The level control of the boiler drum

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SAVONIA UNIVERSITY OF APPLIED SCIENCES **THESIS**
Abstract

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Abstract

Level control uses the boiler drum as a controlled object, and uses the level as a controller value. By making sure the level control is attached accurately we get better dynamic performance. I use the cascade control to make the difference to the traditional control.

In this thesis, I summarize many problems with the level control in the steam boiler field as the false level phenomenon. I design three methods for the level control process system with different ways. I make the final choice at the end. I also do the SAMA figure to show the systems way of running.

The automation is one of the main points with the level controlling system in the thesis.

At the end of this thesis, I was able to achieve the automatic controlling for the steam level.

Keywords
Level control, Automation, SAMA figure, Steam boiler

CONTENTS

SYMBOLS AND ABBREVIATIONS

FC	Flow Controller
FT	Flow Transmitter
LC	Level Controller
LT	Level Transmitter
Σ	Sum

1 INTRODUCTION

This part includes thesis goal and background information on the stream drum level control and also on the level control of the boiler drum in power plants.

1.1 Thesis goal

The main research part in this thesis involves boiler drum feed water control system, level control method, feed control system operation. The designing of an automation system for the level control in drum is the main goal in this thesis.

1.2 Thesis background

In this part, I introduce the background of the level control history and the previous system about the drum boiler. After that, I can find the reasons for designing this system.

1.2.1 The feature of the process control

Level control system means the automatic control system controlling the level as a variable value in the industrial producing process. As goals that guarantee the quality and working safety, I should control the level value in a determine value or changing follow a discipline.

The level value changes not only caused by the external influences, but also it caused by the internal influences. In the process the influence parameter should be more than one value. The functions are also very different. It increases the complexity in the process parameter control. As a result of that, I can get the features below:

1) The object hysteresis
The hot productions always happen in huge production equipment, the objects have huge storage capacity and inertia. There are some resistances during the media flow or hot energy transfer, and they have the trend to get the balance. In a word, when flow in (or out) objects' weight or energy has changed, cause of the capacity, inertia and resistances, the parameter cannot change immediately. System called the phenomenon as hysteresis.

2) The object nonlinear

The features of the object always change by the load. The most of the production are nonlinear. To guarantee the nonlinear production reasons the properties of the non-linear are very significant.

3) The control system complexity

When thinking the safety production, system tries very hard to guarantee the steadiness of the design and production process, and the parameters changed cannot go over the limit range. There is more than one parameter which needs to be controlled, and all of them have different features. I need to make different control systems for the different parameters.

1.2.2 Development status of the level control system

Because of the developments of the science technology, the control system becomes huge nowadays. To guarantee the industrial production under safety and efficient, there is a hot point which I research in the process control area that I monitor online and control the production situation in time and accurately. In the light industry, it is very normal that I use the level control. There are many examples like the simple float level switch, ultrasonic wave level test and high accuracy isotope level test system.

It is very normal that I use the level control system in the different areas in our daily lives. However, from the controller of the level control in China, there is still the gap with some developed country. [Liu Zhenjiang, 2007]

2 DYNAMICS OF THE BOILER DRUM LEVEL PROCESS

The drum is very important power equipment whose task is to supply qualified stable steam to support load need. The level of the boiler drum is the most significance value to guarantee the process safety.

2.1 The total introduction

The following system is controlling to level, with the knowledge I have learned.
Application area: using the element with detector, controller and actuators etc. to control the level.
Function introduction with this system: it can show the value of the level. When the disturbances get in the system, the value can be made to the stable value without any kind of manual work.

2.2 The formation of the false level phenomenon

The false level means that the untrue level value in the boiler running process. When the pressure dramatic decreases are saturation temperature decreases to the low pressure temperature value. It will make the boiler water exothermic and to evaporate, and form a lot of bubbles. The volume of the mixed water and air expand a lot. As a result of that, it makes the level increase a lot, and I get the false level.

When the heat load is changed, the fire is extinguished safety valve behaviour and combustion instability also can result in the false level. When the load is changed rapidly, the pressure of the steam also will change, and it will be the false level. More rapid the load is changed higher the false level it will be.

As the solution for the false level, I can lead a steam flow signal to the input port and designing feed forward adjustment for the level system. When the steam flow increases, it can put more water inside and the temperature will become lower. It will infect the false level.

2.3 The factors of influence steam level

First of all, I should analyse the dynamic characteristics of the steam. Figure 1 shows it below. The feed water adjustment in the inverter adjusts feed water value W, the steam turbine valve angle controls the steam turbine consumption D.

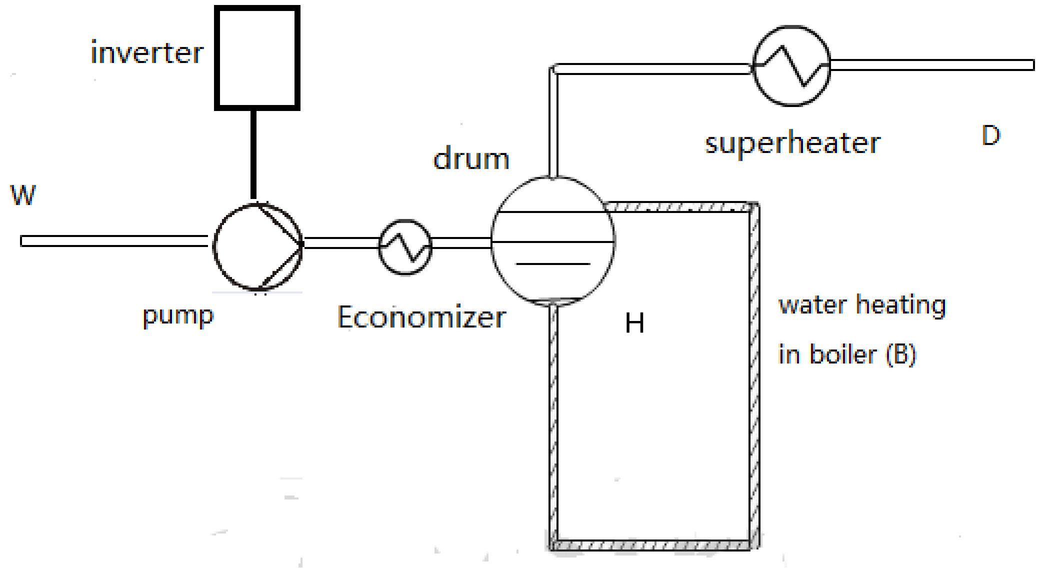


Figure 1. Boiler process and feed water regulating object

At first glance, a dynamic characteristic of steam level is the same with the single packaging sink. Feed water flow and steam flow influence the drum level. However, the true situation is not like that. The most different point is the water cycle system full of the steam water, and the Volume V of the steam is changed with the drum pressure and furnace heat load changing too. If some reasons influence, the total volume is changed. Although the water value in the water cycle has not changed, the drum level will also change and influence the stability of the water level.
The most significant influence factor for the drum level H is feed water value W, consumption of turbine D and the amount of fuel B.

2.3.1 Feed water disturbance influence

If I make the drum and its water cycle system as a single packaging sink, curve of the feeding water disturbance response should be like Figure 2 curve H_1 shows. I think about the feeding water temperature lower than the saturated water in the drum. When it enters the drum, the water absorbs some heat from the original saturated water in the drum. The steam flow in the boiler will decline. Total volume of the steam under the level will decline and the water level will decline too. It is like Figure 2 curve

H_2 shows. Actually the response curve should between curve H_1 and H_2 like H. It is integral part with the delay time, the higher sub cooling value, the longer the responds time it will be. The transfer functions should be like in formula 1 [Lin Zunji]

$$G_1(s) = \frac{\varepsilon_1}{s(1+\tau s)} \qquad (1)$$

In the (1), there are

ε_1= Gain

τ = Process time constant,[Second]

G_1(s)=Transfer functoin=H(s)/W(s)

s=Laplace operator

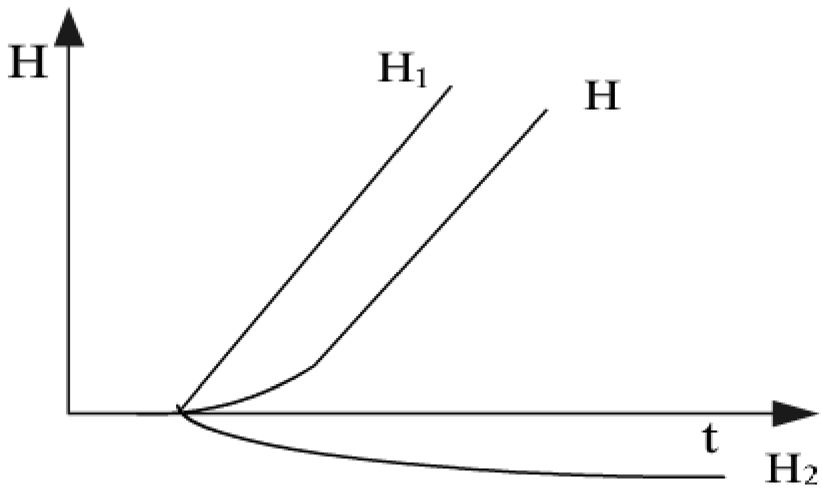


Figure 2. Feeding water responding level curves in drum [Li Zunji, 2010]

2.3.2 The influence of consumption of turbine

When the consumption D of the turbine increases, it changes the substances balance situation to make liquid in the drum evaporation and level become lower. I can see the curve H_1 in Figure 3. At the same time, the consumption of turbine D increases and the bubbles become more. Because of the amount of fuel unchanged the pressure of the bubbles become lower. It will make the bubble under the water expand and total volume V increase. The result is the drum level increases. I can get the curve like H_2 in Figure 3. The true level response curve should be H which is the sum of the H_1 and H_2. If I talk about the huge size of the boiler, the influence is bigger of H_2 situation than in H_1. As the result of that, when the load increases in a period of time, the level will be increased instead of decrease. This is a phenomenon I called "false level phenomenon". That the function should be like below [Lin Zunji]:

$$G_2(s) = -\frac{\varepsilon_2}{s} + \frac{K}{1 + T_0 s} \qquad (2)$$

In the (2), there are

ε_2 = The speed of steam flow increase

T_0 = The postpone time of "false level phenomenon".

K= Gain

s=Laplace operator

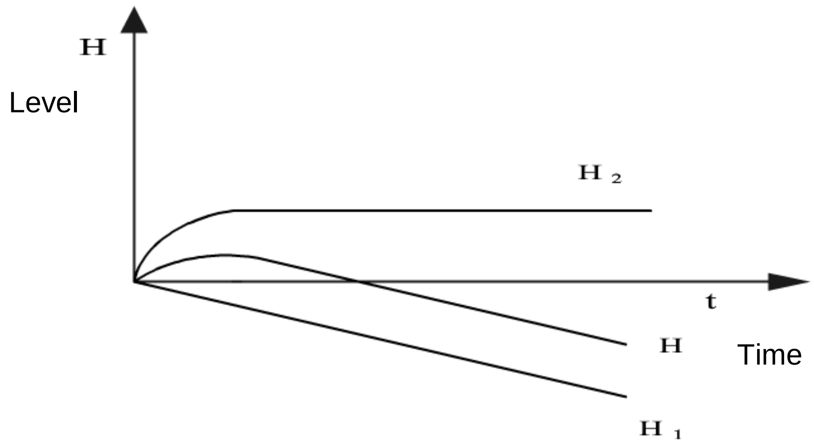


Figure 3. Consumption of turbine respond curve

2.3.3 The influence of the fuel disturbance

The fuel disturbance must make the change of steam flow D to change. System can also get the "false level phenomenon". However, there is lot of water in the drum water cycle system, and there is lot of heat storage in the drum and water-cold system. As the result of that, it has the thermal inertia. The increase of fuel can just make the amount of steam increase slowly. At the same time, the pressure of the steam will increase slowly. It will make the volume of bubble decrease. The "false level phenomenon" under the fuel disturbance is more alienated with load disturbance.

From the analysis, I can get the response of feed water disturbance that is hysteresis. The load disturbance has "false level phenomenon". Those kinds of characteristics make the drum level change under a lot of factors, and it is hard and complex to control it.

3 DRUM LEVEL CONTROL SYSTEM DESIGN

From the feedback I can easily get that the drum level as a feedback value. The feed water value is a controlled value. I get a single-loop feedback control system. It is also the level single impulse control system. P&ID-diagram should be like Figure 4, and it is a basic control plan. The block diagram is Figure 5. For the small capacity boiler, because the volume of the water is bigger, the volume under the drum that is under level that cannot occupy large rate is not very big. The false level phenomenon is not very obvious. I can use the drum level single impulse control system to control the drum level.

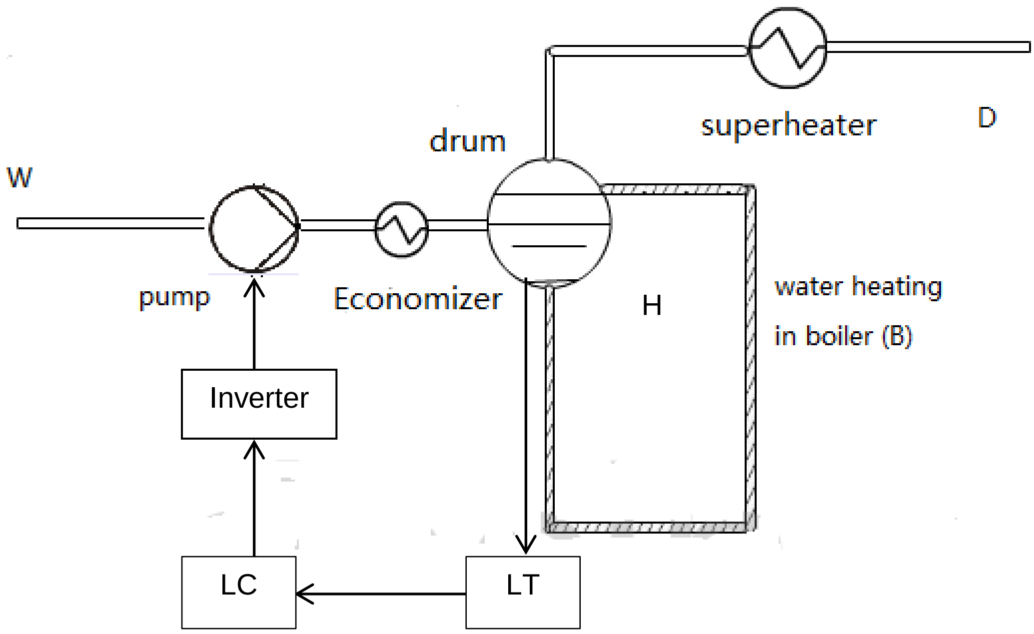


Figure 4. Drum level single impulse control systems P&ID-diagram

However, for the middle size or the huge size boiler, the plan cannot be suitable for the control requirement. The steam value of turbine load disturbance will lead to the false level phenomenon and make the malfunction of the feed water system. It will lead to the drum level fluctuating deeply and influence the equipment lifetime and safety. The middle or huge boiler cannot use only the drum level single impulse control system to control. System should find other method to control the level.

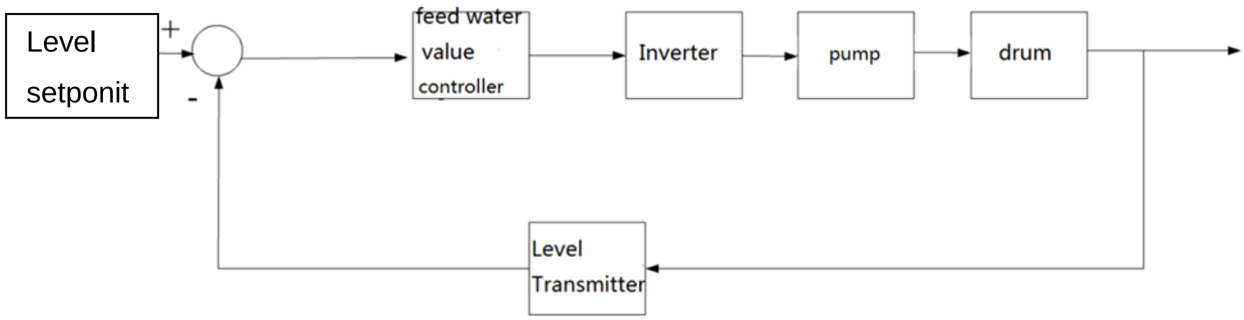


Figure 5. Drum level single impulse control system block diagram

Analysis can start from the Mass Balance theory. If I can make sure that the feed water value always equal to the evaporation of the steam, system can make sure the drum level is stable.

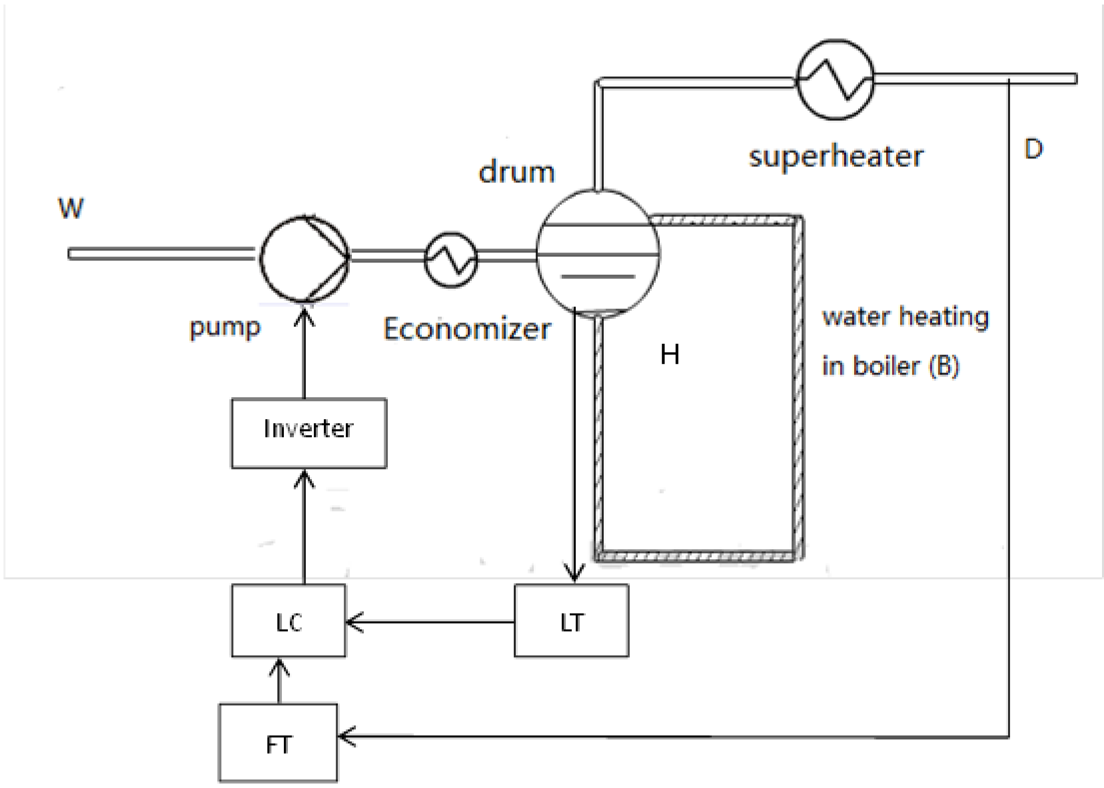


Figure 6. Steam flow servo control systems P&ID-diagram

System can use the steam flow servo control system, and for the flow regulator I use a PI controller. It makes the steam value of the turbine as a system set point, and the water flow changed follow the steam flow changed. It established a servo control system to make sure the drum level remains constant. You can see the block diagram as Figure 7.

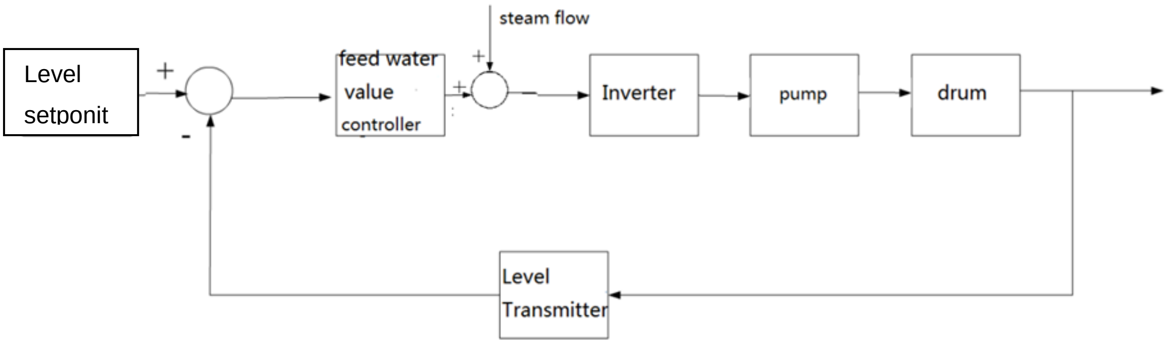


Figure 7. Steam flow servo control system block diagram

The advantage of this system is that it is based on the Mass Balance to work; the feed water flow is based on the turbine steam consumption. The false value will not affect the feed water adjustment system. However, the system is an open loop control system for the drum level. Because the feed water and steam flow are inaccurate measurements and other disturbance of the boiler make the ratio of the steam flow and feed water value is not exact. Because the deviation for the two values is integral relation, so the small difference will lead to huge level difference. As a result of that, I cannot use the steam flow servo control system.

If I combine the two systems, system can get the drum level double impulse control system as in Figure 8 and in the block diagram in Figure 9. The double impulse means that system use two measurement signals: the drum level and steam flow.

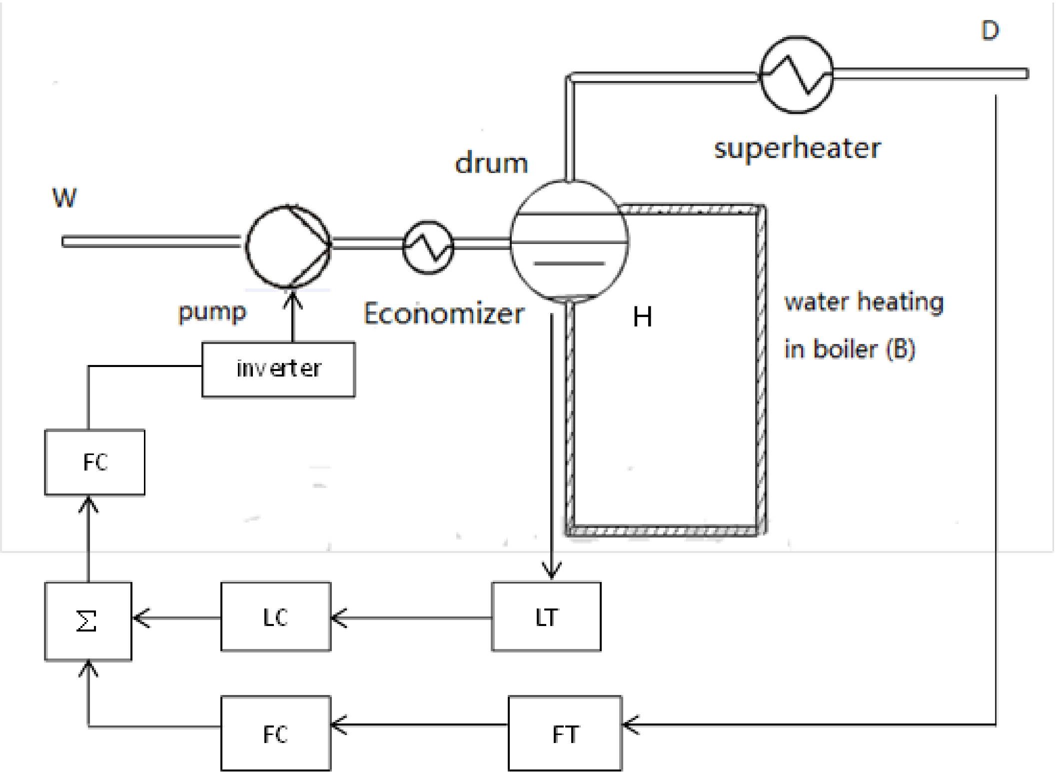


Figure 8. Drum level double impulse control systems P&ID-diagram

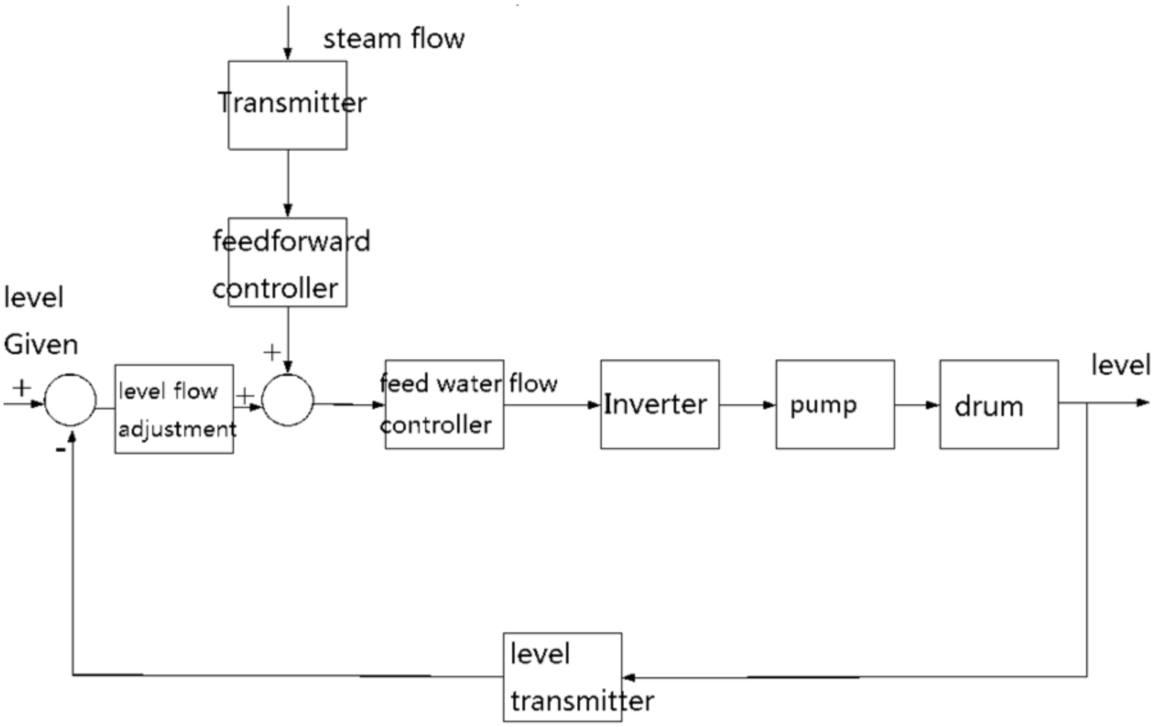


Figure 9. Drum level double impulse control system block diagram

This system can improve high quality of the drum level control. When the steam consumption of the turbine becomes high, the “false level phenomenon”, the drum level becomes high temporarily, and it makes malfunction to reduce the feed water value. On the other hand, the higher of the consumption of the turbine it will increase the feed water value with the control of the ratio control system. The actual feed water situation should make sure with parameter tuning based on the actual situation. When the false level phenomenon disappears, the level and steam signal will control the adjustment action. If the parameter tuning is right, the feed water value must equal with the steam water value to make the level constant.

In this point, I consider that the change of the feed water flow can be adjusted through inner loop by itself with a cascade controller. The system like Figure 10 shows the three impulse control systems. The block diagram shows it in Figure 11.

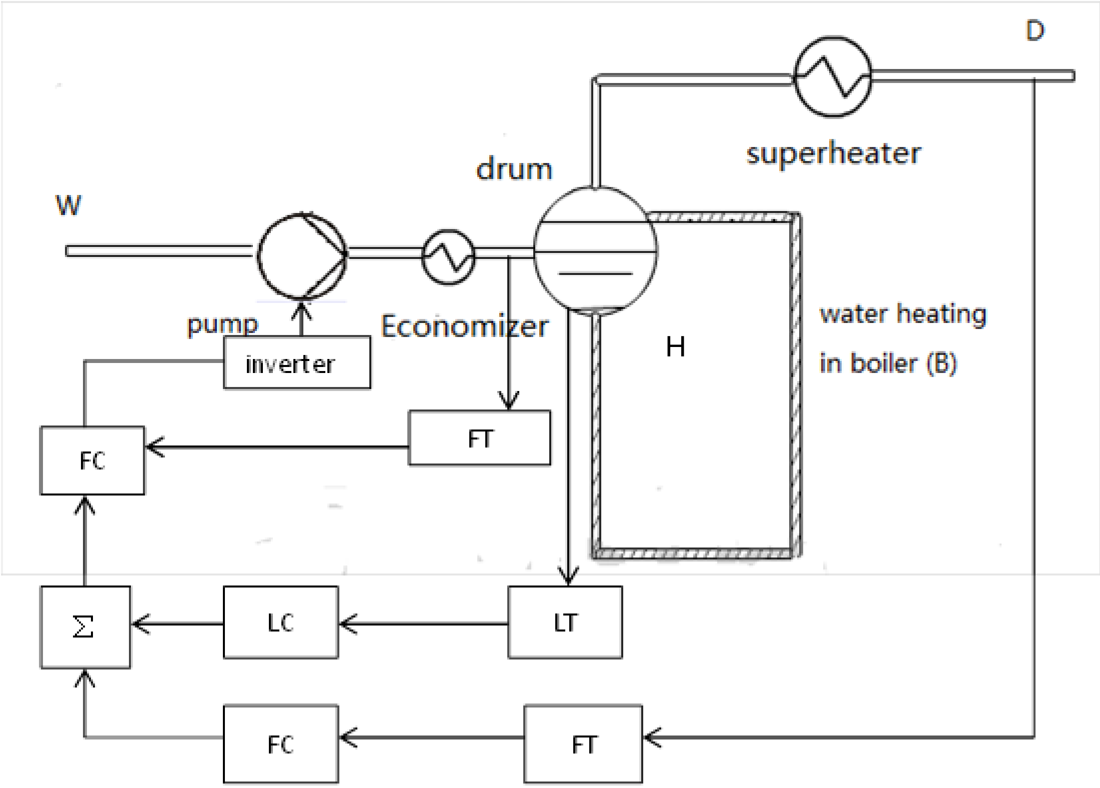


Figure. 10 Drum level three impulse control systems P&ID-diagram

It is a feed forward-feedback-cascade mixed controlled system. This three impulse control system includes a water flow control loop and a drum level control loop with a steam flow feed forward passage. In fact, it is a steam flow feed forward-flow cascade composed of a mixed control system.

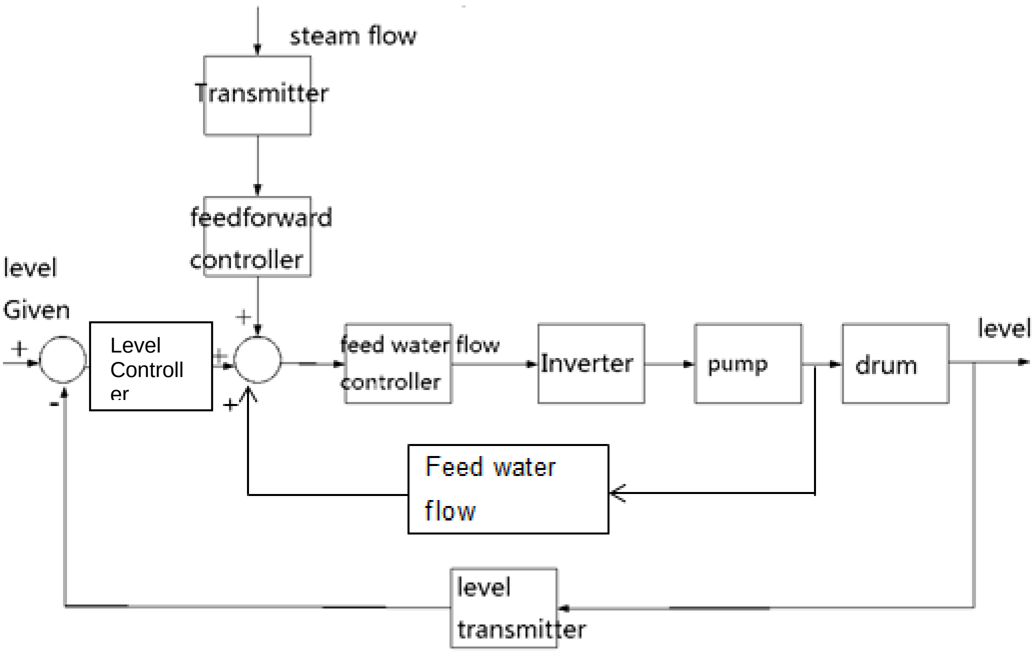


Figure 11. Drum level three impulse control systems block diagram

In this cascade control system, the main parameter is drum level, the amplitude parameter is the feed water flow, the main regulator is the feed water flow regulator, the amplitude regulator is the level regulator. On the one hand, it can overcome feed water disturbance, and make feed water flow self-regulation. On the other hand, it can overcome the “false level phenomenon”. When the steam flow changes, the feed water flow control loop in the boiler drum level control system can change the feed water value immediately to accomplish controlling. After that, the drum level regulator accomplishes fine tuning to keep the drum level stable.

4 ENGINEERING OF LEVEL CONTROL SYSTEM

Feed water process automation means that the process for feeding water in the boiler is totally automated. It means that when the controlling equipment is running normally, company do not need other resources for working with this system

4.1 Whole feed water process introductions

System should make sure that the drum level is in the range of the system. It is more complex with the normal feed water system. As a result of that, I present some requirements about the automation control system below [SAMA, 2006]:

1. I can change the adjusting door degree of opening to accomplish the feeding water process control. It means that I can change the resistance in the pipes to change the water volume to change the pumps speed. It also means that the change in the pressure of water is reduced to change the feed water value. The first method will lead to a big loss with the throttling. There is too much power consumption in the pumps. It is not economic. As a result of that, I use the second method in many big boilers. In the whole process of feeding water, not only I should feed the requirements of feeding water value adjustment, but also I should make sure that the pump is working in the safety range. In most of the time, it should be two controlling systems to accomplish this process. It is what I call two part adjustment.
2. Because the unit will show different object properties in different loads, the controlling system should fit for this property. With the load changing, the system will begin with a single impulse to change to three impulses, or begin with three impulses to change to a single impulse. It will bring the problems about the shift of system. System must be two controlling circuits without any interference between each other with these two systems.
3. Because the big working ranges of the whole controlling system, it should be higher requirements about the measurement.
4. In the complex switching processes in different adjustment mechanisms, the feeding water system must be without any interference. High and low loads need different regulating valves. I should solve the problems with switching. The sectional doors switching need a period of time, and it bring troubles with keeping the water level. At the same time, it brings the over switching problems between regulating valve and a regulating speed pump. The pressure is growing a lot. Because the boiler is without any output steam value, the feed water value changed

very little, so the single impulse adjustment system is not very good. System should use the method with opening regulating valve to control the water level.

5. The feeding water system should be suitable with aircrew in constant pressure or sliding pressure. At the same time, I should make the system adapt cold starting or warm starting.

5 AUTOMATION APPLICATION OF DRUM LEVEL CONTROL SYSTEM

I use a 600 MW unit aircrew feeding water system as an example to introduce the whole process of feeding water system running principle and characteristics. There are some important parts in the feeding water system like drum level, main stream flow, main feeding water flow and water pumps controlling. I will introduce each part with the function and operating principle. At the end of this part, it will be a SAMA figure to show the system. [TAKEO IMANAKA, 2000.]

5.1 Drum level measurement and correction

When the boiler starts normal running process, the steam pressure changed all the time. Because the density of saturated water and saturated stream in drum changed with the pressure changed. It will influence the accuracy of measurement about the drum level. For the measurement saturated water with differential pressure principle system, system should make pressure with differential pressure signal, and correct temperature before system can get a true drum level.

The key point of differential pressure type level gauge when measuring drum level correctly is the accurate conversion between level and differential pressure. This kind of conversion uses the balance container to stride the reference water column to accomplish the task.

When the differential pressure type level gauges work, it will compare the drum level water column pressure with the water column level together with balanced ratio of a container. The basic point of comparison is the water side of the centreline water table sampling hole. Because the reference height in the column is kept constant, the measured pressure can directly reflect the drum level. After installing the balance container, the reference height of the water column is a fixed value. The differential pressure transmitter range is equal with the height of the reference level.

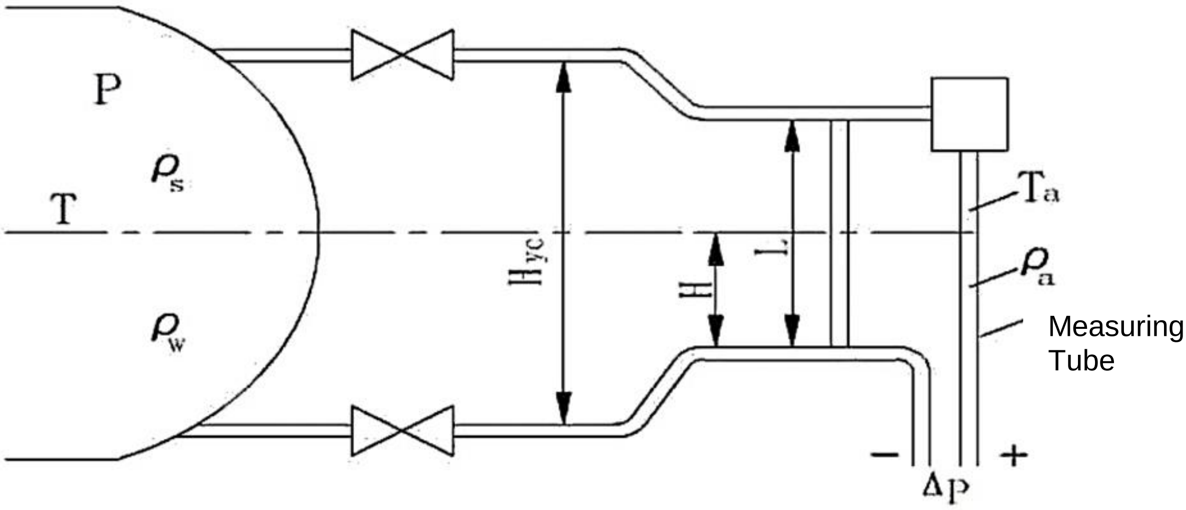


Figure 12. Drum level measurement

ρ_s=Density of saturated steam inside the drum, single-valued function of drum pressure
(kg/m^3)
ρ_w=Density of saturated water inside the drum, single-valued function of drum pressure (kg/m^3)
ρ_a=Density of balance within the single-chamber container unsaturated water, it is a function with pressure and temperature (baseline water column) (kg/m^3)
L=Differential pressure level range (mm)
H_{yc}=Single room balancing container extraction pipe center distance (mm)
H=drum actual level (mm)
ΔP=single room balancing the measured differential pressure vessel (Pa)
T=Drum pressure corresponding saturation temperature (^{0}c)
Ta=Unsaturated water temperature in Single room balancing container (^{0}c)

From the FIGURE 12 that the differential pressure measured by the differential pressure transmitter is:

$\Delta P=(P+g\times L\times\rho_a)-[P+g\times(L-H)\times\rho_s+g\times H\times\rho_w]$ (3)

$H=[L(\rho_a-\rho_s)\times g-\Delta P]/(\rho_w-\rho_s)\times g$ (4)

In (3) and (4) g=gravity (m/s^2)

From the above equation, the water Level Range L is a known value as a constant. ΔP is measurement of differential pressure transmitter, ρ_w, ρ_s is single-valued function of the drum pressure. Based on the saturated water and saturated steam nature table, I can use the function module in the control system. Not only has the pressure influenced the ρa, but also the balance container cooling conditions and environment temperature. When the pressures of steam and environment temperature are changed, this value will also change. As a result of that, system should make up those two factors.

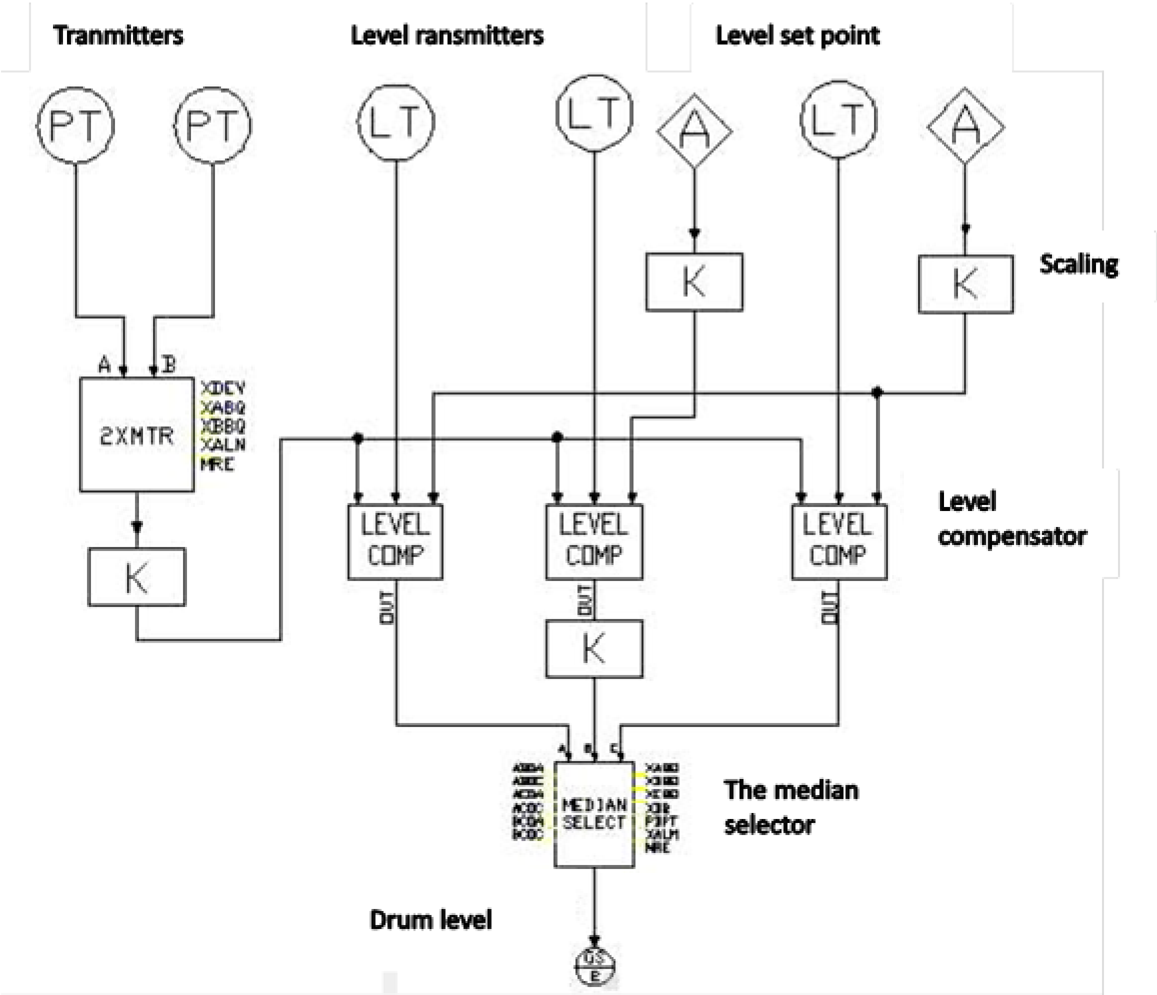


Figure 13. Drum level measurement and correction instrumentation

In this figure, the “2XMTR” means the dual measurement processing algorithms. The function is to choose two in one. 2XMTR is a text algorithm in WDPF. It monitors two analogy transmitters input, and checks their quality and deviation. The output of this kind of algorithm should be either a or b. Also it could be bigger value, smaller value or average value. Operating persons can choose them by WDPF provided Graphical interface.

5.2 Measurement and correction for steam flow signals

Steam flow is the steam flow in the boiler outlet. The steam flow in the boiler outlet is the sum of turbine inlet flow and bypass flow. Middle or small size generators main stream flow measurement always use throttling element marked----standard nozzle (differential pressure method). However, in the huge size of the generator, the steam flow is big and diameter of pump is big. It needs big size of nozzle and it is hard to install. As a result of that, I do not use this method to measure the flow.

Friuli Siegel flow formula is the most common way in the steam flow calculation nowadays. The measuring principle is: When each level turbine has enough level inside, each level steam pressure, temperature and steam flows have this kind of relationship.

$$D = f(P1) \times \sqrt{\frac{T_{01}}{T_1}} \qquad (4)$$

In equation (4)

T_1 =speed temperature (^{0}c)

T_{01} =speed temperature under rated pirating conditions (^{0}c)

P_1 = pressure for speed temperature. (Pa)

Figure measurement and correction for steam flow signals can be found in the Appendix 2.

5.3 Measurement and correction for main feeding water flow signals

Because the flow of superheater spray desuperheater is reducing warm water and flow of reheater spray is reducing warm water there will be steam flow in the end, so the main feeding water flow is boiler feeding water flow plus superheater and reheater reducing warm water flow. This system with reducing warm water through superheater has 1, 2 level desuperheater (each level with A, B two side), which have four reducing warm water flow signals totally and one reheater reducing warm water flow.

Figure measurement and correction for main feeding water flow signals is shown in the Appendix 3.

5.4 Single impulse and three impulse control figure

Single impulse or three impulse controlling switch figure can be found in appendix 4. In the low load situation, system just uses the drum level signal to controlling. It is single impulse way for controlling. When it is in the high load situation, I use the three impulses to controlling. The drum level signal works in the main controller input to correct level deviation. The steam flow signal which as a feed forward signal works in deputy controller input to overcome the false water level. Feed water signal is a feedback signal in inner closed loop.

5.5 Feeding water SAMA figure

The SAMA figure shows in Appendix 1.

This example is a 600 MW generator with three pumps. Rate is 30% electric water pump; each has 50% TDBFP (steam pump). Electric water pumps are always start pumps and standby pumps. There are two TDBFPs in normal running time.

In the low load, when the electric pump is running, system uses the single impulse controlling method. When the load decreases, steam pumps start running. I use the three impulses controlling method. When in the unusual circumstances, system switches to manual method.

Manual, automation switching conditions:

1 Steam level deviation is big.

2 Steam level signals have problems.

3 Electricity pumps do not run.

4 Inputs signals problems in electricity pump

5 Feeding water flow signals have problems when underling three impulse controlling.

6 Steam flow signals have problem when underling three impulse controlling.

5.6 Introduction about the SAMA figure

SAMA (Scientific Apparatus Makers Association) figure is a control system structure which includes all control devices. SAMA legend is easy to understand and it can clearly indicate that the system functions. SAMA figure can reflect all the control and signal processing functions of the control system and design ideas by designers. [SAMA, 2006]

When I compose the system, I must first control process according to the requirements and a process control block diagram is drawn in accordance with SAMA legend. Then I select the appropriate rack-mounted instruments and instrument panel mounted under the block diagram.

Legend shape meaning SAMA is featured in four categories, each of which has a definite meaning,

① ○ Measurement or signal readout

② □ Auto Signal Processing, generally expressed in the instrument function control cabinet.

③ ◇ Manual Signal Processing, generally expressed in the operating device.

④ ⏢ Actuator

When the control system block diagram expresses SAMA legend, I often draws together some of the symbols representing a specific module (meter) what are the functions. Such a block diagram of the control system and the main diagram clearly express how big specific module (meter is).

The SAMA figure will show those function below:

1. Signal Processing

A) Live signal and the control room signal conversion;

B) The quality of the signal inspection, testing whether it is within the valid range;

C) The important parameters should be multi-point measurement, integrated treatment

D) Compensation processing the measurement signal.

2. Automatic Control

A) Reflects the control of the control structure diagram of

B) Reflect the dynamic rule Controller

C) Reflect the direction of a controller action

D) When the system is run manually, the regulator should have the tracking function to enable the system to achieve bump less switching.

3. Control system hand / auto switch and manual operation

A) In the control system generally each actuator should be equipped with an operator; operator may need to run manually according to the system / automatic switch, manual operation and valve position are displayed, the value and the measured value display are set.

B) Control system Hand / automatic switching of the basic principles:

System is normal. The operators on the operator by pressing keys ‘automatically’ are put into automatic mode the system. In system failure or poor quality control system control, the control system should be automatic state automatically switch to manual states.

C) When the regulators of output corresponding operators to manually cut the corresponding output of the regulator should be cut to track status. The goal of that is to enable the system to achieve bump less switching.

4. Signal alarm

For critical parameters, system should make sure the provisions of its high and low alarm value according to process requirements.

5 Chain protections

Chain protection system means that when the production faces a serious failure, in order to ensure equipment and personal safety, all devices stop operation in a certain order or operation of the emergency in a particular state.

5.7 Parameters tuning and feeding water system process

This unit is about the parameters tuning for this final method process system.

5.8 Feeding water controlling system tuning

The feeding water controlling system includes feeding water three impulses controlling system, feeding water single impulse controlling system and the pressure controlling system in the output of pumps. When system begins to run, system should tune these three parts.

5.9 Feeding water three impulse controlling system tuning

In the system prototype, like Figure 14 shows, there are three loops tandem with each other. They are input flow regulation loops, (total) feeding water flow regulation loops and level regulation loops. The parameter tuning of regulator (adjustment assembly) is based on dynamic characteristics of objects. In a normal cascade control system, the vice-loop adjustment process is much faster than the main circuit. As a result of that, when the vice-loop perturb ate by leapfrog, the adjustment process could end in a short time. At the same time, basically it does not participate in the operation of the main circuit. When the main circuit join the adjustment, the main-loop operation has prefect action with function. In other words, the main loop can be seen as an approximate percentage of links in the main circuit. As a result of that, the parameters of two adjustments can be respectively tuned.

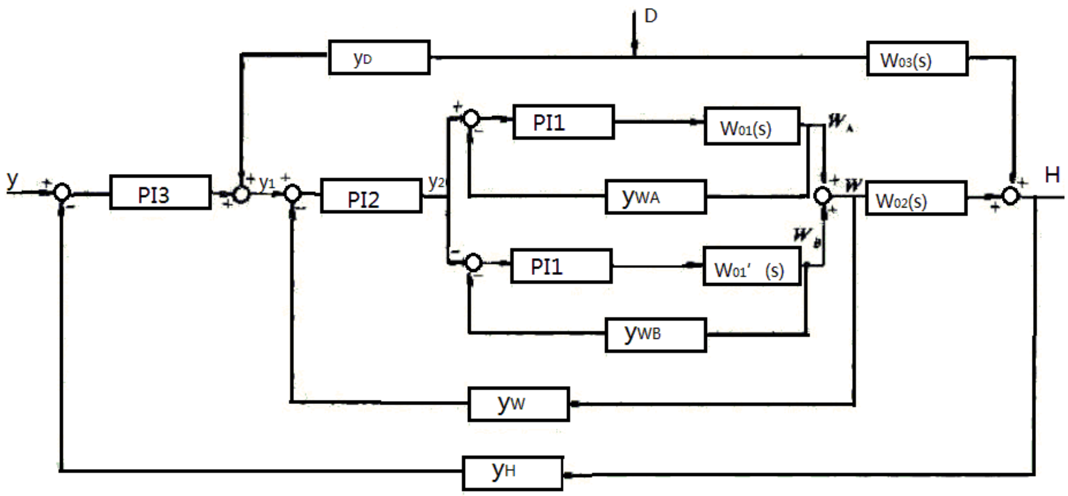


Figure 14. Feeding water system prototypes block diagram

6 CONCLUSION

This thesis introduced the design of the level controlling system in the drum boiler. I have compared many methods for the controlling system and I made the choice in the end.

In the process of building the level control system, there are still some variability points in this process. There is huge development about the level control system that I found some new types of the level controller, like the ultrasonic wave level controller, radar level controller and optical level switch. Most of them are used the radio waves refraction and reflection theories. The light could be refraction and reflection in the sub-interfaces between different media. These kinds of the controllers appeared to develop the control system accuracy a lot and to complete the diversity of the control system.

I use the SAMA figure to show the process and controlling method.

In this design process about this system, I have studied so many new things on Industrial Management. I use the knowledge about the automation and process controlling. This knowledge is very important parts in Industrial Management. I have learned more and got some new knowledge that could further influence my future work and career.

REFERENCES

Liu Zhenjiang “coordination and feeding water process controlling” 2007 China Electric Power Press

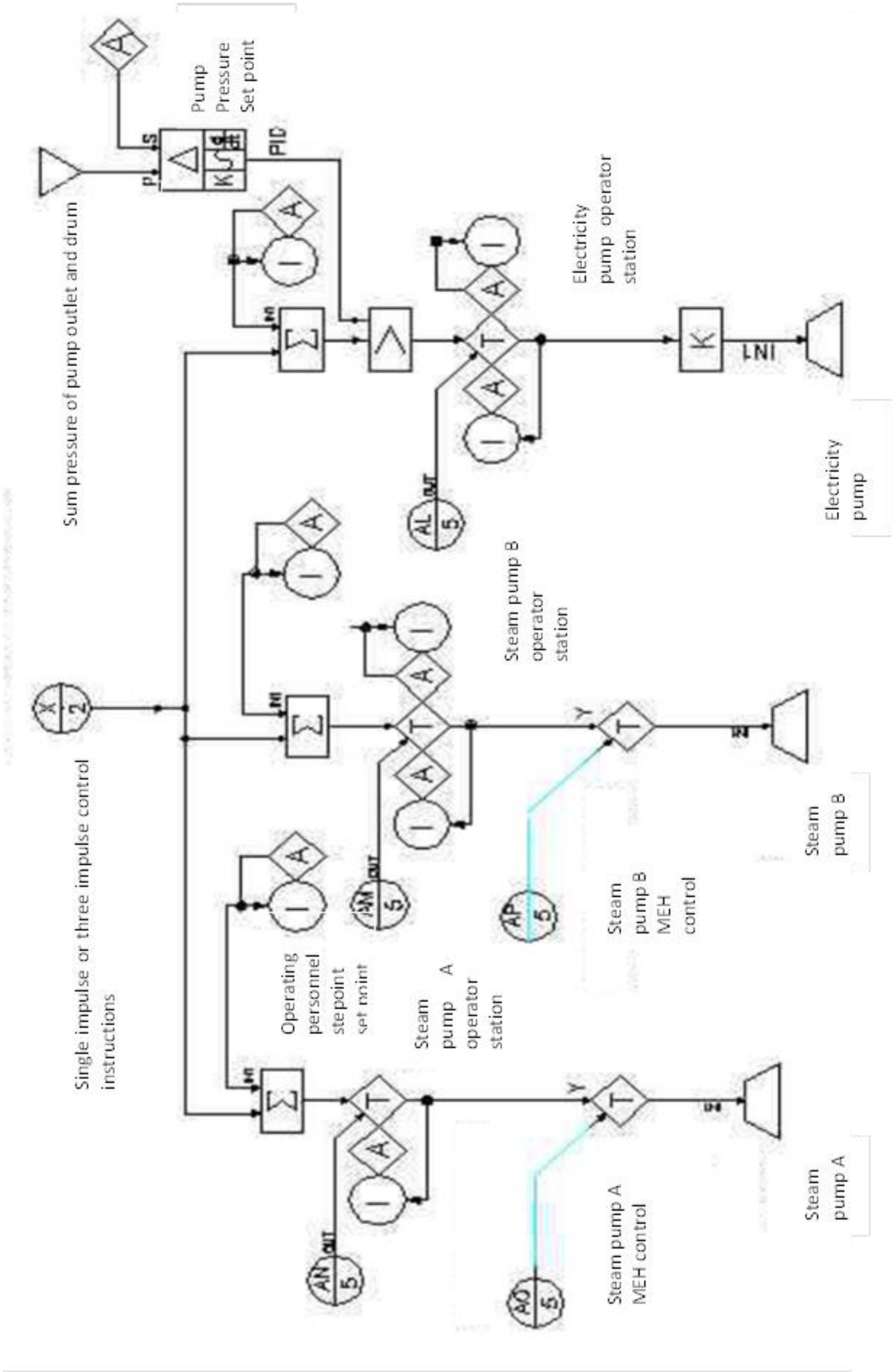
Li Zunji “Thermal automatic control system” 2010 North China Electric Power University Press

600MW Coordinated Control System SAMA figure 2006

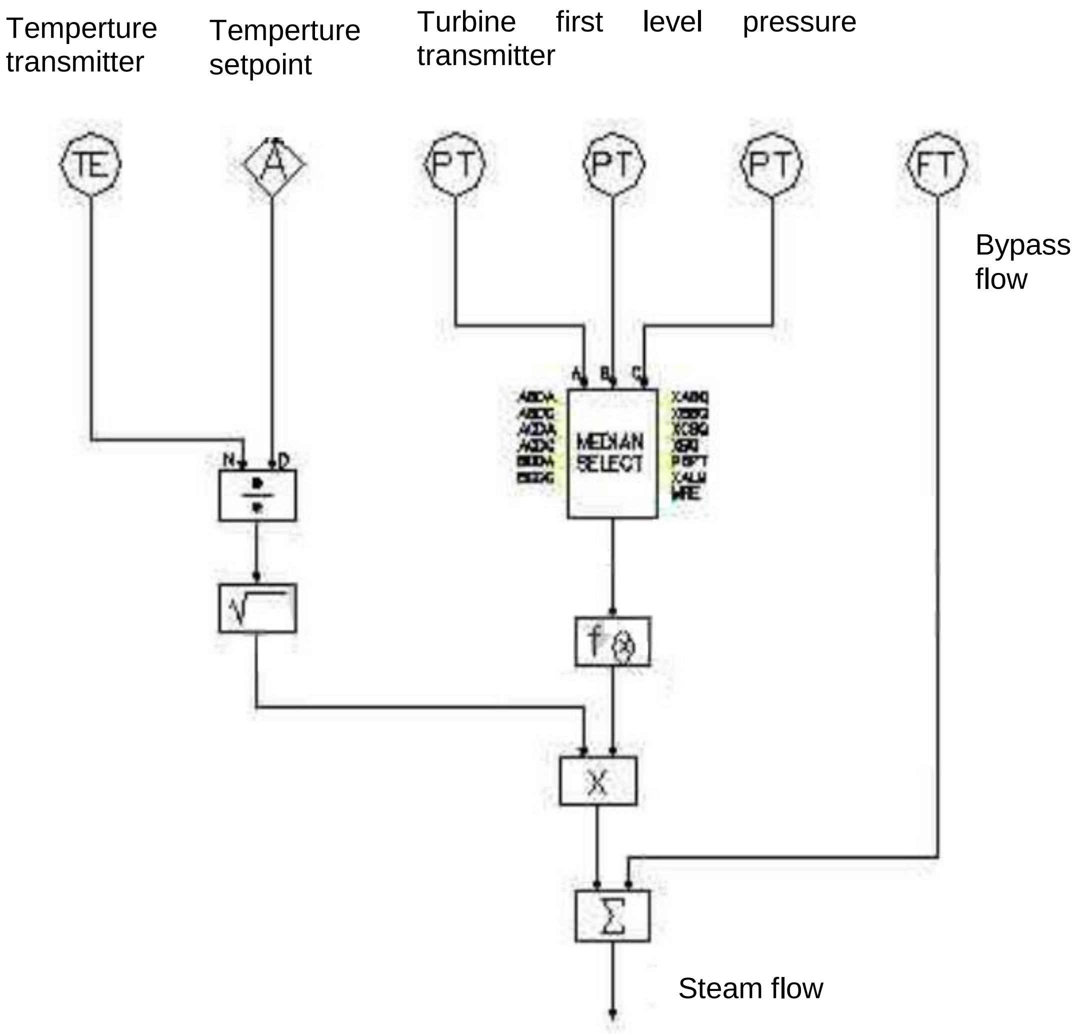
TAKEO IMANAKA, A study on locational configuration of DCS, Electrical engineering in Japan, 2000

Appendix

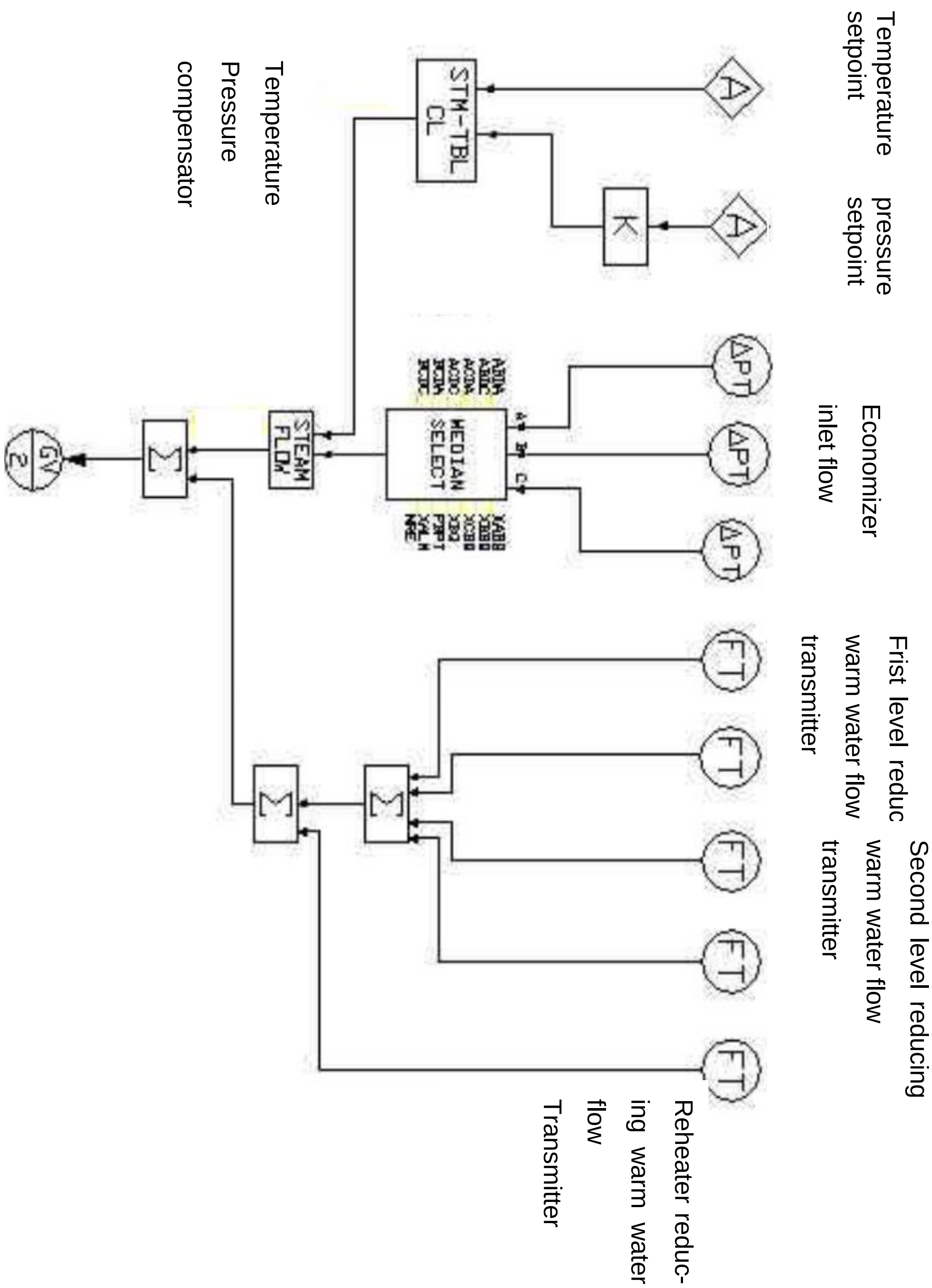
Appendix 1 Feeding water SAMA figures



Appendix 2 Measurement and correction for steam flow signals



Appendix 3 Measurement and correction for main feeding water flow signals



Appendix 4 Single impulse or three impulse controlling switch figure