

# Optimal Design Approach of Inductors for Mass Heating Processes

SCURTU Gheorghe Lucian

University of Oradea, Romania, Department of Electrical Engineering  
Faculty of Electrical Engineering and Information Technology 410087, Oradea, Romania

## ABSTRACT

*The paper presents an optimal design approach of inductors for mass heating processes, pointing out the aspects that need to be taken in account when we consider designing an inductor. One of the main parameters in designing inductors for mass heating processes is coil turn space factor  $K_{space}$ . The coil turn space factor  $K_{space}$  is an important parameter of the coil design and should be as high as possible. The coil space factor represents how tightly the coil turns are wound. The space between turns should be as small as possible, but large enough to leave room for electrical insulation. The focus of the paper is to show through some simulations, done in ANSYS package, the influence of coil turn space factor in designing inductors for mass heating processes.*

**Keywords:-** induction mass heating, numerical modeling, electromagnetic and thermal field.

## 1. INTRODUCTION

When designing an inductor for mass heating processes we have to be very elaborate in developing a suitable inductor for the given application. One important aspect for an optimal design approach of inductors in mass heating processes is establishing the electrical parameters. Selection of main induction heating parameters as: power, frequency, coil length is quite subjective, depending upon the type of heated metal, the temperature uniformity requirement, heating time and other parameters. Frequency is one of the most critical parameters in these applications. If the frequency is too low, an eddy current cancellation within the heated body will take place, resulting in poor coil efficiency. Nevertheless, when the frequency is too high, the skin effect will be highly pronounced, resulting in a current concentration in a very thin surface layer compared to the diameter/thickness of the heated workpiece. In this case, a lengthy heating time will be required to provide sufficient heating of the internal areas and the core. Bigger heat time results in an increase of the radiation and convection heat losses that, in turn, reduce the thermal efficiency of the inductor and decrease the main advantage of induction heating. Heating time is a complex function of different factors, including the size of the workpiece, frequency, heating mode, power density, maximum permissible temperature, material properties and the required surface-to-core temperature uniformity [1]. Another important step in designing the optimal inductor is the determination of the length of the coil line. Coil design is, of course, an extremely important factor in designing an efficient induction heating system. Helical type multiturn coils are most often used in induction heating applications. There are lots of different types of induction heating coils. The ability of any coil is to establish a magnetic field depends upon the ampere-turns of the coil, geometry and its electrical circuit. The electrical efficiency and coil coupling have a marked effect on the coil's ability to deliver heating power to the workpiece. Smaller gaps between the surface of the heated workpiece and the coil result in better electromagnetic coupling and consequently, higher coil efficiency. Nevertheless, it is wise to remember that the total efficiency of the induction coil is a product of electrical efficiency and coil thermal efficiency. Almost all induction coils used for heating prior to hot forming of metals consist of thermal isolation (also called refractory or liners) between the coil and the heated workpiece protecting the coil windings from heat exposure and providing a thermal barrier. Hence, the probability of thermal shock is reduced and heat loss is minimized in water recirculating through the induction coil [2], [3]. The thermal refractory can drastically decrease the heat losses from the surface of the heated workpiece. At the same time, the use of a refractory necessitates larger coil-to-workpiece gaps, which in turn deteriorates the electromagnetic coupling between the induction coil and the heated workpiece, leading to a reduction of coil efficiency. Thus, the refractory allows one to improve coil thermal efficiency, but it also reduces coil electrical efficiency. In the great majority of mass heating applications and, in particular, in heating prior to hot working, it is advantageous to use refractory [4], [5]. Another aspect usually needed to take in account for induction mass heating processes is workpiece sitting rails. Internal water-cooled skid rails that protect linear surfaces must be robust enough to carry the full load of heated billets with minimal deflection. From another perspective, they should be transparent enough to the electromagnetic field that they will not be significantly heated. Water cooled rails occupy space inside the coil and consume additional coolant, thus increasing the kilowatt losses. To extend the life of water cooled rails, they are wear coated [6].

## 2.COMPUTATION

From the above listed steps in designing an optimal inductor for mass heating processes, the focus will be at the coil design aspect, and particularly analyzing the influence of coil turn space factor  $K_{space}$ . Coil windings are designed to accommodate the tube size, coil geometry, number of turns and overall length with the workpiece size, shape, production rate and load matching with the power supply.

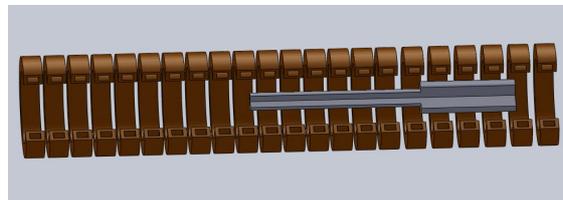
The coil turn space factor  $K_{space}$ , is an important parameter of the coil design and should be as high as possible. The coil space factor represents how tightly the coil turns are wound. The space between turns should be as small as possible, but large enough to leave room for electrical insulation [7].

The application under discussion and for which there will be conducted an analysis about the influence of coil turn space factor is presented in Figure 1.

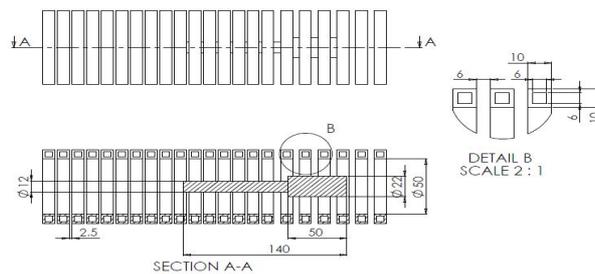


**Figure 1** Initial inductor and wokpiece for our investigation

The application is a static mass heating for forging with automatic or hand presses, resulting in a clipper handle. The owner for the application is the company Ages S.R.L. from Sîngeorgiu de Mureş, which is specialized in building up inductive installations for applications as mass heating for forging, mass heating for flattening, molding, stretching and injection molding, melting, hardening, brazing, tube bending, heating for cutting and other special applications. Ages S.R.L. is also offering subassemblies as converters, inductors, heat exchangers, pyrometers, furnaces and capacitor banks. Together with Ages S.R.L. we agree to reduce the workpiece and the inductor to a cylindrical shape for a faster feedback of numerical modeling. As a result the inductor and the workpiece are presented in Figure 2 and Figure 3.

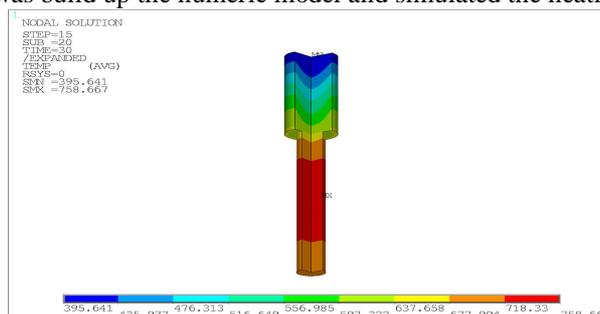


**Figure 2** 3D representation of reduced billet and inductor



**Figure 3** 2D representation of reduced billet and inductor

For above presented geometry was build up the numeric model and simulated the heating of the billet (Figure 4).

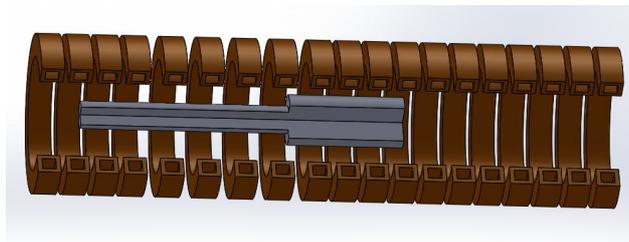


**Figure 4** Distribution of the temperature inside the billet at time  $t=30s$ , current  $I=800A$  and frequency  $f=2000Hz$

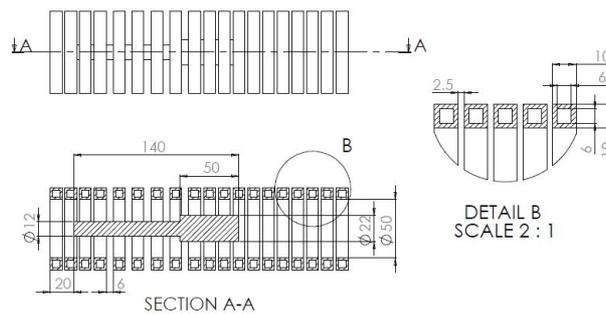
Initially the billet is placed with the bigger diameter where the coil turn space factor  $K_{space}$  is smaller, due to the fact that being bigger should heat faster than the other side of the billet that is smaller. Since the magnetic field intensity is stronger at the middle of the inductor, the skin depth is the same for the whole length of the billet and taking in account that because of the conduction, at the beginning of the induction heating, the temperature will be bigger in the smaller diameter of the billet, it was decided to place the billet somewhere in the middle of the inductor [8]. The temperature distribution plotted in Figure 4 is showing a temperature difference bigger than 350 degrees. Taking into account the above presented phenomena there will be presented three cases of the same positioning of the billet but different coil turn space factor.

### 3. RESULTS AND DISCUSSIONS

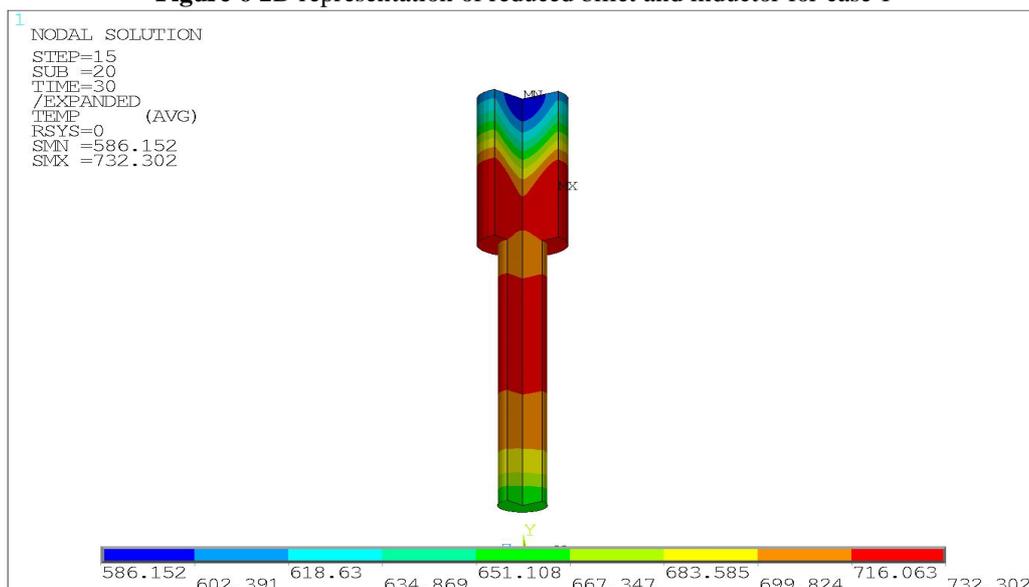
Case 1 –the inductor is having three windings less from initial geometry (from 22 windings to 19 windings) and the billet is place in the initial position but moved at the left side of the inductor, at 20mm from the first winding (Figure 5 and Figure 6). As it is shown in 2D representation of the inductor, the values of the coil turn space factor remain the same (2.5mm and 6mm), only the areas with these values were shifted. The inductor’s area with the coil turn space factor smaller was shifted to side of the billet where it is smaller and vice versa.



**Figure 5** 3D representation of reduced billet and inductor for case 1

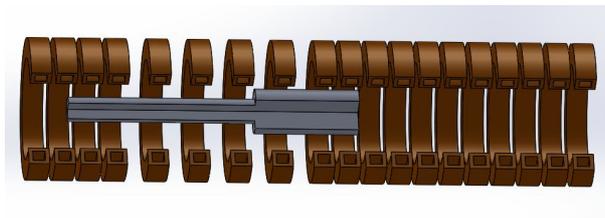


**Figure 6** 2D representation of reduced billet and inductor for case 1

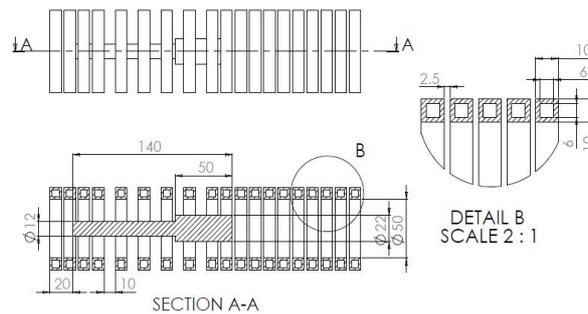


**Figure 7** Distribution of the temperature inside the billet at time  $t=30s$ , current  $I=800A$  and frequency  $f=2000Hz$  for case1

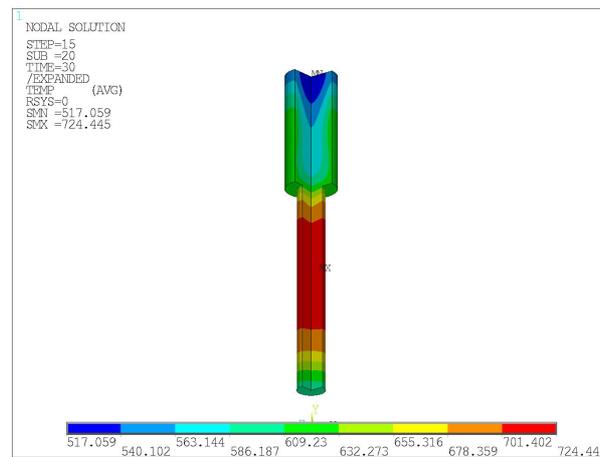
Case 2 – the inductor is having the same number of windings as case 1, but we decreased the coil turn space factor as it is shown in Figure 8 and Figure 9.



**Figure 8** 3D representation of reduced billet and inductor for case 2

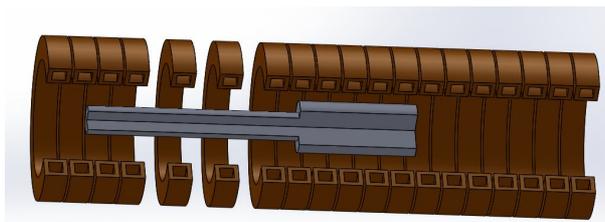


**Figure 9** 2D representation of reduced billet and inductor for case 2

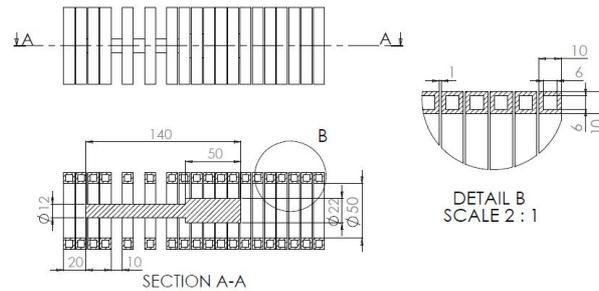


**Figure 10** Distribution of the temperature inside the billet at time  $t=30s$ , current  $I=800A$  and frequency  $f=2000Hz$  for case 2

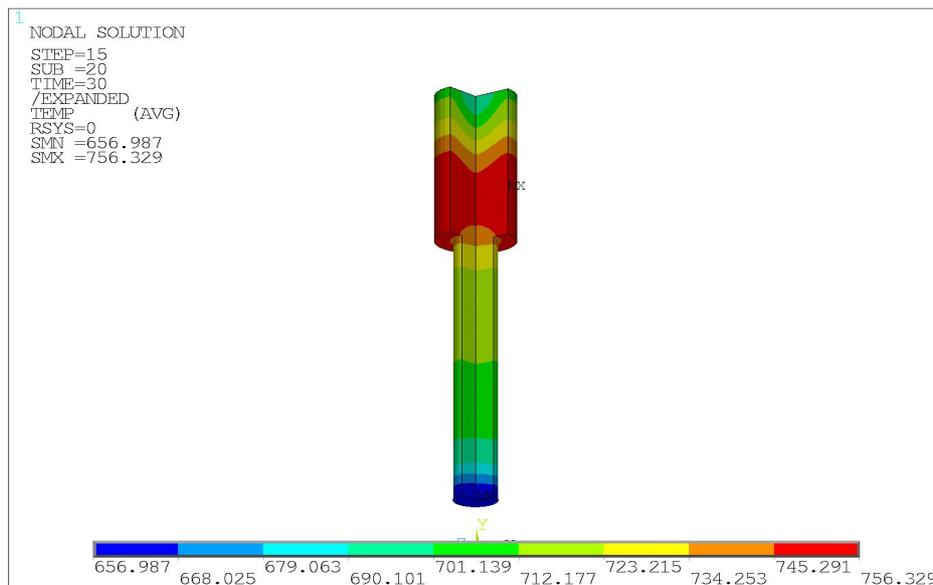
Case 3 – the number of the windings was kept, also the distance of the windings of the area of the billet were it is smaller in diameter, as for case 2, but for the other areas of the inductor we increased the coil turn space factor. The geometry of the inductor and the positioning of the billet inside the inductor, for case 3 are represented in Figure 11 and Figure 12.



**Figure 11** 3D representation of reduced billet and inductor for case 3



**Figure 12** 2D representation of reduced billet and inductor for case 3



**Figure 13** Distribution of the temperature inside the billet at time  $t=30s$ , current  $I=800A$  and frequency  $f=2000Hz$  for case 3

#### 4. CONCLUSIONS

Analyzing the distribution of the temperature for the three presented cases (Figure 7, Figure 10 and Figure 13), it proves that the coil turn space factor  $K_{space}$  is an important parameter for an optimal design of the inductors for mass heating processes. Starting from a temperature difference of more than  $350^{\circ}C$ , in initial case, this was improved to around  $100^{\circ}C$  in case 3. Although, it is an improved temperature distribution with the changed geometry of the inductor for case 3, the geometry of the inductor still can be improved to achieve a better temperature distribution. Even if we speak about a static inductive mass heating process or about an induction heating of moving billets, temperature uniformity inside the billet is the goal and coil turn space factor can help us designing the suitable inductor for a given billet.

**Nevertheless, two aspects need to be remembered:**

- the coil turn space factor  $K_{space}$ , is an important parameter of the coil design and should be as high as possible.
- the space between turns should be as small as possible, but large enough to leave room for electrical insulation.

#### REFERENCES

- [1] Edgar Rapoport, Yulia Pleshivtseva, "Optimal Control of Induction Heating Processes", CRC Press by Taylor & Francis Group, 2007
- [2] V. Rudvev, "How do I select inductors for billet heating", Heat Treating Progress, May/June 2008
- [3] Edward G. Nisbett, "Steel Forging: Design, Production, Selection, Testing and Application", ASTM International, 1 January 2005
- [4] Taylan Altan, Gracious Ngaile, Gangshu Shen, "Cold and Hot Forging: Fundamentals and Applications, ASM International, 2005
- [5] V. Rudvev, K. Schweigert, "Designing induction equipment for modern forge shops", Forging, Winter, 1994, 56-58

- [6] Stanley Zinn, S. Lee Semiatin, "Elements of Induction Heating: Design, Control and Applications", ASM International, 1988
- [7] V. Rudnev, D. Loveless, R. Cook, M. Black, "Handbook of Induction Heating", Marcel Dekker Inc., New York, Basel, 2003
- [8] E.J. Davies, "Conduction and Induction Heating", Peter Peregrinus Ltd, London, 1990