IMPLEMENTATION AND CONTROL OF BOILER SYSTEM

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Abstract. The present paper describes the steps and functions needed to configure a boiler control system in Honeywell Experion PKS, following guidelines and modifying the Human Machine Interface (HMI), so that the operators can understand and control the process better.

Keywords: Experion, Honeywell, HMI, Configuration studio, Steam generation, Boiler control.

1. INTRODUCTION

The basic principle of the boiler is very simple and easy to understand. Essentially, the boiler is a closed vessel with water. The fuel is burned in the furnace chamber, and hot gases are produced. These hot gases come into contact with the so-called downpipes, where the heat of the hot gases is transferred to the water, and as a result, steam begins to form in the boiler. The steam is then reheated several times until the required parameters are reached and fed to the turbine or a collecting manifold (Fig. 1).

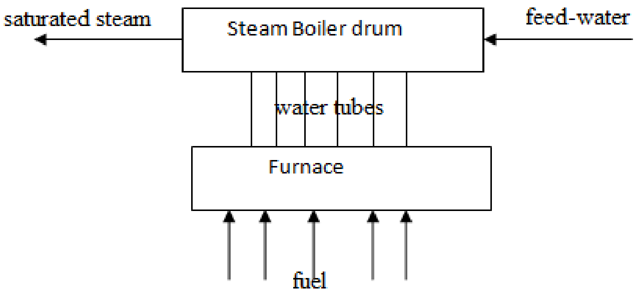

Fig. 1. Principles of steam boiler operation

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The design principle uses the difference in density between cooler water in the down-comer and the steam/water mixture in the riser to drive the steam/water mixture through the tubes. The boiler drum separates steam from water and contains inventory to accommodate operational changes. Water enters the riser tube, is heated, and undergoes a transition from a single-phase liquid to a mixture of saturated liquid and steam. As heat input increases, the proportion of steam vapor in the riser tube increases. The water/steam interface level is subjected to several disturbances in the water/steam drum, not the least of which are drum pressure and feedwater temperature [1]. As steam pressure rises or falls due to load demand, there is a transient change in drum level due to the expansion or contraction of the steam bubbles in the drum water. When the steam pressure is lowered, the water level rises as the steam bubbles expand (swell). Conversely, as the steam pressure rises, the water level lowers due to compression (shrinking) of the steam bubbles [2]. This makes the object non-minimally phased (Fig. 2), which leads to control problems when adjusting the level in the drum.

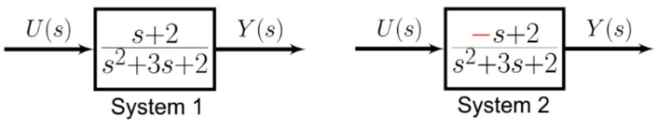


Fig. 2. Transfer functions of a minimal and non-minimal phase object

These are two systems with the same poles but different zeros. System 1 has zero s=-2, and system 2 has zero s=2.

Let's divide System 1 (Fig. 3) into two parts – a part with zeros and a part with poles.

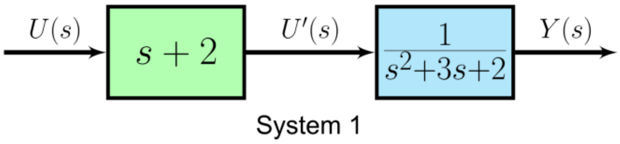


Fig. 3. System 1[26]

Let us call the output of the zero system U’(s). We analyse the transfer function of the zero system [3]:

$$\frac{U'(s)}{U(s)} = s + 2 \tag{1}$$

$$\rightarrow U'(s) = (s+2)U(s) \quad (2)$$

$$L^{-1}\{U'(s)\} = L^{-1}\{(s+2)U(s)\} \quad (3)$$

$$\rightarrow u'(t) = \frac{d}{dt}u(t) + 2u(t) \quad (4)$$

If we use the same procedure for System 2, the result will be:

$$u'_{System\ 2}(t) = -\frac{d}{dt}u(t) + 2u(t) \quad (5)$$

The only difference is the negative derivative in the resulting expression. This negative derivative is the reason why the step response diagram of system 2 has a negative part at the beginning (Fig. 4) [3].

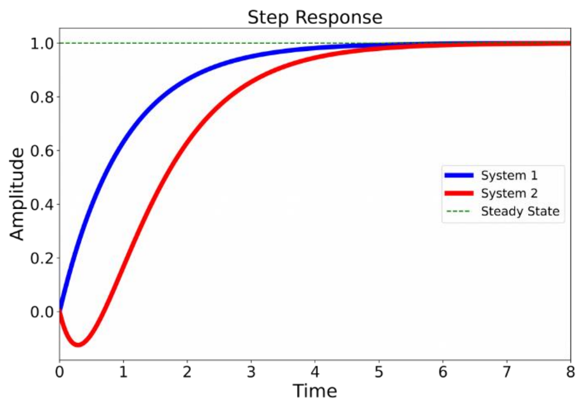


Fig. 4. Step Response diagram for system 1 and system 2

2. STAGES IN THE STEAM GENERATION PROCESS

There are different components present in the feed water and steam circuit of the boiler. Some of the essential components of these circuits are economizer, boiler drums, evaporator, water tubes, and superheater.

Production of high-pressure steam is carried out using high- and low-pressure drum-boiler units according to the following process.

Economizer stage: Water fed by the pump supplied to the drum inlet is preheated in order to reduce energy consumption. Economizer is a component that consists of water pipes that are placed on the track of fuel gases after the evaporator pipes. Economizer pipes are made of steel or cast-iron materials that are able to withstand high heat and pressure. Economizer serves to heat feed water before it enters the steam drum and evaporator. Because the Water fed to the evaporator is at a high temperature and the temperature difference is not high, the evaporator pipes are not easily damaged due to thermal equilibrium.

Evaporator stage: Due to the gravity, water flows down through a downcomer-riser closed loop, producing saturated steam which flows along the riser tubes before being collected and fed back into the drum. The evaporator is one of the components that serve to convert water into saturated steam. Evaporator pipes in steam boiler are usually located on the floor (water floor) and also on the wall (water wall). In these pipes, the quality of saturated steam at 0.80 to 0.98, so most are still shaped in a liquid phase. The evaporator will heat water that falls from the steam drum, which is still in the liquid phase, to form the saturated steam so it can be forwarded to the superheater.

Superheater stage: The saturated steam flows through the water level till it exits upon reaching the drum outlet. Then it is reheated one more time, producing superheated steam supplied to the turbine/plant. Superheater is basically a heat exchanger in which heat is transferred to the saturated steam to increase its temperature. In the superheater, the rate of heat absorption is higher. Hence, in modern water tube boilers, there are more superheating surfaces. Super-heater tubes are exposed to the highest steam pressure and temperature on the inside and the maximum gas temperature on the outside (Fig. 5) [1, 4, 5].

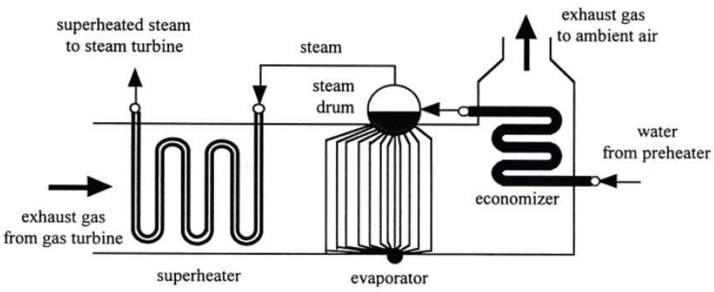


Fig. 5. Heat Recovery Steam Generator

The simplified process relevant to my analysis concerning steam generation using the drum-boiler unit is illustrated in (Fig. 6). Supplied inflow from the feed-water pump is regulated using one control valve. As for the steam flow rate leaving the drum, it can be regulated using different valves connected in parallel with distinctive construction and functionalities.

1. Water tank control valve: always kept open at a predefined position.
2. Bypass valve: A butterfly valve handling the heat supply.
3. Security valve: for safety matters when the drum pressure exceeds limits.
4. Feed water control valve: controls the inlet water.

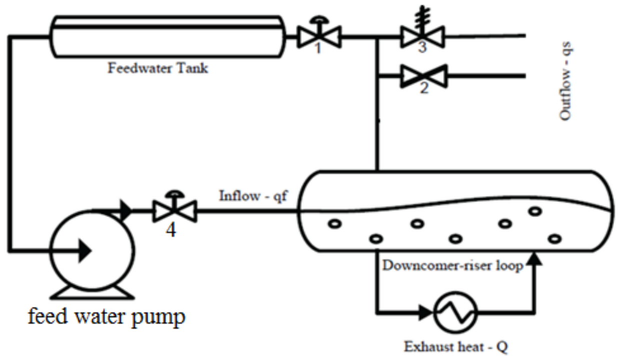


Fig. 6. Schematic diagram of the steam generation process

The water tank control valve regulates the flow of water from the source to the water tank and also controls the condensation water flow released from the drum. The bypass valve (butterfly valve) controls the outflow of saturated steam generated in the drum to the superheater. Valve 3 is placed for security use to prevent damage due to water overflow and to relieve the drum if excess steam is produced. Valve 4 is the feed water control valve, which controls the water flow to the drum, which is pumped by the water pump.

3. BOILER DESCRIPTION

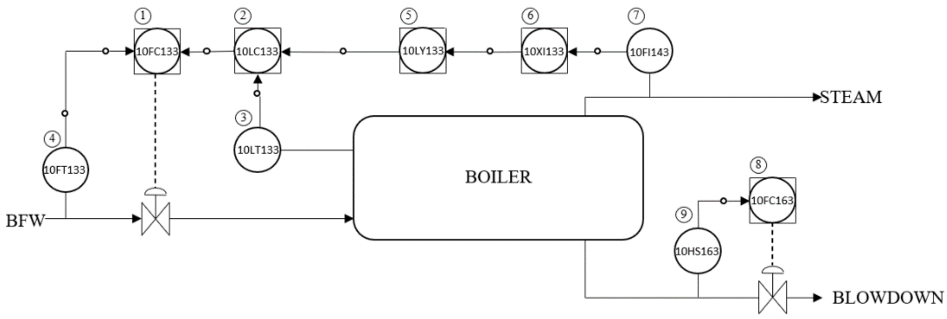


Fig. 7. Design scheme for level control in the drum in the boiler F – 1011; 1 - feed water control regulator; 2 - drum level regulator; 3 - level transmitter; 4 – water flow transmitter; 5 - ratio control regulator; 6 - indicator of the mode of the coresponding regulators; 7 - steam-flow; 8 - water flow continuous purges; 9 - manual hand switch

For the purposes of this paper, a gas boiler (Fig. 7) F-1011 with four burners, with forced and induced draft and flue gas recovery, and with a capacity of 70,000 Lbs./Hr is selected. It has a feed water economizer that uses exhaust flue gases [6].

This steam generator is part of several steam generators operating in parallel, connected to a common collector. The pressure in the collector is maintained. Each boiler has an individual heat load regulator, which receives a setpoint for the pressure in the collector from the main heat load regulator. The steam flow from the boiler is measured by a transmitter named 10-FI-143.

The boiler feed water enters the middle of the drum. The water level in the drum is monitored by redundant transmitters - 10-LT-731X and 10-LT-731Y, which are part of the low-level interlock in the drum, and is controlled by the 10-LC-133 controller. The pressure in the drum is measured by the 10-PT-731 transmitter, which is also part of the high steam pressure interlock in the drum.

Feed water circulates from the bottom of the drum and travels through the boiler tubes and back up to the top of the drum to a water diffuser. Steam with water droplets returns to the liquid level in the drum. The steam entering the top or superheater is saturated steam. The water in the diffusion plate (continuous blowdowns) is superheated and exits the drum to the refinery. The superheater outlet temperature is monitored by a 10-TI-941 transmitter.

The feed water for the boiler is supplied from the refinery. Both the main and auxiliary feed water collectors are connected to the valve regulating the flow of this water. The flow rate of the feed water into the boiler is measured by the transmitter 10-FT-133, which is the input of the controller 10-FC-133. The liquid level in the drum is measured by 10-LC-133. The level control in the drum is implemented by a three-element control scheme acting on the feed water [6].

The signals used are drum level, water flow, and steam flow. The drum level controller operates in cascade mode, receiving a leading signal from the difference between steam flow and water flow, and is fed back - the error is calculated not as a difference between the setpoint and execution, but as a difference between execution and the setpoint. Table 1 presents the names of the control modules implemented in the plant management system.

Table 1. Control modules

Control module	Description	Mode	Normal mode
10FC133	Feed water controller	Auto/Manual/Cascade	Cascade
10LC133	Level control regulator	Auto/Manual/Cascade	Cascade
10FC163A	Blowdown control regulator	Auto/Manual/Cascade	Auto

3.1 Implementation and execution

The previously mentioned boiler has been implemented in the El Paso refinery in the USA. The El Paso refinery is located approximately three miles east of downtown El Paso, Texas. The refinery was originally two facilities, with the north portion built by Chevron in 1928 and the south portion built by Texaco in 1931. The operations of both sites were modernized over the years, and the two plants were combined in 1993.

The Marathon El Paso refinery has a crude oil refining capacity of approximately 133,000 barrels per calendar day (bpcd). The refinery processes sweet and sour crudes into gasoline, distillates, heavy fuel oil, propane, asphalt and natural gas liquids, and petrochemicals, and has access to the Permian Basin shale region. Products are delivered from the El Paso refinery by truck, rail, and pipeline [6].

The control strategy for the boiler is done in the Honeywell Experion Process Knowledge System (PKS), which is a modern distributed control system with an integrated modern process automation platform. This programming environment is also presented and discussed in the following paper [8]. Programming and configuration of control strategies in the system is done through the Control Builder software package (Fig. 8). It provides a graphical interface for building process control strategies.

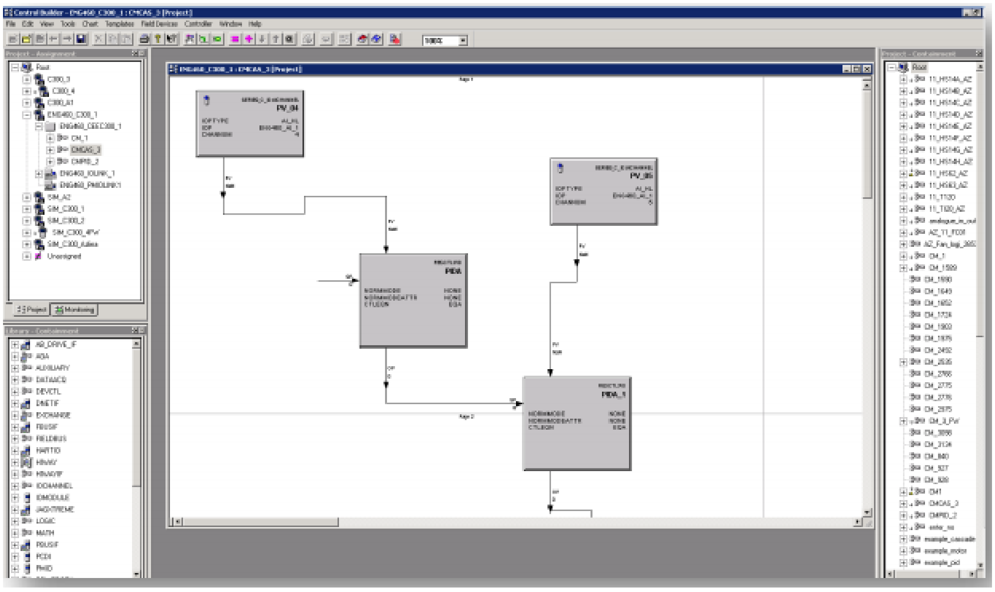


Fig. 8. Control Builder

The control builder allows the user to create logic or process control strategies with the help of specific blocks, which can be found in the system library. For creating the boiler system, the following functional blocks are used:

- LEADLAG – it provides dynamic lead-lag compensation for changes in its input (P1). It subjects a change in the input value (P1) to one lead compensation and two lag compensation factors. There is a user-configurable time constant for each compensation factor. You can suppress a compensation factor by setting its corresponding time constant to zero (0).
- AUXCALC - The Auxiliary Calculation block lets the user write up to eight expressions for computing a PV value. Each expression may perform arithmetic or logic operations, test conditions, etc. Status information is made available for both the inputs as well as the expression results. Through configuration, you can assign the result of an expression, a status, or an input to PV and PVSTS parameters. It looks like this graphically.
- DATAACQ - it processes a specified process input value (P1) into a desired output value (PV). A new functionality is added in the DATAACQ block, which allows you to configure a separate alarm description for each alarm type. This description is displayed as a process alarm description in the Experion Station. This functionality allows you to override the block "Description" (DESC) of any alarm type with a specific alarm description. Two new alarm parameters, Enable Description (ED) and Description (DESC), are added to each alarm type to support this functionality.
- PIDA - The PID block is a regulatory control block that operates as a proportional-integral-derivative (PID) controller. It supports the Ideal form of calculating the PID terms. The Ideal form is often called the digital-computer version of the PID controller. The PIDA block provides five different equations, and for this specific boiler system, it is decided to use equation A:

$$CV = \frac{K}{L}[\left(1 + \frac{1}{T1s} + \frac{T2s}{1 + a * T2s}\right) * (PVPs - SPPs)] \tag{6}$$

Where, CV is the PID output in percent, K is the gain, L is the reverse Laplace transform, s is the Laplace operator, PVP is the process input value in percent, SPP is the setpoint in percent, $T1$ is the integration time in minutes, $T2$ is the differentiation time, and a=1/16 is a specific coefficient to the Honeywell PID controller equation. In equation A, the proportional, integral, and derivative parts act on the error (PV-SP). This can provide the user with maximum customization.

Figure 9 shows the control module 10LC133 for controlling the level in the drum, where LEADLAG, DATAACQ, ADD, MUL, SUB, NUMERIC, and PIDA function blocks are used.

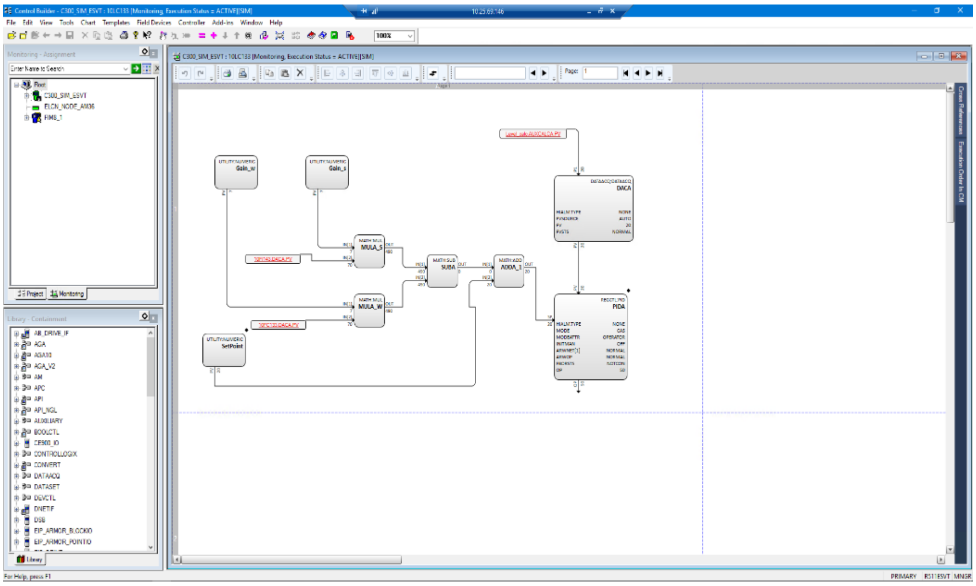


Fig. 9. Control module 10LC133

Figure 10 shows the control module 10FI143 for steam consumption, in which the DATAACQ functional block participates.

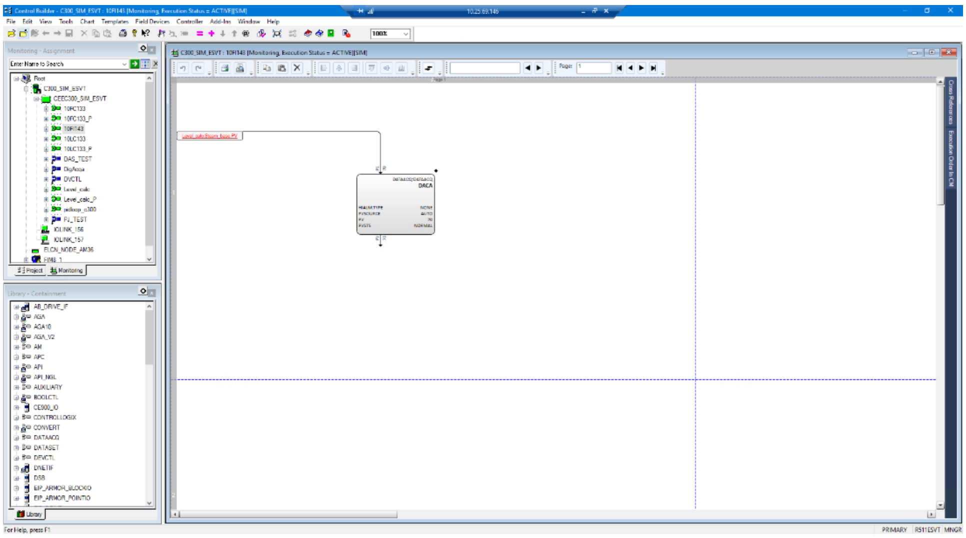


Fig. 10. Control module 10FI143

Figure 11 presents the Level_calc control, which is used for simulating the level in the drum. In this control module, LEADLAG, SUB, NUMERIC, and AUXCALC function blocks are used.

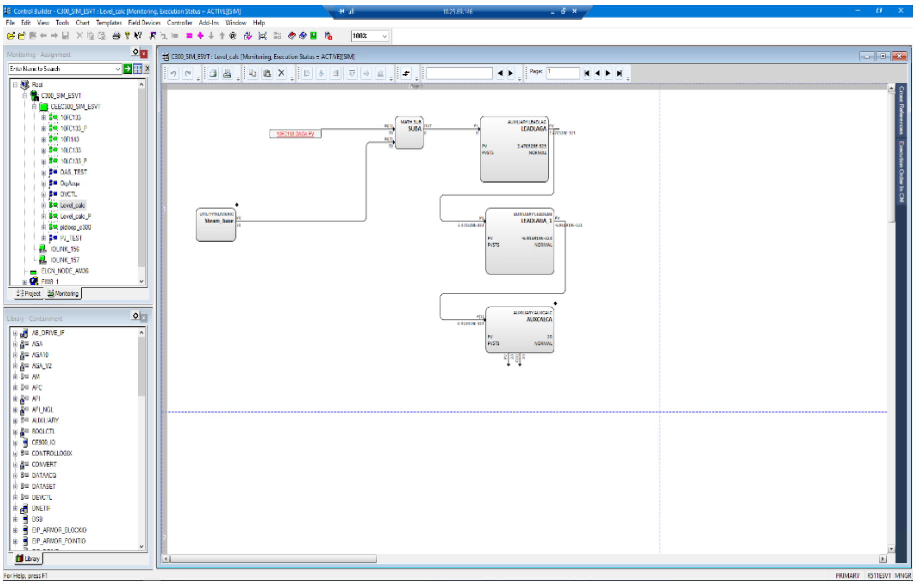


Fig. 11. Control module Level_calc

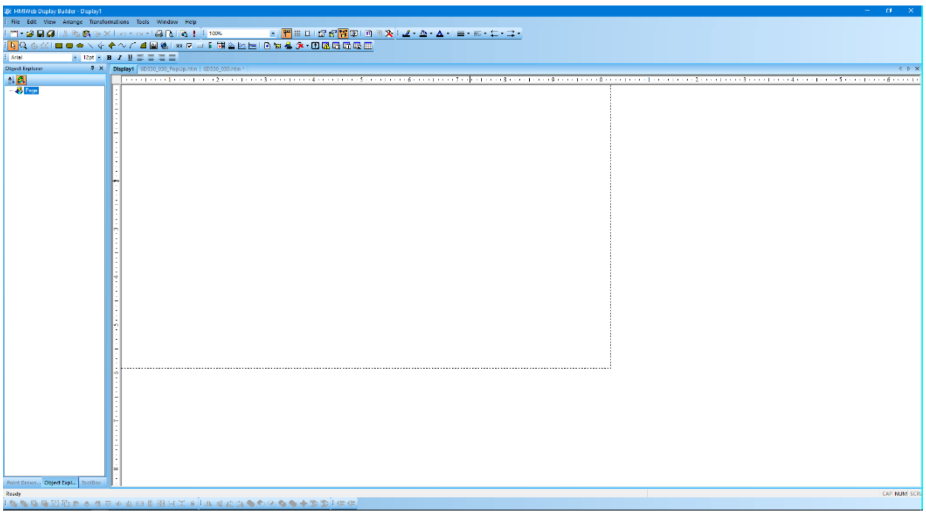
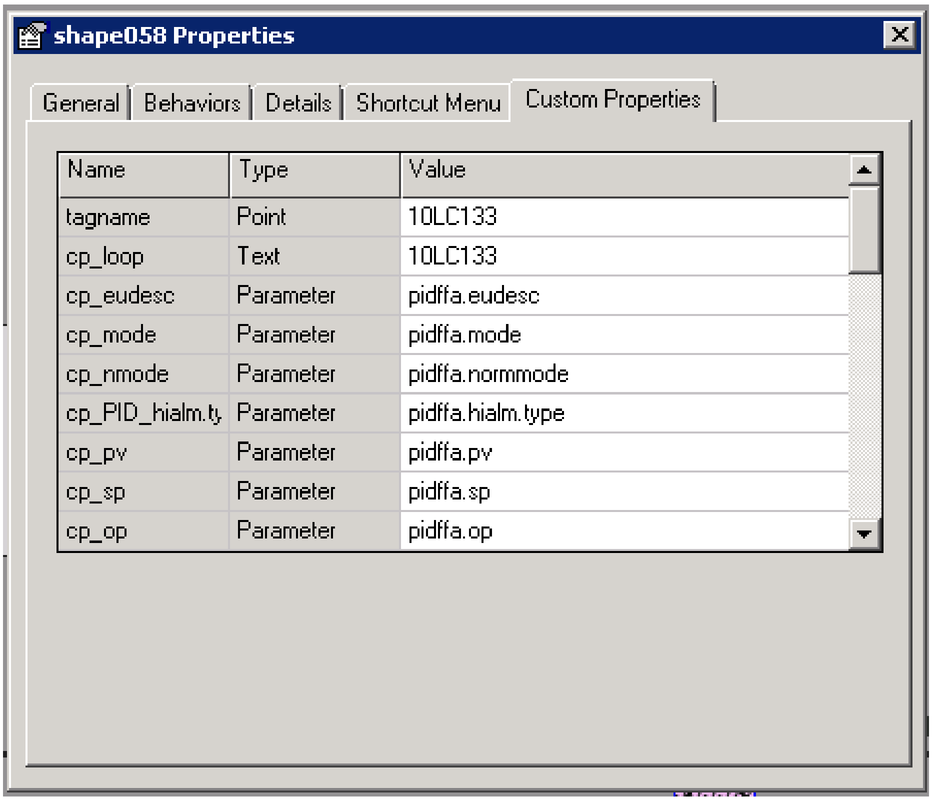


Fig. 12. HMI Display Builder

After creating the process control strategy, the next step involves creating a display, from which the operators can see what is happening with the boiler system in real time. This is done in the HMI Display Builder.

This package was used to create the boiler system control display. HMI Display Builder is part of the Experion Process Knowledge System and is a graphical tool for creating user displays using Web-based functions. Several embedded graphics are available in the library of objects (regulators, pumps, motors, indicators, alarm objects, trends, etc.) that users can include in the displays. Figure 12 shows a view from the HMI Display Builder, and Fig. 13 shows the necessary parameters for configuring a graphical object [8].



Name	Type	Value
tagname	Point	10LC133
cp_loop	Text	10LC133
cp_eudesc	Parameter	pidffa.eudesc
cp_mode	Parameter	pidffa.mode
cp_nmode	Parameter	pidffa.normmode
cp_PID_hialm.ty	Parameter	pidffa.hialm.type
cp_pv	Parameter	pidffa.pv
cp_sp	Parameter	pidffa.sp
cp_op	Parameter	pidffa.op

Fig. 13. Necessary parameters for configuring a graphical object

The created display can be called up by the operator from the station. From there, the operator can control the drum level of the boiler and see exactly what is happening with the system in real time, and thanks to features like command disagree, he can determine if the valve, for example, is fully closed or not (Fig. 14).

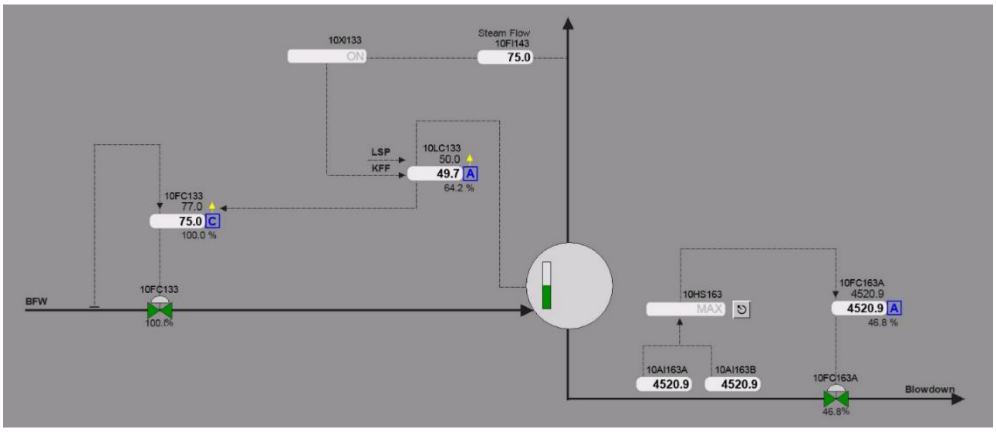


Fig. 14. Overview of the process

From here, it is possible to change the mode of the level control regulator from auto to manual, as well as other parameters can be altered, which are necessary for the level control. This is shown in Fig. 15 and is called a detail display; the operator can access it and, during the start-up of the process, can simulate the behaviour of the regulator in real time.

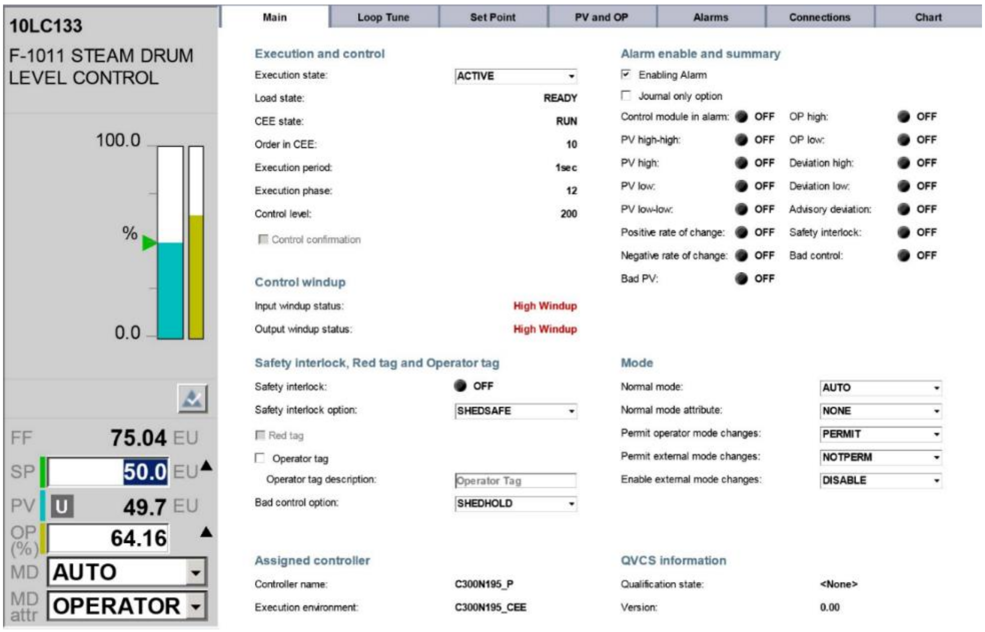


Fig. 15. Detail display for control module 10LC133

The Experion PKS Control Builder also allows the user to see the process in real time while it is switched to MONITORING mode, but this mode is only available for engineers due to safety concerns.

The problem with this particular system is the control part, due to the fact that the system is a non-minimal phase object. The transfer function for this boiler is shown in equation 7.

$$W(s) = K\frac{Tls+1}{(T1s+1)(T2s+1)} \tag{7}$$

If the initial drop, which is typical for non-minimal phase objects, is not controlled properly, this can cause severe damage to the system. But with the implementation of the logic in the Experion PKS, it is easier for the engineers to modify and test without causing problems to the production [7].

4. CONCLUSION

This paper explains how it is possible to implement and control a boiler system using the Honeywell Experion PKS environment. By using the Experion library pre-defined functional blocks in Control Builder, and thanks to the HMI Display builder, it is easier for the users to understand and improve the control system and thus increase productivity. The Experion Station allows the users to see in real time what is happening with the system and modify the values of process parameters more easily and quickly.

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