Control of inductors for formation of the required temperature profile in tasks of control and design

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Abstract. Here, we introduce current design trends in modern machine building inductor installations on the example of inductor installations for heating before treatment. A particular focus is given to the numerical simulation, whose importance increases due to modern strict requirements for the technological process as well as computational power increase. Nowadays, numerical computations are required not only to calculate electromagnetic and thermal fields for separate devices but also to simulate the whole technology. New trends in computing developments allow using real-time computational model control by inverse solution (inductor parameters calculation according to the given temperature profile).

1. Introduction

Current progress in power supplies design brings serious changes into architecture and construction of inductors for heating before treatment [1-3]. This process is directly connected with the possibility to reduce power supplies' dimensions, with sharp increase in electro-thermal condensers' volumetric capacity, decrease in sizes and efficiency improvement of heat exchangers. This makes leading manufacturers of induction equipment produce induction heater as a set of modules, which have built-in frequency converters, cooling stations, capacitors banks and single-path control units.

Module structure in induction heating technology has several advantages: independent control of induction modules that allows thermal mode adjusting according to technical requirements; faults minimization during transformation processes in the system; possibility to apply heating at several frequencies; enhanced resistance to emergency situations. Simultaneously, achievement of these characteristics requires using net-work control for the induction heater to optimize installation in-service disturbance, which results in non-stationary thermal modes [4].

Basing on these, we can say that analysis, development, design of modern computerized multi-module induction heating equipment nowadays is impossible without software mathematical simulations [5]. Besides, controllability of module induction heaters in high requirements for heating quality and resources saving raises new optimization and heating control issues, as well as those solved by simulation immediately at the production site.

2. Different heating modes implementation via module construction of induction installation

In the modern induction installation the number of heating modules can vary from one to the unlimited number, but the most rational from the point of view of variability control over thermal field distribution in the workpieces it is better to use three and more heating zones. Modules number and length depends on installation productivity, heating quality requirements and workpieces parameters. Individual control of heating power in every module allows adjusting thermal modes to technological requirements such as: heating uniformity or oxide scale formation decrease.

Table 1. Comparison of workpieces heating parameters at different heating modes (for steel workpieces with diameter 130 mm, with the performance 4.125 t/h)

Temperature profile	Efficiency, %	Total power, kW	Radial temperature difference, °C	Oxide scale formation conditions	Fronts weldability conditions
1	73	1185	110	+	+
2	70	1287	50	++	+++
3	67	1380	50	+++	++

Fig. 1 shows cylindrical steel workpieces heating profiles with diameter 130 mm before treatment. They were received at different distribution of power supplies among modules of the continuous action heater with three heating zones with productivity 4.125 t/h. The lower, 1st profile, corresponds to smooth heating mode with final temperature ununiformity along the workpiece cross-section 110 °C, and the upper, 3d profile and middle, 2nd profile, corresponds to accelerated heating of different intensity with final temperature ununiformity along the workpiece cross-section 50 °C. Smooth heating mode is characterized by low oxide scale formation and high energy efficiency, accelerated heating allows minimizing surface and center temperature differences at the required productivity. Depending on the technological process requirements a necessary temperature profile can be chosen. Workpiece heating parameters at different heating modes are shown in Table 1.

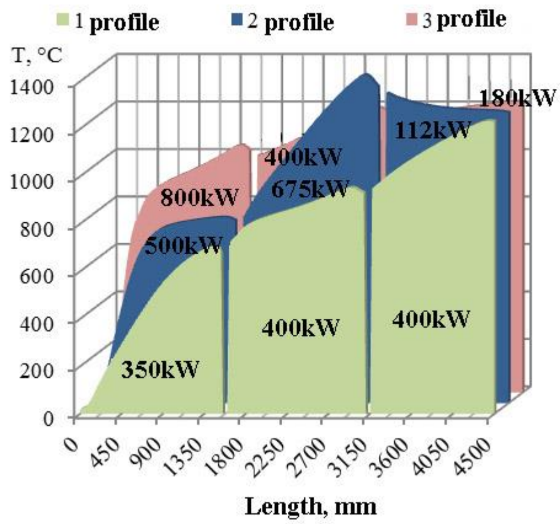


Figure 1. Temperature distribution along the heater on the workpiece surface in three modes.

3. Numerical simulation role

Increase in power, dimensions and induction installations' complexity requires profound scientific and engineering work. Traditional analytical methods of equipment design are low effective; only computer simulation can guarantee the absence of costly errors and time wastes in designing and pre-commissioning activities.

Gradual development of computer technologies during last 50 years resulted in the development of induction heating installations numerical simulation. Computer simulation had great development stages, from simple problem solution, for example, receiving active and reactive resistance for coordination with the power supply to the whole technology modeling. It means, on the one hand, taking into account all the aggregates in the continuous processing line both before and after the induction installation, on the other hand, conjugate physical processes during induction heating [6-8]. We can say that application of mathematical models is the main way of scientific knowledge enlarging, as well as the main factor of further development of induction heating theory and practical application.

Nowadays, there are two ways to simulate electro-technical installations. The first is with the use of such general software as Ansys, Flux and so on, based on finite element method (FEM). But, there are few users of this software, that is why this general software is not adjusted to induction heating problems, also, they are expensive and difficult to use. The second way is using software for fast solution of narrow professional problems, which take into account most features of the technological process. Universal 2D is used most of all for induction heating installations simulation before treatment of cylindrical bodies. It is specialized software created in the Saint Petersburg Electrotechnical University "LETI" [9].

Whereas, the finite-element method is the most popular for solving in-field problems it has several drawbacks in simulating installations for continuous induction heating before treatment, which are caused by the length of the simulated system and heated workpiece movement. That is why the software Universal 2D for induction heating installation simulations of cylindrical bodies uses a combined method of electro-thermal model construction (Fig. 2). This approach allows fulfilling a cost-effective model and reducing calculation time without accuracy loss by effective combination of different methods: integral equation method (IEM) for external problem solution (air and inductor side), finite-elements method (FEM) or finite-difference method (FDM) for internal problem solution (load side).

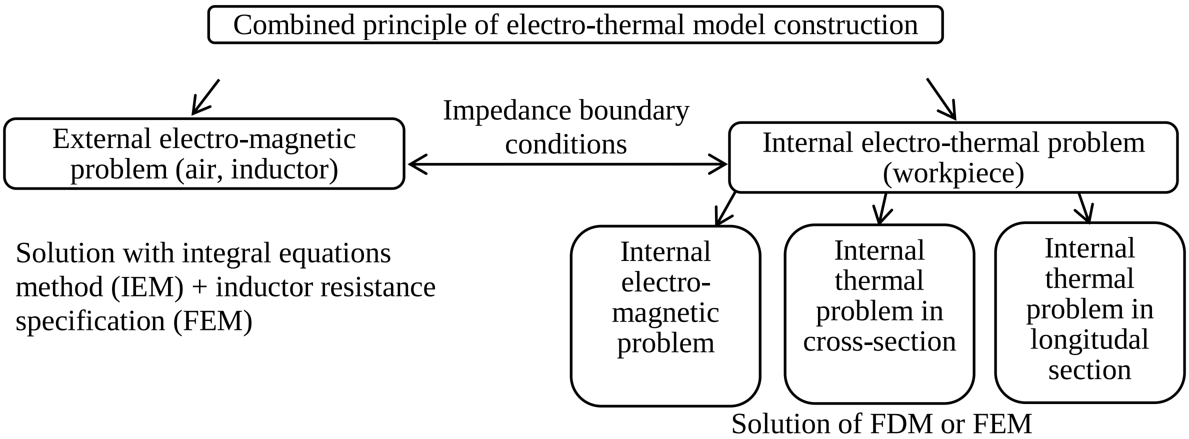


Figure 2. Universal 2D combined model scheme.

4. Inverse solution in control and design problems

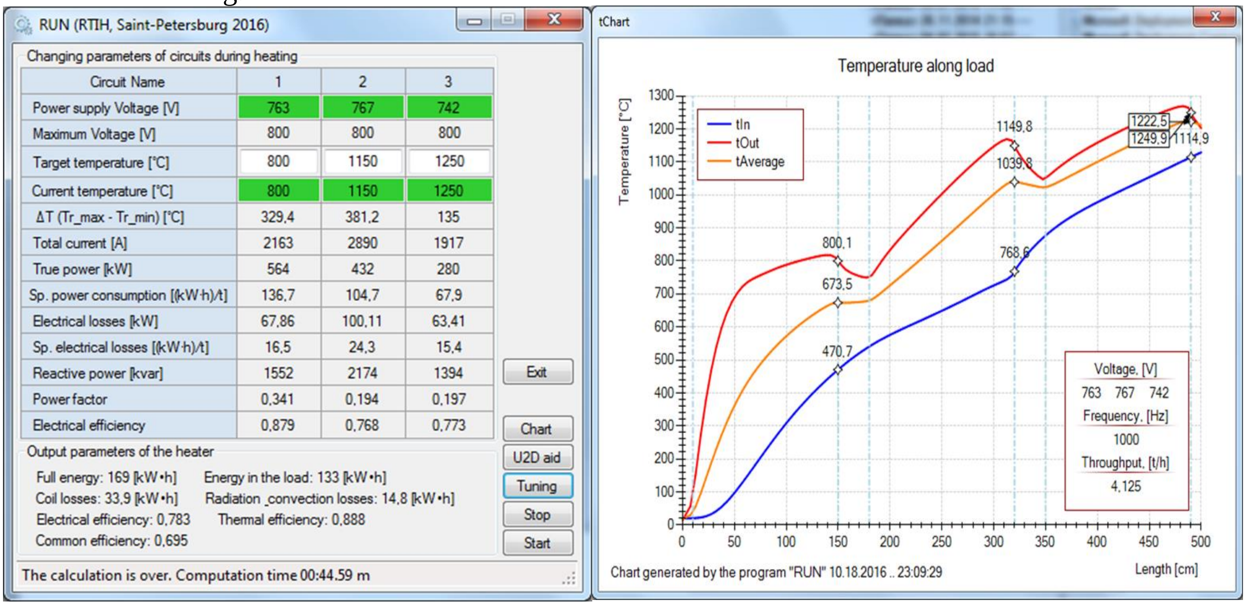
As it has been mentioned above, module constructions of induction heaters allow flexible solution for technological process problems. At the same time, this flexibility brings out new requirements both to the results and to the modeling process itself. It necessitates inverse solution (calculation of induction installation parameters according to the given temperature profile) [10-13]. So, requirements to computer-aided calculations increase that result in implementation of modern mathematical physics and computational mathematics adaptive methods into induction devices models.

Saint Petersburg Electrotechnical University “LETI” has developed inverse solution software for module continuous heaters modeling. Software TERMOPROF-CONTROL is used for power (voltage) control of module induction heaters for achieving the required temperature profile in load surface. Simulation results can be used both at the designing stage for control systems development and at the production for correction of every module voltage depending on the stock list of the heated goods and thermal treatment mode. In the last case it is done in off-line mode prompts for the technological line operator. Software TEMPPROF-DESIGN is used for designing and allows automatically finding optimal quantity of coil’s turns of a continuous module induction heater at the given surface thermal distribution and power supply. As external computational model both software use Universal 2D and its capacities in the induction heaters modeling.

Fig. 3 shows the example of TERMOPROF-CONTROL software functioning, which demonstrates the example of the continuous heater of three modules. In the main window (Picture 3.a) the required temperature is given in three points of the line (at three inductors outlet): 800 °C, 1150 °C and 1250 °C, and Picture 3.b shows the temperature final graph. Necessary voltage at every inductor after calculating, as well as other system energy parameters are shown in the main window in Fig. 3.a.

5. Conclusion

Implementation of modern automated multi-module induction installations into induction heating resulted in revolutionary changes in heating before treatment. But, to use all the advantages of these new constructions it is necessary to implement the network control of induction heaters, whose development is impossible without mathematical simulation. It increases the importance of both computer simulation and problem quality for them. Such requirements come to the front as total automation, computation speed, which allows inverse solution within reasonable time. Hence, the demand for special software development increases for narrow field application contrary to general software modeling.



a b

Figure 3. TEMPPROF-CONTROL software windows for uploading the required parameters and receiving the results.

Industry development in production computerization, software and simulation methods development allows saying about topicality of numerical model control in real-time via feed-back with control systems and inverse solution.

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