# The Influence of the Geometry of the Inductor on the Depth and Distribution of the Inductively Hardened Layer

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***Abstract*** – The induction hardening of ferromagnetic details is widely used for his high efficiency, versatility, quality of products and the ability to precisely control the heating process.
Disadvantage is that the majority of industrial induction systems are limited in capacity and frequency to the large variety of hardened details.
This requires the use of inductors with shape and dimensions, providing optimal application of the advantages of this method and increasing the efficiency.
To investigate the influence of the geometry of the inductor on the distribution and depth of the hardened layer is necessary to analyze the electromagnetic and thermal processes in the detail.
For this purpose a computer model of the system inductor-detail is developed. Metallographic analysis on pre-hardened specimen of ferromagnetic steel was performed and the dimensions of the hardened layer were reported.

***Keywords*** - induction hardening, hardened layer, modeling the system inductor-detail.

## I. Introduction

The hardening of internal cylindrical surfaces of ferromagnetic details require to achieve a rate of heating ensuring uniform hardened layer in depth of the detail [2-6]. To meet these requirements is necessary to create an appropriate distribution of the temperature field in the volume of the detail.

The reason for the variability is caused by the electromagnetic field distribution, which is associated with proximity and annular effects [1] and the influence of the boundary effects [7].

The purpose of this paper, based on the theoretical model proposed in [8], is to present a specific solution to design the shape of the inductor used to heat the inner surface of the cylindrical sleeve type detail - Figure 1, with a composition of the material referred in Table I.

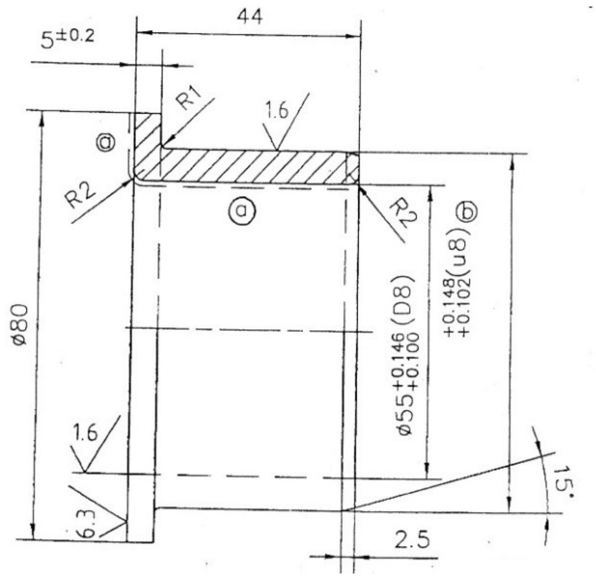


Fig.1. Overall dimensions of the detail

Table I
Chemical composition of steel type C50 EN 10 083-2

| C | Si | Mn | Cr | S | P | Cu | Ni |
|---|---|---|---|---|---|---|---|
| 0,47-0,55 | 0,17-0,37 | 0,50-0,80 | 0,25 | 0,04 | 0,04 | 0,25 | 0,25 |

The heating and hardening of the detail shown in Figure 1, is carried through an inductor with ferromagnetic core - Figure 2, powered by a tube generator, with duration of the process 10 s.

Fig.2. Inductor with ferromagnetic core.

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The quality of hardening is determined by metallographic analysis - Figure 3 and Figure 4.

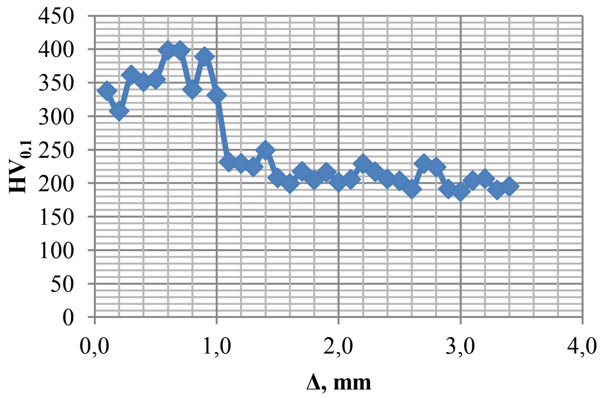


Fig..3. Change of hardness in the depth of the detail.

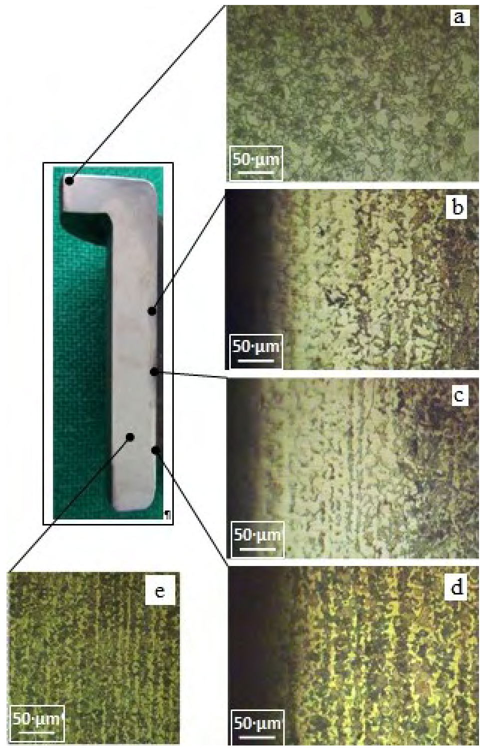


Fig.4. Structural condition of the detail after the process of heat treatment:
a - troostito-sorbite structure in the area with intensive induction and respectively thermal effects;
b, c - a transitional area between areas with concentrations of magnetic field lines and respectively with thermal effects on the material and the base;
d,e - basic textured ferrite-pearlite structure.

From the results presented in Figure 3 and 4 it is found that after the heat treatment, the resulting structure is non-heterogeneous along the axis of the detail, which determines insufficient degree of the necessary hardening, defined by the technical documentation.

This requires further research to clarify the shape and dimensions of the inductor.

## II. Theoretical Investigation

A study using axial symmetric model presented in Figure 5, is performed.

The inductor Ω2 is without ferromagnetic core and is composed of four coils made of profiled wire.

The detail Ω3, subject to heat, is concentrically located to the inductor.

The size of the air field Ω1, encircling the inductor-detail system is consistent with the distribution of the magnetic field.

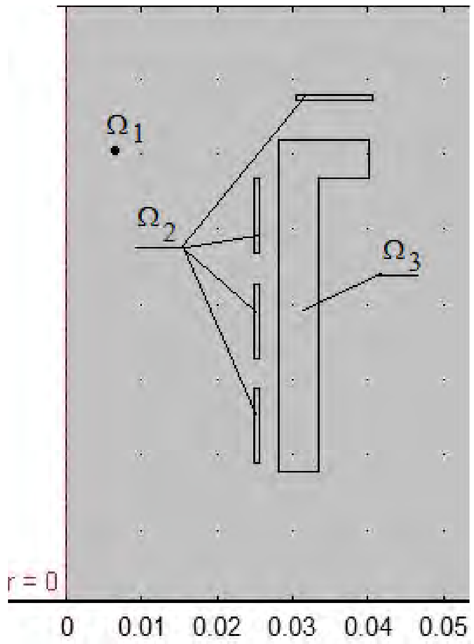


Fig.5.The system inductor-detail

With the so prepared model are conducted multiphysics model analysis – quasi steady state electromagnetic (1) and transient thermal (2) analysis:

$$\nabla \times \left(\frac{1}{\mu(H,T)} \times \nabla \times \dot{A}\right) + j \cdot \omega \cdot \gamma(T) \cdot \dot{A} = \frac{\dot{U}_{coil}}{2 \cdot \pi \cdot r} \quad (1)$$

$$\rho(T) \cdot c(T) \cdot \frac{\partial T}{\partial t} = \nabla(\lambda(T) \cdot \nabla T) + \frac{1}{2} \cdot \gamma(T) \cdot \omega^2 \cdot \dot{A}^2 \quad (2)$$

In these equations $\dot{A}$ is the vector magnetic potential, $H\ (A/m)$ is the strength of magnetic fields, $j = \sqrt{-1}$, $\mu\ (H/m)$ is the magnetic permeability, $\omega (rad/s)$ is the circular frequency, $\gamma (S/m)$ is the electric conductivity,

$\dot{U}_{coil}(V)$ is the voltage in the induction coil, T (K) is the temperature, $\rho(kg/m^3)$ the specific density, $c\ (J/kg.K)$ is the specific thermal capacity, t (s) is the time, $\lambda\ (W/m \cdot K)$ is the thermal conductivity.

The results for the distribution of the electromagnetic and thermal fields are presented in Figure 6 and Figure 7.

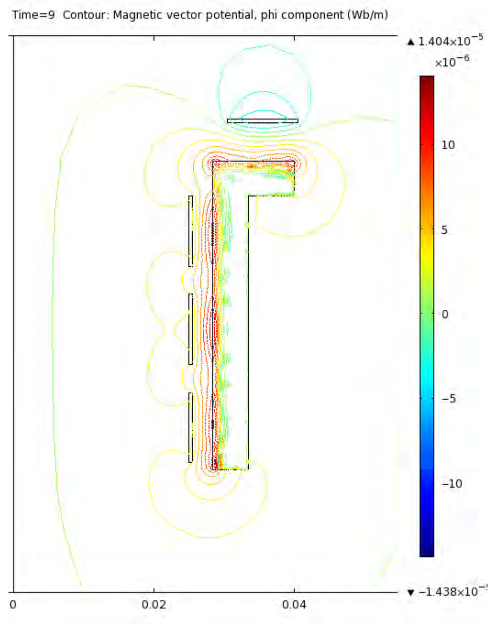


Fig.6. Distribution of the electromagnetic field.

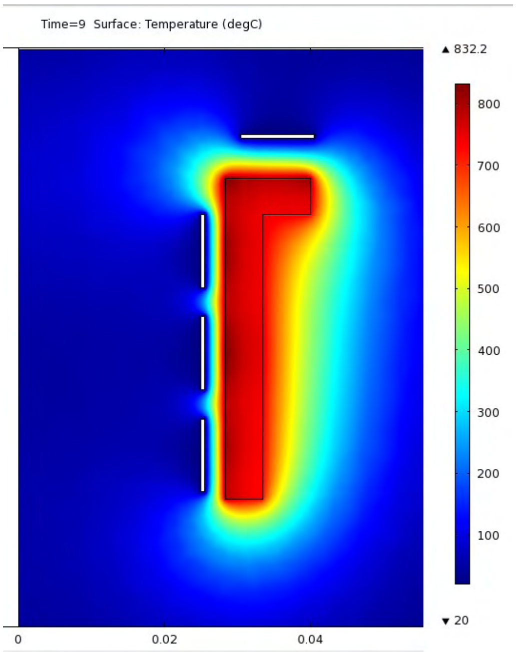


Fig.7. Distribution of the temperature field.

## III. Conclusions

The following conclusions based on the presented results are found:

- The system inductor-detail with specially shaped inductor, corresponding to the hardened surface provides the necessary distribution of the electromagnetic field in the depth of the detail that determines the appropriate temperature distribution along his longitudinal surface;

- The results show that relatively small sizes and distance between the inductor and the detail require the use of profiled wire for making the inductor. This determines the relatively better electromagnetic connection and a more even distribution of the electromagnetic field opposite the wires;

- The lack of internal core of the inductor set loss reduction, respectively redistribution of the active power and increases the ability to reduce the number of turns of the inductor. Accordingly, this leads the increasing of the magnetic flux and power emitted in the detail that provides high-speed heating.

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