DIAGNOSIS IN AUTOMATION AND MONITOR SYSTEMS OF INDUSTRIAL FURNACES

Alexandru VOICU[1], Mihai Octavian POPESCU[2]

Over the past years a tendency of improving efficiency and lowering production costs can be easily observed regarding the heavy industry of metals. Besides improving application and machinery performance one of the subjects of great interest is reducing the downtime of machinery in order to lower production loses. This paper will present software implemented diagnosis, safety features and preventive maintenance procedures focused on a specific application of forging furnaces that aim to achieve a near 100% availability of machinery with scheduled and predicted maintenance interventions in order to lower production costs and loses.

The research was implemented at Zirom Giurgiu S.A. factory within the acquisition project of a system composed of two gas fired forging furnaces for titanium bars with a common heat recovery system delivered by Electro-Total SRL Bucharest.

Keywords: industrial automation, diagnosis, industrial furnaces, monitoring systems, preventive maintenance

1. Introduction

Taking in consideration the current industrial economical context which puts a high pressure on production efficiency and lowering production costs one of the most important points in this process is avoiding production loses and maintaining a high availability of machinery in order not to alter the production flow and also the specific cost of production units.

The heavy metal industry is a slow developing industry. Industrial furnaces for melting, forging, standard heat treatment, special heat treatment, etc. are not built in series production but are designed according to the requirements of the technological process in each factory [1], most of them being unique designs. For this reason, the modernization or replacement of these production units is a slow and costly process which implies advanced knowledge in order to improve their safety, efficiency and production capacity [3]. In Romania and other countries, there can be found furnaces that are in production for more than 50 years without any intervention of modernization except for current maintenance

[1] Engineer, Electro-Total Bucharest, Romania, e-mail: alexandru.voicu@electro-total.com
[2] Professor, Electrical Engineering Faculty, University POLITEHNICA of Bucharest (Romania), e-mail: mihaioctavian.popescu@upb.ro

works in order to ensure their operation. Safety features as flame supervision, tightness control, temperature protection [21], etc. or even auto diagnosis [20] are practically nonexistent. According to current regulations [13-14] these furnaces shouldn’t even be in operation, but the same regulations specifies that a furnace must be brought in accordance with the current safety requirements only when it is upgraded. As long as these furnaces operate according to their initial project and initial regulations for which they were approved they have the right to operate for an undetermined period of time, so legally speaking their operation cannot be stopped even though it can be life-threatening.
The main groups of heavy industry factories started to reach the conclusion that for remaining competitive in the current international market they are forced to bring improvements and optimizations to their productions process for increasing their performance and lowering the productions costs and loses [12]. Moreover, their main clients developed more restrictive audit procedures [20-21] that cannot be achieved by an ageing technology. Following this trend, the main players in this market which wanted to remain competitive started a large-scale modernization process for existing machinery and also acquiring new and modern machinery. With this being said an opportunity emerged for furnace production companies to bring new innovations and methods in order to lower productions loses.

In order to achieve better figures regarding security, efficiency and availability there is a need for better diagnosis and preventive maintenance systems.

2. Case study presentation

This case study is based on the acquisition project of two gas fired forging furnaces for titanium bars with a common heat recovery system [16] delivered by Electro-Total SRL Bucharest to Zirom S.A. Giurgiu factory that are commissioned and currently in production which followed the implementation of modern safety, diagnosis and prevention methods.

This case study will present an overview of these methods and their advantages brought to the improvement of production process.

Main characteristics of the furnaces:

- Interior usable space: 3000x2000x5000mm
- Insulation: ceramic fiber
- 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 per furnace

- Heating rate: 150 °C/h maximum, 20 °C/h minimum
- Average natural gas consumption: 90 Nm3/h /furnace
- Average electrical energy consumption: 22.5 kWh /furnace
- Automation monitoring and control level 1: PLC based
- Operator control and monitoring level 2: SCADA system

The study follows the conception, design and implementation of the monitoring and diagnosis system for furnace automation by utilizing specific PLC and SCADA programming software.

The application structure (Fig. 1) consists of:

- Main PLC for acquiring all sensor information and control of all execution elements
- HMI panel for local monitoring and control of the furnace from the automation cabinet located near the furnace
- SCADA PC for view, control, monitoring, diagnosis and data storage and analysis

Structure of actual application:

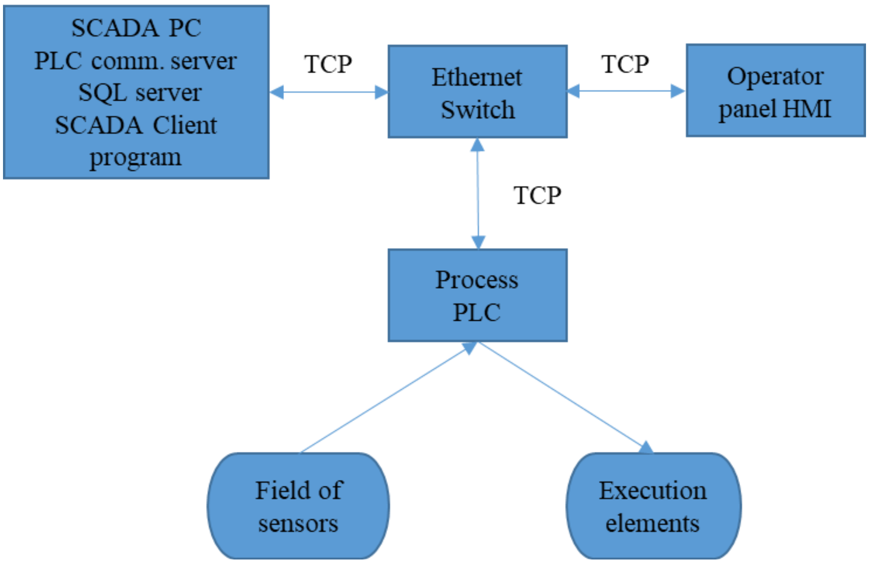

Fig. 1. Actual application structure

Taking in consideration the complexity of the project an XGI modular series PLC from LS Industrial Systems was chosen which is appropriate for use in large and medium scale solutions regarding processing speed, memory and expansion capabilities.

The PLC program is designed in ladder and structured text language depending on the routines' complexity, generally ladder is used for logical sequences (start, stop, conditions, etc.) and structured text for math operations (if, for, while, etc.) The SCADA PC software is designed in Visual Studio.

The interior of the furnace is shown below (Fig. 2) at nominal temperature (1250 °C) with the titanium bars ready for forging and 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.

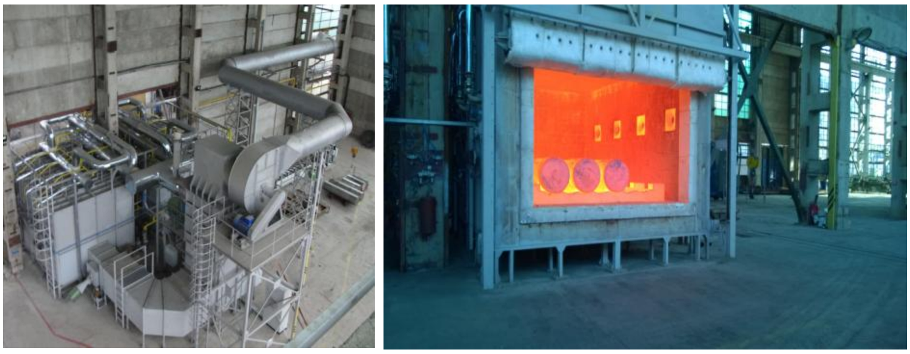

Fig. 2. Overview of the furnaces [19]

The diagnosis procedures are implemented both in the PLC system and SCADA system depending on their type. For example, real-time procedure with decision making routines regarding safety and functional aspects are integrated in the PLC system and analysis routines involving data base processing are integrated in the SCADA system.

The automation hardware cabinet with PLC and HMI integrations shown below (Fig. 3) controls the furnaces operation and implements the safety and diagnosis features.

Fig. 3. Automation PLC cabinet and HMI panel [19]

3. Diagnosis procedures and safety features

3.1. Main gas pipe and burner pipes double tightness test

The specific execution elements and sensors mounted on main gas pipe (Fig. 4) are used for providing proper safety operation and conduct the necessary automatic diagnosis procedure regarding safety tests.

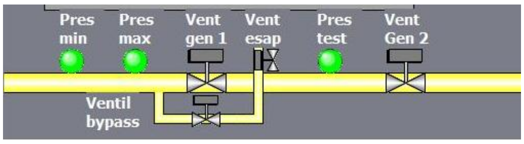

Fig. 4. Tightness test between main gas valve 1 and 2 [19]

The gas tightness test [16] is a safety and diagnose feature which is subdivided in to 2 tests:

- First test determines if either of the main gas valves have leakages
- Second test determines if either of the burner valves have leakages

The main risk of faulty valves is that they can lead to a gas accumulation in the furnaces chamber which can lead to a massive explosion during the ignition of the burners [4].

The regulations [13,14] states that every gas valve has to be doubled in order to increase the safety regarding methane gas leaks but in this case each group of 2 valves is treated as whole and energized together with a single command. This means that a single tightness test will only identify a faulty group of valves.

The unique feature of this test is the capability of automatically checking both the individual main valves and the burner valves. The standard and usual test considers each group of 2 valves as a whole thus checking the functionality of each group of valves in contrast to checking the functionality of each individual valve. By performing this double test, the automation system will identify each individual faulty valve.

As a safety feature it is automatically performed by the PLC software during the start-up phase of the furnace. If this test fails, the furnace enters in a lockdown mode which prohibits the starting of burners. Logical sequence (Fig. 5) of the 2 tests [16]:

- First test between V1 and V2 main valves
- Test OK -> carry on; Test Fail -> lockdown
- V2 = open
- Second test between V1 and burner valves
- Test OK -> carry on; Test Fail -> lockdown

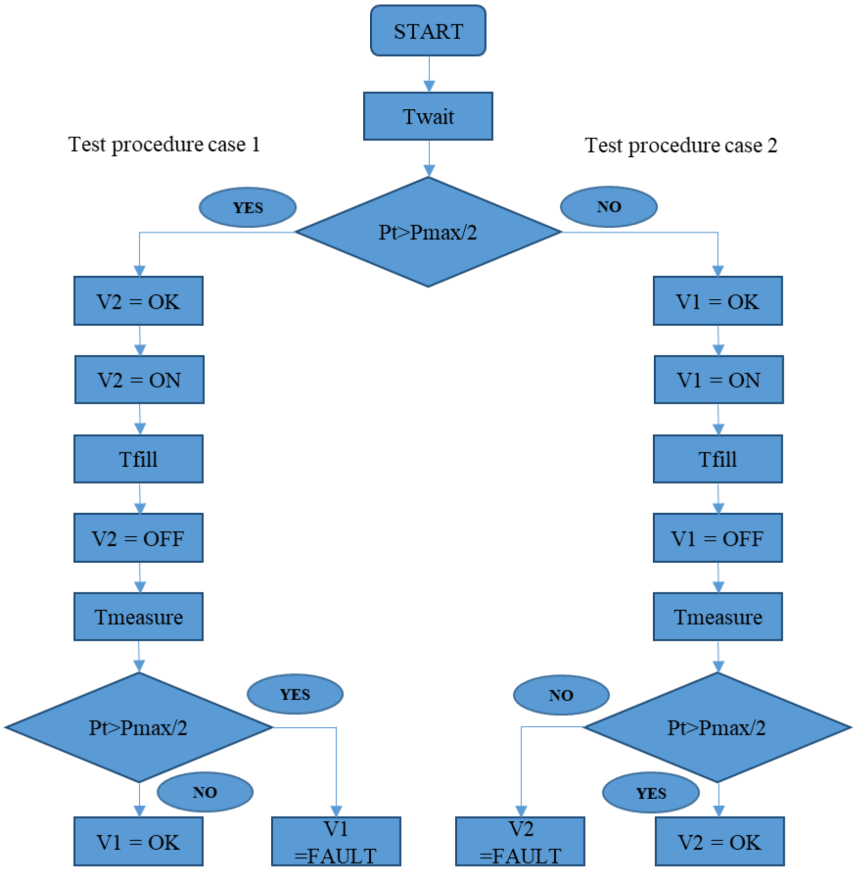

Fig. 5. Logical diagram of the tightness test [16]

Pmax = maximum supplied gas pressure
Pt = test pressure (for equal sensitivity transition from 0->Pmax or Pmax ->0 Pt=Pmax/2)
V1 = main valve 1
V2 = main valve 2
Tfill = necessary time for filling pipe with gas between V1 and V2
Tmeasure = waiting time for pressure changes

3.2. Burner startup and flame supervision

Furnace gas burners are ignited by a spark electrode and supervised by an ionization electrode or an UV sensor depending on the output power of the burner.

The flame supervision in gas fired furnaces is a safety condition especially when the furnace is operating bellow the methane gas auto ignition temperature. During this type of operation flame supervision is mandatory. Flame supervision eliminates the danger of gas pocket accumulation inside the furnace chamber which can lead to explosions.

Bellow it is shown a logical diagram (Fig. 6) of the burner supervision routine which achieves the following:

- Safety lock chain verification in furnace start-up before this step
  - Safety lock if a previous operation of the safety chain failed during start-up
- Check for flame presence without start command
  - Possible valve tight fault
  - Possible flame detection fault
  - Possible relay command fault
  - Possible cables fault
- Start sequence of the burner
  - Open gas valve
  - Turn on spark ignition for a predetermined time
  - Check for flame presence
- Auto restart sequence management
  - The automation is allowed to execute a maximum of 3 unsupervised burner ignition attempts after a flame failure during a 90 min period of time
  - If there are more than 3 flame failures during a 90min period time all without successful reignition the automation activates the safety lock
  - After a successful reignition due to flame fault and after every 30 minutes period of continuous operation without flame fault the automation increments +1 to the allowed auto restart tries value to a maximum limit of 3
  - After finishing all the auto restart tries the automation activates the safety lock
  - After safety lock activation the automation permits a maximum number of 10 supervised manual restart tries before activating the whole safety lock chain
- Fault management
  - Close gas valve
  - Safety lock activation
  - Fault signaling

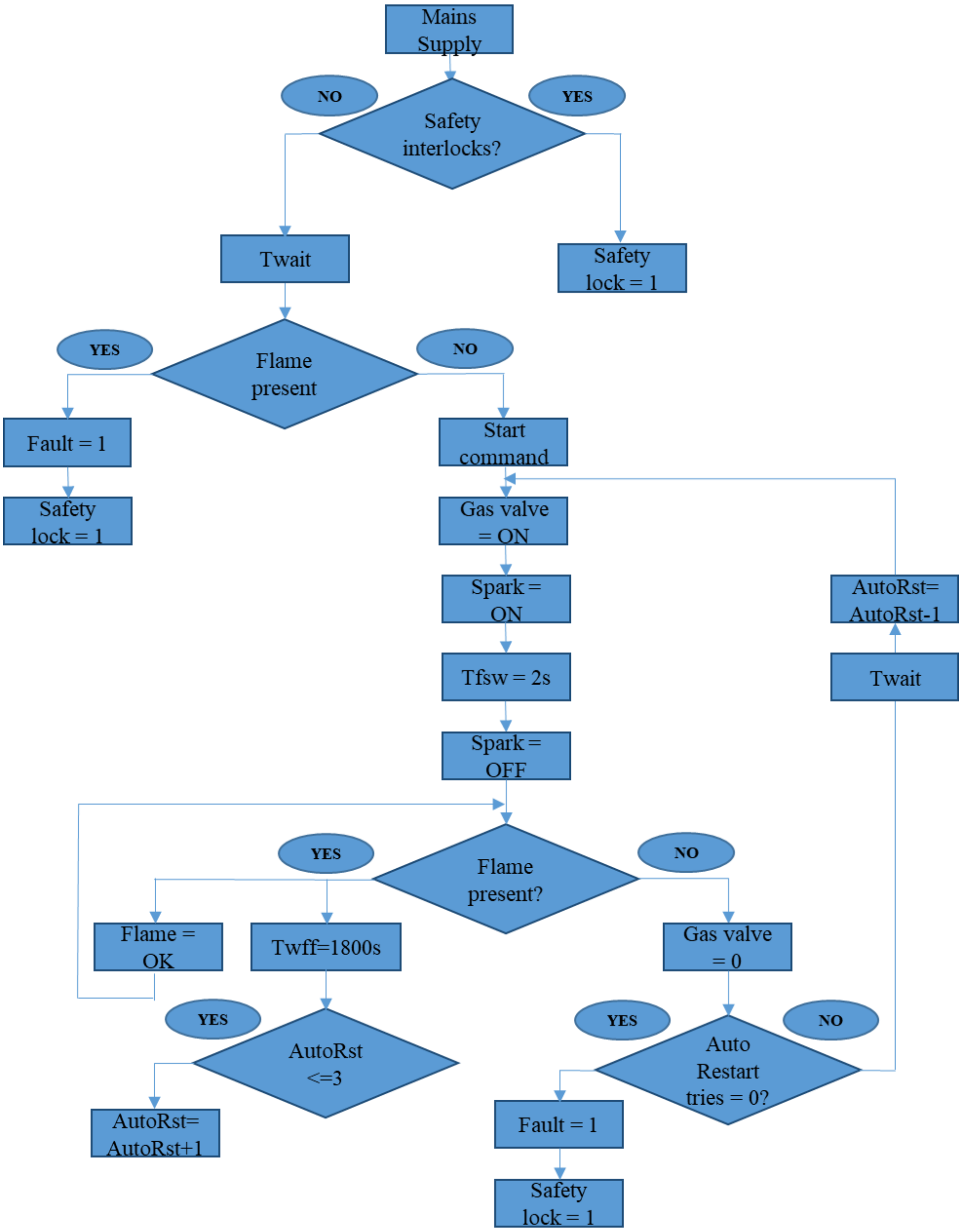

Fig. 6. Logical diagram of burner startup and supervision [15]

Safety interlocks = chain of safety interlocks (example tightness test fault or not done)
Tfsw = waiting time for flame stabilization
Twff = time without flame fault

4. Preventive maintenance procedures and features

4.1. Alarms frequency recurrence

Alarm frequency recurrence is a diagnostic method used for preventive maintenance. The PLC routine detects when a certain alarm frequency is starting to exceed the average occurrence frequency of the past days/month depending on the routine setup.

For example, it is quite common that in gas fired furnaces to have a few burner flame faults during a 24-hour working time, but when this frequency occurrence is starting to rise this could signal an abnormal functioning and the forming of a much greater defect in the burner system itself.

After identifying the rise of an alarm frequency occurrence (Fig. 7), the PLC will signal this event by a specific alarm which alerts maintenance department.

The main advantage of this function is that the system can be maintained/repaired before a full system malfunction/shutdown occurs that disturbs the production flow and causes production loses.

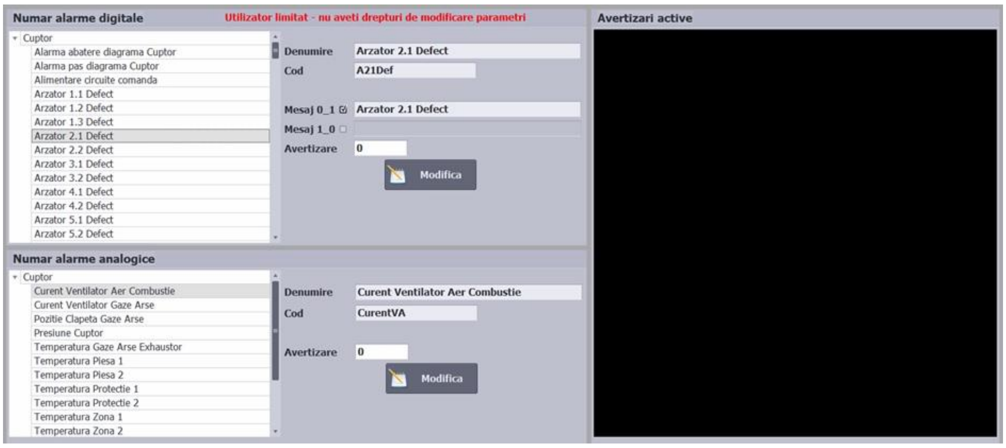

Fig. 7. Alarms frequency recurrence SCADA window [19]

4.2. Logic comparison and plausible values in different temperature point measurements

Throughout the whole route of the flue gases and air combustion in the furnace the PLC continuously compares different measurement values in key points of the furnace in order to determine if certain values are plausible or if they signal a possible fault in one of the measures or in the system itself.

Taking a simple example into consideration one comparison is between the input and the output flue gas temperature of the heat exchanger (heat recovery system) in which the input temperature value should always be much higher than the output value. If the measurements are not as described above this could indicate a possible fault. The automation system signals through an alarm a discrepancy measure value in this part of the furnace which should be inspected.

4.3. Increasing/decreasing value pattern

The classic alarm routine of an analogic measured value from the field of sensors consists of an alarm value of the measure, fault value of the measure, hysteresis value, minimum trigger occurrence time and others. This way the abnormal functioning is detected when it occurs.

The analysis of the pattern (Fig. 8) means the automation system can calculate based on past data base values if a measured value tends to increase or decrease to the alarm/fault value and roughly calculate when it will hit these values. For example, all the large fans in this furnace (air combustion fan and flue gas fan) are monitored through vibration sensors. When the automation system detects an increase pattern of the vibration values it calculates and signals the possible date/time when these values will exceed the alarm/fault values. This way the maintenance department can organize and schedule it’s maintenance for replacing the fan bearings, cleaning the fan and dynamic balancing of the fan.

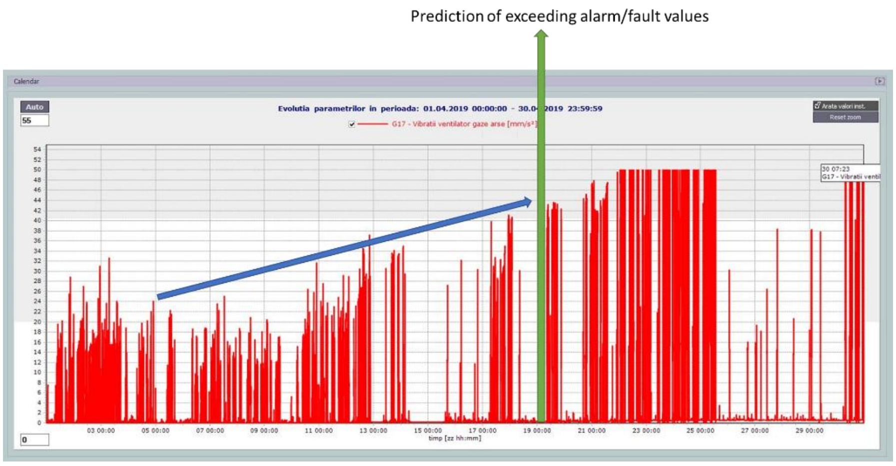

Fig. 8. Alarms/Faults prediction [19]

The main advantage of this technique is that an alarm/fault will not take the maintenance department by surprise but it can be prevented from occurring in the first place. This translates to better availability figures for this furnace.

4.4. Scheduled maintenance monitoring

Scheduled maintenance is the part of the automation system which monitors all the equipment and maintenance operations which should be done.
Usually all equipment has a scheduled maintenance operation described in the technical manual which are introduced in the SCADA software.

The automation system monitors the operating hours/time from last maintenance and alerts the operator with a predetermined time in advance that some maintenance operations should be done.

5. Conclusions

The PLC software and diagnostics procedures are developed by the author of this paper. The application is commissioned and fully working at the beneficiary site of production with very well results in real life working environment. Software implemented diagnostics can be categorized in primary diagnostics and extended diagnostics. Primary diagnostics are common procedures that can be implemented regardless of the type of application (ex: open loop detection, measurement value increase beyond safety limit, etc.). Using these types of diagnostics procedures can mainly identify faulty equipment.

Extended diagnostics are industry type specific procedures related to the particularity of each application and developed accordingly (ex: logic comparison of plausible values, pattern analysis, etc.). Using these types of diagnostics procedures can identify faulty equipment and also more complex problems like inadequate automation response to system feedback, PID loop control out of tune parameters, etc.). Preventive maintenance can identify faults that are about to happen, equipment that has a tendency of an increasing malfunction behavior and also keep track and announce scheduled maintenance operations for each individual equipment according to the manufacturer maintenance program.

The contribution of this research made by the author and implemented in a real working application at Zirom S.A. Giurgiu factory is the developing of new extended diagnostic and preventive maintenance solutions in relation to the particularity of the system composed of two gas fired forging furnaces for titanium bars with a common heat recovery system which achieved the following results in relation to the usual diagnostics procedure that are widely used:

- Increased availability of the furnace production uptime
- Better fault detection
- Better maintenance track of operations
- Higher percentage of performed scheduled maintenance operations
- Traceability of maintenance work
- Traceability of faults and malfunctions
- Unit production cost and specific consumption decrease
- Lower maintenance costs by early identifying problems
- Close to “0” unscheduled shutdown of the furnace due to unexpected faults

Future work can be based on other technics of extended fault detection which can rely on a very good understanding of the technological process and functioning of the furnace or a unique value of the furnace heath [0-100%] based on all the measurement parameters and faults which can be categorized in different types (light, medium, severe, emergency lockdown) and which have a different impact on the overall heath value and availability of the furnace. Based on this overall value of the furnaces health and its tendency pattern the automation system may calculate the imminence of a capital repair and maintenance work shutdown necessity and approximate its due date.

The main difference of this technique would be that the capital repairs and maintenance shutdown schedules won't be fixed as they are now but they can be actively and constantly adjusted by automation system based on the system actual state of health thus resulting in higher furnace production availability and lower maintenance costs.

R E F E R E N C E S

1. J.H. Brun Klaus s.a., "Cuptoare industriale" [Industrial furnaces], Editura Tehnica, 1977
2. I.G. Cara Bogdan s.a „Instalații termice industriale" [Industrial thermal installations] , Editura Tehnica, 1983
3. V.P. Lincevschi ,"Cuptoare de încălzire" [Heating furnaces] , Editura Tehnica, 1952
4. M. Marinescu s.a. „Instalații de ardere" [Combustion installations], Editura Tehnica, 1985
5. W. Trinks „Industrial Furnaces" , Editura Wiley, USA 2004
6. Peter Mullinger „Industrial and process furnaces" , Editura Elseview Science & Technology, UK, 2017
7. K. Ogata, "Modern control engineering" (5th edition), Pearson, 2009
8. Norman S. Nise, „Control Systems Engineering" (7th edition), Wiley, 2015
9. Teoreanu I. „Instalatii termotehnologice" [Thermotechnological installations], Editura Tehnica, 1979
10. Badea, A., ş.a. „Echipamente şi instalaţii termice" [Equipment and thermal installations], Editura Tehnică, Bucureşti, 2003
11. Carmen Ionescu-Golovanov „Măsurarea mărimilor electrice în sistemul electroenergetic" [Measuring of electric quantities in the electric power system], Editura Academiei Romane, 2009
12. Roxana Patrascu, Eduard Minciuc "Analysis of energy efficiency of external recuperation of heat from flue gasses from industrial processes" U.P.B. Sci. Bull., Series C, Vol. 75, Iss. 3, 2013 ISSN 2286-3540
13. European Union standard "EN 746-2:2010" Safety requirements for combustion and fuel handling systems
14. Government of Romania „PT A1-2010" Aparate de încălzit alimentate cu combustibil solid, lichid sau gazos [Heating devices fuelled with solid, liquid or gaseous fuels]
15. Electro-total „ Internal company documentation and know-how"
16. Alexandru Voicu, "Forging furnaces for titanium with central heat exchanger" – Heat Processing - International Magazine ISSN 1611-616X, pages 148-150, Germany, no.3/2015
17. Elster Kromschroder „Optimal control and reliable safeguard", Osnabrück Germania 2014
18. Elster Kromschroder „Electronic system process heat", Osnabrück Germania 2015
19. Zirom S.A Giurgiu actual pictures of the delivered project in real life working conditions
20. SAEAerospace (Society of Automotive Engineers) „AMS 2750D", United States of America, 2005
21. SAE Aerospace (Society of Automotive Engineers) „AMS H81200", United States of America, 2014