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Practice of Computer-Assisted Design of induction installations

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Abstract

Company FREAL-Ltd, St. Petersburg, produces a wide range of induction installations and power supplies and uses in it's practice ELTA 6.0 and 2DELTA for design installations for forging, heat treating hard-facing and other technologies. To prove the efficiency and accuracy of the above mentioned software a lot of calculations and analysis of electromagnetic and thermal processes was carried out. One of them is the specially designed coils with non-uniform distribution of turns. Simulation allows improving the design of inductors, and obtaining optimal power value, heating time and frequency of HF power supplies. It is worth to mention that the programs are very useful for matching coils and generators with different layout of the power supplying circuits. Presentation is illustrated by description of some induction installations designed and produced by FREAL-Ltd using ELTA and 2DELTA.

Introduction

Designing of induction heaters is very interesting and creative process. Usually, the consumer wants to obtain the installation, which can realize the required technology of the thermal processing. The technologies are widely varied, for example, heat treatment, induction hardening, and many others. Possessing rich practical experience of designing the designer can find for itself the possibility of the creation such installation. After consent to execute this work he must define the necessary constructive elements of system and can develop the technical requirement.

The designer of installation has to know the main parameters of the induction system, e.g. configuration, turns number of coil, shape and size of the tube, thickness of heat insulation and other parameters to meet the necessary requirements of heating technology. He must choose also power supply, the electric or mechanical drive for moving the workpiece, cooling system, system of temperature control and other elements. In this case the approximate expenses of development and a final cost of induction installation can be basically calculated. Modern developers rarely use in practice the approximate methods of calculation to obtain even the main integral parameters of inductor. More often computer methods of calculation and analysis are used.

ELTA 6.0 and 2DELTA programs open wide opportunities for the specialists employed in design and production of induction heating installations. Many types of cylindrical and flat shaped parts are used in industry and they have to be heated by induction method with different technologies. Above mentioned programs are effectively used in practice of work and Computer-Assisted Design process of FREAL-Ltd research-and-production company.

1. Feature of ELTA and 2DELTA

Modified program ELTA 6.0 and completely new program 2DELTA may be effectively used in design of induction heating installations [1–3]. These programs allow quick obtaining of rather accurate results for typical practical applications of induction heating. Advantages of programs consist in opportunity of their use without special training and programming skills, good for practical tasks accuracy and a lot of additional options such as water cooling of the coils, convenient database, multiple modes of coil energizing and circuits for power delivery, etc.

The calculation programs ELTA 6.0 and 2DELTA can solve many tasks in process of computer-assisted design, allowing to obtain:

- integral parameters of inductors (efficiency, power factor, impedance, current, voltage, reactive power, etc.);
- temperature distribution in the workpiece cross-section for ELTA 6.0 and in the workpiece cross-section and on the length for 2DELTA (during the heating and cooling cycle, including quenching);
- power of source;
- rational type of resonant circuit;
- parameters of water cooling system (flow rate, pressure, temperature etc.);
- electro-dynamic forces (in the workpiece and in the coil);
- cooling diagram for induction hardening of steel, etc.

2. Iinstallations designed and produced by FREAL-LTD

Some examples of computer-assisted design for induction systems are shown bellow. The first example is specially designed coils with non-uniform distribution of turns. The main parameters of induction system are:

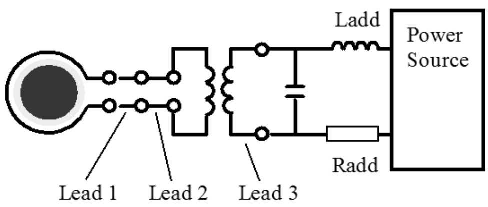
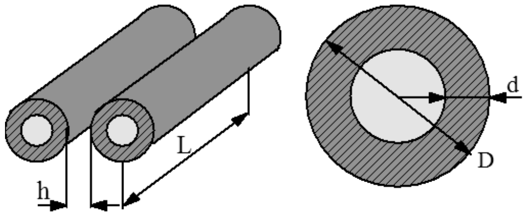
- length of inductors – 11.8 cm;
- turn number – 10;
- internal diameter of coil – 7 cm;
- frequency of power source – 71.8 kHz;
- length of workpiece – 10 cm;
- external diameter of workpiece – 2.8 cm;
- cylinder material – steel 40.

Technology requirements:

- final temperature – 220 ± 15 °C;
- temperature difference on the length of surface – 5 °C;
- required speed of heating – 5 °C/s.

In the first stage of computer design with ELTA a preliminary 1D-Model is built. The main scope of this modeling is obtaining the main integral parameters of the induction system and process productivity. An inductor with uniform distribution of turns is taken into account for this model. Configuration of induction system is shown in the Tab. 1. A standard high-frequency converter of FREAL-Ltd with PWM is connected to the induction system, and a power source in the model is selected. The initial value of generator power in calculation is 1000 W, the final is 2000 W. Series of simulation showed that to ensure the speed of heating about 5 °C/s on external surface the generator power can be approximately 1600 W. The total heating time in this case is about 42 s. The electrical parameters of inductor for this power are shown in the Tab. 2.

Tab. 1. Parameters for 1D-Model

Circuit	Leads
	
Trafo ratio = 6, Magnetization current = 6 %, Voltage Drop = 15 %, Transformer Efficiency = 85 %	Lead 1: type: round; D=0.6 cm; d=0.2 cm, h=10 cm, L=20 cm. Lead 3: type: round; D=0.6 cm; d=0.5 cm, h=0.2 cm, L=200 cm.

Tab. 2. Average values of integral parameters (1D-modelling)

Parameter	Value	Parameter	Value
Coil Voltage, V	123.68	Frequency, kHz	71.8
Coil Current, A	70.175	Generator Current	1.995
Coil Impedance, Ω	1.764	Generator Power Factor	0.968
Coil Power Factor	0.157	Total Efficiency	0.716
Workpiece Power, W	1162.8	Generator Power, W	1600

In the second stage of design 2DELTA is used and 2D model is built. The main scope of this investigation is obtaining the temperature distribution versus length and radius. Configuration of induction system is the same. Results of calculation temperature along cross-section are shown in the Fig. 1.

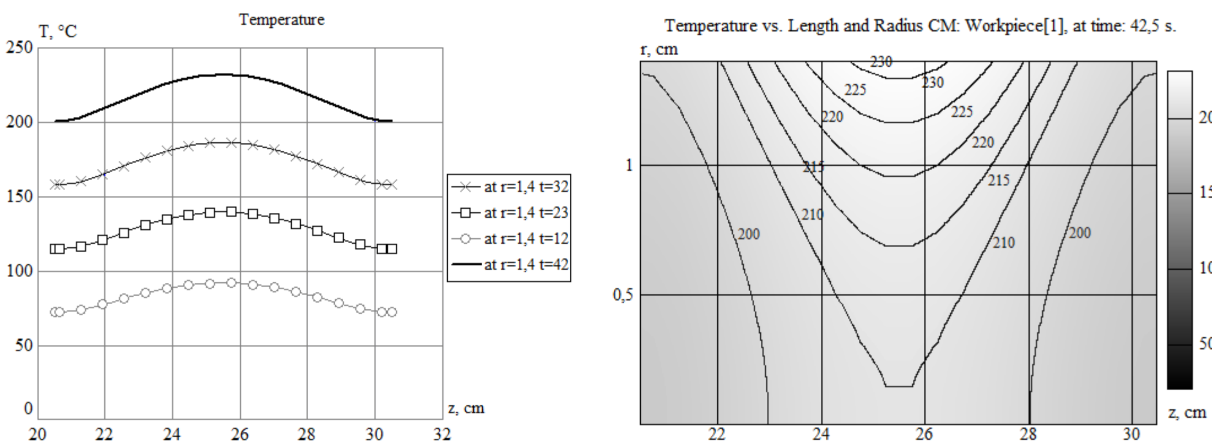


Fig. 1. Temperature distribution along the cross-section of workpiece

Temperature difference along the workpiece length is more than ± 10 °C. Such variant of the inductor does not provide the required technological parameter of the heating. In the third stage a step of turns in the border regions of the inductor is changed as shown in Fig. 2. Results of calculation are presented in Fig. 3. Temperature distribution is comparatively uniform and temperature difference along the workpiece length is less than ± 5 °C.

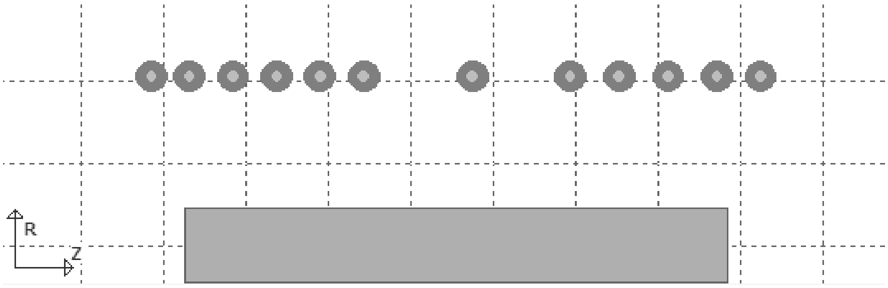


Fig. 2. Sketch of the induction system with non-uniform distribution of turns

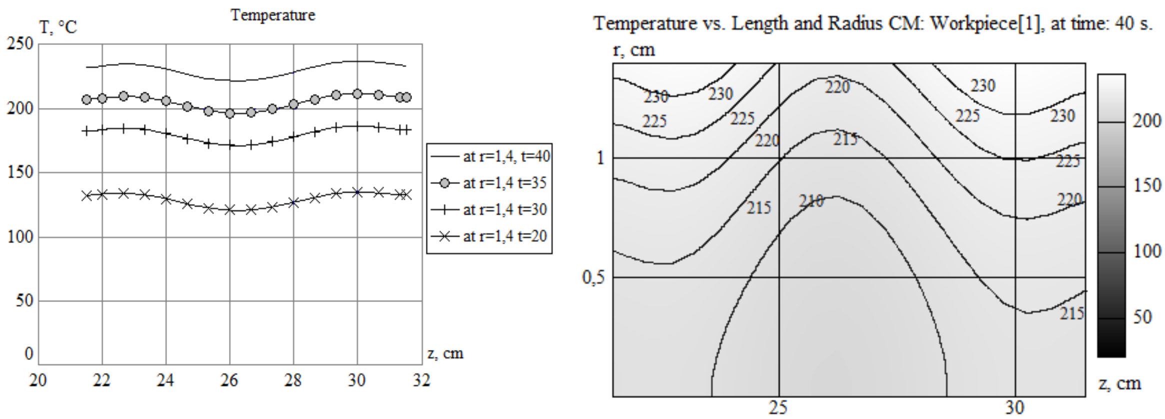


Fig. 3. Temperature distribution along the length and cross-section of workpiece

The next variant of induction heating system is coil with a specially designed magnet yoke and thermal insulation (see Fig. 4).

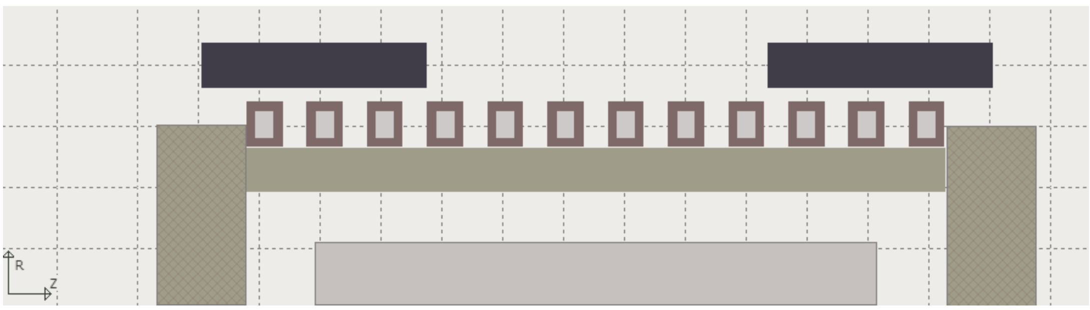


Fig. 4. Sketch of the induction system with magnet yoke and thermal insulation

The main parameters of induction system are:

- length of inductors – 15.5 cm;
- internal diameter of coil – 7 cm;
- turn number – 12;
- frequency of power source – 21.0 kHz;
- length of workpiece – 12.5 cm;
- external diameter of workpiece – 2.8 cm;
- material of workpiece – steel 40;
- material of magnet yoke: ferrite;
- permeability: 600;
- thickness: 1 cm;

- length: 5 cm;
- interior radius: 4.8 cm.
- Material of thermal insulation: ceramics (α=0.02 W/(cm·°C); ε=0.7).
- Inductor insulation:
- Length: 15.5 cm;
- Thickness: 1 cm;
- End covers:
- Height or radius: 4 cm;
- Thickness: 2 cm.

Technology requirements:

- final temperature – 1200 ± 30 °C;
- temperature difference on the length of surface – ± 35 °C.

Temperature versus length on the external surface is shown in Fig. 5. Temperature difference along the surface length is 145 °C, 120 °C and 70 °C for cases without magnet concentrators, with end insulation covers (TI), with magnet concentrators and with end insulation covers (TI+MY) respectively. The magnet yoke and insulation covers allow obtaining the required temperature difference along the length of workpiece.

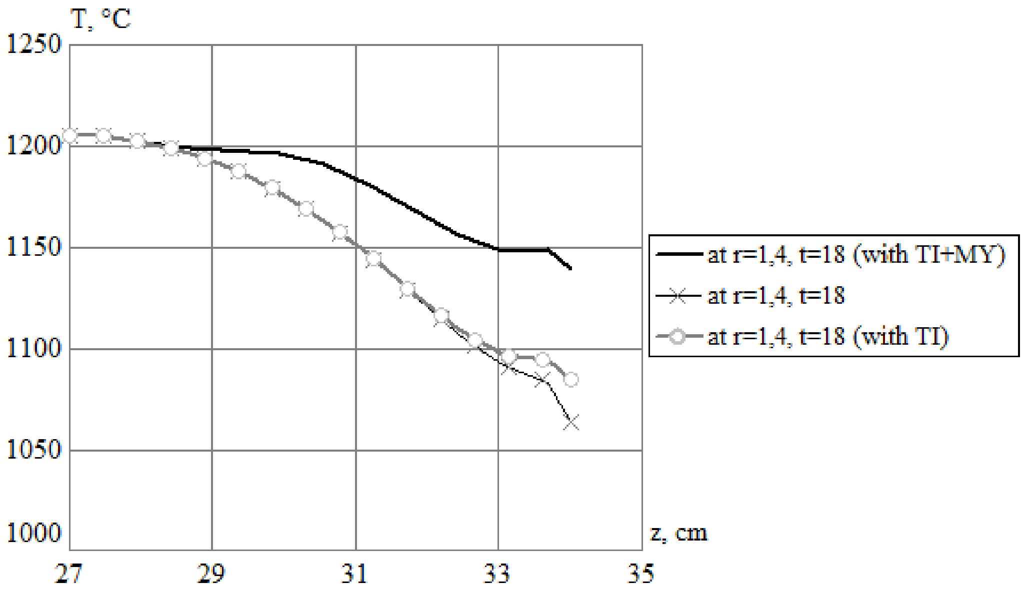


Fig. 5. Temperature distribution along the length of workpiece on external surface

The new addition of the ELTA 6.0 program for heating parts with rectangular cross sections allows to predict temperature distribution in such parts used for special applications. The design of induction equipment for heating square cross section of aluminum part is also carried out.

The main parameters of induction system are:

- length of inductors – 15,5 cm;
- internal dimension of inductor window – 7 cm;
- frequency of power source – 21,0 kHz;
- length of workpiece – 12,5 cm;
- cross-section dimension of workpiece – 2,8×2,8 cm^2;
- material – aluminum.

Technology requirements:

- final temperature – 500 ± 30 °C;
- temperature difference – ± 30 °C.

Temperature distribution along the perimeter of ¼ part of cross-section and color map of power density is shown in Fig. 6 as example of researches.

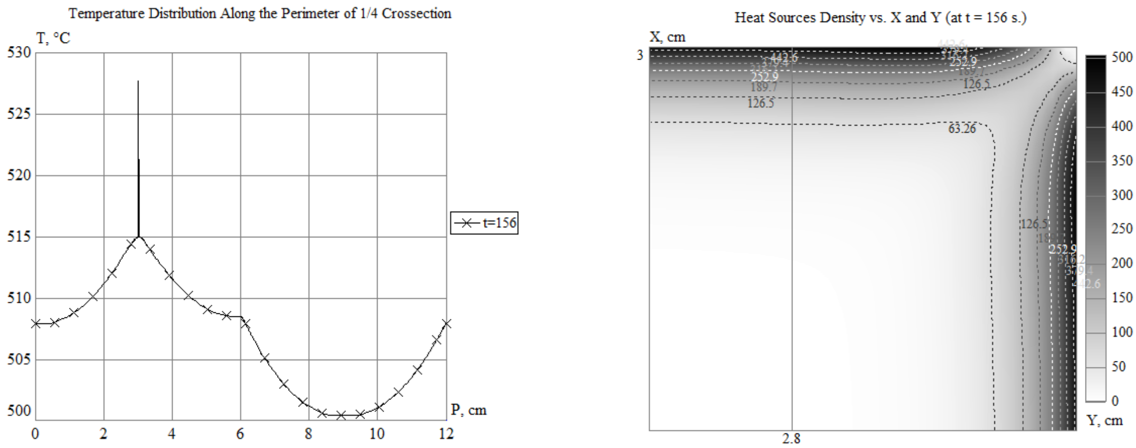


Fig. 6. Temperature distribution and color map of power density in the cross-section

Required speed of heating is obtained at generator power about 10 kW.

Conclusions

The subject oriented programs ELTA 6.0 and 2DELTA have been effectively used in the practice application of research-and-production company FREAL-Ltd allowing to design the wide range of electrothermal processes in the workpieces of cylindrical and rectangular cross section. Investigations of temperature for different workpieces of real technological processes have been carried out.

References

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[2] Nemkov, V., Bukanin, V., Zenkov, A.: *Learning and teaching induction heating using the program ELTA*. Proceeding of the International Symposium on Heating by Electromagnetic Sources. Padua, May 18-21, 2010. pp. 99 – 106.

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