mode at 460 W, and in manual mode at 600 W, $U_{1max/automat}$ = 120 V, $U_{1max/manual}$ = 150 V, radiant surface S_r = 1.2 m^2, $\theta_{max/automat}$ = 84 °C, $\theta_{max/\mathrm{manual}}$ = 92 °C, with temperature regulator design for working in automatic microsystems.

For the last case the maximum power of the 1.600W heating equipment was electronically limited to approximately 600 W, so that the temperature of the radiating surface does not surpass the safety temperature of 90°C, over which there is the danger of causing fires in the event of direct contact with other objects. The power of this heating equipment may be increased to the maximum value, but keeping the temperature of the radiating surface at the level of the safety temperature, by adequately increasing the secondary's radiant surface. Due to the constructive limits, this solution could not be put into practice. In figure 5 there are shown some of the main characteristics of the tested induction heating equipment.



a. b.

Figure 5 a. The variation of the main electrical and thermal parameter for induction electro-thermal converters: a. P_{1max} = 600 W; b. Thermal characteristics for variant with P_{1max} = 1.600 W.

Conclusions

The method of images give solutions to magnetic field problems in a particularly simple manner, not cause large errors for practical core configurations and in rapport to finite element or difference method is not time consuming.

The variants of electro-thermal converters have allowed a successive improvement in the construction and thermal efficiency so that the final solutions presented represent competitive alternatives in relation to the solutions used at the present moment. Through the solutions adopted, it has been accomplished the creation of a special system fitted for some applications in which the inherent losses caused by operation are regulated in a large extent in useful thermal fluxes, which may be used in heating processes.

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