

Simulation of Induction Heating of Slab

**Elta 6.0 B1101
1D and 2D Options**

November 2, 2013

Induction System Description

Slab:

- Material – low carbon steel
- Dimensions: L x B x D = 200 x 120 x 20 cm
- Temperatures: initial 20 C, final before transportation 1150 ± 75 C
- Weight of slab – 3.75 t
- Production rate – 33 t/hr

Frequency selection:

• Optimal frequency may be found using two major criteria: uniform heating in width and good electrical efficiency. Both criteria correspond to ratio $D/\delta = 3$ (exact ratio must be π). If we use frequency 50 Hz, for hot conditions $\delta = 7$ cm and $D/\delta = 2.86$. Frequency 150 Hz was selected for the third inductor ($D/\delta = 5$) in order to compensate slightly lower than optimal frequency of the first two inductors and thermal losses from the slab surface.

Simulation strategy

- 1D option was used for preliminary simulation, i.e. heating time, number of coils and their design, etc. This method isn't actually 1D; special algorithm was developed in order to take into account heating of end zones. However this algorithm does not provide accurate results and does not give temperature distribution in the whole slab cross-section.
- 2D option was used for final adjustment of installation, calculation of the inductor parameters and temperature distribution in the slab cross-section.
- Both 1D and 2D options allow us to count for a final length of the system, including difference in lengths of the coil and work-piece

Single – Stage Heating; 1D Simulation

With several iterations using 1D simulation it was found that one-stage heating requires power 1.45 MW and heating time 3600 sec.

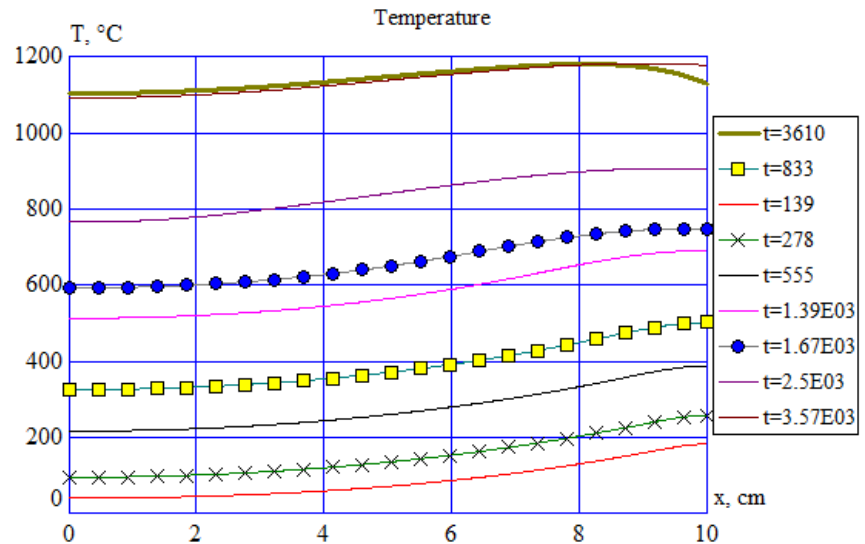
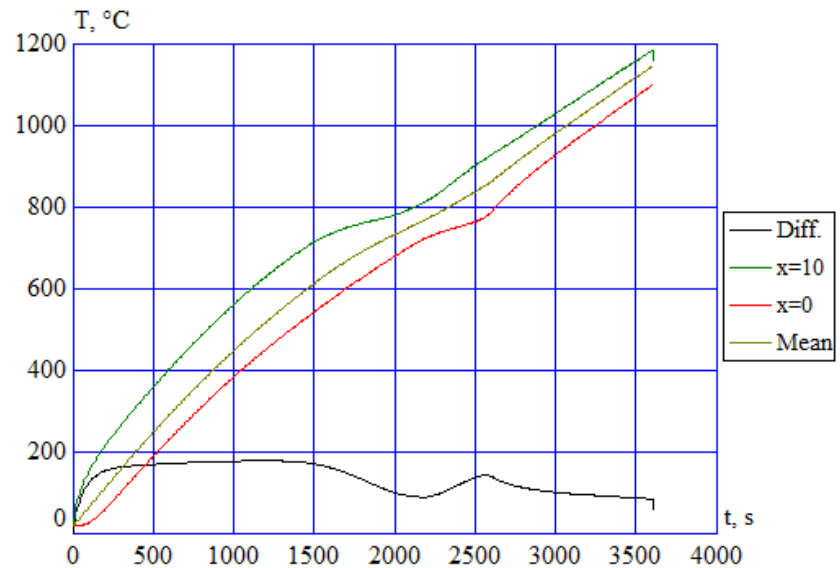
Temperature variations in time and in slab thickness are shown in figures on the right.

Temperature at the end of heating is in the range of 1100 – 1180 C.

After 10 sec of slab transportation the surface temperature drops to 1150 C.

To provide required production rate it is necessary to use 9 parallel lines.

Specific energy is 308 kWh/t.

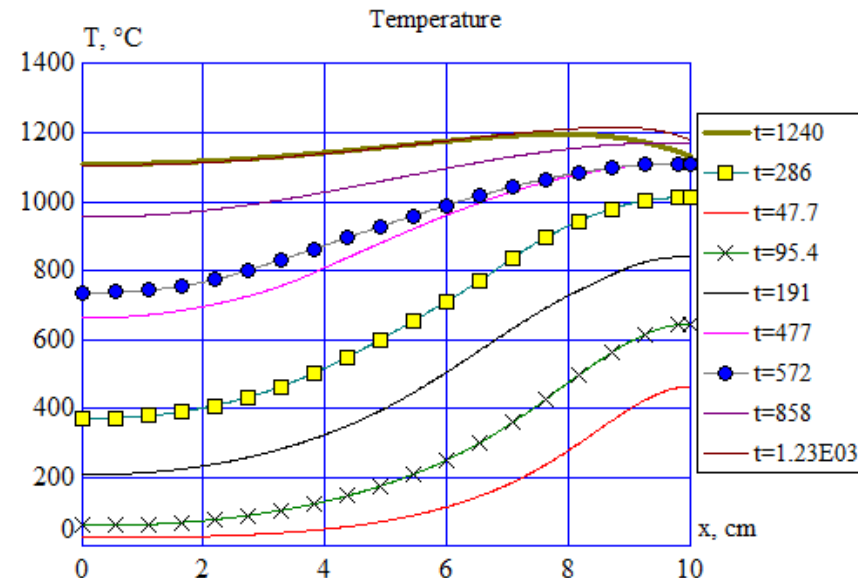
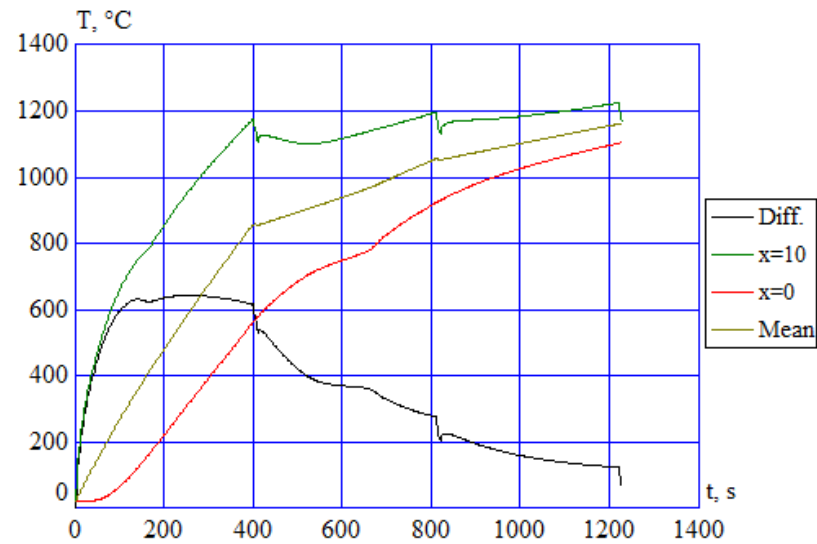


Accelerated Heating; 1D Simulation

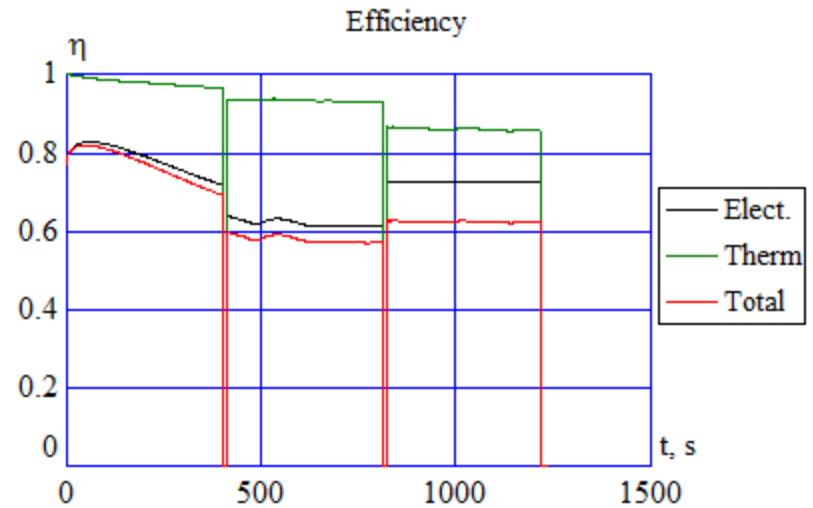
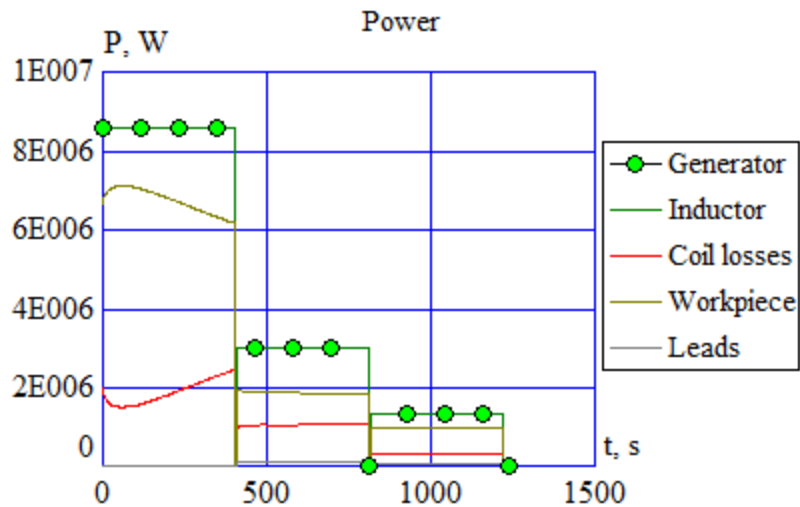
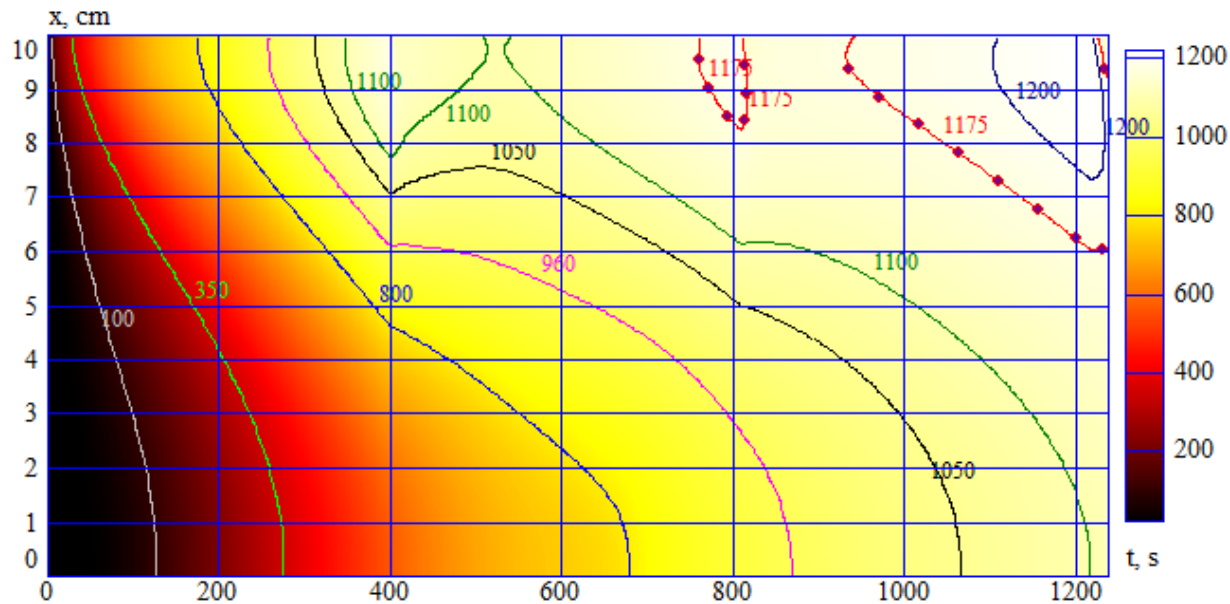
1D simulation was used for optimization of heating. Heating line contains three inductors with different turn numbers and thermal insulation. Transportation time from one inductor to another was selected 10 sec. It was found that total heating time may be reduced to $3 \times 120 + 2 \times 10 = 1220$ sec when using accelerated heating.

Mean power of inductors must be 8.6, 3.0 and 1.3 MW to achieve approximately the same temperature distribution as at one-stage heating (see pictures).

It was found that it is reasonable to use slightly higher frequency (150 Hz) for the 3rd inductor in order to compensate surface temperature reduction during the transportation.



Accelerated Heating; 1D Simulation



Elta 6.0 2D Option

In addition to standard 1D calculations, 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 - $T = f(x, t @ \text{any } y)$ or $T = f(y, t @ \text{any } x)$
- All color maps have a possibility to change scale range of presented values (use [Scale](#) button); it make possible to visualize gradients of presented values
- Curves of temperature, heat sources and field strength along horizontal or vertical centerlines for any instants $T, w, H = f(x @ y = 0 \text{ or } y @ x = 0 \text{ for any } t)$

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.

Report Pages with Some Input Data



Date: 11/2/2013 11:35:20 PM

Page 1 of 9

Version: 6.0

Project: Slab heating

Project Information.

Task type: Heating of a big magnetic steel slab (B x H x L = 150 x 20 x 200 cm) in three different inductors

Input Data.

Workpiece:

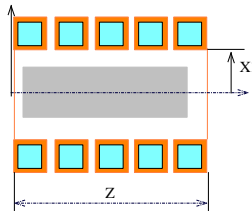
Shape: "Plate". Length (Z): 200 cm, Width (Y): 150 cm, Finite system length.

Layers:

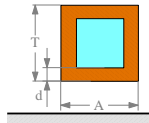
1. "0.4 % C Steel anneal", $X_{in} = 0$ cm, $X_{ext} = 10$ cm, width= 150 cm, $T = 20$ °C.

Inductors:

No 1: X: 17 cm, Z: 230 cm. Y: 164 cm. Number of turns: 36.



Tube profile: rectangle; A= 5 cm; T= 3 cm; d= 0.5 cm; Resistivity: $2 \cdot 10^{006}$ W • cm.



Insulation:

Layer 1: "Portland-cem. concr.", thickness: 4 cm.



Date: 11/17/2013 5:58:03 PM

Version: 6.0

Project: Slab heating

Processing Stages:

- "Heating/Power", duration: 400 s.
f= 50 Hz, $P = 8.6 \cdot 10^{006}$ W.
Used inductor: 1

Media temperature:
 $T_{ext.surf} = 20$ °C.

 $a_{outside} = \text{"Natural"}$.
- "Cooling", duration: 10 s.
Media temperature:
 $T_{ext.surf} = 20$ °C.

 $a_{outside} = \text{"Natural"}$.
- "Heating/Power", duration: 400 s.
f= 50 Hz, $P = 2.8 \cdot 10^{006}$ W.
Used inductor: 2

Media temperature:
 $T_{ext.surf} = 20$ °C.

 $a_{outside} = \text{"Natural"}$.
- "Heating/Power", duration: 400 s.
f= 150 Hz, $P = 1 \cdot 10^{006}$ W.
Used inductor: 3

Media temperature:
 $T_{ext.surf} = 20$ °C.

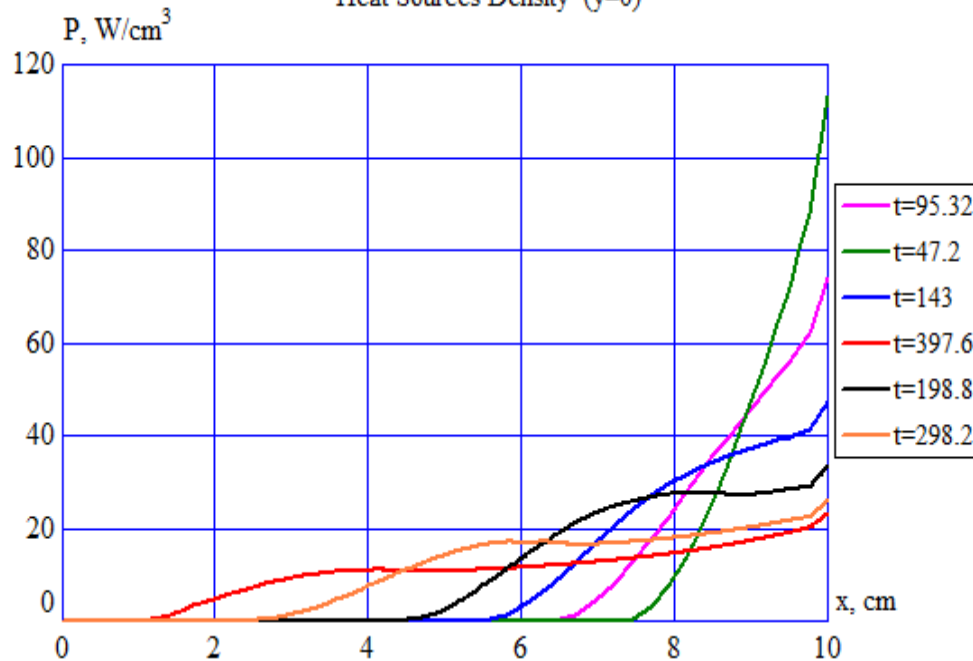
 $a_{outside} = \text{"Natural"}$.
- "Cooling", duration: 10 s.
Media temperature:
 $T_{ext.surf} = 20$ °C.

 $a_{outside} = \text{"Natural"}$.
- "Cooling", duration: 10 s.
Media temperature:
 $T_{ext.surf} = 20$ °C.

 $a_{outside} = \text{"Natural"}$.

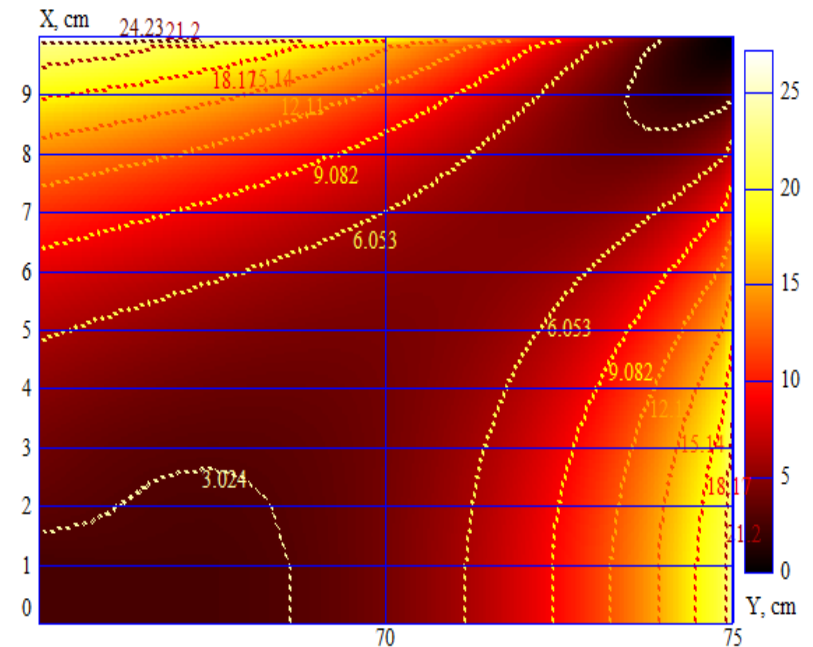
Heat Sources in 2D Simulation

Heat Sources Density (y=0)



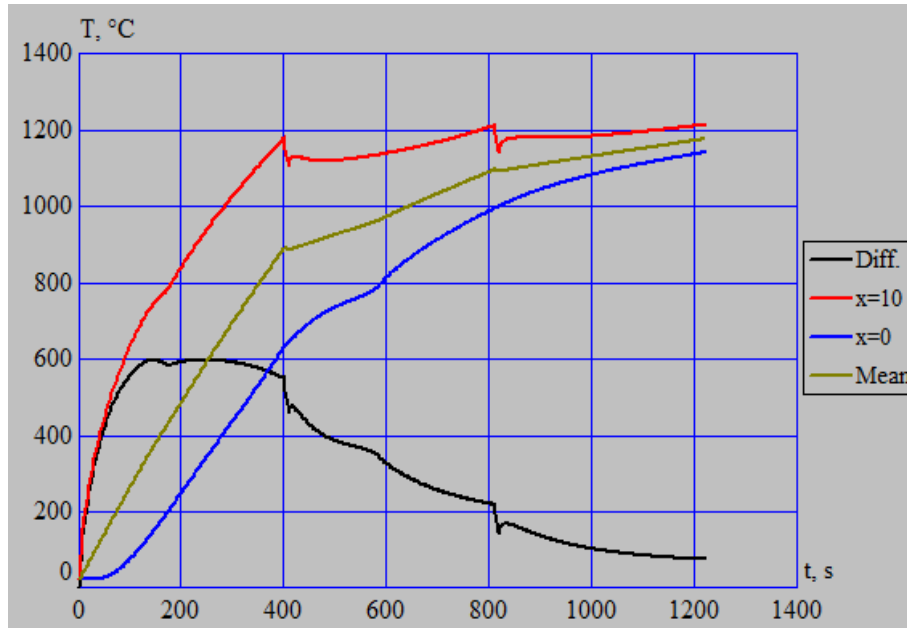
Heat Source distribution along vertical centerline for different instances of the first heating stage

Heat Sources Density vs. X and Y (at t = 400 s.)

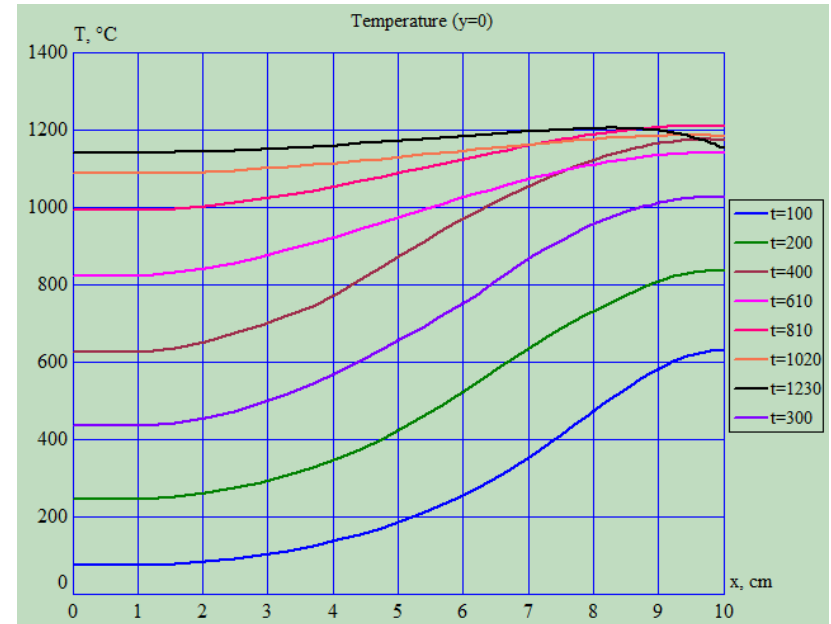


Heat Source color map for a right corner of slab at the end of the first heating stage, demonstrating power edge effect

Temperature Curves



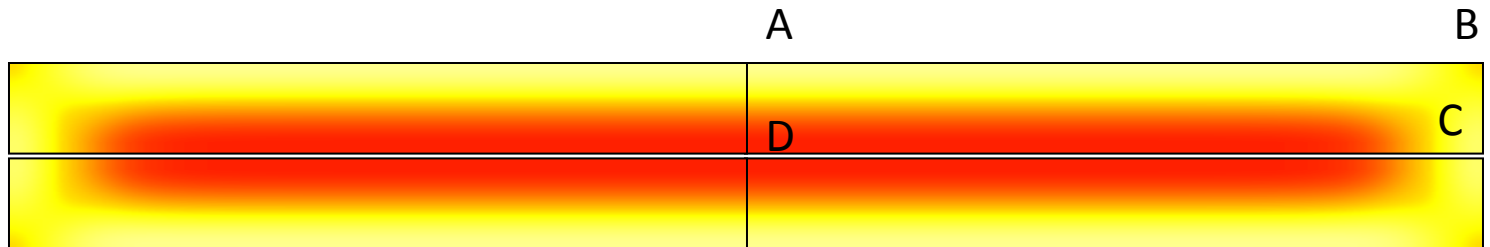
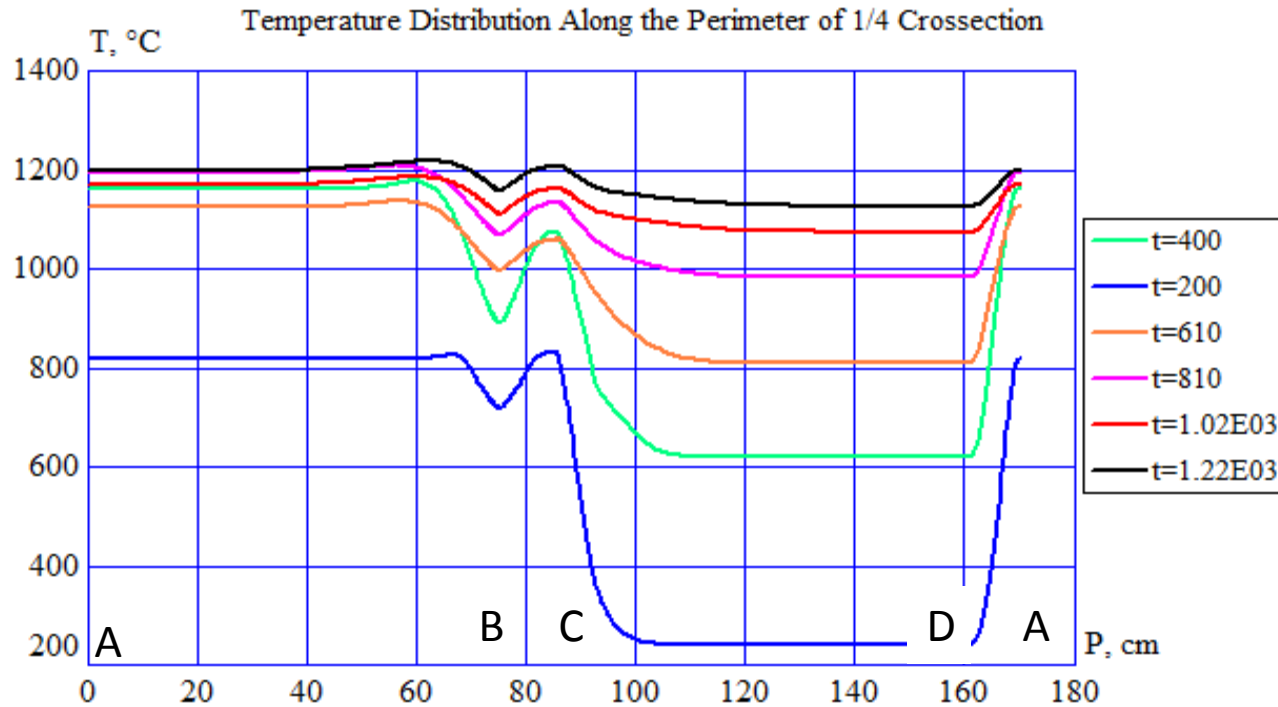
Temperature dynamics: $T(x = 0$ and $x = D/2 = 10)$, mean value and temperature difference in thickness



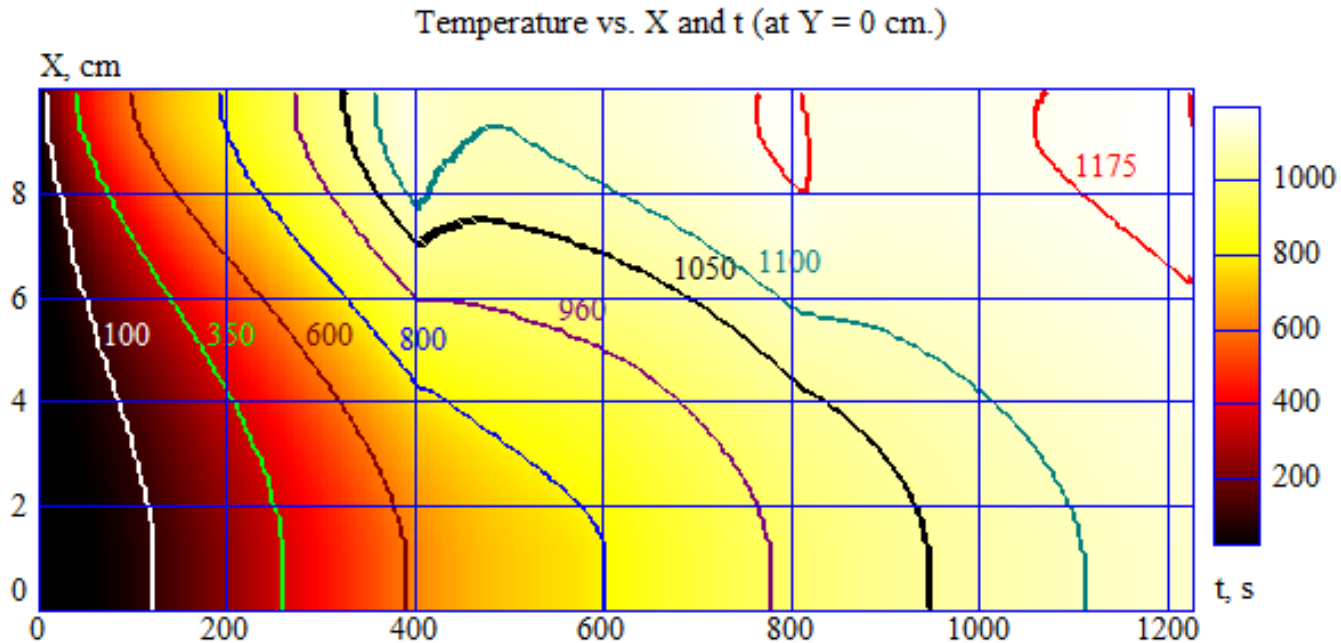
Temperature distribution along the vertical centerline at different t

Temperature Distribution along Perimeter

Temperature curves are presented for the middle and end points of each heating stage

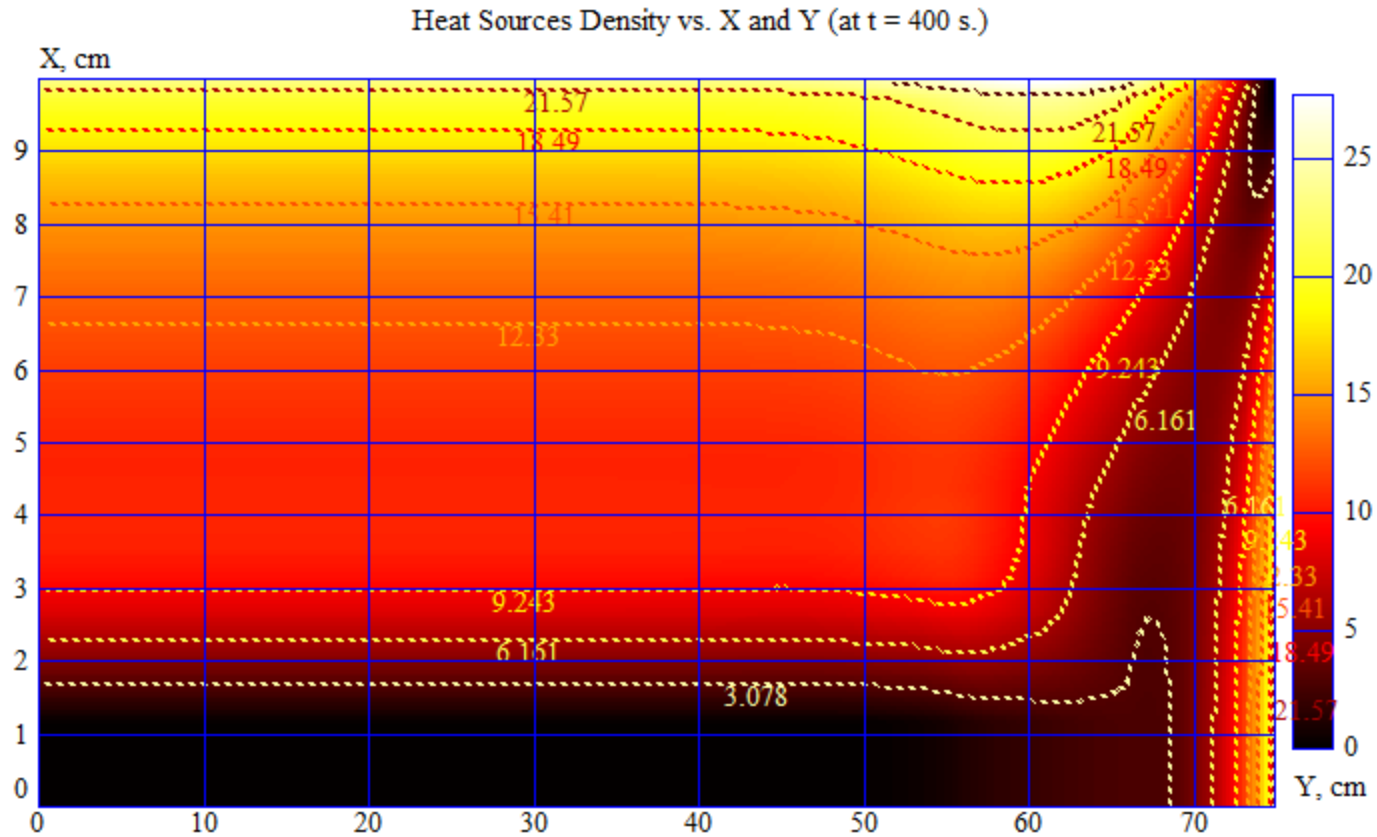


Map of Temperature along the Slab Thickness vs. Processing Time



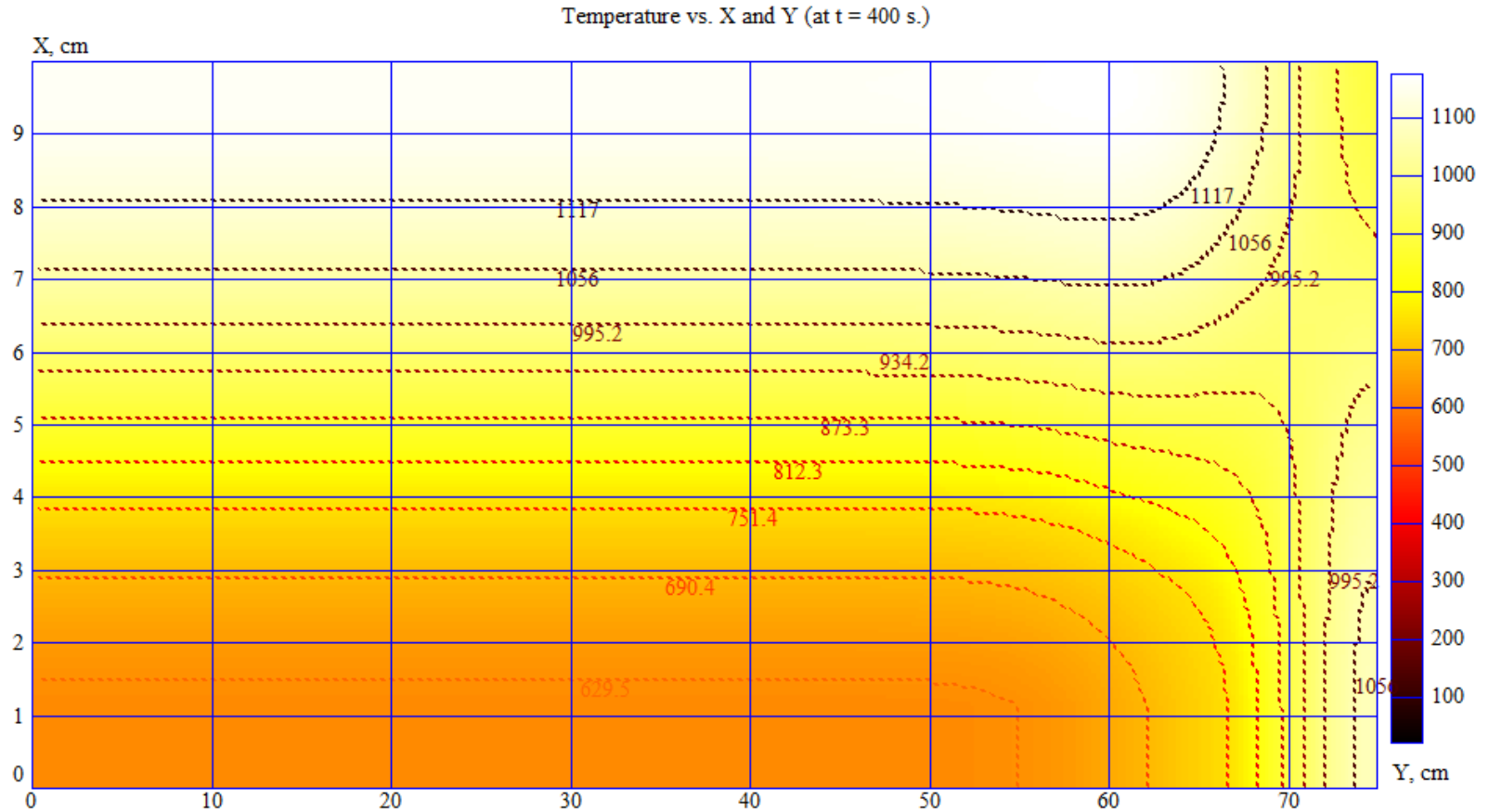
Map is similar to that for 1D simulation

Power Density at the End of the First Heating Stage, W/cm^3

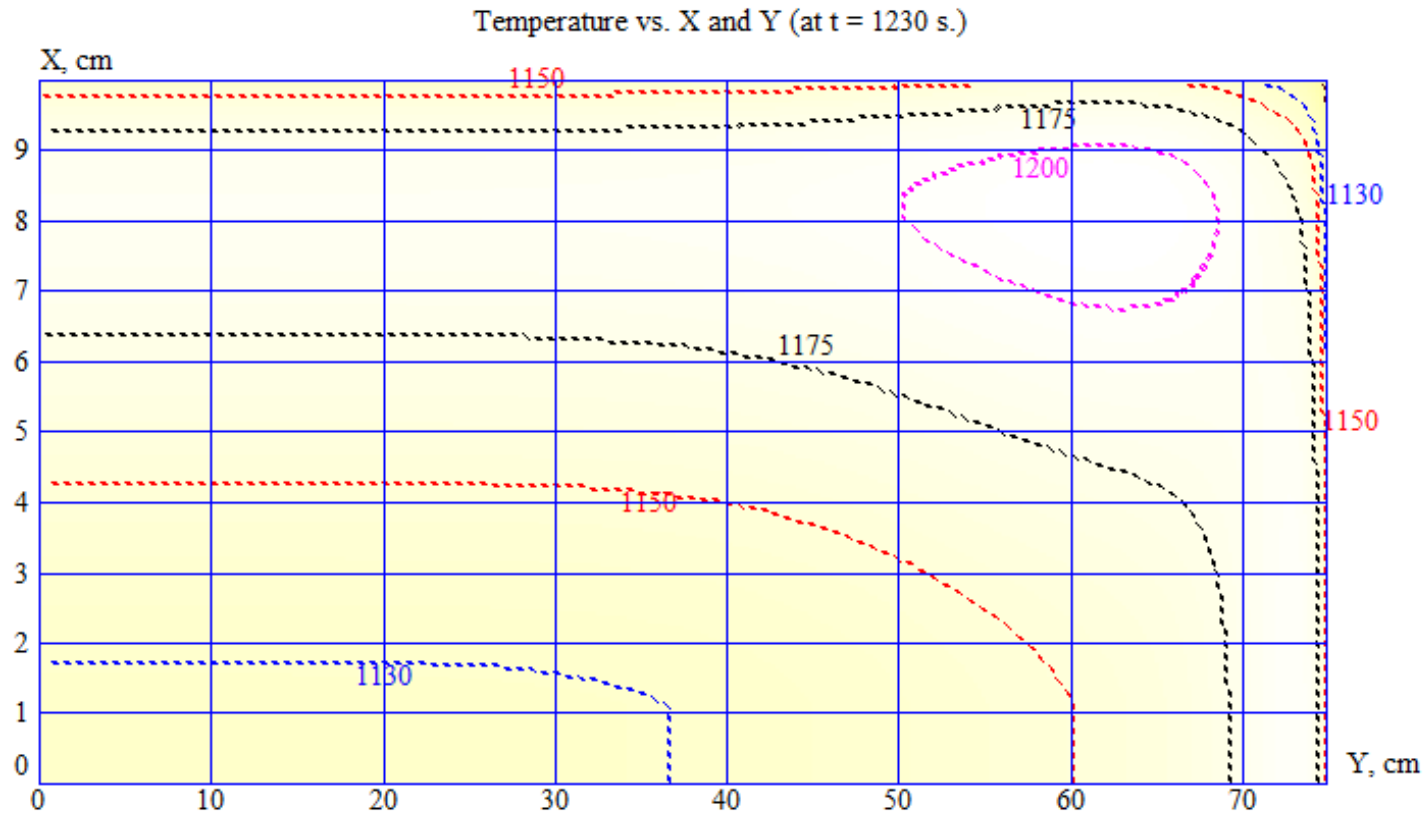


Frequency 50 Hz

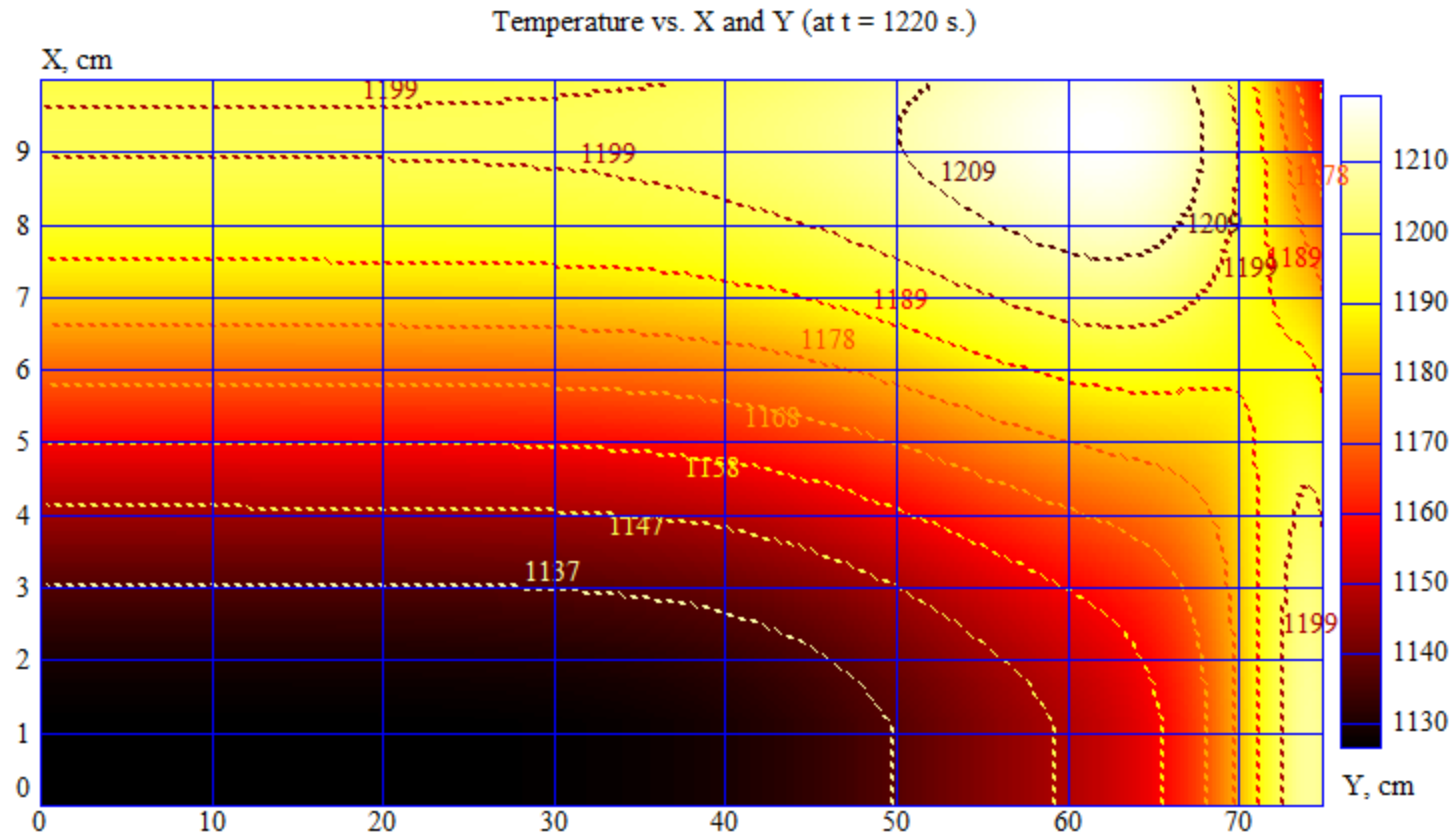
Temperature Map after the First Heating Stage



Temperature Map at the End of Processing

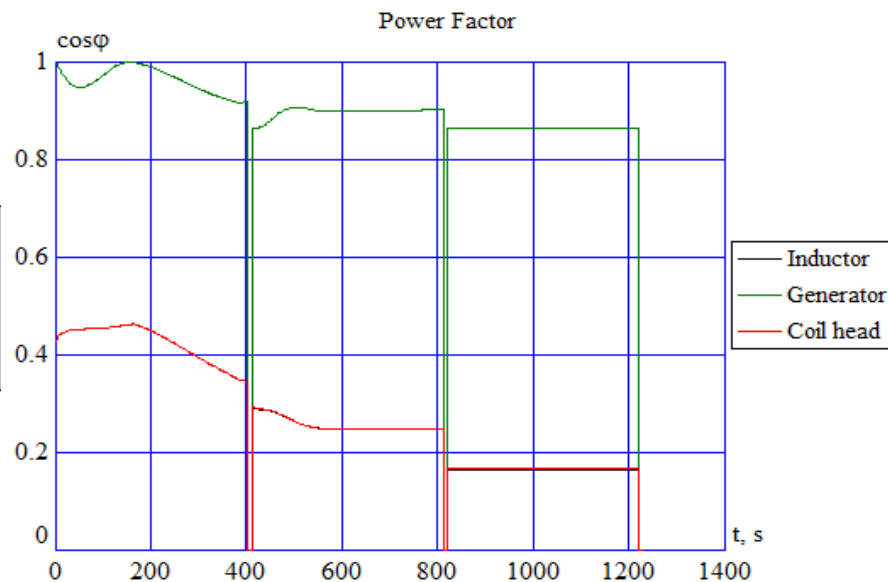
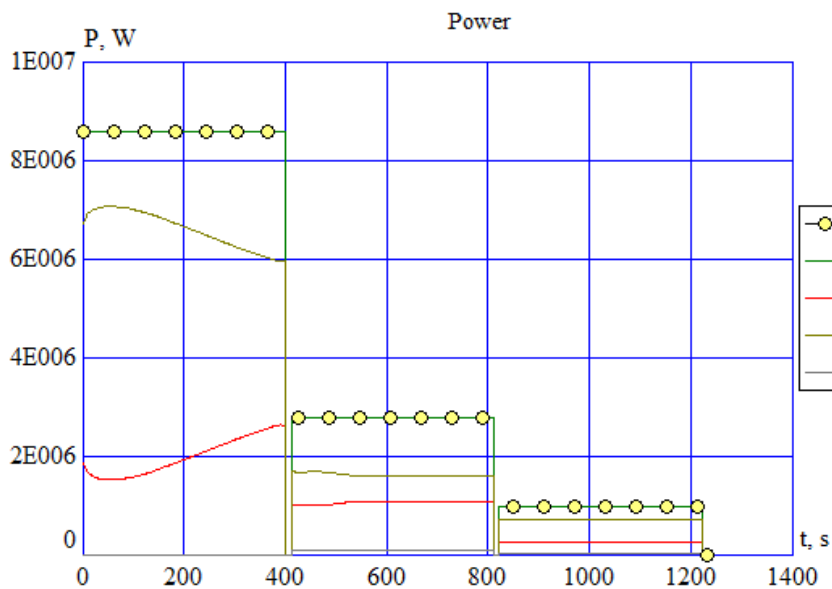
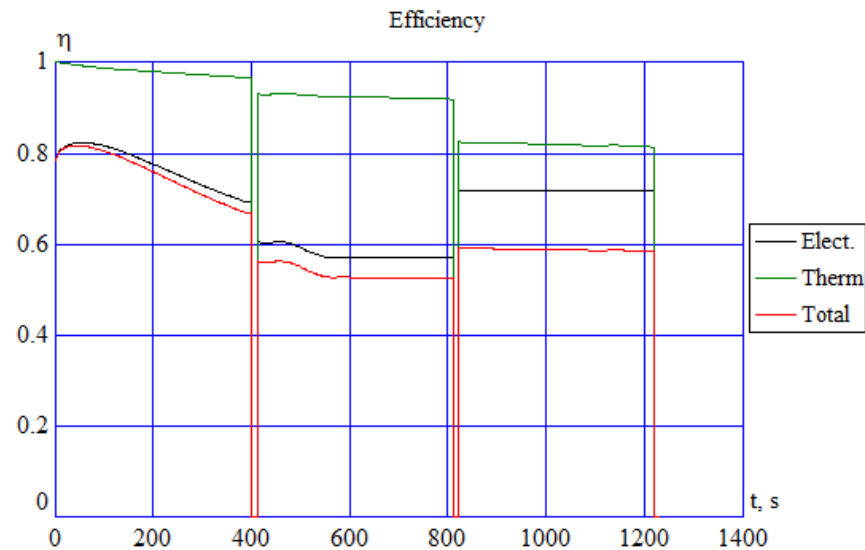
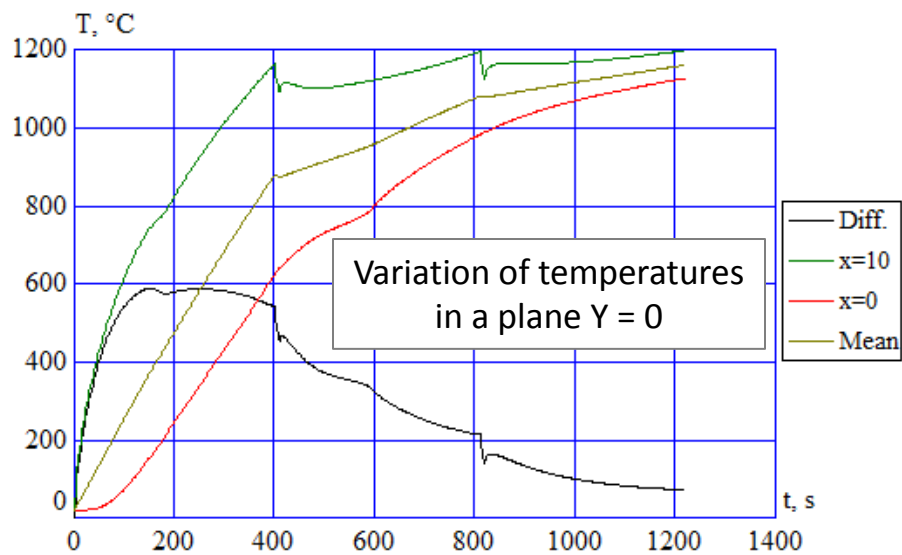


Map of Temperature Difference after the Third Heating Stage

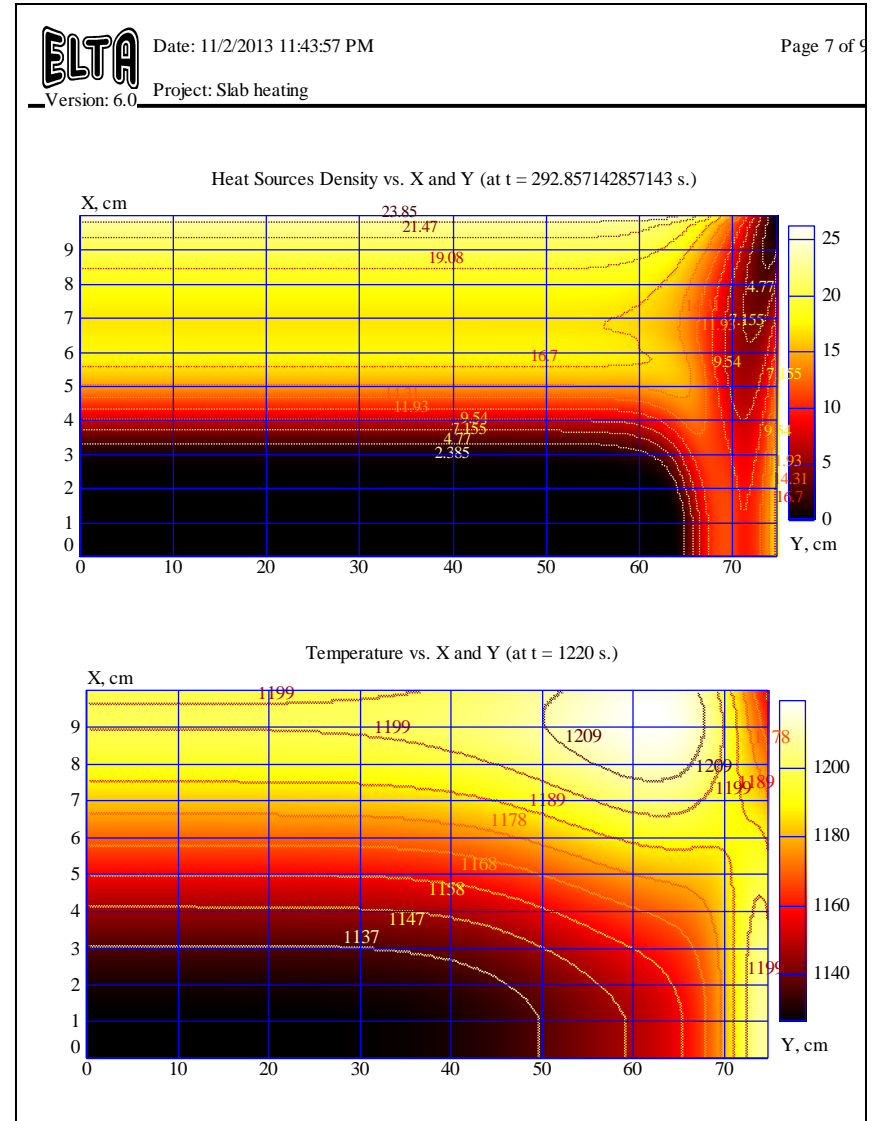
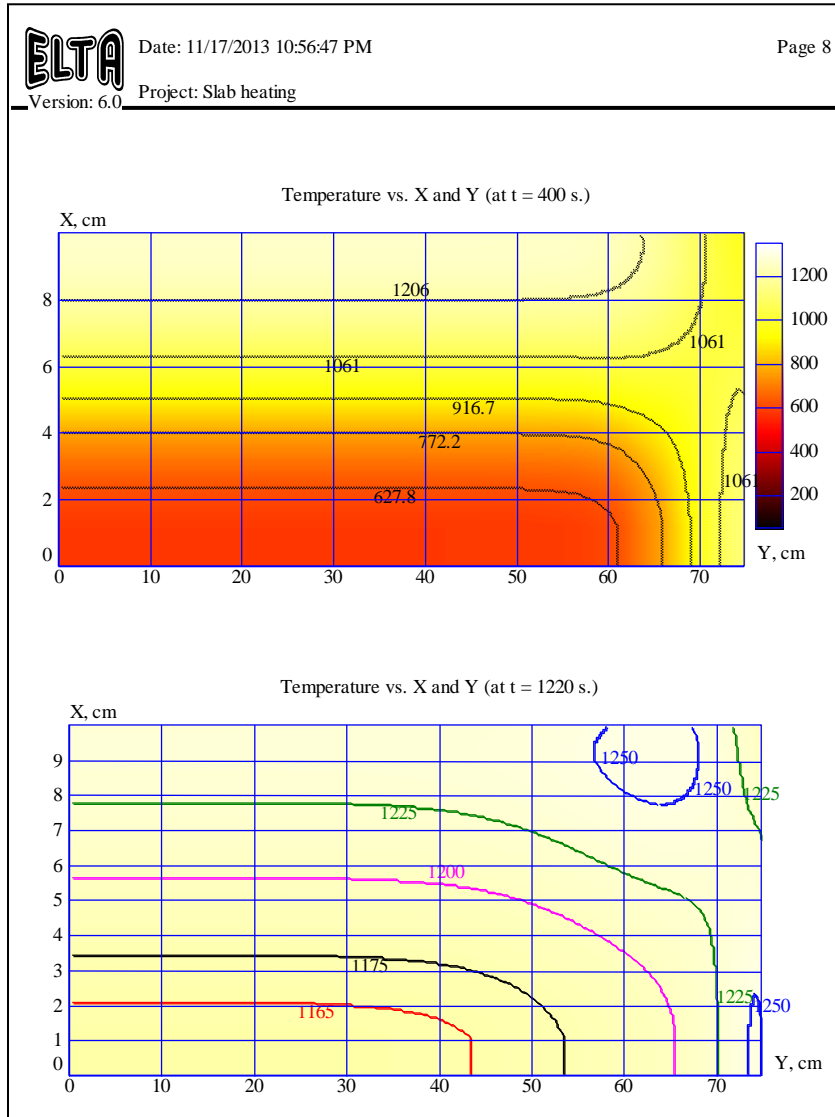


Numbers on the curves show real temperatures; colors correspond to temperature difference relative to the slab center

Dynamics of the Installation Parameters



Examples of Report Pages



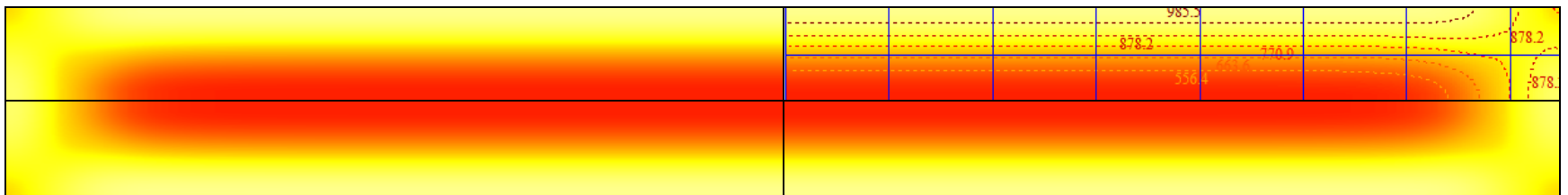
Comparison of Powers

Case	Description	Coil Power , kW			Total Power, kW	Specific Energy kWh/t
		Coil 1	Coil 2	Coil 3		
1	1D one step	1.45 x 9			13050	308
2	1D accelerated	8600	3000	1300	12900	300
3	2D accelerated	8600	2800	1000	12400	292

- 1D and 2D simulations (cases 2 and 3) give close results in integral power parameters
- Accelerated heating allows to use one line with three inductors instead of 9 inductors for a single-stage heating providing the same production rate
- Due to faster heating and optimized coil design used in accelerated version, specific energy was reduced for 5.2%

Conclusions

- Elta 6 has all the options of previous versions of Elta including Elta 5.5 plus an option of 2D simulation of rectangular body heating
- Integral parameters of induction heater calculated using 1D and 2D options are rather close and 1D may be used for preliminary design of induction process (frequency selection, power stages, time)
- 2D simulation may be used for final design and accurate calculation of temperature in the whole cross-section of slab
- Elta 6 simulates 2D tasks in several minutes and may be effectively used for system and process optimization including multistage processes



Example of temperature distribution in the whole slab cross-section