

MODERN TECHNOLOGIES OF INCREASING THE ELECTROMAGNETIC CONVERSION EFFICENCY AT INDUCTIVE HEATING SYSTEMS

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ABSTRACT: This is a short presentation of some personal researches regarding to some modern technologies of constructing the inductors used in the inductive heating systems, intended to increase the efficiency of their conversion. Here are presented construction technologies of the inductors and also technologies witch use revolutionary materials in their construction.

KEYWORDS: electromagnetic field, multilayer inductor, inductive heating, magnetodielectric material

INTRODUCTION:

Processing trough electromagnetic induction is the result of electric current produced trough electromagnetic induction into a conductive material situated in a magnetic field variable in time. Heating the conductor is produced by the Joule-Lenz effect of the eddy inductive current.

The source of the electromagnetic field is the heating inductor trough witch the alternative electric current. Introducing in the inductor a conductor trough witch eddy currents will run, they will determine the direct heating or melting of the object trough the Joule effect. In the inductor – object system the eddy currents are forced to the exterior of the conductors – the skin effect, that can handle the influence of the currents from the nearby conductors – proximity effect.

If the material exposed to heating is magnetic, to the thermal effect of the current the effect of histeresis is added. The power produced trough histeresis is proportional with the fields frequency and the area of the magnetizing cycle. The proportion of the inducted currents power and histeresis is expressed trough this relation:

$$\frac{P_i}{P_h} = a \cdot f \cdot H^{0,4} \quad (1)$$

Were H is the density of the magnetic field and “a” is a constant of the material.

In general the power produced by histerias is under 10% from the general effect of induced current, exceptions are tough steel,

with powerful hysteresis, were the energy produced by histeresis can reach 50% from the one corresponding to the inducted currents.

The inductive heating method is based on the following laws and phenomenons:

1. the electromagnetic induction law;
2. the skin effect;
3. proximity effect;
4. modifying the properties of steel trough heating process;

The skin effect is the inductive is the base of heating phenomena, and it is consist by the nonuniform repartition of the current density across the conductor section, the current density is maximum in the exterior part of the conductor section, and minimum in the center part of the conductor.

The parameters of the electromagnetic field verified the Maxwell equations:

$$\text{rotH} = J + \frac{\partial D}{\partial t} \quad (2)$$

$$\text{rotE} = - \frac{\partial B}{\partial t} \quad (3)$$

where :

$B = \mu_0 \cdot \mu \cdot H$ - is the magnetic induction

$D = \varepsilon_0 \cdot \varepsilon \cdot E$ - is the electric induction

$\mu_0 = 4\pi \cdot 10^{-7}$ -vacuum magnetic permeability

$\varepsilon_0 = \frac{1}{4\pi \cdot 9 \cdot 10^{-9}}$ F/m – vacuum permittivity

ε - relative permittivity of the medium
 J – current density

The equation (2) and (3) is the differential forms of the magnetic circuit's law and electromagnetic induction law.

In the industrial applications, to increase the electromagnetic conversion efficiency in the inductor – work piece system, it is possible, some technological principles to be done. This technological principles relate the construction of the inductor and it is possible to relate the materials used.

Focused on these problems, in the next part of the paper, the authors will present some technological procedure that was explored.

For each technological method it was made a numerical modeling and simulation, using FLUX2D professional software.

MULTILAYERS INDUCTOR

To increase the electromagnetic field intensity to the processing piece level, in the interior of the inductor, one of the technological procedures who were study is the utilization of multilayer inductor.

The increasing of the number of the layers, to the first view it is possible to be a happy solution. More layers give an increase of the electromagnetic density field, witch will produce a more powerful heating of the work piece. In reality from the third layer, because of the big air grip, cumulated with the proximity effect of the coils, the influence of the electromagnetic field is insignificant, so that is why the number of layers has been reduced to two layers.

For the numerical modeling and simulation of the heating process, there has been created a study geometry presented in fig.1. The supply parameters for the inductor are: voltage-80V, work frequency 2500Hz.

To highlight the influence of stacked coils there has been made a study regarding the repartition of the current density in the section of the inductor coil – picture 2 – the sector marked in pictured 1.

From the repartition of the current density on the studied sector, you can see that the current density presents a considerable maximum on the interior part of the first layer, and a lower value on the

exterior face of the second layer. This results that the density of the current is a non optimal distribution.

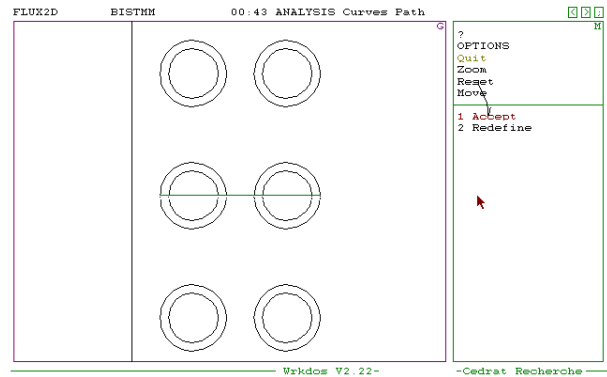


Fig.1. The geometry for the double layer inductor

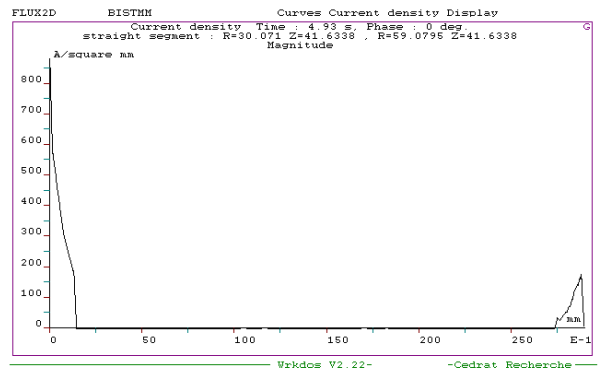


Fig.2. Repartition of the current density on the section of the inductor

From the repartition of the current density on the studied sector, you can see that the current density presents a considerable maximum on the interior part of the first layer, and a lower value on the exterior face of the second layer. This results that the density of the current is a non optimal distribution.

To improve this repartition there has been created a study geometry in witch the inductor coils are unequally set between them, obtaining the study figure presented bellow:

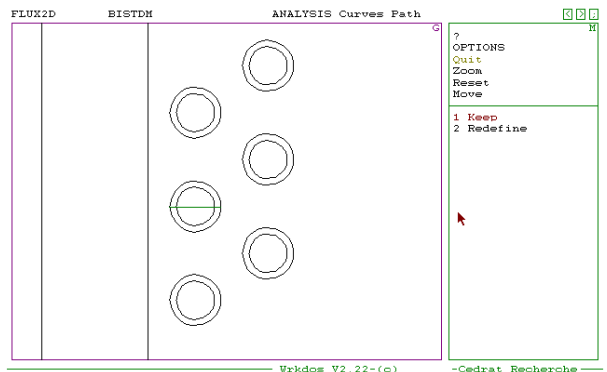


Fig.3. The geometry of the double layer inductor, with unequally set coils

The repartition of the current density on the inner and outer coil, obtained through the simulation of the heating process is presented below:

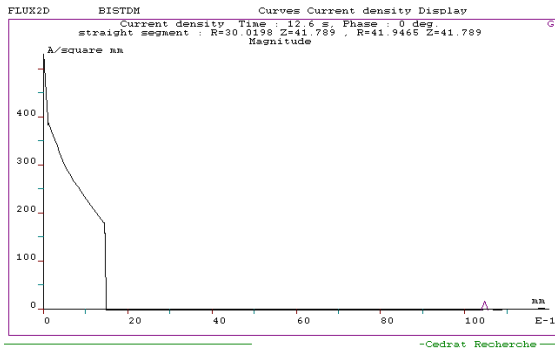


Fig.4. The repartition of the current density on the inner coil of the inductor

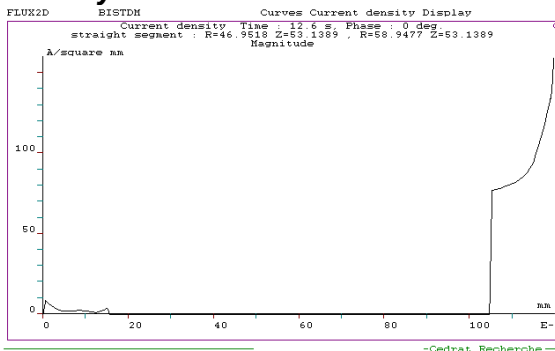


Fig.5. The repartition of the current density on the outer coil of the inductor

From the diagram analysis of the pictures you can see a decrease in the current density value, from 850 A/mm² to 525 A/mm² for the unequal setting of the coils, resulting a higher possibility in the charging of the inductor.

Based on the results obtained through the numerical modelling and simulation, there has been created an inductor which after measurements and tests proved the theoretical results. The experimental inductor is presented in the image below when the tests were carried out at the University of Oradea.



Fig.6. The double layer inductor in the heating process

USAGE OF THE MAGNETODIELECTRIC MATERIALS

Another technological possibility which helps to raise the conversion efficiency, analysed in this study are the usage of the magnetoelectric materials.

These are composite materials, resulted from magnetic and dielectric material particles. They help as links and electric isolators of the magnetic particles.

The magnetic properties of the magnetodielectric materials depend on the properties of the constitutive particles, on their shape and volume.

The mechanical and thermal characteristics depend mostly on the ratio between the base material, a magnetic one and the bonding material, a dielectric one. In general the properties of the magnetodielectric materials depend on the way they were built.

Here are presented the results obtained at the achievement of a magnetodielectric material concentrator, carried out in a study at the University of Oradea.

To achieve the magnetodielectric material, dielectric material from electro paste was used, obtained from two epoxipoliamidic resins, without solvents, with room temperature drying and in the oven (80°C). The mixing ratio of the components A/B is 2/1. The product is used in electrotechnic and energetic, as epoxidic resin which consolidates and fills some details of the motors and generators.

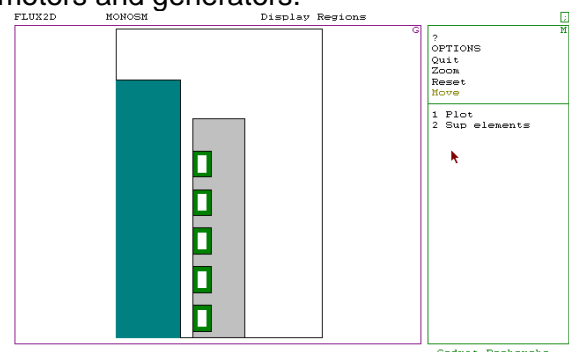


Fig.7. The geometry of the unilayer inductor with a field concentrator

The material characteristics were determined at the University of Oradea. In this study a unilayer inductor was modelled through a heating process in case in which a field concentrator made of magnetodielectric material with the help of FLUX2D software.

The geometry of the study domain is presented in fig.7.

The temperature variation on a certain point was analysed throughout the heating process– Picture 8.

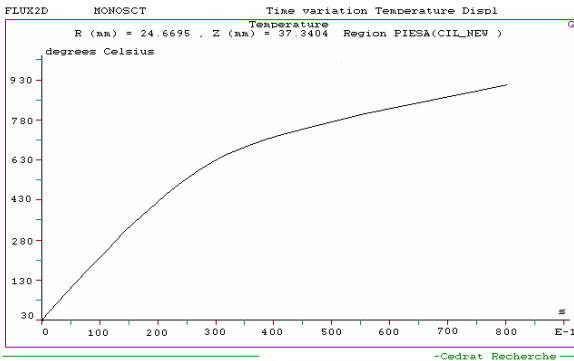


Fig.8. The temperature variation in the heating process of the unilayer inductor with a field concentrator case.

Base on the modelling and simulation results an identical inductor was made with the referral one, but a layer of magnetodielectric material was added. The inductor in the heating process is presented in the following image.



Fig.9. The inductor with the field concentrator in the heating process

The voltage absorbed from the input network of the inductive heating installation was 60A, and the line voltage was 378V. The initial temperature of the bench mark and of the magnetodielectric material was 12°C. The final temperature of the bench mark was 840°C, the temperature reached this peak in 80s. In the end the temperature of the external layer was 14°C.

The main objective of the study was the highlighting of the electromagnetic conversion efficiency of the inductor – part assembly, in

the case in witch a magnetodielectric material field concentrator was used.

For this a study was carried out comparing the diagrams of the temperature variations in time, in the case of numerical simulation and in case of experimental values. In picture 10 we can see the comparative diagram witch was obtained.

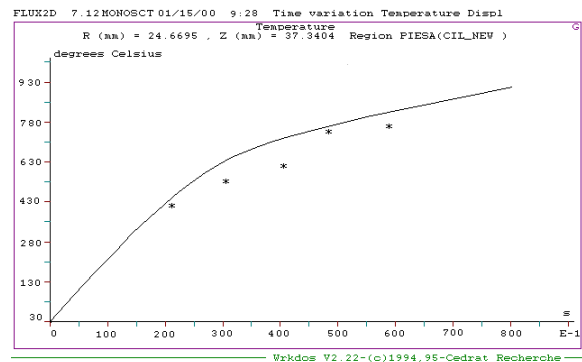
From the 10-th picture diagram we can see that the temperature differences do not overtake value of 10%, witch means that the modelling witch was carried out is pretty closet of reality.

The efficiency values for this case, determined from the data resulted after the modelling are:

$$\eta_{i \text{ reg. cold}} = 96\%$$

$$\eta_{i \text{ reg. hot}} = 69\%$$

Comparing this results with the one obtained for the reference inductor, without a concentrator where we have the efficiency values $\eta_{i \text{ reg. cold}} = 81\%$, $\eta_{i \text{ reg. hot}} = 54\%$, we can se a significant increase of 15% in case of the cold and hot regime of the electroenergetic conversion efficiency.



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Fig.10. The variation of temperature in time in case of modelling [---] and experimental [* * *] for the unilayer inductor with a field MDM concentrator.

These values highlight clearly the advantage of the electromagnetic process system usage to heat what the field concentrators made out of magnetodielectric materials have in composition.

In this paper, the influence of the magnetodielectric concentrators, in the bilayer inductor case, was analysed.

In the first time, de geometry of the bilayer inductor, with magnetodielectric field

concentrator, was built, and for this case, the layers are upper one by one positioned.

The power density induced in the work piece, for this case, was analysed by numerical modelling and simulation. The results of the numerical modelling and simulation, in the next picture is shown.

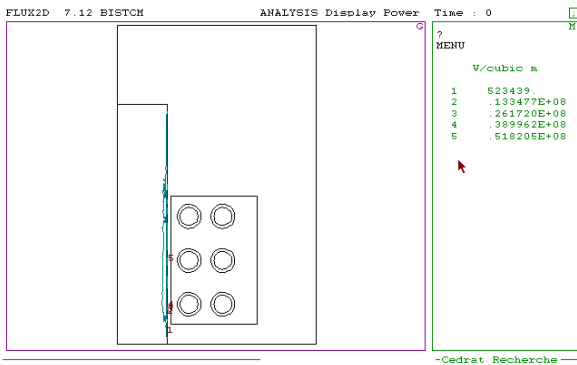


Fig.10. The The power density induced in the work piece, in the first case of the study

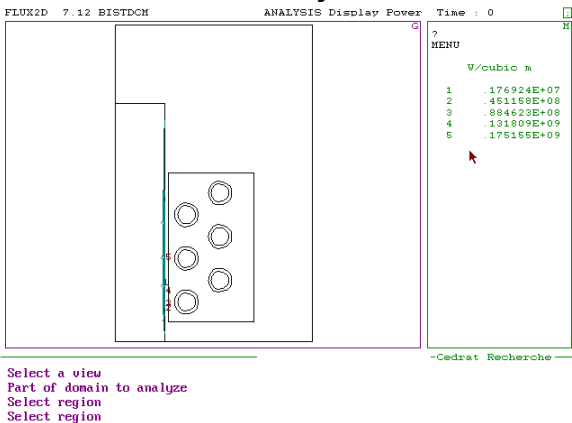


Fig.11. The The power density induced in the work piece, in the case of the delayed position of the coils

The next step of this part of the study was focused on the case of delayed position of the coils.

Same in the anterior case, it was simulation the function of the inductive heating, in same supply parameters and it was analysed the power density induced in the work piece. The results of the numerical simulation, in the next picture it is shown.

If made a comparative study, for these two cases, about the maxim value of power density induced in the work piece, it is possible to see, that for the first case this maxim value is $0,518205 \cdot 10^8 \text{W/m}^3$, and for the second case the value of the power density indeced in work piece is $0,175155 \cdot 10^9 \text{W/m}^3$.

From this two value, it is possible to conclude, that the second location of the coils is more efficient.

CONCLUSION

From the study witch was carried out we can clearly see that the usage of innovative technologies in the construction of the inductors for inductive processing of materials either constructive technologies either in the usage of revolutionary materials leads to high performance in the process of inductive heating. This is why these studies are worth to be continued, in order to obtain higher results.

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