Digital Control Systems for Thermal Regimes in Industrial Furnaces

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Abstract

This paper presents methods and solutions for controlling the thermal process in a gas fired furnace system for titan forging. The software implemented solutions aim to achieve better temperature uniformity inside the furnace chamber, possibility of choosing a more cost-effective hardware equipment for lowering initial investment cost, developing the software control in order to achieve a universal temperature furnace suitable for both low and high temperature without the need of recirculation fans, development of software control methods in order to better adjust the burners air/gas ratio in order to obtain a correct furnace atmosphere relative to titan forging technological process demands and reducing NOx emissions. The research was implemented at Zirom SA of Giurgiu within the acquisition project of a system composed of two gas fired forging furnaces with a common heat recovery system delivered by Electro-Total SRL Bucharest. The main results of the implementation are: a temperature uniformity inside the furnace's chambers of ±5 °C according to the temperature uniformity survey test for both holding temperatures of 650 °C and 1250 °C, a control temperature precision of ±1.5 °C according to the system accuracy test, a very well maintained inside furnace pressure taking in consideration the unique design with a common heat recovery system, a very well maintained low oxidizing atmosphere (λ=1.09) inside the furnace and a very low flue gas emissions (NO_x=149 mg/Nm^3).

Keywords: industrial automation, software control, industrial furnaces

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1. Introduction

Gas fired heat treatment/forging furnaces have evolved over time [20]. These types of furnaces are generally divided in 2 categories: high temperature furnaces and low temperature furnaces, both categories are designed with specific hardware and software control according to the type of heat transfer [1].

One of the most important performance parameters is the temperature uniformity inside the furnace chamber which has to be maintained in a specific range according to the utilization of the furnace [18].

The heat transfer for low temperature furnaces is mainly achieved by convective transfer. In order to achieve good uniformity results inside the chamber there is a need for installing recirculation fans in order to mix the furnace atmosphere [5].

The heat transfer for high temperature furnace is mainly achieved by radiation transfer. Due to radiation heat transfer there is no need for recirculation fans in order to achieve good uniformity results [5].

The current conception model of these furnaces [23] is to design and build a low temperature furnace for low temperature requirements and applications and a high temperature furnace for high temperature requirements and applications. Even if a certain factory/factory department uses a technological process that requires the use of both high and low temperature holdings the solution is to build 2 different furnaces with specific design for the temperature needs which they are used for.

This solution raises many problems regarding: economical factor, deployment space, energy consumption, emissions, spare parts stock, maintenance department overload, logistics and many others derived.

The main challenge is to design and build a universal furnace that can deliver both good uniformity results in low and high temperature with the same hardware. The main problem in this case is that the recirculation fans which work very well in low temperatures are prone to failure in high temperature and have a very high acquisition and maintenance cost.

This paper will present a fully working solution of burner control method in order to obtain a very good temperature uniformity inside the furnace both for low and high temperatures without the need of installing recirculation fans.

Another topic to be discussed is the emissions control. The main emissions for gas fired furnaces are [24]:

- carbon dioxide (CO_2), which has a greenhouse effect;
- carbon monoxide (CO), which in high concentration is life threatening;
- nitric oxide (NO_x), which has a greenhouse effect.

Methods of reducing emissions in gas fired furnaces are [16]: using ultra low NO_x burners with internal flue gas recirculation, flue gas recirculation at furnace level, reducing flame temperature, expanding burner flame to a larger surface, stage firing, urea injection, and maintaining a precise air/gas ratio [14].

This paper will address the significance of air/gas ratio precise control using extended methods in order to decrease furnace emissions.

The main and most effective method of reducing emissions is by obtaining a close to ideal stoichiometric air/gas ratio both for the individual burners themselves but also for the general atmosphere inside the furnace [15].

Conventional furnaces are usually equipped with mechanical air/gas ratio regulators [12], which are based on pneumatic principle with an internal balancing diaphragm which can do a decent job of maintaining an approximate air/gas ratio [1].

The reason why most furnaces use this type of mechanical control is because it is simple to put in practice and also cost effective taking in consideration the ratio between delivered performance and costs, it can be seen as a compromise solution.

The main disadvantage of this solution is that mechanical regulators cannot consider the following factors: equivalent air volume relative to its temperature, fluctuating calorific power of methane gas, limitation of mechanical precision and system feedback.

This paper will present a fully working solution using a 2-stage electronic control of air/gas ratio and also other electronic controls for other furnace parameters which indirectly improves emissions.

Another topic to be discussed is using and controlling a single heat recovery system for 2 furnaces.

Conventional furnaces have individual recovery systems that are individual controlled by each furnace automation system [8].

Due to the need of optimising the technological process it was opted for a system composed of 2 furnaces.

2. Automation and software system solutions

This case study is based on 2 gas fired forging furnaces for titan bars (Figure 1) with a common heat recovery system (Figure 2) that were designed and built by Electro-Total SRL Bucharest for Zirom SA Giurgiu. The furnaces are fully working in the factory's production program.

Figure 1 shows the interior of the furnace at nominal temperature (1250 °C) with the titan bars ready for forging.

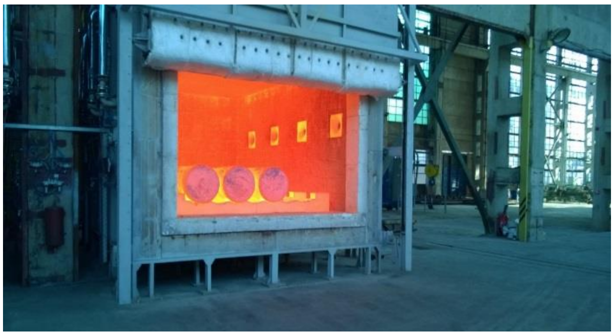

Figure 1. Working furnace

Figure 2 shows the entire structure designated for both furnace with a common heat recovery system and exhaust flue gas fan along with all the execution elements and sensors highlighting the unique conception and built of this application.

Figure 2. Overview of the furnaces

The need of building a 2-furnace system derived from optimising the technological process in order to achieve a 3 full working shifts production time.

So, to further explain when one furnace is in the forging process the other one can heat up the next batch of titan bars for the forging process. After the forging process of furnace 1 completes they will switch places and the whole process starts over.

Taking in consideration the fact that usually the whole system of 2 furnaces will work together it was opted for a common heat recovery system to be installed in order to decrease initial investment costs.

The technological demands were:

- ±5 °C temperature uniformity for both 650 °C and 1250 °C holding temperature;
- a very accurate control of burner air/gas ratio in order to obtain a slightly reduction atmosphere in the furnace chamber (oxidizing atmosphere is prone to develop unwanted chemical reaction in the titan bars);
- using and controlling a single heat recovery system for both furnaces for better gas consumption efficiency.

Furnaces specifications were:

- interior usable space: 3000 x 2000 x 5000 mm;
- insulation: ceramic fibre;
- power capacity: 2.5 MW /furnace;
- maximum temperature: 1300 °C;

- maximum temperature for preheated air:400 °C;
- nominal load: 15 t /furnace;
- control areas: 2 /furnace;
- number of burners: 8 /furnace (4 /zone);
- heating rate: max. 150 °C/h, min. 20 °C/h,
- average natural gas consumption: 90 Nm^3/h /furnace;
- average electric energy consumption: 22.5 kWh /furnace;
- automation monitoring and control level 1: PLC based;
- operator control and monitoring level 2: SCADA system.

Taking into consideration the complexity of this project, a level 2 SCADA system (see Figure 3) was designed and implemented, in order to achieve a better monitoring and control of the application.

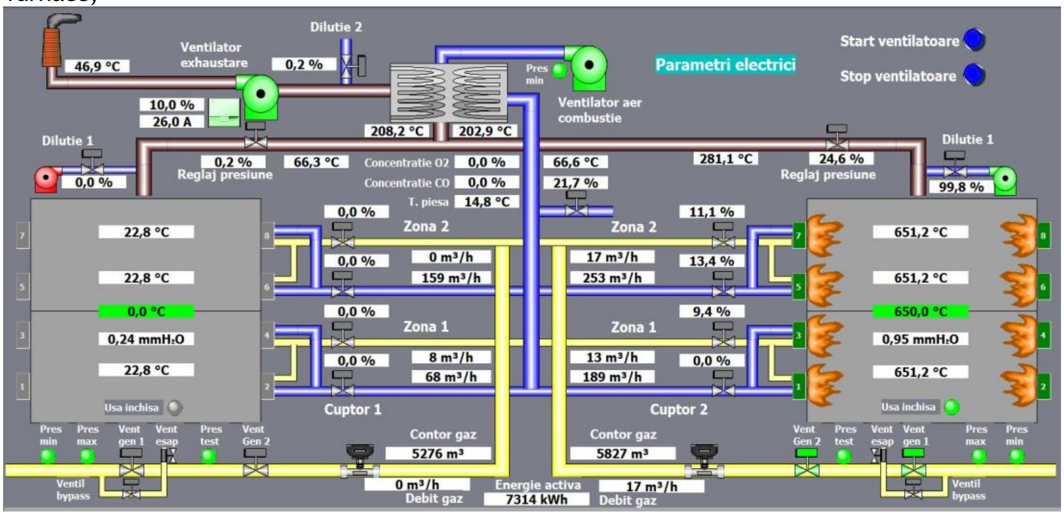

Figure 3. Automation software (synoptic)

Figure 3 shows the main SCADA screen as the synoptic which is used to supervise the whole furnaces operation, measured values from the system, state of execution elements and others in order for the operators to overview the system operation in one single software screen. All other screens (settings, alarm list, graphics) are separately designed.

2.1 Solution for demanded temperature uniformity

Our research intended to find the best solution for maintaining the demanded temperature uniformity for both low temperatures (650 °C) and high temperatures holdings (1250 °C) without recirculation fans.

The furnace was equipped with high velocity flat flame burners without furnace atmosphere recirculation fans. This hardware configuration represented a challenge regarding the temperature and burner control in order to achieve good uniformity results.

Each furnace has 2 temperature control zones. The temperature control is implemented with software PID controllers using 3 types of control (see Figure 4, *infra*):

- continuous control for high power demands;
- burner alternation on-off subzone control for low power demands with 4 ignited burners (2 for each zone);
- full on-off control for very low power demands.

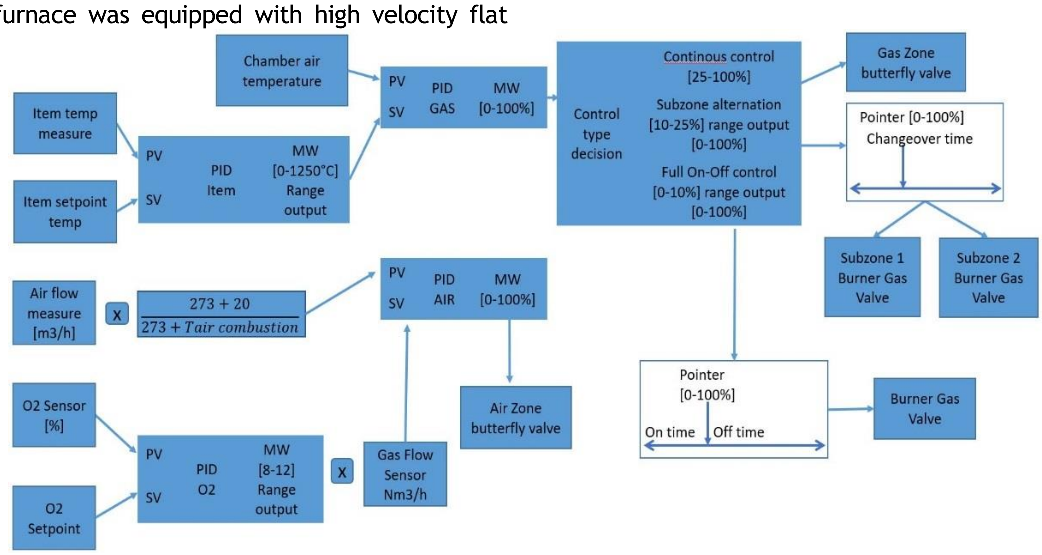

Figure 4. Logical diagram for temperature and air/air gas ratio control

Figure 4 shows the concept and logical behaviour of combining the 3 different types of burner control along with a 2-stage air/gas ratio burner control in order to improve both temperature uniformity and lower the emissions

The advantage of changing the control type during operation is that regardless of the temperature inside the furnace the temperature uniformity can be maintained in the desired limits especially at low furnace temperature where the heat transfer is mainly convective. Using short bursts of high-power ignition burner periods achieves a very good result in mixing the furnace atmosphere by the high velocity of burner flue gases.

The furnace power domain output of the PID temperature control is divided in 3 ranges (see Figure 4, *supra*):

- 0-10 % output – full on off control;
- 10-25 % output – subzone alternation control;
- 25-100 % output – continuous control.

The full on-off control means that all of the furnace burners are ignited for the ON time period and turned off for the OFF-time period.

The ON time and OFF time are established by a pointer which glides through the time base accordingly to the PID output which sets a greater ON time or a greater OFF time.

The subzone alternation control works in the same manner as the ON-OFF control, but the main difference consists in the fact that the pointer controls the variable time when the burners will changeover.

The continuous control works with all the burners ignited and the temperature is controlled by modifying the zone burner's power by adjusting the flow of methane gas and air.

The implementation of subzone alternation and on-off control was necessary both for temperature uniformity and temperature accuracy as follows:

- temperature uniformity at low power demands and holding temperatures is improved by short bursts of high-power flame from the burners which will result in mases of air movement. These mases of air movement will improve the convective heat transfer thus resulting in a better temperature uniformity;
- generally, all burners have a minimum constructive operating power for which they can maintain a stable flame without flame failure. If the necessary power demand in order to maintain the desired furnace temperature is below the minimum burner constructive power the temperature would continue to increase above the desired temperature when using continuous control. Therefore, by using subzone alternation and on-off control the temperature accuracy is improved especially at low temperatures but also at holding high temperatures.

Furthermore, for optimizing the accuracy of temperature control considering that the thermal response of the furnace (thermal inertia) is different when operating in low temperatures (convection heat transfer) from high temperatures (radiation heat transfer) there were implemented 4 sets PID parameters (Kp, Ki, Kd) as follows:

- first set for low temperatures (convection heat transfer);
- second set for borderline temperatures;
- third set for high temperatures (radiation heat transfer);
- fourth set for drying hearth diagram.

The automation system will automatically switch between the 3 sets of PID parameters according to the furnace temperature therefore achieving a more precise control adjusted to the furnace needs.

When there is a need for a furthermore precise control there is also an option for measuring and controlling the temperature directly on the material that is being heated by a contact thermocouple and an additional PID that will cascade the atmosphere PIDs. This option can be activated or deactivated by the furnace operator in the SCADA system.

2.2 Solution for maintaining an accurate control of the burner air/gas ratio

For controlling the burner air/gas ratio, a flow measurement and a motorised valve are installed on each control zone (2 per furnace) both for air and gas.

Moreover, considering that the furnaces are equipped with a heat recovery system, the air combustion temperature is measured in order to compensate the air density and calculate the equivalent air volume regardless of its temperature (Figure 4).

An oxygen sensor is installed on the flue gas pipe in order to measure the precise O_2 concentration in the flue gases and marginally adjust the air gas ratio value.

This translates in a two-stage air/gas ratio control (Figure 4). The first and primary stage of control is based on the measured flow of the air and gas that enters the burners and is maintained at a stoichiometric ratio of 1 to 10. Furthermore, the information of the O_2 concentration of the flue gases is processed by the O_2 PID (secondary stage control) which can fine adjust the desired ratio (the air SV PID) in a restricted interval from 1/8 to 1/12 for safety reasons. Generally, the desired O2 concentration in the flue gases should be anywhere from 1 % to 3 %. Using this method, it was obtained a more precise air gas ratio control which is capable of compensating any flow measurement errors in order to obtain a better control.

Taking in consideration that the worst-case scenario is having an oxidizing atmosphere which can cause some unwanted chemical reactions in the titan bars, it was opted for using a cascaded PID controller with the master loop command on the gas valve. Using this method, the master temperature PID commands the burners' gas flow and the slave PID commands the burners' air flow. This method known as "the air follows the gas" reduces the risk of having excess oxygen in the furnace.

Considering the fact that the gas and air control of the burners is simultaneous adjusted on the whole zone consisting of 4 burners with only 1 execution element (1 motorized valve for air and 1 for gas) the automation system also has a specific routine that will take in account the number of active burners in order to readjust the air flow.

For example, if one burner is malfunctioning it will be switched off resulting in the fact that all the measured gas flow that was distributed evenly through the 4 burners is now distributed to only 3 of them resulting in a 33 % increase of gas flow per burner. However, in the same time the air flow remains at the same flow level because only the burner gas has a shutoff valve. This behaviour will lead to an incorrect air/gas ratio. In order to correct this massive error, the automation will compensate the air flow calculation according to the number of burners that are online thus increasing the airflow to the remaining burners by the proportion between all the existing burners and the online ones. Following this adjustment, the air/gas ratio of each individual functioning burner will be sufficient in order to obtain a satisfying flame stability. Taking in consideration that the burner that is malfunctioning will still inject air in the furnace, the overall furnace chamber atmosphere will be altered. For sorting this matter the oxygen sensor will detect an increase in its O_2 level that will be sent to the O_2 PID which will readjust the desired overall air/gas ratio of all the burners resulting in a correct atmosphere in the furnace chamber.

As we can see here this is another advantage of using the secondary stage control for the air/gas ratio using the O_2 and cascaded O_2 PID.

2.3 Solution reducing NOx emissions

NOx formation is facilitated by excessive oxygen levels in the flue gases which react with azote at high temperatures.

CO formation is facilitated by incomplete methane gas combustions process by insufficient oxygen that participate in the burning process.

Taking this in consideration we can see that excessive oxygen leads to NO_x formation and insufficient oxygen leads to CO formation so there is tiny borderline of oxygen value in the flue gases which will lead to a reduction of emissions.

As we can see in Chapter 2.2 the importance of a precise oxygen calibration in flue gases not only by indirect regulation (flow measurements) but also by direct regulation (O_2 measurements in flue gases) is needed in order to obtain a more precise adjustment of air/gas ratio burner control.

Having this said the automation system provides the operator of the furnace the tool and possibility to fine adjust the desired oxygen value in the flue gases in order to adjust the balance between demanded technological process regarding low oxidizing inside atmosphere, emissions control, furnace efficiency and consumption. This method of control opens the possibility for using these furnaces also for other materials besides titan.

Therefore, the system control presented in Chapter 2.2 besides calibrating the correct furnace atmosphere in relation to titan forging has another advantage in reducing emissions.

2.4 Solution for controlling the inside pressure of the furnace chamber for both furnaces with only 1 exhaust fan

The flue gas piping execution elements are:

- butterfly valves at each furnace exhaust;
- central exhaust fan equipped with a variable frequency drive mounted after the common central heat recovery system.

The furnace pressure monitoring elements are:

- differential pressure sensors for each furnace (between chamber pressure and atmosphere pressure).

Regulating the furnace chamber inside pressure is very important to be maintained to a slightly positive value (1-2 mbar). Taking in consideration the fact that a furnace chamber cannot be totally tight, this control is necessary in order to eliminate any infiltrations of false air in the furnace chamber or any furnace atmosphere leaks outside the chamber through any chamber tightness defect. These leaks can occur depending on the excessive negative or positive value of the pressure.

The negative effects of false air infiltration (excessive negative pressure) are incorrect furnace atmosphere (excess O_2 resulting in an oxidizing atmosphere) and excessive gas consumption resulted from the unnecessary heating of the infiltrated air.

The negative effects of atmosphere leaks (excessive positive pressure) outside the furnace are human poisoning with CO which is life-threatening.

Taking in consideration the unique design of this furnace with a central common heat recovery device and exhaust fan, the technical difficulty is implementing a control system that uses 2 measurement elements with 3 execution elements which have to work both individually and together.

The solution is the following:

- PID controller for furnace 1 pressure:
  - PV1 = pressure sensor 1;
  - SV1 = desired pressure for furnace 1;
  - MW1 = butterfly valve 1;
- PID controller for furnace 2 pressure:
  - PV2 = pressure sensor 2;
  - SV2 = desired pressure for furnace 2;
  - MW2 = butterfly valve 2;
- PID controller for central exhaust fan:
  - PV = MAX (MW 1, MW 2);
  - SV = 80 %;
  - MW = exhaust fan speed.

Figure 5 shows the concept and logical behaviour of controlling 2 measured values with 3 execution elements using a combination of 3 PID's controllers that have to work both individual and together in order to maintain the desired parameters.

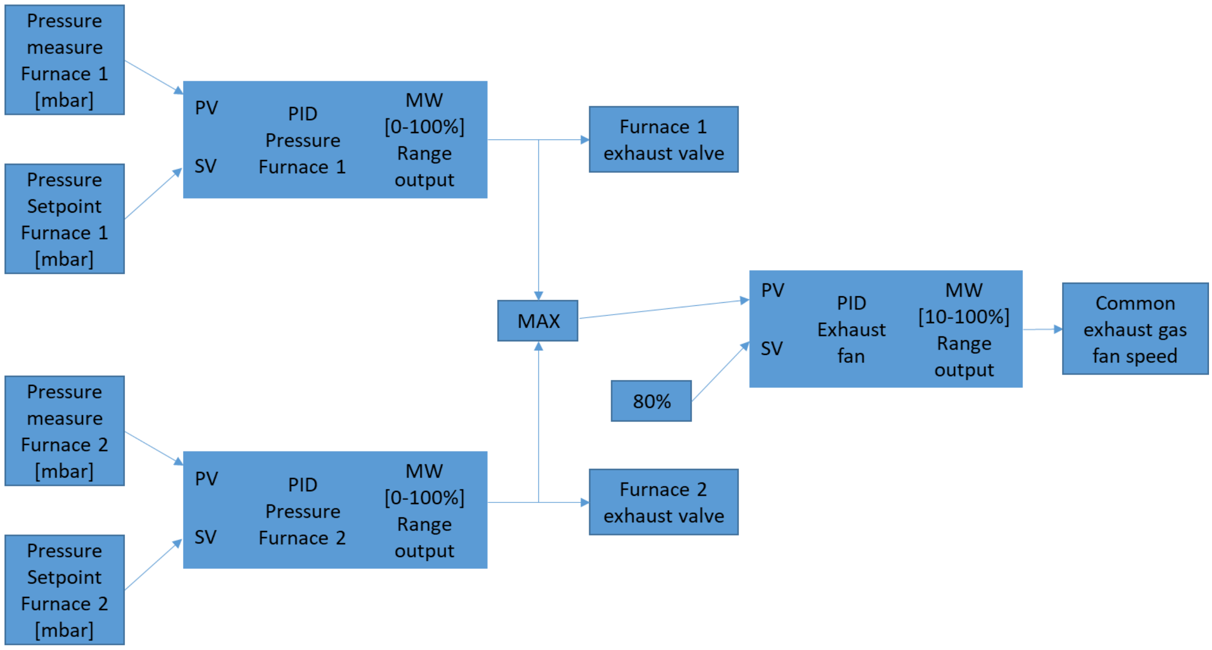

Figure 5. Logical diagram for controlling the inside pressure of both furnaces

We used this 3 PID configuration, as shown in Figure 5, and the obtained results in the following operating mode were:

When the pressure for furnace 1 is exceeding the desired set value, the furnace 1 pressure PID will increase the opening of the butterfly valve.

If the effect on the inside pressure is not satisfactory until 80 % opening, beyond this value the PID for the exhaust fan will start increasing the fan speed in order to keep the response of the furnace 1 pressure PID below 80 %.

Presuming that furnace 2 pressure was in a steady state operation before these pressure alteration on the common exhaust pipe, the result is in decreasing the pressure in furnace 2 chamber so following this pressure modification the furnace 2 pressure PID will decrease the opening of the butterfly valve 2 in order to keep the pressure in the desired limit.

The 80 % set value of exhaust fan PID represents the point in which the pressure butterfly valve PID's of each furnace signals the exhaust fan PID that they need a greater negative pressure on the common flue gas exhaust piping in order to cope with the desired value of the furnace pressure.

The fixed 80% value was chosen in accordance with the specific flow curve of any butterfly valve. The butterfly valves have a specific "S" type nonlinear opening/flow curve which means that at an opening greater than 80 % the effect in increasing the flow becomes smaller.

For this reason, when the butterfly valve reaches the opening point in which the effects on increasing the flow become minimum the exhaust fan will increase its speed in order to help the furnace pressure PIDs

As it can be seen in Figure 5 (*supra*), the role of the exhaust fan PID is to supply the necessary additional pressure decrease when any of the furnace pressure PID 1 or 2 requests it.

The other furnace pressure PID which haven't requested additional pressure decrease will automatically readjust to compensate additional pressure decrease caused by exhaust fan PID.

Following this control configuration all the system's PIDs react together in order to achieve the desired inside chamber pressure for both furnaces.

3. Results

As presented in the past section there were many challenges involved in designing a 2-furnace system with a central common recovery system capable of maintaining a good temperature uniformity both for high temperature and low temperature operation.

Main results:

Temperature uniformity inside the chamber furnace of ±5 °C according to the TUS test (see Figure 6).

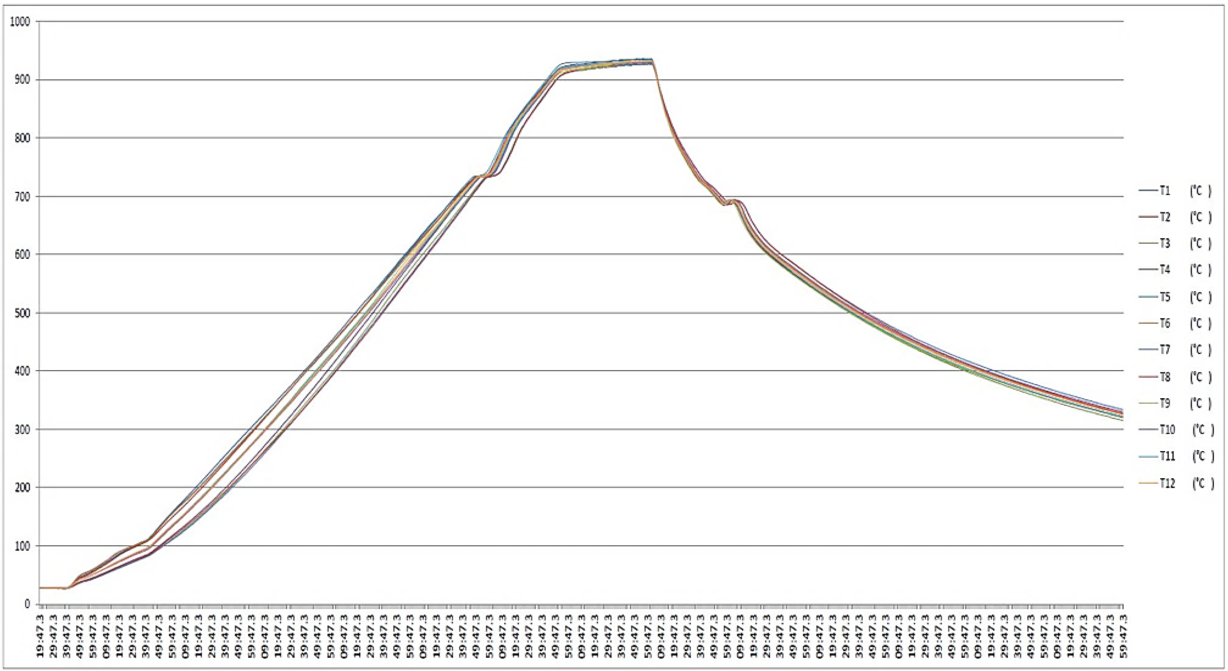

Figure 6. TUS test

Figure 6 shows the graphic of temperatures evolution for all the 12 thermocouples during the TUS test.

In order to confirm the temperature uniformity inside the furnace a specific test is done according to AMS 2750 [10] called the TUS test (temperature uniformity survey).

The regulation regarding the TUS test states that in accordance with the usable volume inside the furnace and its graded class a certain number of measurement points should be done inside the chamber. The TUS measurement system is completely separated from the furnace's automation measurement system and acts as a completely stand-alone system in order to act as a blind performance verification procedure.

In our case a frame with 12 thermocouples disposed evenly in the chamber volume was introduced inside the furnace. The test is done according to AMS regulations with no charge meaning that the furnace has no load thus increasing the difficulty of obtaining good uniformity results.

Nevertheless, the test was a success, the furnaces automation system managed to obtain ±5 °C temperature uniformity and the holding temperature (see Figure 7) both at low and high temperatures (650 °C and 1250 °C).

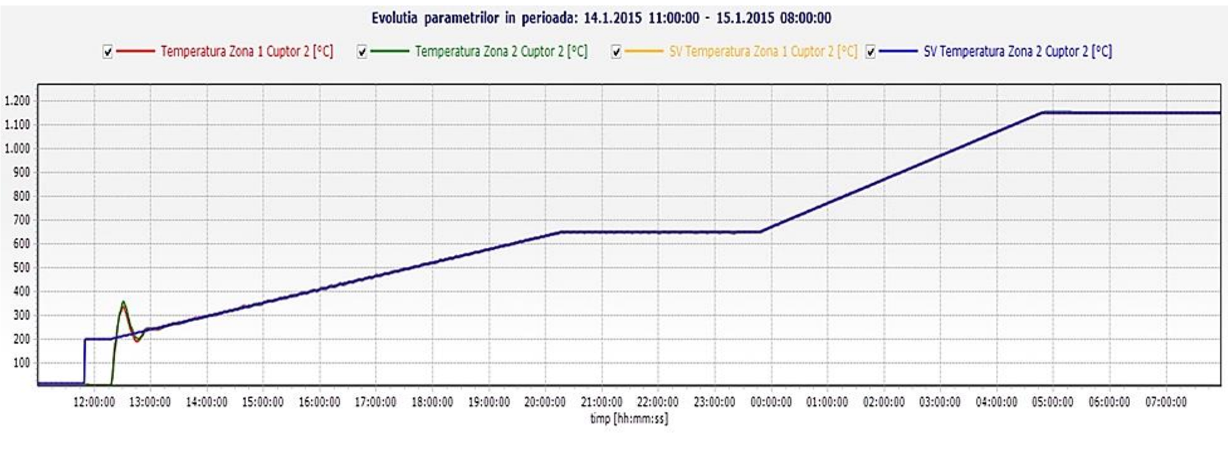

Figure 7. Temperature holding at 650°C and 1250°C

Figure 7 shows the graphic of temperatures evolution together with the set value temperature for both thermal zones inside the furnace. The yellow line represents the set temperature value for zone 1, the blue line represents the set temperature value for zone 2, and the red line represents the measured temperature value for zone 1 and the green line represent the measured temperature value for zone 2.

In order to confirm the possibility of maintaining a holding temperature at low temperatures (650 °C) a test was done in normal working conditions with a charge composed of 15 t of titan bars driven by a temperature diagram with an intermediate holding temperature at 650 °C.

As it can be seen in Figure 7, in the SCADA recorded parameters the automation system managed to obtain a steady intermediate holding temperature without any problems.

- temperature accuracy regulation according to SAT test;
- Obtained temperature accuracy regulation: ±1.5°C;
- flue gas emissions;
- CO= 55 mg/Nm^3 (maximum allowed according to EU regulations: 100 mg/Nm^3 - normalised at 3 % O_2);
- NO_x= 149 mg/Nm^3 (maximum allowed according to EU regulations: 300 mg/Nm^3 - normalised at 3% O_2);
- inside chamber atmosphere;
- Very low oxidizing atmosphere:
  - O_2=1.8 %;
  - λ=1.09.

4. Discussion

The starting goal of this project was to design and build a system of 2 furnaces with a common heat recovery system that can be used both for high and low temperatures without the need of furnace atmosphere recirculation fans thus producing very good results regarding temperature uniformity, fuel consumption and low emissions.

The originality of the research stands in designing and combining different methods of burner control, inside chamber pressure control and air/gas ratio 2 stage control that were implemented by the author of this article in the system's software control logic in order to achieve these results.

This is system is derived and related to another system implemented in a heat treatment furnace designed, built and commissioned at Cameron Ploiesti factory by Electro-Total within the same research of developing a burner control system that can substitute hardware components (recirculation fans for temperature uniformity during convection heat transfer specific temperatures) [25].

The results at that time were considered a world premier regarding this type of control and the results obtained. The Cameron furnace system was specifically implemented for heat treatment of steel drilling bits using a burner control system that can individually control and adapt on the fly each burner's output as in continuous control, on-off control, and high-low-off control in each furnace area (for each burner) in order to obtain very good temperature uniformity results during convection heat transfer by mixing the furnace atmosphere with the help of burners flue gases velocity by exactly pin pointing the area which needs better uniformity and adjusting each burner control accordingly.

The general advantages of implementing this type of control on furnace are:

- lowering investment cost by eliminating the need of building a specific low temperature furnace in addition to a high temperature one;
- lowering investment cost by eliminating the need of installing recirculation fans;
- lowering investment cost by eliminating the need of a hearth drying installation. Hearth drying requires a very precise regulation of temperature at low temperatures that is impossible to be obtained by furnaces burners with classic control. The advanced control of this system makes the hearth drying possible with the furnace's burners;
- Lowering maintenance costs.

Starting from this idea the Zirom control system was developed by adapting and modifying the system accordingly to titan forging needs and resulted in a different control system consisting of controlling the burner by continuous control, subzone alternation control and on-off control.

The results obtained in Zirom furnace are very important in order to show that the old concept and standard design of building these types of furnaces can be upgraded to a new one that has many advantages over the old solution.

The main advantages are:

- performance (temperature uniformity for low temperature regimes) was improved by changing the old concept of temperature control to a new design;
- cost reduction of initial investment was made by eliminating the need of an additional heat treatment furnace in order to obtain the low temperature uniformity at a holding temperature of 650 °C related to specific titan forging regarding aviation standards;
- cost reduction of initial investment was made by eliminating a heat recovery system and an exhaust fan;
- the use of a single heat recovery system (common heat recovery and exhaust fan) for both furnaces in order to lower the initial investment has led to a new inside chamber pressure control design in order to satisfy the new architecture of sensors and execution elements;
- increased reliability of the system was made through modern design and solutions;
- lower maintenance costs were achieved by eliminating sensitive equipment that is prone to failure and needed constant supervision and maintenance;
- cost reduction of initial investment was made by eliminating the need of a separate hearth drying installation. The advanced software burner control can manage to obtain a very precise temperature regulation even at very low temperatures.

The implemented solution of burner control which combines 3 types of control resulted in a better thermal convective transfer at low power demands and temperatures thus managing to obtain a temperature uniformity at least as good as a conventional furnace equipped with atmosphere recirculation fans according to performed TUS test. The TUS test is an undoubtable proof that this method of control delivers very good results in terms of performance also having a second advantage in eliminating the recirculation fans necessity.

The precise control of the air/gas ratio both for burner input but also for general furnace atmosphere is obtained by introducing a second stage regulation control loop for oxygen concentration in flue gases which can precisely adjust the air gas ratio resulted from the flow ratio control, thus managing to obtain a more precise oxygen concentration in the flue gases

This precise control managed to achieve the following:

- precisely calibrating the furnace atmosphere in order to maintain a very low oxidising even with defective burners as described in the paper;
- lower emissions and the fact that the system is capable of functioning within the regulations emissions limits even with defective burners as described in the paper.

Taking into consideration the unique approach of this project which implies a common heat recovery system for both furnaces, a new solution for controlling the furnace inside pressure was developed which is capable of producing very good results in order to limit the false air infiltrations.

Following this project, it was observed that the software routines and complexity is constantly evolving and capable of taking over and substitute different types of hardware equipment with notable results as shown in this paper which can only lead to engineering progress in developing better and specific solutions for industry needs.

The software engineer who designs these complex routines has to have a very good understanding of the overall process which involves a multidisciplinary knowledge (mechanical engineering, thermodynamics engineering, electrical engineering, metallurgical engineering and others) in order be able to design the software for driving all the equipment to the desired result.

5. Conclusions

The purpose of this research was to design and implement different automation control routines in order to achieve a better temperature uniformity inside the furnace without the need of recirculation fans, better air/gas ratio control, better pressure control taking in consideration the hardware design with one heat recovery system for both furnaces, better emissions control and to prove that the current conception of building these furnaces can be changed to a better one regarding cost efficiency and delivered performance.

The main conclusions are:

- the achieved temperature uniformity of ±5 °C according to the TUS test is compliant with the international aviation standards for temperature control in titan forging class 2 furnaces AMS 2750D and AMS H81200. This performance is obtained both for 650 °C and 1250 °C holding temperatures without the need of recirculation fans due to the advanced temperature control system implemented in the PLC software;
- the achieved temperature regulation accuracy at very low temperatures and power demands of ±1.5 °C according to the SAT test is compliant with aviation standards class 2 furnaces AMS 2750D;
- the precise control of the O_2 concentration of the furnace atmosphere is obtained by introducing a flue gas analyser value in the control loop which can precisely adjust the air gas ratio resulted from the flow ratio control, thus managing to obtain the correct furnace atmosphere in relation to titan forging;
- the precise oxygen control loop of flue gases and burner control system managed to lower the NOx emissions well below the maximum values according to EU directives even though the furnaces are working with preheated air which increases the standard cold air flame temperature that facilitates the formation of NO_x;
- using one heat recovery system for both furnaces is made possible by advanced control software routines previously presented which lead to a reduction of initial investment costs of the overall project and a better fuel economy.

The furnaces are currently in operation at Zirom Giurgiu with constant and good results regarding the targeted performance parameters. An interesting feedback was received from the beneficiary who said that given to their temperature uniformity performance in some situations they have also used these furnaces for different heat treatment procedures. Taking in consideration the fact that an initially designed forging furnace was used successfully for heat treatment speaks for itself about the delivered performance.

The overall conclusion of this project is that by using advanced software routines it was made possible to design and build a furnace that is able to maintain a holding temperature within the aviation standards for both high and low temperature regimes without the need of recirculation fans.

Till now furnaces were built to answer specific holding temperatures regimes (specific design for low temperature and specific design for high temperature). If a factory needed both high and low temperatures regimes with a specific temperature uniformity the only solution was to build 2 types of furnaces that will answer the specific demands of each individual process.

Now, it can be stated that these furnaces can be considered universal furnaces for both high and low temperature in contrast to the way furnaces were built in the past.

6. Appendix

Table 1. Abbreviations

PID	Proportional integral derivative controller
PV	Process value of PID controller
SV	Setting value of PID controller
MW	Manipulated value of PID controller
Kp	Proportional gain of PID controller
Ki	Integral gain of PID controller
Kd	Derivative gain of PID controller

TUS	Temperature uniformity survey
SAT	System accuracy test
AFR	Air to fuel ratio
λ	$AFR/AFR_{stoichiometric}$
PLC	Programmable logic controller
SCADA	Supervisory control and data acquisition
Nm^3	Normalized m^3 in relation to pressure and temperature
NOx	Generic term for nitrogen oxides as sum of NO, NO_2, NO_3
CO	Carbon monoxide

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