Induction Heating Spiral Inductor– Comparison between Practical Construction and Numerical Modeling

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Abstract *- The induction heating phenomenon is well known and has been used for a long period in practice. It's numerically modelling lets us better understand the parameter influence on the effects of this phenomenon. This paper represents a comparison between the results obtained for an induction heating spiral inductor and its numerical modeling for different parameter values of the spiral inductors considered. Numerical modeling of the induction heating spiral inductors could also decrease the manufacturing costs for induction heating devices due to the fact that the influence of different parameters can be determined and an optimum can be achieved before the actual construction.*

Keywords – *practical construction, comparison, numerical modeling, multilayer spiral inductor, spiral inductor parameter variation*

1. INTRODUCTION

The electromagnetic induction phenomenon underlies the operation of most electric generators and also the induction heating process.

Compared to other methods, heating through electromagnetic induction is distinguished by the fact that the conversion of electric energy in heat takes place in the heated environment and its speed and heating temperature can be rigorously enough controlled and varied.

Also, the induction heating has its advantages like the fact that it doesn't pollute the environment when used in industry, it eliminates the inconsistences and quality problems associated with the flame heating process or other types of heating methods and the energy consumption is decreased.

The induction heating process has many applications like melting, keeping in heated state or overheating metals, superficial thermic treatment of the steel or cast iron parts used in machine building, in depth heating of the metals in order for them to be hot processed and others. [3]

In this paper, considering an induction heating device constructed for this study, the influence of different parameters on its efficiency and heating speed will be determined with the help of its numerical modeling and practical testing [1][2].

Also, the practical and numerical modeling results will be compared throughout the entire study.

2. ELEMENTS USED FOR THE STUDY

A device was constructed in order to study the induction heating process. Its electrical scheme can be observed in figure 1.

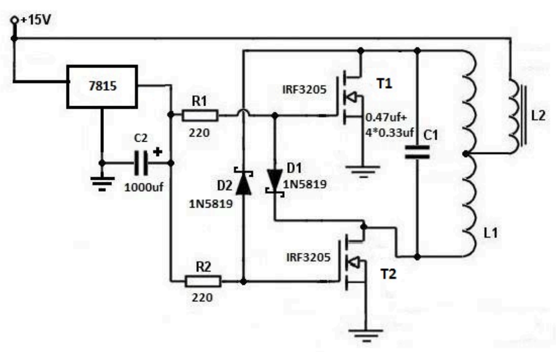


Fig. 1 Induction heating device's electrical scheme

The first step in the construction of the practical device was finding the materials and components needed. For the construction of the device presented in figure 2 some capacitors, a positive voltage stabilizer, a diode, transistors, resistances, a filtering coil and a source were needed. In order to reduce the components temperature when the device is operating a cooler was placed above the device. Also, some spiral inductors for the heating process were constructed from copper wire with different interior diameters as it can be observed in figure 3. These spiral inductors are interchangeable.

After the materials and components were obtained, the wiring design was drawn, the board was dimensioned and the wiring was printed on the board which was after that corroded with ferric chloride.

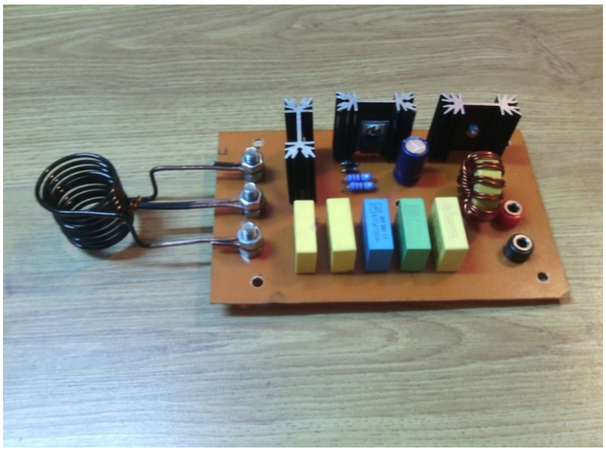


Fig. 2 Induction heating device


Fig. 3 Spiral inductors constructed for the induction heating device

The analysis of the influence of the spiral inductor's interior diameter, its conductor diameter and the influence of an object inserted in the spiral inductors will be presented as follows [6].

The heating inductor spirals were also modeled with the help of a numerical modeling program, namely Ansoft Maxwell 3D [5]. Their magnetic field strength and magnetic inductance were determined in order to compare their values with the heating time of an object inserted in the spiral inductors.

Also, modeling the induction heating spiral inductors, made the variation of different parameters maintaining the other ones constant easy, while in practice some of the parameters suffered slightly changes due to the fact that at this scale their realization is hard (the distance between the turns for instance is very hard to maintain constant if it's not made in mass production with special equipment).

Also, the influence of the current passing through the spiral inductors will be determined.

The object inserted in the induction heating spiral inductors will have the shape as presented in figure 5. The study was conducted for an iron object and also for a ferrite one. For the numerically modeled coil in figure 5 b) a line passing through the center of the coil can be observed. On this line the values of the magnetic field strength and magnetic inductance are represented for a better understanding of the values.

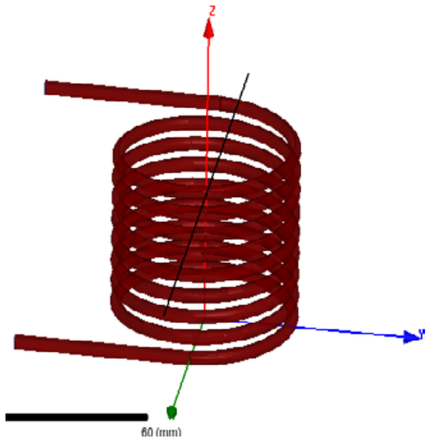
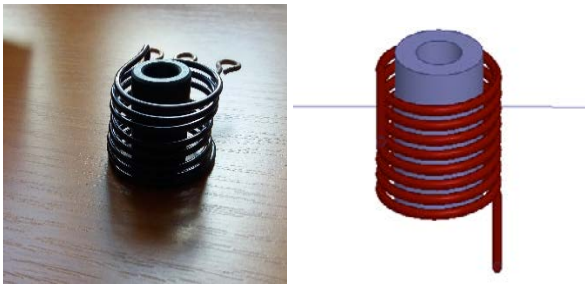


Fig. 4 Induction heating spiral inductor


a) b)
Fig. 5 Shape of the object inserted in the induction heating spiral inductor

3. CASE STUDY

3.1. Influence of the thickness of the conductor from which the spiral inductors are constructed

The conductor thickness for the scale of the spiral inductors can't be varied a lot, thus for the study there are two thicknesses considered, namely 2 mm and 2,5 mm. The spiral inductors considered have 8 turns each and their interior diameter is considered to be 28 mm.

In figure 6 the magnetic field strength for the considered coils is presented in vectorial form. The differences are not significant for the two considered cases for this type of representation.

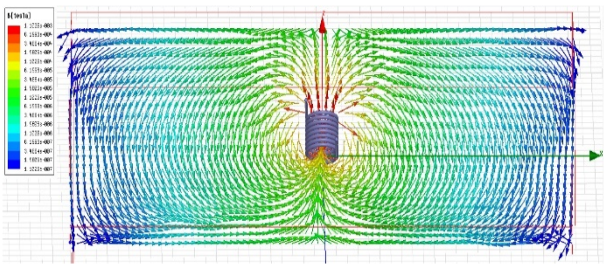
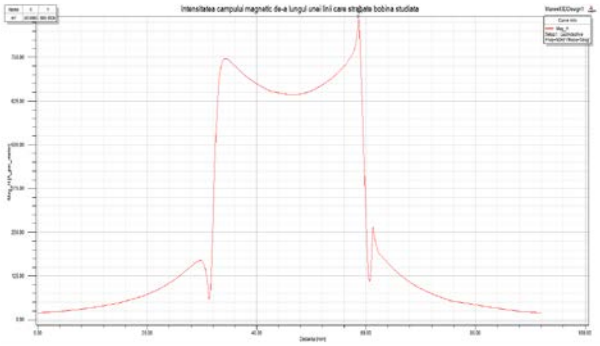
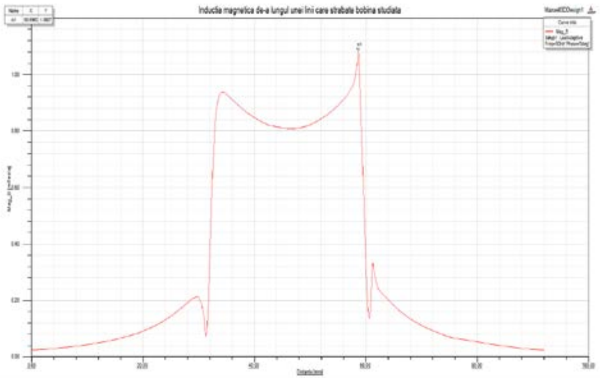


Fig. 6 Representation of the magnetic field strength for the coils considered in vectorial form

After analyzing the analytical and numerical results it can be observed that the magnetic field strength increases with the decrease of the copper conductor's thickness from which the spiral inductor is made.



a) For the 2 mm wire thickness



b) For the 2.5 mm wire thickness

Fig. 6 Representation of the magnetic field strength for the spiral inductors considered

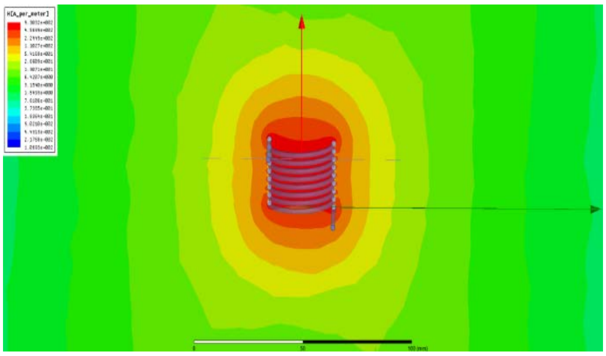
3.2. Influence of the interior radius of the spiral inductors considered for the induction heating process

For this study three spiral inductors were considered. Their interior radius was considered to be 12.5 mm, 14 mm and 15 mm. The thickness of the conductor from which the spiral inductors are made is considered to be 2 mm and the number of turns is 8. All three spiral inductors were assigned a current of 3 A.

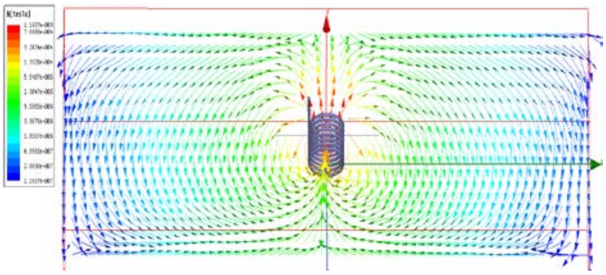
The magnetic field strength and their magnetic inductance were determined for all three spiral inductors in order to determine the influence of the interior diameter on their values.

The color code representation of the magnetic field strength and the vectorial representation of the magnetic field induction for the first spiral inductor considered are presented in figure 7. For the other two inductors considered in the study the representations have the same allure, only the values differ, fact that is more easy to notice in the representations on the line passing through the coils.

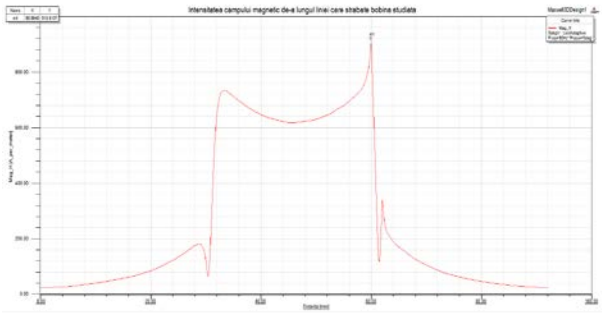
Analyzing the obtained graphs for the three spiral inductors, it can be observed that once the interior diameter is increased the magnetic field strength and magnetic inductances decrease inside the coil. Also, it can be said that the field is concentrated inside the spiral inductor, fact which leads to the temperature increase of the objects inserted in the coil.



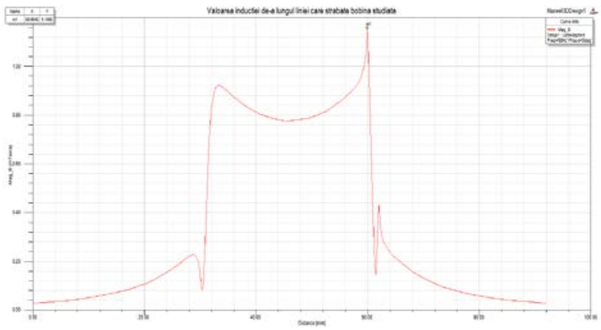
a) Color code representation of the magnetic field strength



b) Vectorial representation of the magnetic field induction



c) Magnetic field strength through the line



d) Magnetic field induction through the line

Fig. 7 Representation of the magnetic field strength and magnetic induction for the first spiral inductor

All the representations have the same allure, but the maximum value is different.

The results obtained through numerical modeling were also verified with the practical device. In this case, it was observed that for the spiral inductor with a 14 mm radius, after inserting an object as presented in figure 8, it will heat after approximately 21 seconds, while for the 15 mm radius spiral inductor, the time increases to 26 seconds, almost double than the time necessary for the object to be heated when inserted in the spiral inductor with the smallest diameter, namely 12.5 mm, which took 14 seconds.

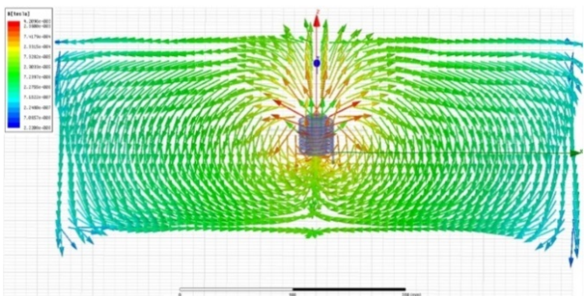
Fig. 8 Case study- time necessary for an object to be heated with the help of the device constructed for the spiral inductor with 14 mm radius

3.3. Influence of the interior radius of the spiral inductors considered while an object is inserted in the coils

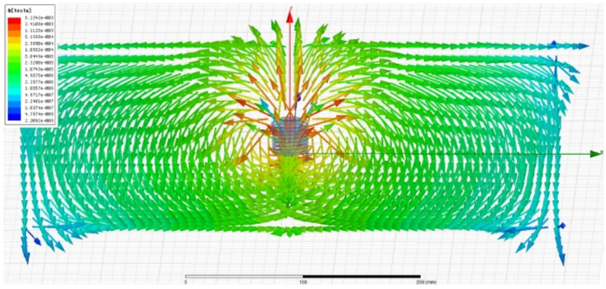
It is known that if we insert an object from a conductive material inside a spiral inductor, it will heat. The characteristics of materials influence the heating process [4].

Because it is known that it is easier to heat magnetic materials, due to the fact that in addition to eddy currents there is also the hysteresis effect which inducts heating, for this study a ferrite object is considered. In order to have a comparison, another object, from iron, with the same geometrical dimensions as the one mentioned above is introduced in the same coil and the results are represented. The studied ensemble, practical and numerically modeled, is the one presented in figure 5.

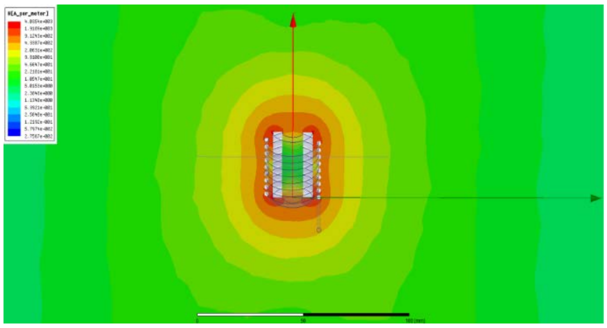
The color code and vectorial distribution of the magnetic field strength and magnetic field induction have the same allure for the three different radius spiral inductors, thus in this paper only one representative graph will be presented in figure 9. The differences between the two considered cases, namely inserting a ferrite and an iron object in the considered spiral inductors are not that noticeable, so the representation on the line passing through the middle of the considered coils must be also presented in order to better understand their effects (figure 10).



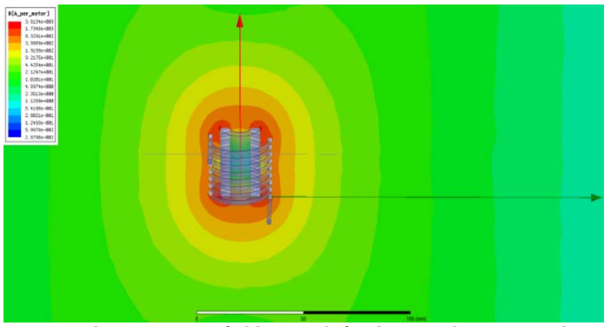
a) Magnetic field induction for the ferrite object inserted



b) Magnetic field induction for the iron object inserted

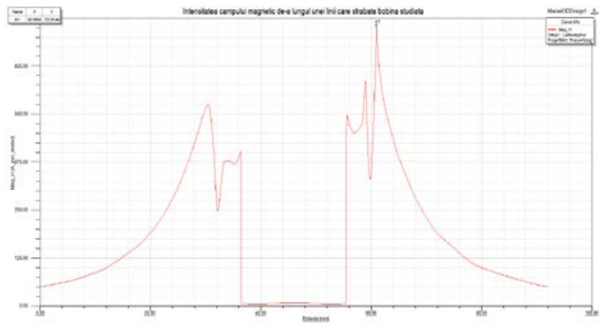


c) Magnetic field strength for the ferrite object inserted

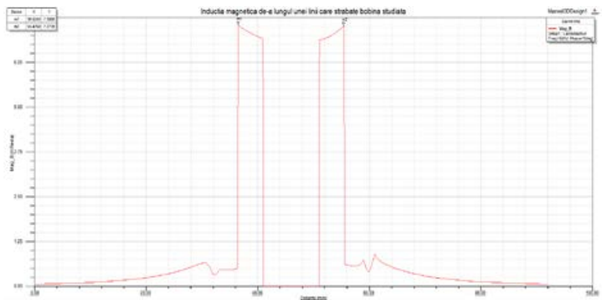


d) Magnetic field strength for the iron object inserted

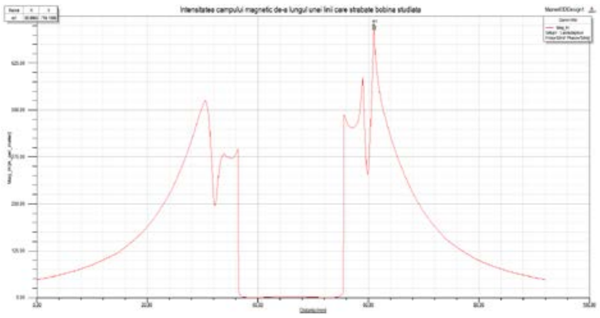
Fig. 9 Representation of the magnetic field strength and magnetic field induction for the studied spiral inductors



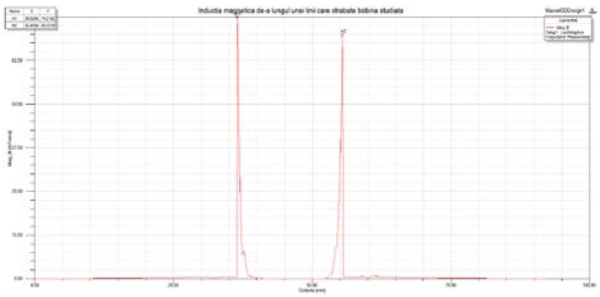
a) Magnetic field induction for the ferrite object inserted



b) Magnetic field strength for the ferrite object inserted



c) Magnetic field induction for the iron object inserted



d) Magnetic field strength for the iron object inserted

Fig. 10 Representation of the magnetic field strength and magnetic field induction for the spiral inductor with a radius of 12.5 mm

It can be observed that the magnetic field is concentrated in the space between the coil and the object to be heated. Also, it can be stated that in the case of the iron object the magnetic field strength and the magnetic induction are more concentrated next to the object to be heated (figure 10 c), d)), while for the ferrite object the values are evenly distributed between coil and object (figure 10 a), b)).

This study was conducted for the three spiral inductors presented in previous studies, namely with the interior radius of 12.5 mm, 14 mm and 15 mm. The conclusions about the increase of the magnetic field strength and magnetic inductances with the decrease of the coil radius remains.

3.4. Influence of the current value from the spiral inductor’s wire

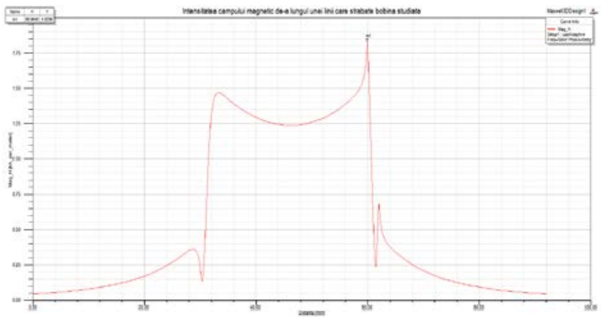
For this case the three spiral inductors with different interior radius (12.5 mm, 14 mm and 15 mm) were considered.

At first this coils were fed with a current of 3 A, while in this study the current value was doubled to 6 A (figure 11).

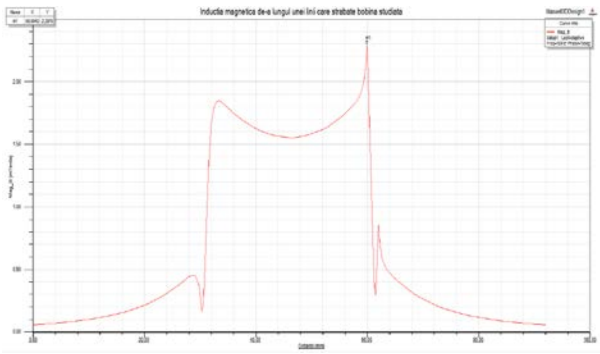
The conclusion about the magnetic field strength and magnetic field induction variation with the interior diameter of the coils remains the same for the 6A current value.

The conclusion for this study is that the magnetic field strength and the magnetic inductance values exponentially increase with the increase of the current value. This can be observed comparing the results obtained for the spiral inductor with an interior radius of 12.5 mm supplied with a 3 A current with the ones obtained for the same spiral inductor alimented with the 6 A current presented in figure 7.

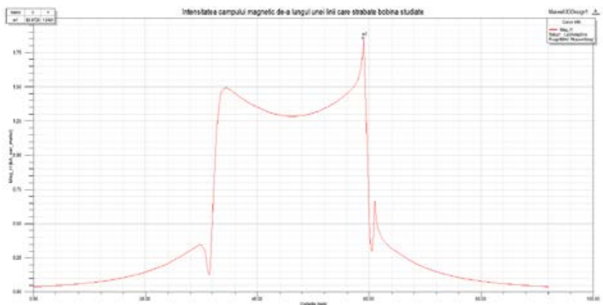
Also, considering the two currents, in the case of the practical device constructed for this study, the time in which it heated the conductor objects inserted inside the interchangeable coils doubled.



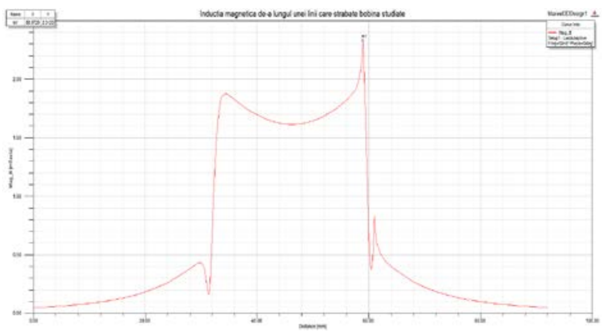
a) Magnetic field strength for the 12.5 mm radius spiral inductor for a 3A current



b) Magnetic field strength for the 15 mm radius spiral inductor for a 3A current



c) Magnetic field induction for the 12.5 mm radius spiral inductor for a 6 A current



d) Magnetic field induction for the 15 mm radius spiral inductor for a 6A current

Fig. 11 Representation of the magnetic field strength and magnetic field induction for the studied coils

4. CONCLUSIONS

This article represents a study of the spiral inductors and their influence in the induction heating process. For this study spiral inductors were constructed and also numerically modeled in order to compare and reach a conclusion about the influence of their parameters on the heating of different materials.

It was determined that the magnetic field is concentrated inside a powered spiral inductor. Considering two spiral inductors with the same interior radius but different wire radius, it was concluded that the magnetic field strength increases with the decrease of the copper conductor from which the spiral inductor is made thickness.

If the interior diameter of the spiral inductor is increased, the time necessary to heat a conductor object, thus the values of the magnetic field strength and magnetic induction, is decreased.

Doubling the current value passing through the spiral inductor will lead to the doubling of the magnetic field strength and magnetic induction values inside the coils.

After inserting an object inside the studied spiral inductors, it can be observed that the highest values of the magnetic field strength are on the exterior surface of the object inside the spiral inductor, fact which leads to its heating. Also it is clear that the maximum values of the magnetic field strength and magnetic field induction are between the spiral inductor and the object situated inside it.

The conclusions were reached comparing the numerical modeling results and the results obtained with the practical device constructed for this study.

5. ACKNOWLEDGEMENT

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