A New Approach to Induction Heating Control

Alexandr Ivanov
St. Petersburg Electrotechnical University (LETI)
St. Petersburg, Russia
ANIvanov@etu.ru

Vladimir Bukanin
St. Petersburg Electrotechnical University (LETI)
St. Petersburg, Russia
VABukanin@etu.ru

Alexei Zenkov
St. Petersburg Electrotechnical University (LETI)
St. Petersburg, Russia
AEZenkov@etu.ru

Valentin Vologdin
FREAL&Co Ltd.
St. Petersburg, Russia
valentin@freal.ru

Vladislav Vologdin
FREAL&Co Ltd.
St. Petersburg, Russia
freal@freal.ru

***Abstract*—A new concept in the implementation of induction heating technologies using smart high-frequency power supplies is described. The smart heating control system consists of a single board industrial computer with built-in ELTA simulation software, several sensors and a visualization system. The real-time heating process is calculated and adjusted according to the required specification. Parameters invisible to sensors, such as the temperature distribution in the heated billet, are calculated and displayed in the process monitoring and documentation system for further analysis of product quality. The results of the study of induction heating systems are presented.**

Keywords—induction heating, smart control system, optimization, ELTA program

I. Introduction

Typically, the induction heating installation of high frequency (HF) consists of the HF power supply, one or more induction coils with the workpiece to be heated, a matching circuit between the power supply and the induction coil(s), and the control system with electrical and temperature sensors. The power supply converts 3-phase 380 V electrical energy of line frequency into single-phase power of frequency 10…440 kHz. The external heating process is controlled by output power, frequency and surface temperature in the HF power supply. DC current and voltage sensors installed after the rectifier allow to determine the power of the power supply. In addition, the power supply has the control and monitoring system for its internal devices.

Problems that are more complex arise when the type of the matching circuit is chosen and its parameters is calculated. The main elements of these matching circuits are the capacitors to compensate for the reactive power of the inductor and the matching transformers to obtain the required voltage at the inductor's input. H. Conrad, et al. (2001) claims that there are two basic schemes of semiconductor convertors with the modern MOSFET and IGBT transistors – parallel resonant inverters and series resonant inverters [1]. It is recommended that parallel resonant inverter should be used at low load impedance, low frequency and big power and series inverter – at high load impedance, high frequency and low power. H. Conrad, at al., (2001), C. Hammouma, at al., (2019), A. Attab, at al., (2019) describe that the high frequency installations with solid-state power supplies (for example transistor IGBT-based full bridge series inverter) have series compensation circuits [1, 2, 3]. If the matching circuit includes the transformer, then it is necessary to know its transformation ratio, approximate efficiency, as well as the voltage drop due to magnetic stray flux and magnetization current.

Typically, a study to optimize the heating process is done in advance, determining the required parameters of the power supply, the heating time for the simultaneous process, the speed of moving for a continuous process, etc. Many optimization criteria are known, the most important of which are obtaining the minimum heating time, the minimum temperature difference in the cross-section of the workpiece, the maximum efficiency of the heating process or some others, described for example by E. Rapoport et al. (2006) [4]. Research on optimization and the creation of new algorithms is constantly ongoing in order to obtain solutions that are more effective by many authors, for example, Yu. Pleshivtseva et al. (2017), P. Di Barba et al. (2014), and many others [5 – 7].

In some industries, the requirement for heating quality is increasing, so innovative approaches are needed to implement induction technologies. Some management systems of product quality have introduced heating control requirements that cannot be identified by sensors and recorded in reporting protocols. Parameters invisible to sensors, such as the temperature distribution in the heated billet, can be calculated and displayed in the process monitoring and documentation system for further analysis of product quality. This requires the use of cyber physical systems with embedded industrial computers and real-time control systems, as described by V. Bukanin et al. (2019) and A. Ivanov et al. (2020) [8, 9].

II. Simulation Part of the Control System

A. Continuous Induction Heating

The results of the real heating process should be documented in the process record for verification in the product quality management system. To meet all the requirements for this, it was necessary to develop a smart control system. The main requirements for this system are preliminary modeling of the continuous heating process, finding the optimal mode for each power supply, adjusting the parameters when conditions change, recording electrical and thermal parameters in the heating protocol. A special application of the program ELTA allows to simulate the process of continuous heating with optimization procedure according to selected criteria. One of the variants for the implementation of the smart control system is shown in Fig. 1. This application may be used in heat tempering, hardening, annealing and forging technologies.

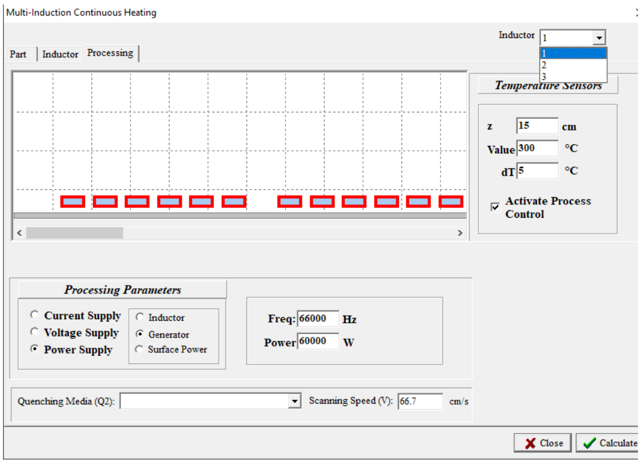

Fig. 1. Window Processing of ELTA application

The main functions of this application are: automatic calculation of the reference value of the output power (voltage/current), real-time calculation and visualization of real temperature profile, real-time temperature control (temperature feedback and power consumption feedback are used).

B. Calculation Algorithm

Operator sets the required temperature on the surface T_{set} and the initial value of the power source S_0, for example power. ELTA calculates the surface temperature T_{cur}. Then T_{cur} is compared to required temperature range $T \pm \varepsilon$, where ε is the allowed temperature tolerance. If T_{cur} is more than $T+\varepsilon$, the output parameter *S* decreases and the calculation continues. If T_{cur} is less than T-ε, ELTA will calculate the process with the increased value of output parameter *S*. If T_{cur} is inside the temperature range $T \pm \varepsilon$, solution is found. This application calculates the integral parameters of the induction coils and temperature profile at the suitable speed for real-time processes, adjusting the parameters of the first and subsequent power supplies to achieve the required temperature, which are programmed and monitored by the temperature sensors. Modification of bisection method is used in ELTA. There are two kinds of this algorithm: the first allows to find required value of generator output parameter *S* for the required surface temperature and the second one allows to find required value of generator output parameter *S* for the required temperature difference between surface temperature and point in the internal layer of workpiece [8].

III. Feature of the Control System

A. The Possible Structure of Control System

Several variants for the industrial implementation of the induction heating control system were considered, taking into account the cost, the possibility of the ELTA program, etc. Programmable logical controller (PLC) is the most popular for the control of many manufacturing processes. Typically, PLC is available in almost all control systems of the HF power supply, implementing various functions (Fig. 2). Modular PLC can be used for the induction heating system especially with multiple inductors and power supplies. It includes the central processing unit (CPU) and several additional units. The *Ethernet communication unit* allows to set at the information level the exchange of technological data (*receipts* and *temperature logs*) between the control system and the subject-oriented software ELTA.

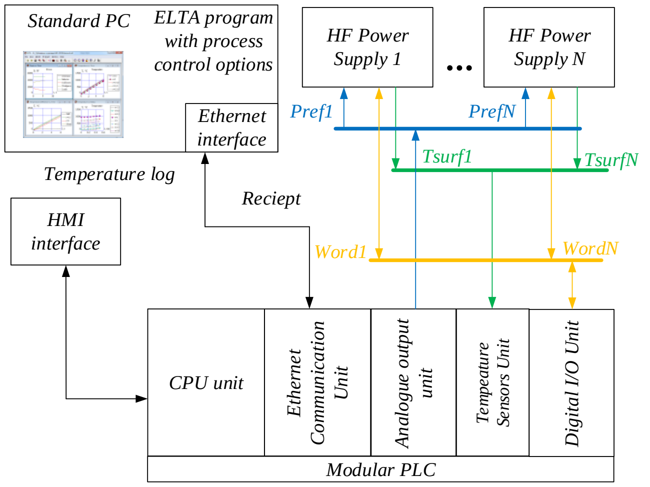

Fig. 2. Structure of the control system for several HF power supplies built on PLC

B. Implementation of Control System

ICO100-839-N3350-2COM-DIO-DC embedded system with Intel® Celeron® N3350, 1.1 GHz 1.1 is one of the most interesting variants that can be completely suitable for solving the problem of optimization and control of the continuous induction heating process. The embedded industrial computer with Windows IoT Enterprise 10 and the ELTA application allows the operator to easily set-up this system to automatically implement technology without further human involvement performing all heating and controlling settings.

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