

When and why ELTA may be used

The dominating number of induction heaters is designed for enough simple geometric workpieces to be heated: rectangle or square cross-section (slab, sheet, tape, plate), as well as cylindrical one. The inductors of rectangle or square cross-section can be a longitudinal magnetic field (Figure 1), transversal magnetic field (Figure 2) or one side (Figure 3).

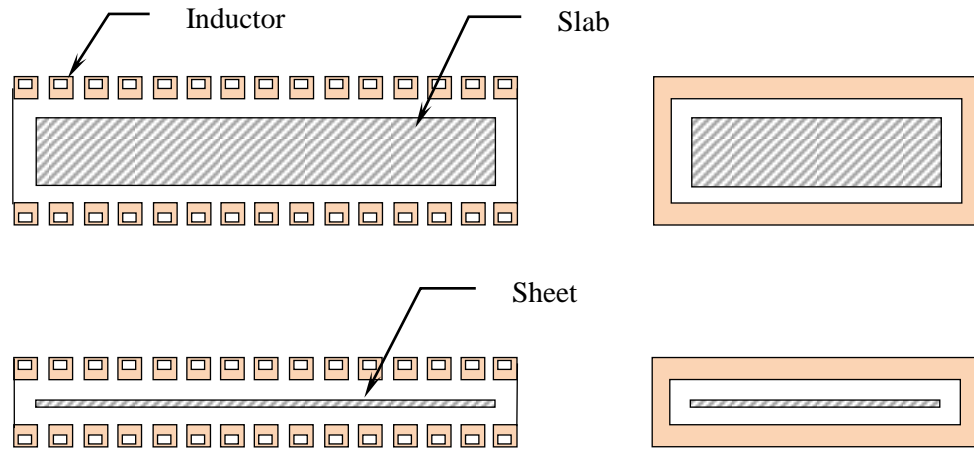


Figure 1. The main type of longitudinal magnetic field inductors

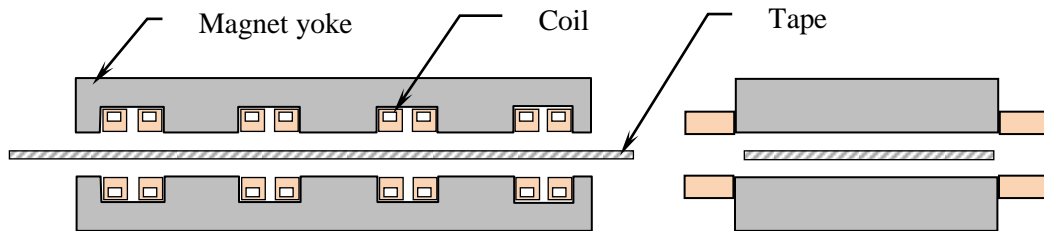


Figure 2. The main type of transversal magnetic field inductors

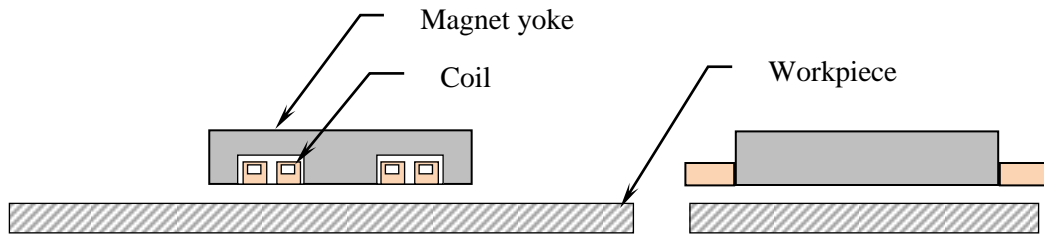


Figure 3. The main type of flat one side inductors

Cylindrical inductors can be external (OD) (figure 4) or internal (ID) (figure 5).

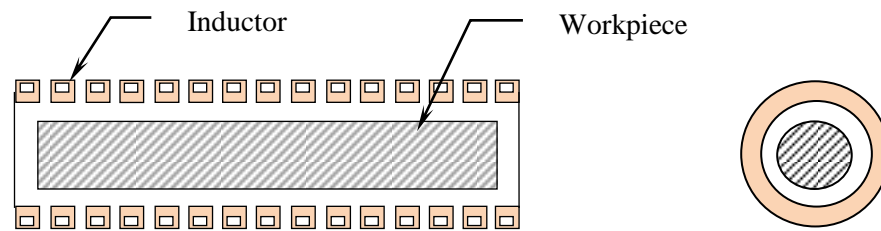


Figure 4. The main type of external cylindrical inductors

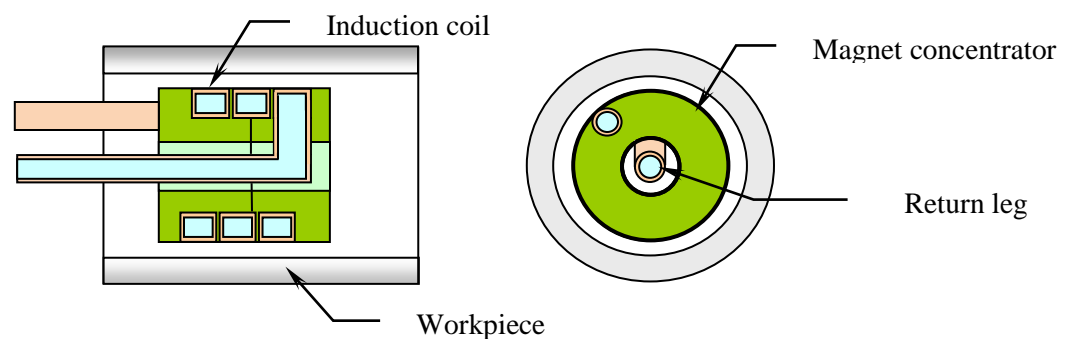


Figure 5. The main type of internal cylindrical inductors

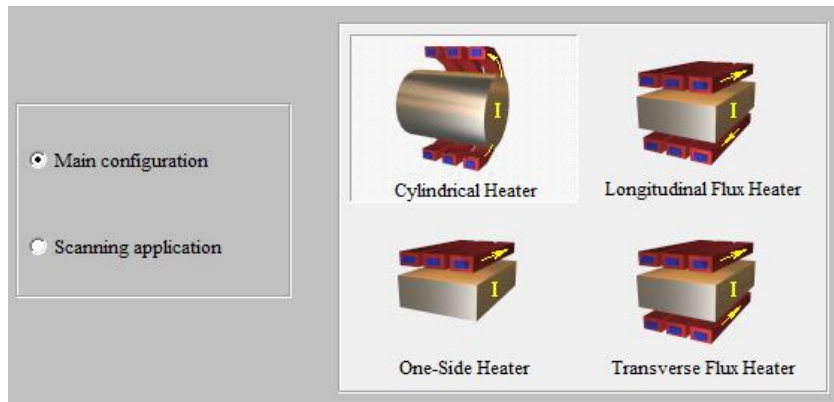
ELTA is a very flexible tool that allows the user to simulate complex processes and optimize them. It is a unique program developed for a wide range of applications including design of induction heating processes and equipment, matching of induction coils to power supply, advertisement, education and self-education [1]. ELTA provides very fast and reasonably accurate simulation of electromagnetic and thermal fields in induction heating using a combination of one-dimensional numerical (Finite Difference) approach and an analytical account for finite lengths of the part and induction coil. It can simulate the majority of basic induction systems: cylindrical or plane, magnetic or non-magnetic, solid or hollow, even with multi-layered load with arbitrary properties and initial temperatures of the layers' materials.

You can simulate and design induction systems for through heating for heat treatment, forging, rolling or extrusion, local heating for induction surface hardening and tempering processes with a multi-stage treatment cycles, indirect induction heating of non-conductive materials in bonding, curing and many others, as well as quenching processes after induction or furnace heating. You can use it even for simulation of a combined induction and furnace heating in different combinations and temperature variation during the transportation time. Versions ELTA 5.5 and 6.0 have improved interface, accuracy and calculation of water cooling of the inductor winding.

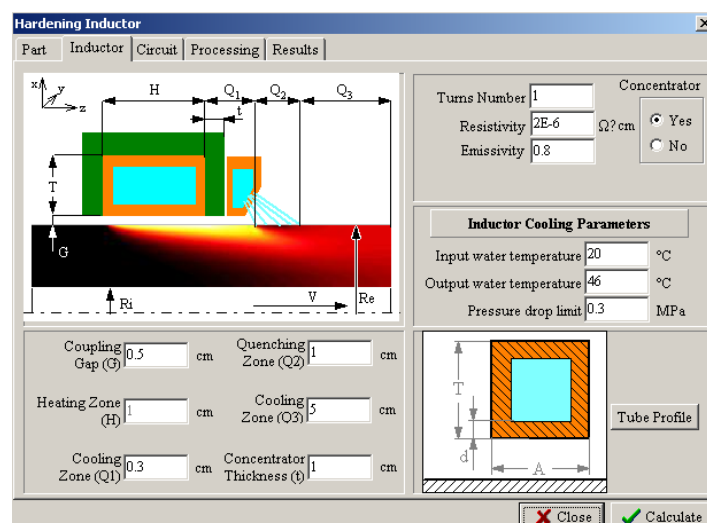
The latest version (ELTA 6.0) has an additional option for induction heating simulation of bodies with rectangular cross-sections (rods, billets, slabs, etc.) using complete numerical **2D simulation** of coupled Electromagnetic and Thermal fields. This option allows the user

to investigate temperature distribution in the whole cross-section of the body. Final length of the system is still taken into account using analytical procedure.

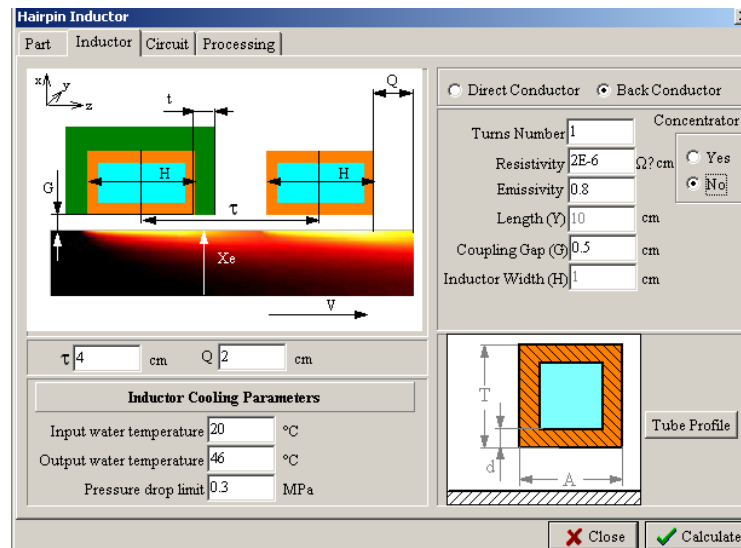
ELTA is at its best in the simulation of induction **PROCESSES**, when it can be used to find an optimal relationship between **TIME, TEMPERATURE** and **POWER DISTRIBUTION** [2]. The design or optimization of any induction system must balance the use of power and time against the required thermal profile in the load. Sometimes tradeoffs are made, sacrificing one feature for the benefit of another. For example, if power is limited, a longer heat time may be necessary to obtain the required temperatures. Simulation with ELTA reveals the relationship between power, time and thermal profile during heating, transportation and cooling/quenching allowing induction equipment users to balance and optimize complex induction processes.



To simulate scanning process, ELTA has a special block **Scanning Application**. Calculations are based upon the Main platform but interface is different and there are several additional options not available in the main block. You can enter into the Scanning Application from File/Open or by selection and modification of existing scanning tasks. There are two coil configurations of scanning systems: Single or Multiturn coils of cylindrical geometry and “Hair-pin” coil typical for heating flat bodies. A single-turn cylindrical coil for hardening the hollow shaft is presented below. The coil may be with or without magnetic concentrator. The user must insert physical parameters in terms close to practical language used by induction heat treaters.



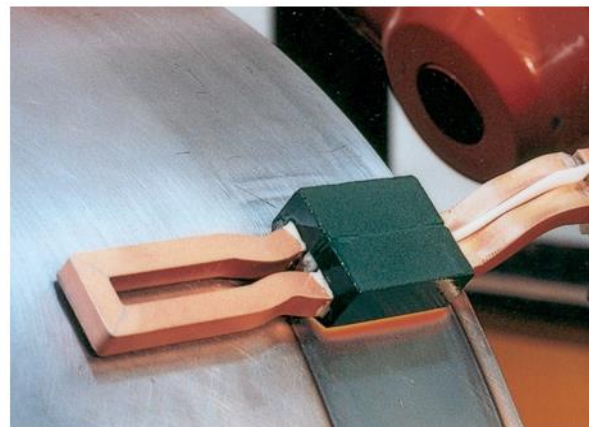
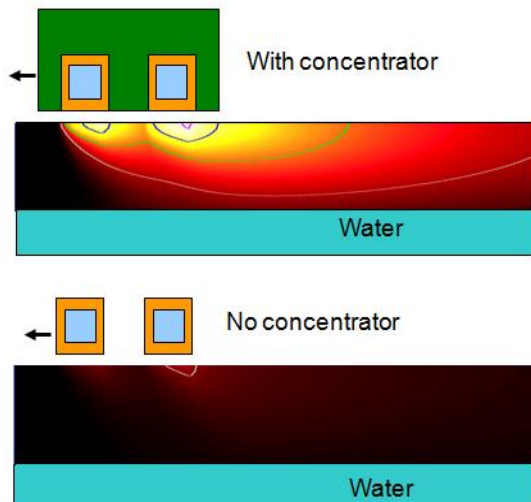
The geometry of a system with a **Hair-pin** coil for flat body hardening is presented below. The user can vary dimensions of **Direct Conductor** and **Back (Return) Conductor**, change distance between the conductors, apply magnetic concentrator, etc.



On the above picture a magnetic concentrator is applied only to direct conductor in order to bring quickly the surface temperature to maximum value. The second leg has no concentrator.

Scanning application allows user to create nice pictures for business presentations, articles and teaching/training tools. The picture on the left shows temperature color map for scan hardening of the shaft. The color map is imported from ELTA. Induction coil and quenchant jets are added in Word.

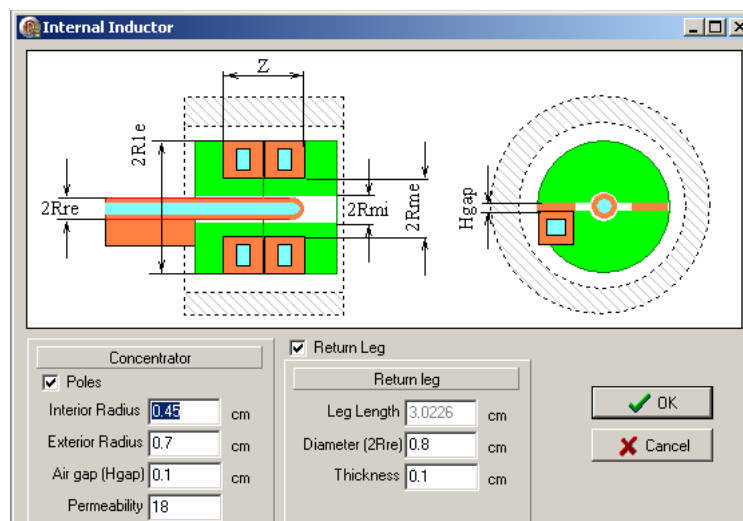
Picture below shows an example of computer simulation for scan heating of flat surface using Scanning Application. The left picture shows temperature distribution in stainless steel plate (12.7 mm thick) that's water cooled from the bottom. Right picture is a photo of an exhibition stand built according to simulation for demonstration of the influence of magnetic flux concentrator on temperature created by the hair-pin coil (Courtesy of Fluxtrol, Inc., www.fluxtrol.com). Coil is being moved along the plate by industrial robot ABB. Experiment confirmed the simulation accuracy.



Internal induction heating is widely used in industry. There are several types of internal (ID) coils: rod inductors, cylindrical (single and multi-turn) and hair-pin inductors [3, 4]. The most popular cylindrical coils may be simulated in ELTA. Internal induction system may be simulated in main block. You only need to select the option **Internal** in Inductor window, see below. In addition to all parameters required for external inductors, it is necessary to describe design of the internal magnetic concentrator (core) and return leg (for multi-turn inductors). Presence of magnetic core and necessity to pull the return lead (leg) through the limited space inside of the winding are special features of internal coils that must be taken into account in design and calculation [3].

The return leg occupies part of the space inside of the coil and leaves small space for the magnetic core, see picture below. As a result, magnetic cores are often working in conditions close to saturation. Also, the return leg creates its own circumferential magnetic field, which flows around the leg perpendicular to main, axial, magnetic field. This additional magnetic field further saturates the core and gives noticeable voltage drop on the return leg. To reduce this field, it was proposed to make internal core of two halves with a gap between them [3] or to locate the return leg asymmetrically by moving it to one side of the orifice.

Superposition of two magnetic fields makes a task actually three dimensional. ELTA allows the user to calculate multi-turn ID coils without core, tubular core and core made of two halves with account for the core saturation. Picture below shows the data form for the most complicated case of the core made of two halves with a gap.



Heating of rectangular bodies (slabs, strips, billets) is actually a 3D problem if we take into account a finite length of the system. Using semi-analytical Total Flux method for account for a finite length of the system, we can reduce it to 2D coupled EM and Thermal task. In ELTA further simplification was admitted: 1D simulation was made for a body thickness in the central zone of the body. This approach gives accurate results in temperature distribution for only for a central zone and correct coil parameters for rather wide slab (Width/Thickness >8).

New option of 2D numerical simulation was developed for ELTA 6.0. As a result ELTA 6.0 can simulate slab heating with 1D and 2D approaches. In both cases the system has two planes of symmetry OX and OY. Simulation is being performed for a quarter of cross-section.

Example of simulation below is presented for mass heating of a carbon steel slab with dimensions $L \times W \times D = 200 \times 150 \times 20$ cm. A complete case story that includes comparison of 1D and 2D simulation, is given in a special presentation [5]. This presentation contains three cases: 1D simulation for heating in a single inductor, 1D for heating in a set of three inductors and 2D simulation for slab heating in the same set of inductors. Different dimensions of coils and utilized frequencies had been selected in order to have optimized process with minimum energy demand and heating time (accelerated heating). Line frequency of 50 Hz was selected for the first two inductors and 150 Hz for the third inductor.

In addition to standard 1D version, 2D option allows the user to calculate and visualize the following items:

- Color maps of temperature, heat sources (power density) and magnetic field strength in the whole slab cross-section for any instant of heating - $T, w, H = f(x, y @ \text{any } t)$.
- Color maps of temperature variation - $T = f(x, t @ \text{any } y)$ and $T = f(y, t @ \text{any } x)$
- All color maps have a possibility to change scale range of presented values using **Scale** button); it make possible to display maps of absolute temperatures and of temperature gradients.
- Curves of temperature, heat sources and field strength along horizontal or vertical centerlines for any instants $T, w, H = f(x @ y = 0 \text{ or } y @ x = 0 \text{ for any } t)$
- Curves of temperature along the perimeter of one quarter of slab for any t.
- Curves of total specific power (absolute) $P = f(t)$ at the edge and centre of slab and (relative) $P/P_{\text{regular}} = f(t)$.
- Curves of total specific power versus thickness and width $P = f(x)$ or $P = f(y)$ for any t in absolute P or relative values $P/P_{\text{regular}} = f(x \text{ or } y = 0)$ for any t.

Because different items must be visualized and represented in the report, it is recommended to create different templates for the same task when using 1D or 2D calculation options.

2D calculations in some cases (big dimensions W and D, high skin-effect, magnetic material, heating mode Power) may be relatively long. In order to adjust calculation parameters (mesh, time steps, etc.), Elta initially makes 1D simulation for a central zone of the slab and uses the results for optimization of 2D calculation process.

The output concentrated and distributed parameters are the same as in 1D case but more options are available for selection of variables for temperature, current density and other distributed parameters.

Several charts for three-stage heating of a steel slab are presented below.

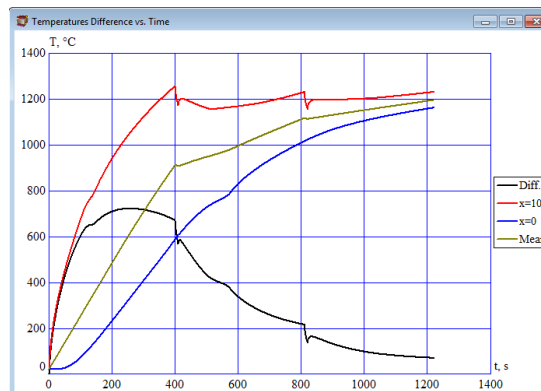
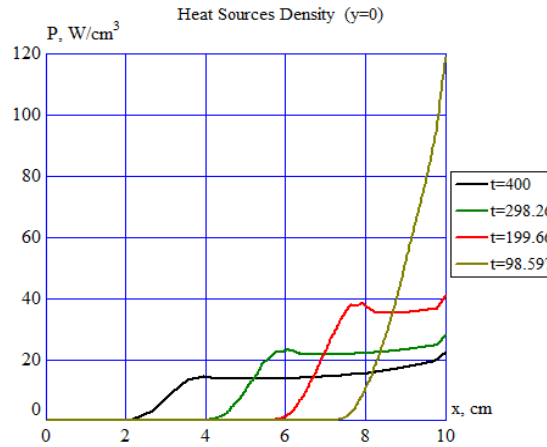
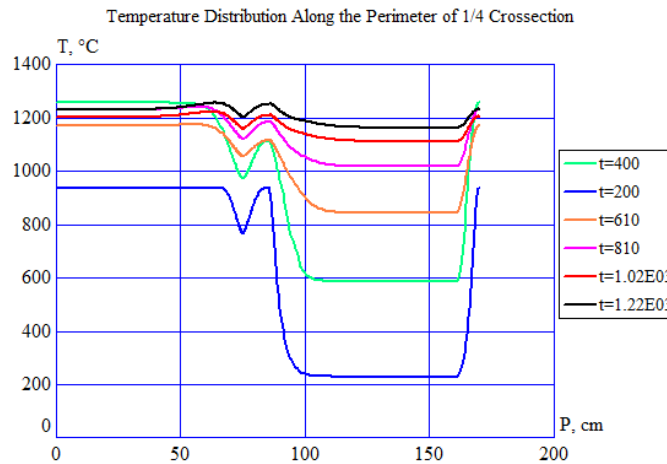


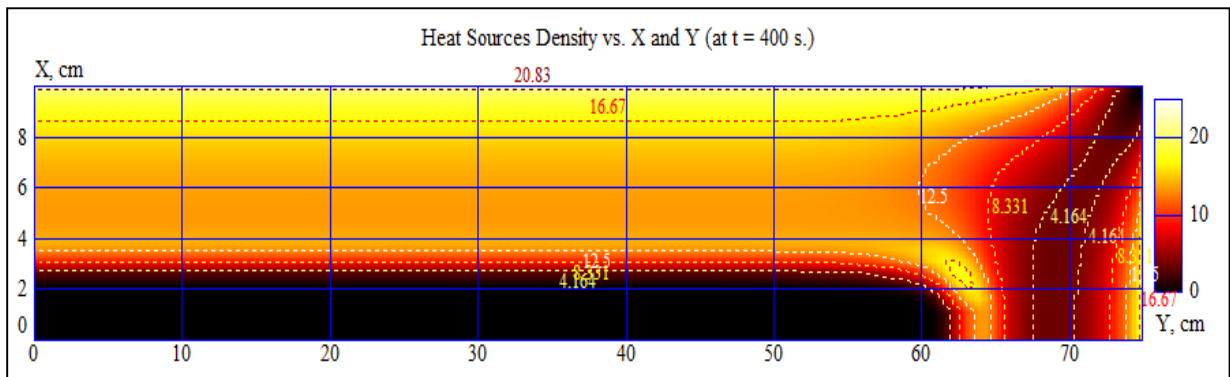
Chart above shows variation of temperatures in the slab centre ($x = 0, y = 0$), on its surface ($x = 10 \text{ cm}, y = 0$), average temperature along a line $x = (0 \rightarrow D/2)$ and the temperature difference "surface – center".



Power density variation in slab thickness at different instances of heating at stage 1.

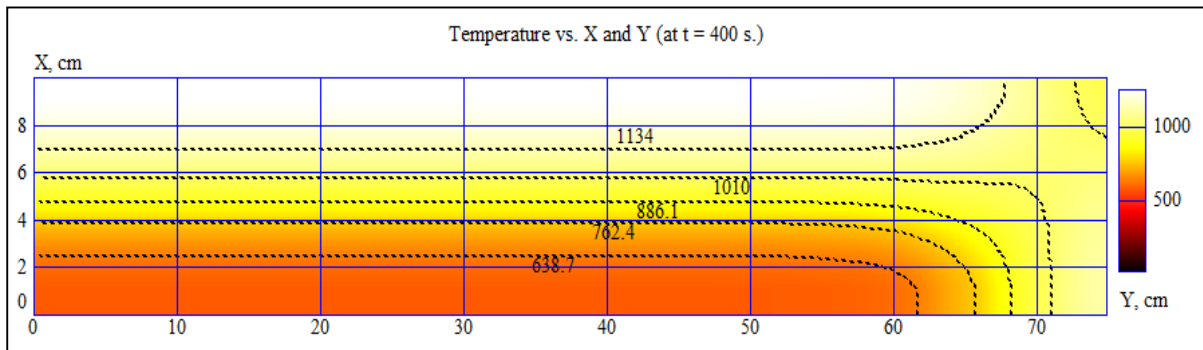


Temperature curves along the perimeter of a quarter of the slab for the middle and end times of each of three heating stage.



Color map of heat source density in a right top quarter of slab at the end of stage 1 of processing ($t = 400 \text{ sec}$). Frequency 50 Hz.

Color map below shows temperature distribution in a right top quarter of a slab at the end of stage 1 of processing ($t = 400$ sec). The whole end zone is slightly underheated due to negative Edge Effect [6] because the selected frequency is lower than optimal.



1. V. S. Nemkov. *Role of Computer Simulation in Induction Heating Techniques*. Proceedings of the International Induction Heating Seminar, Padua, Italy, May 1998, pp. 301 – 309.
2. V. Nemkov, *Modeling of Induction Hardening Processes*, Chapter 10 in Handbook of Thermal Process Modeling of Steels, edited by C.K. Gur and J. Pan, CRC Press 2009.
3. V. Nemkov, R. Goldstein, V. Bukanin. *Optimal Design of Internal Induction Coils*, Proc. HES-04, Heating by EM Sources, Padua, Italy, June 22-25, 2004.
4. Web site www.fluxtrol.com
5. V. Nemkov. *Simulation of Induction Heating of Slab*. ELTA 6.0 B1101, 1D and 2D Options, www.nsgsoft.com, Nov. 2013.
6. V. S. Nemkov, V. B. Demidovich. *Theory and Calculation of Induction Heating Devices*. Leningrad, Energoatomizdat, 1988, 280 p. (in Russian).