# CONTROL SYSTEM OF SMART HF POWER SUPPLY INTEGRATED WITH ELTA PROGRAM

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**ABSTRACT.** The control system of smart high frequency power supply for induction heating of titanium wire is presented. This system is intended for the use in the developments of FREAL&Co Ltd. A program of numerical calculation ELTA integrated in control system of the induction heating installation is described. ELTA calculates a temperature distribution in a cross-section of a cylindrical load taking into account the parameters exported from the power supply.

## INTRODUCTION

Modern power supplies have an intelligent system for control, which ensures diagnostics of system, process regulation, adaptive control and a monitoring. Yue Yang at al. in European Patent High-frequency hardening monitor device (2008) described an apparatus that monitors whether an induction hardening processing to a work is appropriately performed or not [1]. In this patent several variants of monitoring are examined. For example during the induction heating processes the parameters of power supply, the induction system and surface temperature of workpiece are usually measured and acquired. These integral parameters can be output voltage, output current of power source or inductor and frequency. Thus, the control of the deviation of the hardening regime is conducted on the basis of measured power and transmitted energy and determination of the permissible deviation boundaries. The measured parameters are compared with theoretical values and adjusted.

This presentation describes how to provide the high frequency (HF) power supply with some more smart functions. The straight control of the temperature in the cross-section of workpiece close to real is proposed. This task is very interesting, since the thermal imaging systems permit to obtain the temperature distribution on the surface only. In the case of induction hardening it is possible to forecast the value of the penetration depth and the value of the hardness.

The example of smart system for induction heating of titanium wire is described below. The quality of wire in the process of the wire drawing through the draw plate depends on value and uniformity of temperature in the cross section. Since titanium has a low thermal conductivity depending on losses from the surface it is possible to observe regimes of the induction heating, when the temperature in the deep layers occurs higher than on the surface. The proposed method makes it possible to control and to regulate the process of heating in the system consisting of several cylindrical inductors and power sources.

Electric parameters (EP) of HF generator and induction coil (voltage, current, frequency) are measured and indicated on display of panel board as well as heating time and surface temperature of heating part, obtained by an infrared (IR) thermometer or a thermo view imager. Temperature distribution in cross section of heated part is obtained using ELTA program.

## PROBLEM DESCRIPTION

The smart HF power supply with integrated computer takes into account calculated and measured parameters and controls the heating process to meet the technological requirements.

Integration of calculation model in the real technological processes is perspective task that can give the required information about the temperature distribution to control the parameters of induction heating system. One of the problems of model-controlling induction heating systems is deploying of model designed for x86 platforms in industrial workstations with real-time process support. Special application of ELTA program [2] is developed to connect the simulation part with industrial PC in smart HF power supply. This application calculates integral parameters of induction coils and temperature with suitable speed for real-time processes.

Described researches are carried out for the process based on titanium wire continuous heating technology in drawing machine. Diameter of wire is: 1.5 mm to 8 mm. Required surface temperature is 600±30°C. Required productivity is up to 60 m/min. Structure of the induction heating system is shown in Fig. 1.

Temperature sensors allow to measure surface temperature of wire in the center of the coil and in the output end of the coil. Feedback signals of surface temperature (*Tsurf*) allow building a solution of electrothermal model during operation of induction heating system and calculating correction value of output power of the generator (*Pref*).

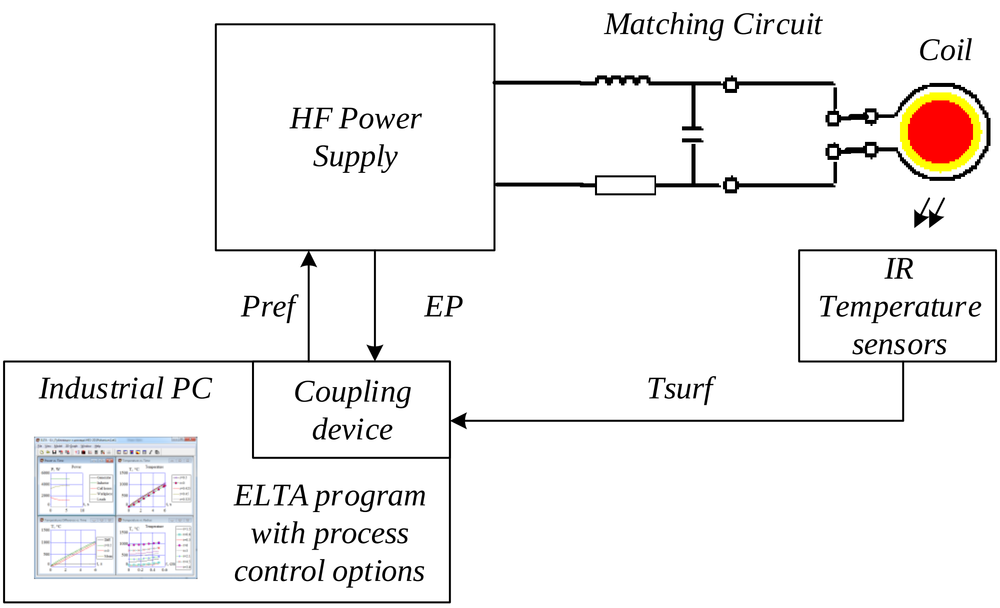


Figure 1. Structure of designed system.

## RESULTS OF DESIGN

There are two ways to control temperature in induction heating process with the adjustable power source: PWM control mode and proportional-type control mode (power-temperature control) [3]. Each mode provides the temperature of 600 °C (reached by 3s at PWM mode and 4.1s for power adjust mode). The calibration diagrams derived for both control modes are presented in Fig. 2. Both approaches may be used with FREAL HF power supplies.

Smart HF power supply system is a set of FREAL HF power supplies and industrial PC with real-time process support. All devices are integrated in RS-485 industrial network for exchange of technological variables.

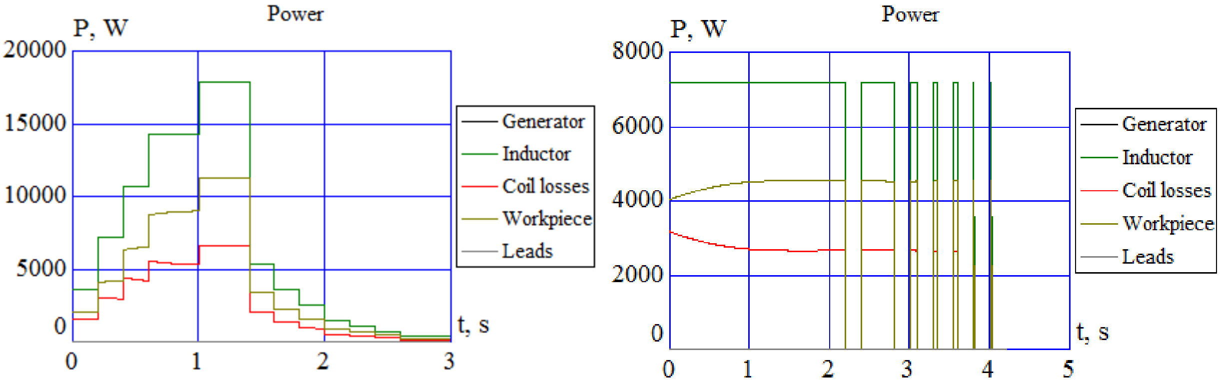


Figure 2. Calibration diagram for the time-temperature control mode (top) and power temperature control mode (bottom).

Current values of surface temperatures (*Tsurf*) from the pyrometers of each inductor are transmitted to the coupling device of industrial PC via RS-485 interface by request of industrial PC. Current values of generators output current, voltage and frequency (*EP*) may be requested from each HF power supply via RS-485. Reference output values of power (*Pref*) for the each generator may be set from industrial PC via RS-485 interface.

Numerical calculation procedure for the Smart HF power supply system is based on ELTA program. Calculation procedure is rather fast and may be used in real-time applications. Configuration dialog of ELTA for the real-time application is presented in Fig. 3.

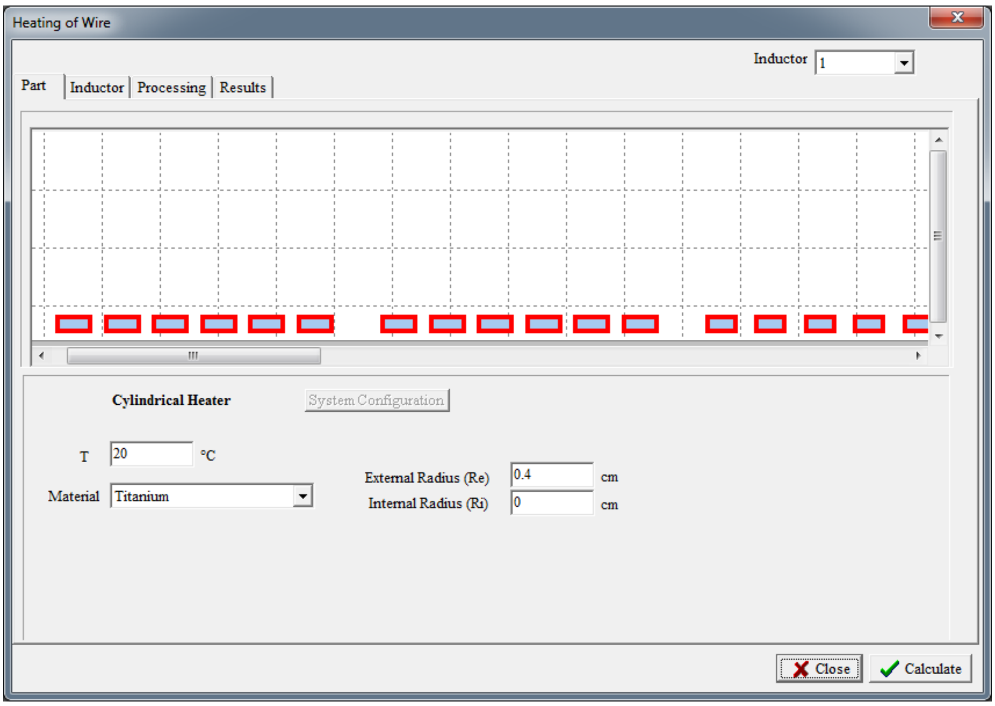


Figure 3. Configuration dialog of ELTA wire application.

Specially designed user interface allows to set parameters of the induction heating machine very quickly. Material of wire, initial temperature of wire and external wire radius may be defined in the "Part" tab. Parameters of the required number of coils (turns number, coupling gap, length, tube profile and etc.), inductor cooling parameters (water temperatures, pressure drop limit) an parameters of the matching circuit (type, leads configuration and etc.) may be defined in the "Inductor tab". "Processing" tab allows to set parameters of heating process: type of HF power supply (constant current, constant voltage, constant power), reference value of *output parameter* (current, voltage or power), frequency and speed of wire motion. Interface of process control functions also presented at the "Processing" tab. It is possible to set precise coordinate of temperature sensor, target temperature and required tolerance for each inductor.

Key features of the smart HF power supply system are: automatic calculation of the reference value of the output power for the selected wire diameter; real-time calculation and visualization of real temperature profile; real-time temperature control.

*Automatic calculation of the reference value of the output power*. If process control functions activated, required values of HF power source *output parameter* will be defined during calculation. If required value of *output parameter* will be more than initial value, calculation will be stopped with the warning message "Impossible to find a solution. Please try to change initial parameters". Initial calculations for the required temperature profile have to be done *before* heat treatment process starts. The main results of this calculation are the reference values of output powers for each HF power supply.

*Real-time calculation and visualization of real temperature profile*. Modern pyrometers and thermal imaging cameras allows to measure surface temperature only. However, it is necessary to monitor temperature distribution during the heat treatment process for the goals of quality assurance. For this mode temperature (*Tsurf*) and electrical parameters (*EP*) have be requested from pyrometers in the real-time. After each request, ELTA starts the simulation with the received temperature as a target temperature. If the difference between calculated and measured electrical parameters is more than allowed threshold, warning message "Temperature profile cannot be calculated" will be shown and registered in the smart HF power supply log. The main results of the calculation are the temperature distributions inside the wire.

*Real-time temperature control.* Several perturbation actions (fluctuations of initial temperature of wire, changing of wire speed, fault of one HF power supply, etc.) may affect to the temperature profile at the real process. Using of real-time temperature control allows to minimize consequences of perturbation actions. For this mode temperature (*Tsurf*) and electrical parameters (*EP*) have be requested from pyrometers in the real-time. After each request, ELTA compares measured parameters with the reference values. If the difference between measured temperature (*Tsurf*) and reference value of the temperature is more than allowed threshold, ELTA starts the simulation with the real value of temperature and changes reference value of the output power for the next HF power supply in the line according to results of calculation. If abnormal deviations of temperature took place after the last inductor, smart HF power supply system generates warring event for the superior control system. For the most effective using of this function model has to be calibrated to the selected wire diameter before heat treatment process will be start.

The first example represents procedure of calculation of reference power for HF power supplies for induction heating system for continuous heating of titanium wire before rolling. The final thermal profile must be as uniform as possible in the radial direction. Target temperature is 600 °C.

<u>Wire parameters</u>: material – titanium, diameter range is from 1.5 mm 8 mm.

<u>Processing parameters</u>: continuous heating, speed of movement is 40 m/min; HF power supply 1: frequency is 66 kHz; max output power is 60 kW; HF power supply 2: frequency is

440 kHz; max output power is 60 kW; HF power supply 3: frequency is 440 kHz; max output power is 15 kW.

Inductors parameters: inductor 1: number of turns – 6, length is not more than 12 cm, internal radius 0.7 cm, profile and dimension of copper tube – rectangular, width 1.6 cm, height 0.8 cm, and thickness 0.2 cm.

Thermal insulation: not applicable.

Temperature sensors (optical pyrometers) are placed at the end of the each inductor.

It is necessary to calculate expected values of output powers of the HF power supply, before heating process may be started. Operator puts the data about diameter of wire and temperatures ($T_1$, $T_2$, $T_3$) according to technology requirements to the smart HF power supply HMI system (see Fig. 4). If selected speed is 40 m/min target temperatures are 300 °C, 630 °C and 600 °C. Results of preliminary calculations are presented in Table 1.

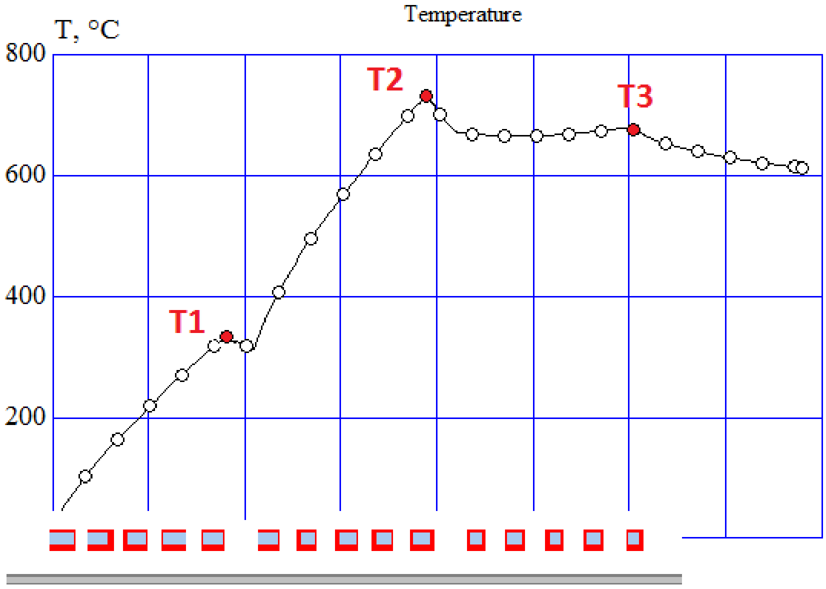


Figure 4. Expected dynamics of surface temperature during heating of wire.

Table 1: Results of automatic setting of smart HF power supply system to the different diameters of wire

| **R [cm]** | **$P_1$ [kW]** | **$P_2$ [kW]** | **$P_3$ [kW]** | **$T_1$ [°C]** | **$T_2$ [°C]** | **$T_3$ [°C]** |
|---|---|---|---|---|---|---|
| 0.4 | 52.65 | 49.95 | 15 | 300 | 630 | 600 |
| 0.35 | 49.95 | 46.17 | 12.15 | 300 | 630 | 600 |
| 0.3 | 48.6 | 42.6 | 8.86 | 300 | 630 | 600 |
| 0.25 | 48.6 | 38.38 | 6.46 | 300 | 630 | 600 |
| 0.225 | 52.65 | 35.429 | 7.174 | 300 | 630 | 600 |
| 0.2 | 60 | 31.87 | 7.971 | 300 | 630 | 600 |
| 0.175 | 54 | 32.77 | 7.174 | 250 | 630 | 600 |
| 0.15 | 54 | 33.65 | 6.23 | 200 | 630 | 600 |
| 0.125 | 60 | 35.43 | 6.06 | 180 | 630 | 600 |
| 0.1 | 60 | 36.75 | 5.5 | 130 | 560 | 600 |
| 0.09 | 48.6 | 51.975 | 7.174 | 100 | 630 | 600 |
| 0.08 | 60 | 55.5 | 13.5 | 100 | 600 | 600 |
| 0.075 | 60 | 57 | 15 | 90 | 570 | 600 |

It is necessary to control temperature profile during the heating process (see Fig. 5). If actual value of temperature difference is more than ±30°C, smart HF power supply system generates warring event. This event is writing to the internal log of HF power supply system. Superior control system may stop the technological process or mark a defective part of wire. Defective part of wire may be removed from the technological sequence.

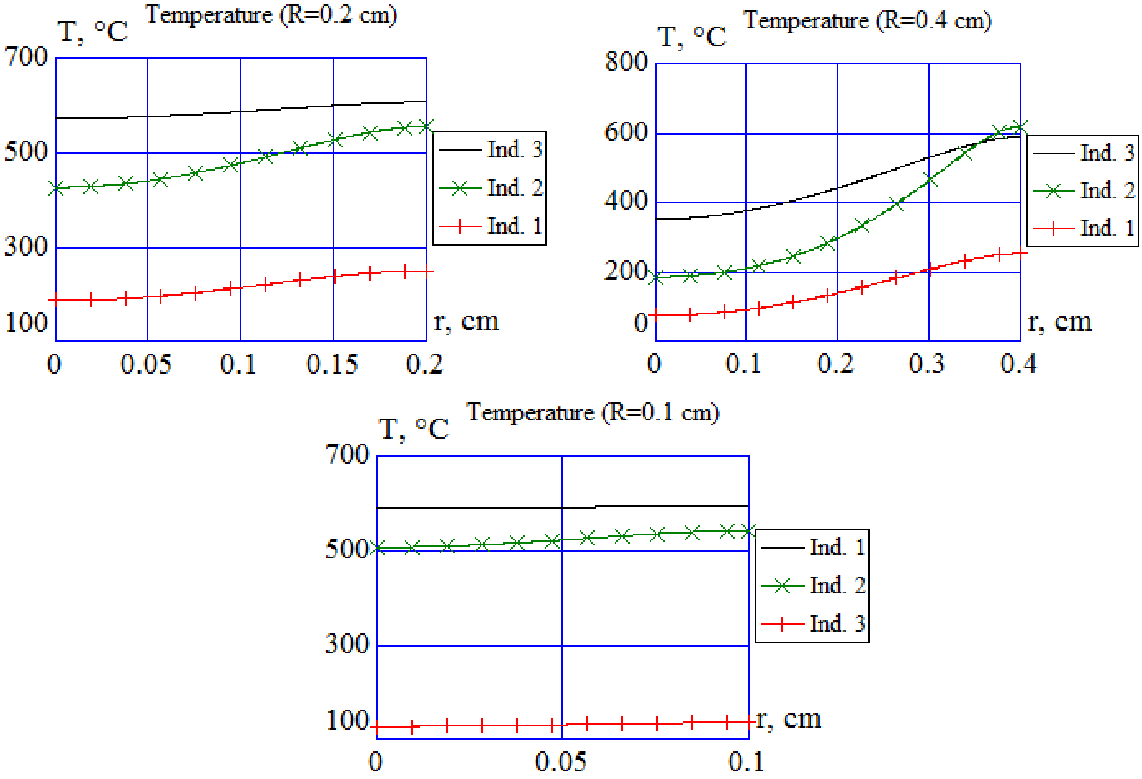


Figure 5. Temperature profile at the end of the heating for R=0.4 cm (top, left), R=0.2 cm (top, right) and for R=0.1 cm (bottom)

Temperature profiles presented in Fig. 5 shows that required temperature profiles may be achieved for the regimes presented in Table 1.

## CONCLUSIONS

Designed system includes process control functions of the FREAL HF power supplies and real-time calculation functions based on ELTA program. Smart HF Power Supply system allows to calculate a required output power for the selected temperature profile from the HMI station. Real-time simulation functions allow to control real temperature profile during the heating process. Presented approach of integration ELTA with the Smart HF Power Supply system may be applied for other induction heating technological processes with continuous heating.

## REFERENCES


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