# PROJETO SENAFOR 2015

## USE OF THE ELTA SOFTWARE FOR STUDY OF ELETROMAGNETIC AND THERMAL PROCESSES IN INDUCTION HEATING STEEL FORGING LINES

Synergetica
Sistemas e Processos

NSG
NEW SOLUTIONS GROUP
Software for Induction Heating

Saint Petersburg Electrotechnical University "LETI"
the oldest Electrotechnical University in Europe
1886

# USE OF THE ELTA SOFTWARE FOR STUDY OF ELETROMAGNETIC AND THERMAL PROCESSES IN INDUCTION HEATING STEEL FORGING LINES

**ABSTRACT:** This work aims to present simulation techniques for validation and revalidation of induction heating forging lines with approach on the thermal process and focuses on energy optimization through the use of the software 2DELTA-**EL**ectro**T**hermal **A**nalysis.

Presentation contains information of induction heating of steel products, material characteristics, electromagnetic and thermal process in inductors, and simulation technique for optimal design of induction heating lines. 2DELTA is also an effective tool for learning induction heating.

2DELTA software allows users to systematically implement simulations for the induction heating applications for the most commonly geometries used in the forging shops. It is used by manufacturers and users of induction heating systems for thermal and electrical design of the induction heating forging line.

General considerations about use of simulation for validation and optimal design of heating lines are supported with an example of validation of one multi-stage line for heating billets for forging purposes.

# USE OF THE ELTA SOFTWARE FOR STUDY OF ELETROMAGNETIC AND THERMAL PROCESSES IN INDUCTION HEATING STEEL FORGING LINES

Eng. José Carlos **Zerbini** _zerbini@synergeticasp.com.br

Synergetica Sistemas e Processos

Dr. Alexander **Ivanov** ivanov_a_n@inbox.ru

Petersburg Electrotechnical University LETI

Dr. Vladimir **Bukanin** vabukanin@nsgsoft.com

Petersburg Electrotechnical University LETI

Eng. Ademir Angelo de **Vasconcelos** ademir.vasconcelos@thyssenkrupp.com

ThyssenKrupp Metalúrgica Campo Limpo Ltda


**Produtos e Serviços:**

**Produtos:** ELTA 5.5 , ELTA 6.0 e 2DELTA (**EL**ectro**T**hermal **A**nalysis**)**

Software de dimensionamento e simulação de processos de aquecimento indutivo

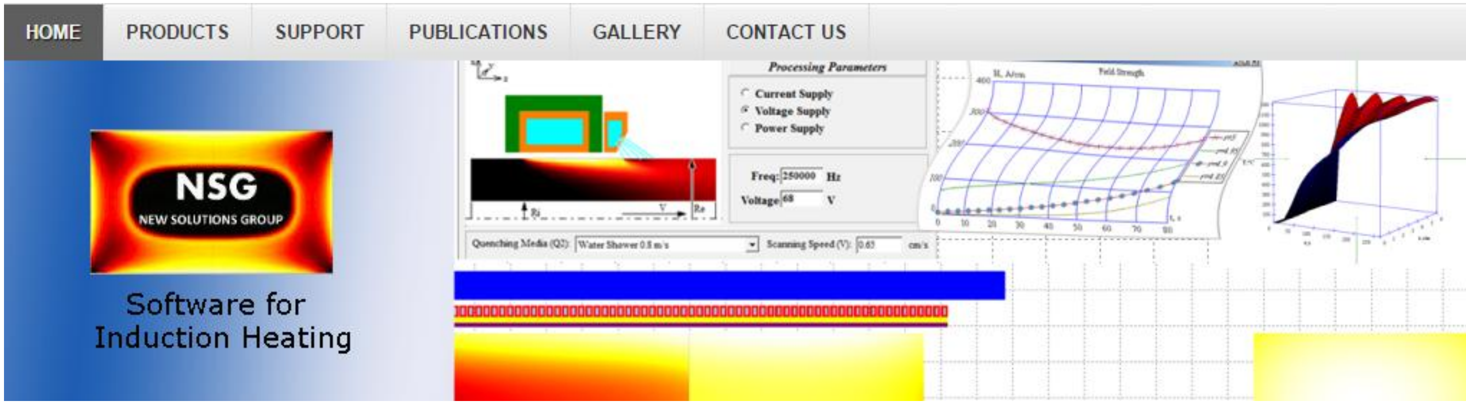
para a indústria e instituições de ensino (laboratório virtual) nas áreas de:

- Tratamento Térmico por indução;
- Aquecimento por indução para conformação à quente;

**Serviços:**

- Consultoria e treinamentos em engenharia elétrica de potência
- Implantação de Sistema de Gestão da Energia – ISO 50001
- Treinamento em processos de aquecimento por indução
- Otimização de processos indutivos

**www.synergeticasp.com.br**




NSG is a group of young Russian enthusiasts, Professors and Students, working on implementation of computer simulation techniques in the field of electrical engineering.

NSG is based out of the world known St. Petersburg Electrotechnical University, Russia, the birthplace of many revolutionary inventions and innovations in Broadcasting, TV, Electrochemistry, Ultrasonics, Electrical Drive, Automation and others.

In the walls of our university (former LETI), Professor Vologdin made his first experiments in Induction Hardening (1934-35) and founded a new direction in industry – Industrial Application of High Frequency Currents.

NSG provides consulting and research services as well as related computer simulation programmes in Induction Heating. Due to its own experience and worldwide networking NSG is able to find effective New Solutions to many difficult problems or assist the customer in establishing business and scientific contacts.

**www.nsgsoft.com**

**A process approach to investigate an induction heating before forging:**

The principle of forging is to obtain, using hot deformation of a metal, by shock or pressure, the approximate or definitive required shape and dimensions of a work piece, while improving its mechanical characteristics.
Induction heating lines are widely used in steel industry for heat treatment and hot deformation (extrusion, rolling, forging) of billets, slabs, tubes and others products.

Multi-zone lines of high productivity are the most effective equipment for this purpose. Simulation of such lines using traditional software package requires multi-stage processing with transfer of heating results from one stage to the next. This presentation will use 2D **EL**ectro**T**hermal **A**nalysis software (2D ELTA) to investigate the electromagnetic and thermal process of an existing induction heating line comparing calculation with field results.

**A process approach to investigate an induction heating before forging:**

By definition a billet induction heating line must deliver work pieces at the right temperature profile and right production rate, defined by the forging process, using the best economical and technical practices .

The design or optimization of any induction system must balance the use of power and time against the required thermal profile in the load. Simulation with 2DELTA reveals the relationship between power, time and thermal profile during heating, transportation and cooling, allowing induction equipment users to balance and optimize complex induction processes.

To enter the simulation into ELTA it is necessary the billet mechanical characteristics and an understanding of the billet heated specification prior to forge. Based on this it is possible to select the proper coil and a preliminary start point for initial calculation to achieve the required thermal specs and adequate coupling to the induction heating power supply.

## 2DELTA calculation approach:

2DELTA (Two Dimensional ELectroThermal Analysis) is a subject oriented program developed to design of induction heating processes and equipment for a cylindrical system [1].

2DELTA program provides a two dimensional simulation of electromagnetic and thermal fields in cylindrical induction heating using both integral and differential numerical methods. A sketch of 2D induction heating system is shown in Figure 1.

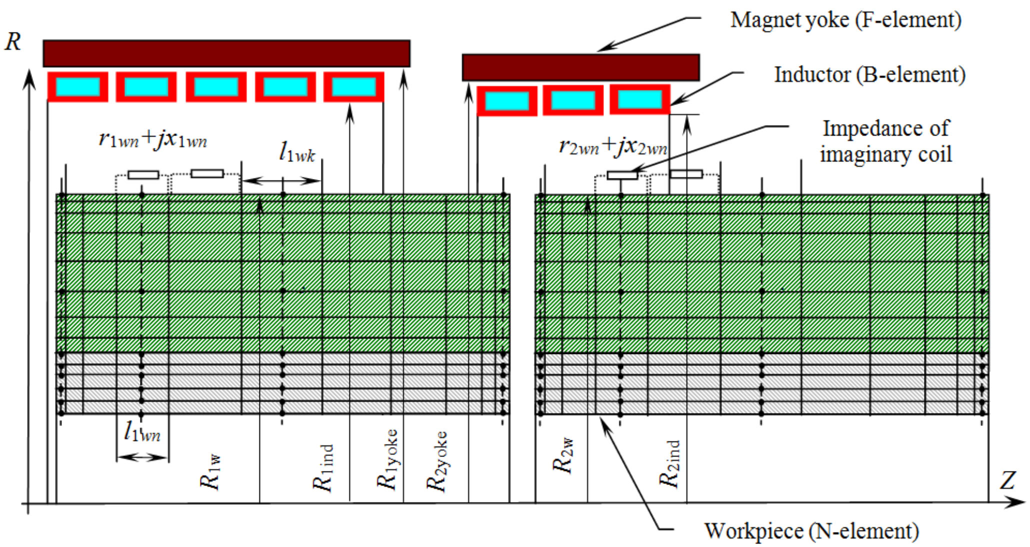



Figure 1. Sketch of calculated induction heating system

Algorithm realization for this works was supported by Dr. V. **Bukanin** and Dr. A. **Ivanov** from St. Petersburg Electrotechnical University LETI and NSG Soft.

# Real technological process on the forging and pressing plant

Specification depends on the final forged piece and related technology being used. This must be taken in consideration when designing / setting up the induction heating line.

For the purpose of this work, a round billet will be investigated in a fully operational induction heating line before forging. The induction heating line for hot forging of steel work pieces consist of two parallel connected coils (Figure 4).


Figure 4. View of investigated induction system in 2DELTA program (100mm displacement)

Parameters of system:

Workpiece: diameter 84 mm, length 250 mm Material: 44MnSiVS6

Induction system: first coil – internal diameter 162 mm, length 2340 mm, turn number 128, refractory thickness 15 mm; second coil – internal diameter 180 mm, length 2340 mm, turn number 128, refractory thickness 16 mm;

Production rate: 2910 kg/h @ 1230 °C +/-30 °C @ Rate of push: 13.50 s

Forging coil line length: 5m Machine type: pusher

As our approach to this work is to check an existing line with 2DELTA we will run calculation at the same frequency (275 Hz) for the actual process and coils characteristics as above. Figure 5 shows evolution of the temperature along the induction heating coil line.

It is very difficult to select the correct value of capacitance in both regimes. In starting regime capacitance must be less than in stationary one, but often the control system of the power generator in some cases doesn't allow to start the heating process.

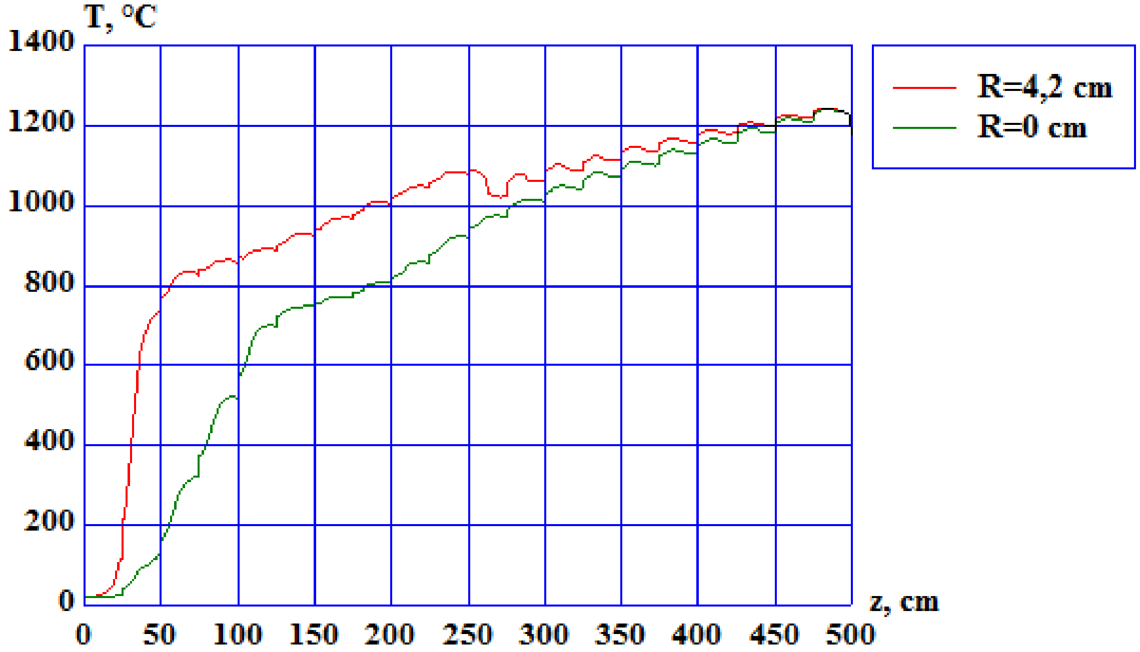
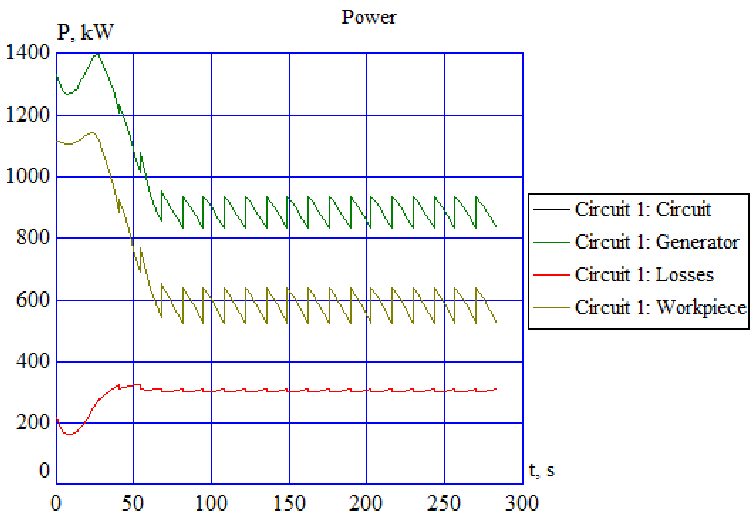
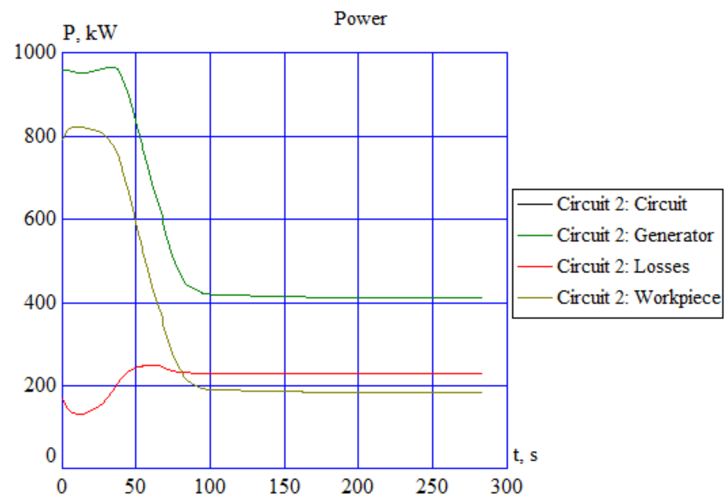



Figure 5. Temperature along the induction heating line in 2DELTA program

At cold start of induction heating line the only possible way to overpass this situation is to heat in stationary the whole work pieces line until generator goes to the set point (out of limit) before starting the pusher mechanism.

Figure 6A and Figure 6B shows that for stationary regime set point (1060 V) initial power should be approx. 1400kW + 900 kW = 2300 kW what is not possible from a 1500 kW (nominal) power converter. Power supply sees a load that is greater than nominal and goes to current limit. In fact the challenge is to balance the high coil power factor of the load at the starting regime to the nominal coil power factor in stationary regime.




Calculation shows that the average converter power in regime will be approximately 1180 kW, not taking into account the skid rails power losses and the time required to reach set point will be approx. 170 sec using an energy approach to estimate the limitation starting time.

2DELTA allows to follow each billet temperature evolution taking in consideration their position at the induction heating coil line.

Results of simulation are shown in Figures 7A (#6) , 7C (#19).

Figure 7A. Temperature difference for work piece #6 in 2DELTA calculation

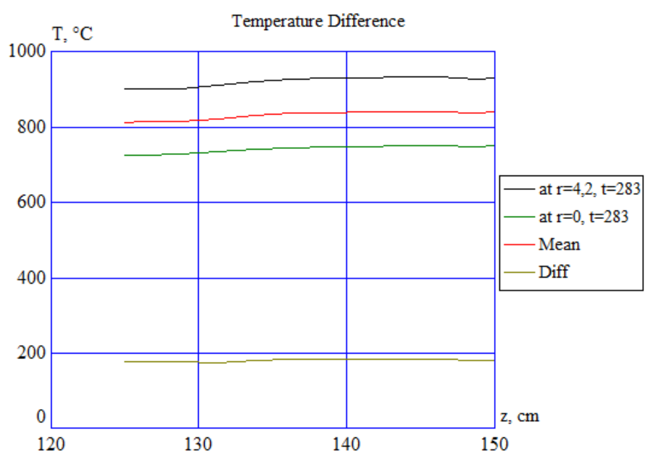
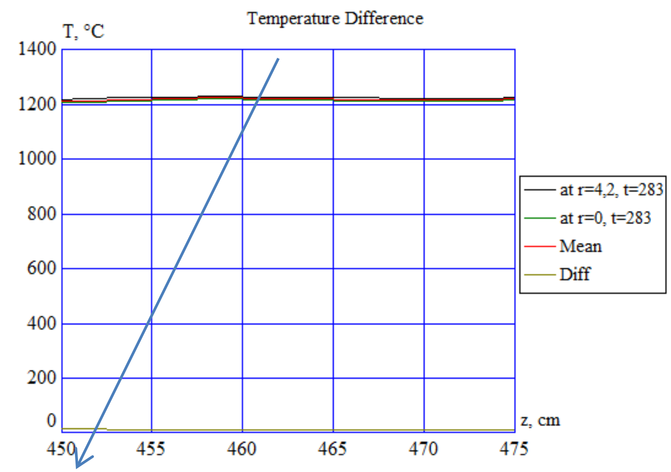
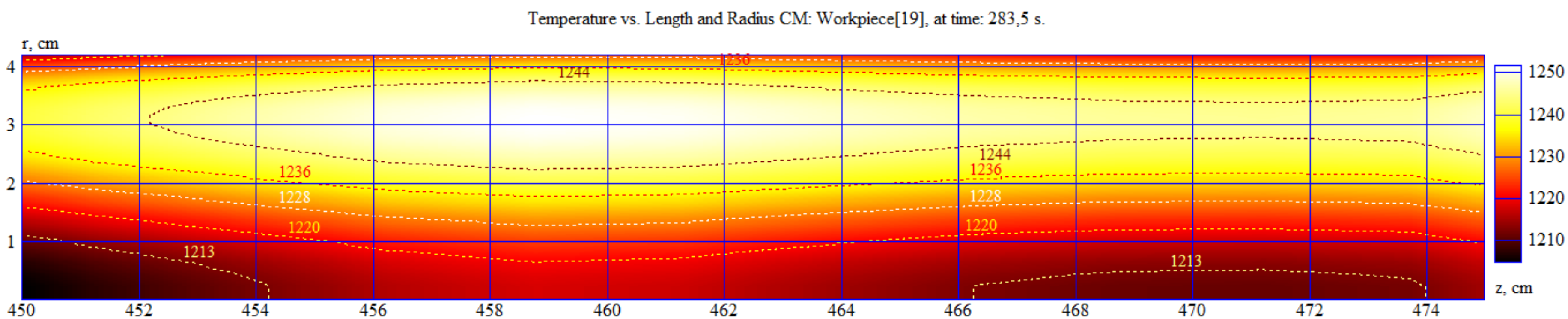


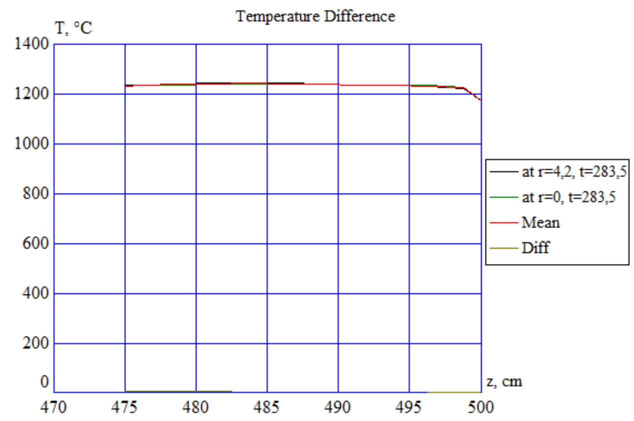

Figure 7C. Temperature difference for work piece #19 in 2DELTA calculation



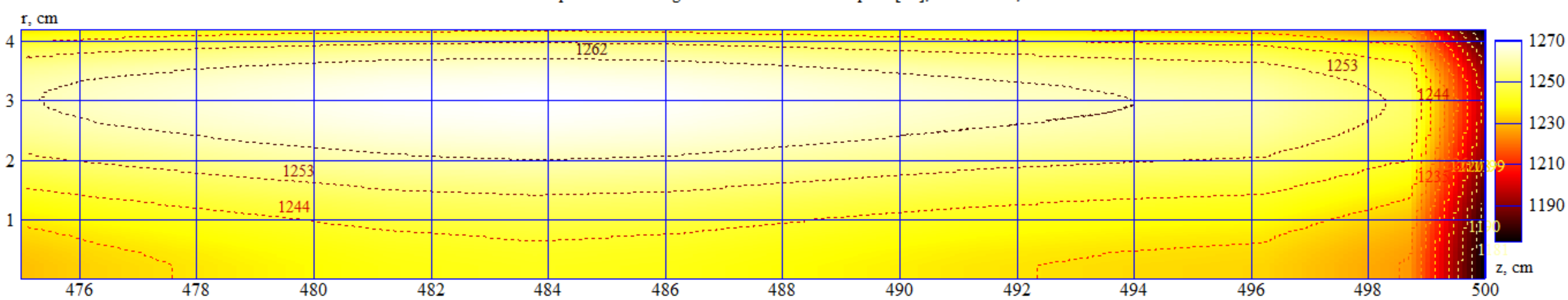



2DELTA allows to follow each billet temperature evolution taking in consideration their position at the induction heating coil line.

Results of simulation are shown in Figure 7F (#20) and in Table 2.

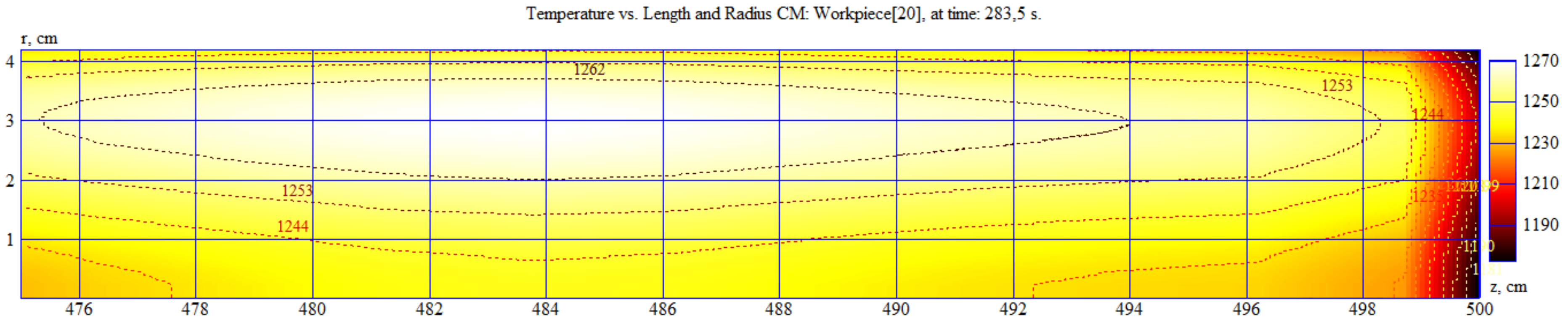



Temperature vs. Length and Radius CM: Workpiece[20], at time: 283,5 s.




Last work piece has an offset of 100 mm as in Figure 4.

Color map shows that due to heat losses from last work piece end to the environment this one is sufficiently under-heated which can decrease the quality of the forgings.




As the last billet is in direct contact with air at the exit of induction heating coil line there are additional energy losses and consequently lower temperatures as well as generation of scale due to the chemical reaction of Fe and $O_2$ for one pusher cycle time. Temperature map feature from 2DELTA calculation helps design temperature gradient along the billet length when required by a specific heating process design like typical aluminum work piece specification prior to extrusion. The values of temperature on the length of last work piece at 40 mm radius are: 1244 – 1252 – 1243 – 1180 °C.

# Real x Calculated Processing parameters:

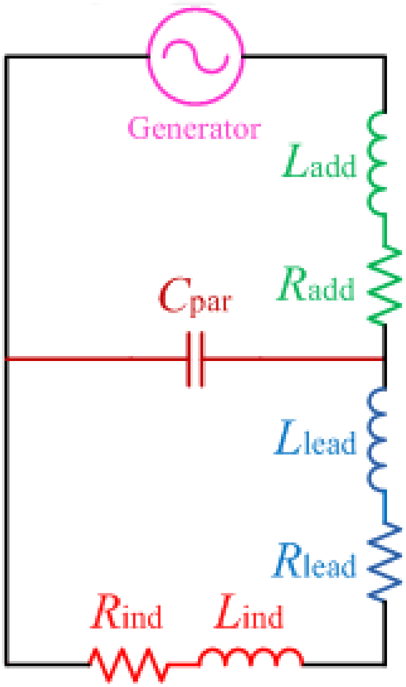
Final average temperature for last work piece 1220±50 °C (1270 -1170), frequency of power converter in stationary stage of heating 275 Hz, constant coil voltage 1060 V (coils are connected in parallel), production rate is 2910 kg/h (rate of push 13.5 sec). Calculation time are found knowing production rate (calculations are made in time, which is related to position of the test point on the part surface in a real process of heating $t = T\times(n+1)$, with $T$ – rate of push and $n$ – number of workpieces in the coil, i.e. heating time for coil line is 20+1 x 13, 5 = 283.5 sec). Results of calculation are shown in Table 1.

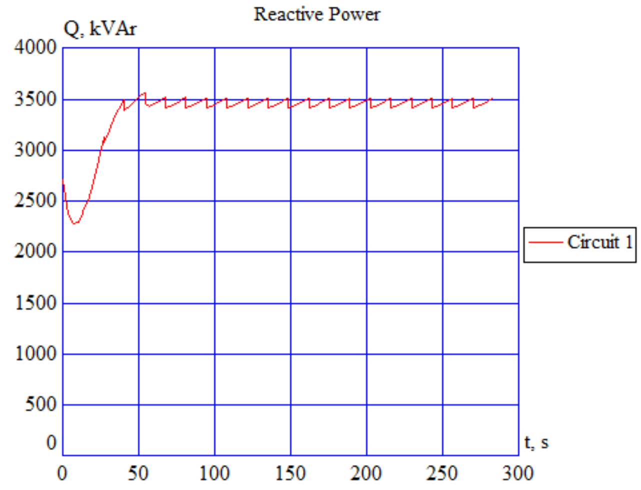
| *N* | *Icoil*, A | *Pcoil*, kW | *Ucoil*, V | cos φcoil | *Zcoil*, Ohm | $\eta_{el.}$ | $\eta_{tot}$ | $T_{mean}$, °C |
|---|---|---|---|---|---|---|---|---|
| 1 | 3342 - 3402 | 936 - 834 | 1060 | 0.264 – 0.231 | 0.317 – 0.313 | 0.680 – 0.628 | 0.645-0.581 | 835 |
| 2 | 2773 | 410 | 1060 | 0.140 | 0.382 | 0.444 | 0.260 | 1213 |

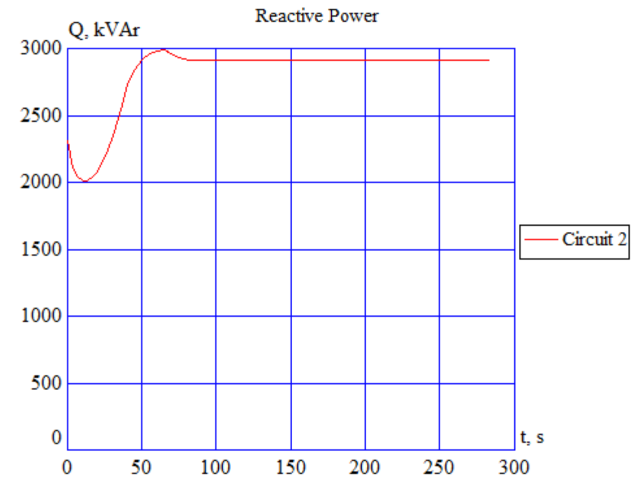
*Table 1.* Integral parameters of induction coils

From Figure 6A and Figure 6B average generator power is 1343 - 1244 kW @ 275 Hz which means that at 2910 kg/h the energy consumption is 462 - 427 kWh/t for this process. Investigated work piece diameter is equal to 84% of maximum coil work piece (100 mm diameter) for this line.

From reactive power Figure 8A and 8B in stationary regime it is possible to calculate the capacitor bank for this application. Total reactive power is 3508 + 2912 = 6420 kVAr.




Cpar from 2DELTA calculation are 1808 and 1500 microfarads.

At the circuit configuration (parallel) running at 275 Hz and 1060 V the capacitor bank will be: 3308 microfarads.

As Ladd, Radd, Llead, Rlead were not available they were let = zero for this case study.

Power meter = 1300 kW , Freq meter = 275 Hz, Voltage meter= 1060 V. Heat station capacitance Cpar = 3190 microfarads (Figure 9).

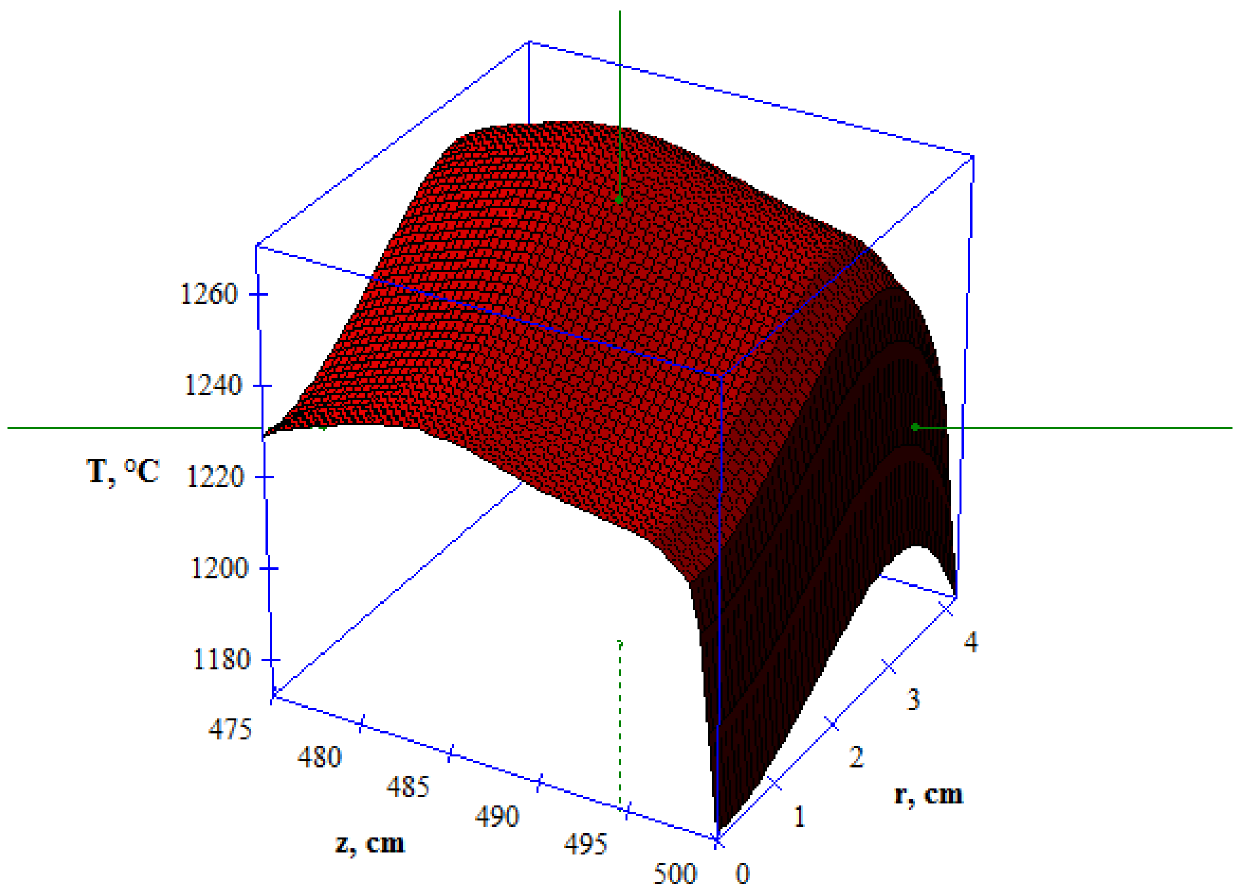
Figure 9. Circuit in 2DELTA

From calculation

At the heat station

Maximum temperature expected from 3D map temperature at the external layer: 1268ºC (Figure 10)
A pyrometer with a peak detect measurement approach is being used at exit of the induction coil line to accept work piece quality temperature .Average peak temperature got from a 10 measurement: 1186ºC
Pyrometer emissivity: 0,95

Temperature vs. Length and Radius 3D: Workpiece[20], at time: 283,5 s.



## USE OF THE ELTA SOFTWARE FOR STUDY OF ELETROMAGNETIC AND THERMAL PROCESSES IN INDUCTION HEATING STEEL FORGING LINES

Conclusion:

This investigation shows that observed results at the real operation condition of an existing induction heating line before forging are very close to the that 2DELTA calculation.

2DELTA calculation shows that thermal temperature quality is within the specification.

Further simulation shows that a better energy efficiency operation (approx. 15%) with the same thermal process can be achieved by improving the coupling of work pieces to the coil.

The time required to the power converter getting to set point was measured as 152 sec and compared with the calculated estimated time of approx. 170 sec. This verification and additional simulation allows end users to simulate stationary regime (starts with cold work pieces) and get the best starting point to the pusher mechanism in order to minimize starting time before first good work piece delivered to the press.

2DELTA is an important tools for teaching, design and troubleshooting induction heating process..

Further investigation must be done to set the influence of the scale generation on the temperature measurement and thermal conductivity restriction at the external surface of work piece.

Agradecimentos :

À comissão do SENAFOR 2015 pela oportunidade de apresentar este trabalho , em especial ao Prof. Dr. Brito e à Sra. Lourdes. .

Ao Eng. Ademir A. de Vasconcelos pela disponibilização do equipamento e apoio para coleta e verificação da medições utilizadas durante a realização deste trabalho.

Synergetica
Sistemas e Processos

**Obrigado pela atenção**