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NEW CENTRAL CONTROL SYSTEM ARCHITECTURE FOR ANODE BAKING FURNACES

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Abstract

Conventional anode baking firing and control systems are composed of several mobile pieces of equipment with their own local controller to manage the high speed local tasks. Redundant central control units synchronize the actions of each local controller.
A fast real time Ethernet network implementation allows simplifying the existing control system architecture: it uses only one real time central controller and remote Inputs/Outputs for each mobile piece of equipment.
The robustness and reactivity of the control as well as the required safety loops are preserved. The maintenance and day to day operation are simplified.

Furthermore, real time network and accurate time synchronisation between the pieces of equipment open new perspectives to improve the baking process management and to enhance safety.

Introduction

Aluminium is produced through Alumina electrolysis by means of carbon anodes. Prior to use in the pot lines, the green anodes produced from petroleum coke and coal tar pitch need to be baked in an Anode Baking Furnace (ABF) fitted with a Firing and Control System (FCS).

Covered with a building, the ABF is made of refractory brick walls built in a concrete casing. (See Figure 1) The ABF is divided in several sections (from 34 to more than 70). Each section is composed of 7 to 10 flue walls delimiting 6 to 9 pits in which the anodes are baked by thermal conduction. One or two Furnace Tending Assembly (FTA) cranes are moving above the FCS pieces of equipment located on top of the Furnace, to load and unload the anodes in/out of the furnace pits.

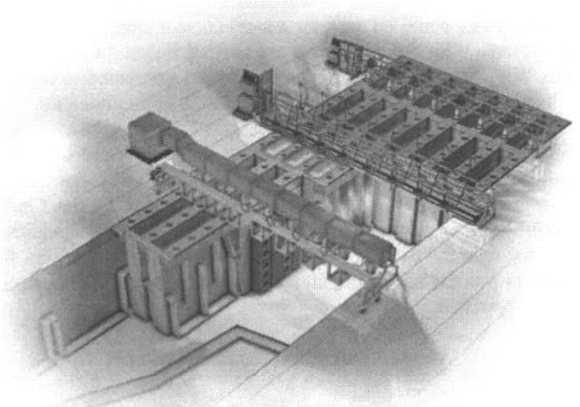

Figure 1 – Anode Baking Furnace

The Firing and Control System is composed of several mobile ramps that are grouped by Fire (1 Exhaust Ramp (ER) + 1 Temperature & Pressure Ramp (TPR) + 2 to 4 Heating Ramps (HR) + 1 Zero Point Ramp (ZPR) + 1 Blowing Ramp (BR)) – The Fires are located on top of the Furnace and are distributed over the various firing sections.
As part of the normal operation, each Fire moves one section forward every day to bake the green anodes loaded in the front part of the fire and to allow unloading the baked anodes from the back part of the fire. For a 4-Fire Furnace with a 24 hour baking cycle time, 20 ramps (4 ER + 4 TPR + 4 HR + 4 ZPR + 4BR) are relocated inside the building every day. At each Fire moving, as part of normal operation, the ER is always replaced by a new ER and sometimes a ramp can be changed by a spare one, for maintenance purpose.

In addition to the ramps, one PLC named Auxiliary Equipment (AE PLC) ensures the interface between the ramps and the Furnace Fume Treatment Plant (FTP), the Furnace fuel supply loop and some other Furnace utilities (for example, emergency stop and explosion vents).

Conventional Control System architecture

All the ramps are locally controlled by a Programmable Logic Controller (PLC) to manage the high speed local tasks (such as injector pulse generation, damper positioning, Heating Ramp fuel circuit process and interlock management).

In the past to achieve the same level of safety as expected by most users and as promoted by Fives Solios, a dedicated safety loop was powering down the furnace power plugs of the ramps, to safely stop the fuel injection in case of FTP draught problem. The use of Safety Integrated PLC (SIPLC) on the key ramps (AE, ER & HR) allows managing the same safety loop while assuring a continuous follow-up of the process data. Indeed, with SIPLC, the ramps can continue displaying their data for the operator follow-up because they can stay power-up while safely stopping the fuel injection.
Safety Integrated PLCs can manage simultaneously process tasks and safety loops within the same controller. They can manage local safety loops (Input and Output on the same PLC) but also manage safety loops across the Network (Input on one PLC and output on another PLC).

The Ramps are controlled and monitored by two hot redundant computers (Central Control System) located inside the ABF control room. The master computer makes calculations based on data collected from each ramp through the communication network and sends commands to the ramps. All commands are sent to each ramp using the same Communication Network.

These data are also displayed on the supervisory computer screens (Real Time Supervisory) for operator follow-up and stored in the Data Management computer (Data Management System).

Few industrial networks with a good bandwidth allow hot connecting and disconnecting of a User without trouble. One of the best available nowadays is Ethernet.
Ethernet is a frame-based computer networking technology for Local Area Networks. It defines wiring and signalling for the physical layer, and frame formats and protocols for the media access control (MAC) (data link layer) and common addressing format. Ethernet is standardized as per IEEE 802.3. Most of the present networks use Ethernet TCP/IP type of networks (IP stands for network layer and TCP (TCP/UDP) stands for transport layer). This choice of technology allows using wireless networks (See Figure 2).

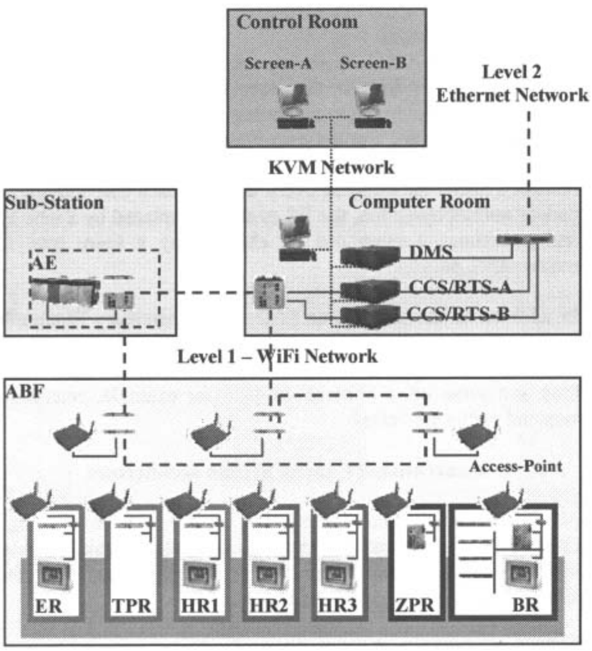

Figure 2 - ABF Control System Architecture

In theory, the Ethernet TCP/IP network of the FCS is open and could be used for several application of the ABF. However because this network is such a critical part of the FCS, it is very often dedicated only to this purpose. A Wired Ethernet TCP/IP Network has a star network topology requiring a heavy infrastructure (Enough Ethernet switches dispatched inside the Furnace building to have one port for each section and wiring up to each section). The infrastructure and the protocol introduce latency time in the communication. WiFi network has simplified the infrastructure. However, the ramp section numbers are not anymore identified automatically by the system and longer communication latency time between the ramps has been introduced. Moreover, WiFi networks are difficult to install, to configure and to maintain because they can be disturbed by other Wireless Networks or radio users (such as meteorological and army radars) [1].

New Central Control System Architecture

A fast real time Ethernet network implementation allows simplifying the existing control system architecture: it uses only one real time central controller and remote Inputs/Outputs for each ramp and for the Auxiliary Equipment (AE PLC) (See figure 3).

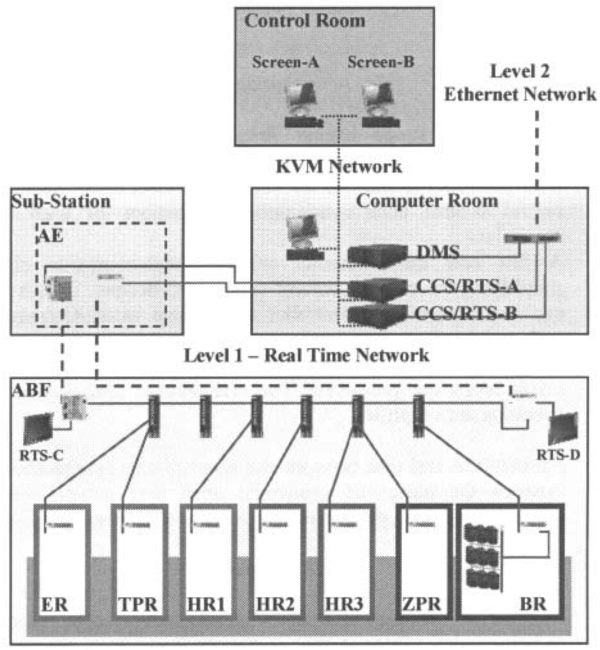

Figure 3 – New ABF Control System Architecture

The day to day operation is simplified, because there is only one controller, there is only one programmed behaviour (no more choice between remote control or local control), one set of parameters and most importantly for the operator only one type of HMI (Human Machine Interface – Control Screens). On the proposed architecture, the ramp screens and their dedicated HMI are replaced by at least one touch screen located on each side of the ABF. These screens are Real Time Supervisory (RTS) HMI as the ones inside the control room.
WiFi tablet PC also with a RTS software similar to the one in the control room could be used for a local control close to each ramp. Therefore, WiFi Access Points are needed inside the furnace but this WiFi network has very few constraints compared to the ones when the network is used for the whole FCS communication.

Signalling and commands located on the ramps are limited to safety functions only: emergency stop, field validation by the operator that the ramp can be remote controlled by the Central Controller and electrical insulation of both flue wall injectors if for any reason, such as maintenance (injector not set on the flue wall) or process management, the operator chooses that they must not be operated.

Anode Baking Process Improvement

Real time network and accurate time synchronization between the ramps open new perspectives to improve the baking process management. One of the main improvements is the accurate sequencing of the injection to avoid flooding situation, incomplete combustion and non-homogeneous injection flame.

According to the fire cycle time, a fire can be composed of 2 to 4 Natural Gas (NG) or Heavy Fuel Oil (HFO) type of Heating Ramp. The two types are equipped with two injectors per flue wall. Consequently, four or eight injectors can inject inside the same flue wall. Combustion air coming mostly from the back (supplied by the Blowing Ramp), has less and less available oxygen as it moves from the first Heating Ramp to the last one.
The injection is done by pulse. The injector power is adjusted either by modulating the opening or closing duration or also by adjusting the injection pressure. Nevertheless, when the injector injects the fuel flow consumption is always at its maximum. For HFO injection duration may vary from 30 to 150ms, and for NG this duration may vary from 0,5s to 4s.

According to the injection sequence between the 4 or 8 injectors located on the same flue wall, there are situations where some injectors inject in the same air volume as the upstream ones. This can either lead to complete combustion where the fuel finds available oxygen (combustion happened but not in the expected place) or to an uncompleted combustion with unburnt volatiles. This phenomenon-happens more often with NG as pulse durations are longer.

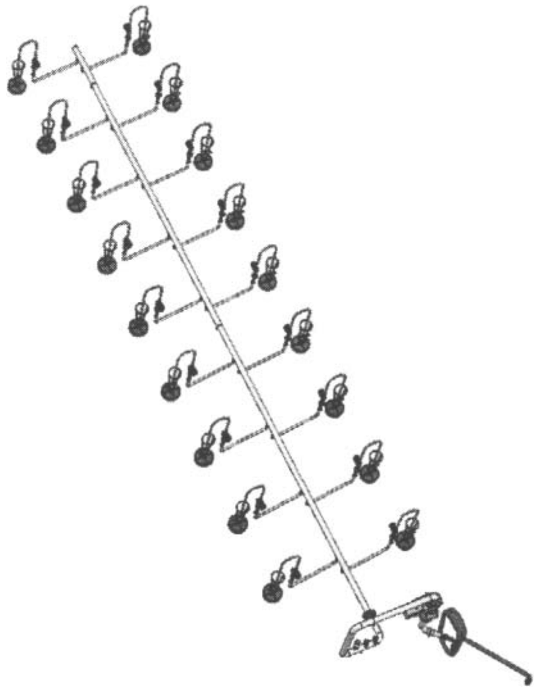

Figure 4 – Heating Ramp gas circuit

Moreover, each ramp is equipped with 7 to 10 pairs of injectors connected to the same fuel feeding piping (See Figure 4). This piping is installed on the Heating Ramp and connected to the furnace piping through a flexible hose.
In average, a Heating Ramp is running at a third of its maximum power, the piping is sized accordingly. With NG, if all injectors open at the same time, the high requested flow makes a consequent pressure drop and the injection flame does not remain homogenous across all flue walls.

The new Central Control System built around one real time controller and a real time network up to the remote Inputs/outputs allows managing all of the injector sequencing accurately across the 2 to 4 Heating Ramps. Indeed, the real time controller manages its tasks on a priority level basis. Consequently, at each cycle time, it acquires all its inputs on all the fire ramps before starting its calculations and it sets all its outputs on all the fire ramps before starting another cycle. The real time network allows that effectively all the inputs and outputs are respectively read and written at each cycle.

A specific algorithm combines the temperature set points set by the operator and the temperatures read for each flue wall with other measurements such as CO, air flow inside the flue wall and so on, to calculate the optimal injector sequencing. This sequencing optimises the air consumption inside each flue wall along with the fuel flow across each Heating Ramp in order to keep a complete combustion and an homogenous injection flame.

Preliminary prototype testing is quite encouraging and allows expecting significant gain on the overall fuel consumption and a reduction of the fuel unburnt residues. Further tests will be made to validate the improvement for the homogeneity and consistency of the baking level inside and across the-various pits.

Central Control System Example

For example, Fives Solios chose to use Ethercat technology [2] for the real time network along with Twincat from Beckhoff as real time controller.

An Ethercat Network is a Class C Ethernet Network that will use dedicated hardware on the slave device side to ensure high performance. The Master uses a Standard Ethernet Controller. TCP/IP is not used for process data communication. A dedicated process data protocol is introduced and transported directly in the Ethernet Frame.

Ethercat network main characteristics are:
- It is the fastest Ethernet network available currently,
- It is a real time Ethernet Network up to the remote Inputs/Outputs,
- It is a wired and redundant network,
- It is TUV certified for application up to SIL3 as per IEC 61508 and DIN EN ISO 13849 PLe standards,
- It is easy to troubleshoot (easy to find where it is cut – either damage components or cables),
- It allows accurate synchronizing of the inputs and outputs.
- It supports hot connection of Input/Outputs groups.

An Ethercat Network is controlled by a Master Controller and all the other components of the Network (Input/Output cards, variable speed drivers and so on) are Slaves. The Master sends only one frame on the Network. This frame will go from the Master to each Slave. Each Slave reads and writes its data inside the frame before sending it to the next Slave. The last Slave of the chain closes the loop and sends the frame back to the Master following the same path in the reverse order. Only one Ethercat frame is present at a time on the Network.

Dedicated electronic chipsets (FPGA or ASIC) are used to manage the Communication to the Slaves, so as to limit the transmission delay. The Network performance does not depend on the micro-controller of the slave devices and is thus predictable.

Each Ethercat Slave has one Network input and one Network output. Consequently, the Network topology is very flexible and only Ethercat components are used to build the Network – no switch or external components are needed. This Network contrary to a Wired Ethernet TCP/IP Network does not require a star network topology which implies a heavy infrastructure. Up to 65535 slaves can be wired in a line structure or with any number of drop lines or branches, providing the most flexible topology. The Network is made of standard 100Mbits/s Ethernet cables and Optic Fiber.

Even if Ethercat network used its own protocol, compatibility with TCP/IP protocol is preserved. Indeed, through specific Ethercat components, it is possible to connect TCP/IP protocol users to the Ethercat Network and their TCP/IP messages are inserted to the Ethercat frame without any impact on the real time control performance.

Twincat is a real time controller running under Windows Operating System. It is pre-emptive and deterministic so has to be not disturbed by any action of Windows.
Twincat is installed on an Industrial Computer using the latest computer processor available which has a calculation power greater than most of the PLC available on the market.
Twincat Controller is also the Master of the Ethercat Network.

Dedicated and TUV certified Safety Controller and Inputs/Outputs are used to managed the safety loops. Communication between the Safety Controller and the Safety Inputs and Outputs are done using the same Ethercat frame that is transiting on the Network.

Enhanced Safety

The choice of this technology has enhanced the FCS global level of Safety.
Safety can be divided in two different categories: either Process Safety that is normally managed by the Controller or Safety Instrumented Functions (subject to SIL - Safety Integrity Level ranking as per standards IEC 61508) and that are additional safety loops for the system. These safety loops must be managed by independent components or by the safety task of a Safety Integrated PLC.

The Process Safety is enhanced as only one Controller manages it. It is not anymore shared by the Central Controller and the Local Controllers. Consequently, the software is simpler, easier to check, to test and to maintain.
By suppressing the latency time of the network which can be observed on a WiFi Network, the Process Safety is improved along with the reactivity of the system.

The Process Safety is enhanced also because the technology allows reliable and accurate locating of the ramp on the furnace. With the generalisation of the WiFi network, unless costly systems were integrated, the system was depending on the operator inputs to know on which section the ramp was localized. Unfortunately, due to lack of additional system to confirm the ramp localization, with a good knowledge of the system the operator can make it work even if the ramps were not physically at the right place. This could have consequences on the Process follow-up and on the Safety. This localization is important because it is used for Process Safety exchanges regarding the level of draft in the pre-heating zone between the Exhaust Ramp and the Heating Ramps, so that these last ones can inject safely. Moreover, this localization is used to store the data intelligibly in the DMS database, so they can be easily found out later for process analysis.

Because the Central Controller is running on an Industrial Computer, there is a great calculation power available. Some Safety Modules developed by Fives Solios such as the blocked flue wall detection becomes more accurate because they have more calculation power available instead of being limited by the local controller on which they were installed.

The safety loops that were managed by the SIPLC task are preserved and managed by dedicated components.

Robustness Improved

The choice of this technology has enhanced the FCS robustness as there is only one Central Controller to maintain and less active components on the ramps.
Moreover, by reducing the number of components on the ramps, their electrical cabinets are simplified and their sizes are reduced along with the solicitations for the air conditioning system.

The Ethercat Network is a redundant wired network. The Communication is more reliable than on a WiFi Network because it cannot be disturbed by external phenomena. Of course this Network could suffer from the same problems as other Wired Networks such as plugs, sockets and cables that are cumbersome and cannot endure cyclic change-over. For that reason, specific cables and plugs were tested to be more resistant and easy to change. Back-up solution such as additional cables and plugs are part of the design so that process continuity is always ensured.

The proposed architecture has hot redundancy for the Network and cold redundancy for the Central Controller and for the Safety Controller. Cold redundancy of the SIPLC was not possible because too costly with the previous Control System Architecture.

Simplified Maintenance Operation

By design the system architecture is simple to understand and to maintain.

The hardware is reduced and simpler than with the previous Control System Architecture (no WiFi Network with very specific settings, no Ethernet component switches or others to be programmed, no complicated IP address plan to be set, no firmware to be updated on all the components, so they can be compatible with each other, and so on).

There are no active components with their own specific settings on the ramps. The maintenance people can easily and quickly change any components.

There is no requirement for a programming console, as the only controller has already its own programming and diagnostic tools integrated.

The system is open. It is easy to add a group of Inputs/Outputs or even just one I/O card inside an existing group. There is no limitation to the number of I/O cards that can be added to a group. Rack size or maximum communication messages manageable by the head controller of an I/O group are not anymore a limitation of the system.

Conclusion

Real time network and accurate time synchronisation between the pieces of equipment open new perspectives to improve the baking process management and to enhance safety.

The maintenance and day to day operation are simplified.

The investment cost (CAPEX) of the FCS is reduced of more than 10%. Also, maintenance work made easier as well as injection improvement will bring significant operation cost (OPEX) reduction.

References

[1] Nicolas Fiot, Christian Coulaud, "Wireless communication for secured Firing and Control Systems in Anode Baking Furnaces", TMS2011.
[2] Ethercat Technology Group – General presentation.