Instrumentation and Process Control

Boiler Control

Courseware Sample
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INSTRUMENTATION AND PROCESS CONTROL

BOILER CONTROL

Courseware Sample

by
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Foreword

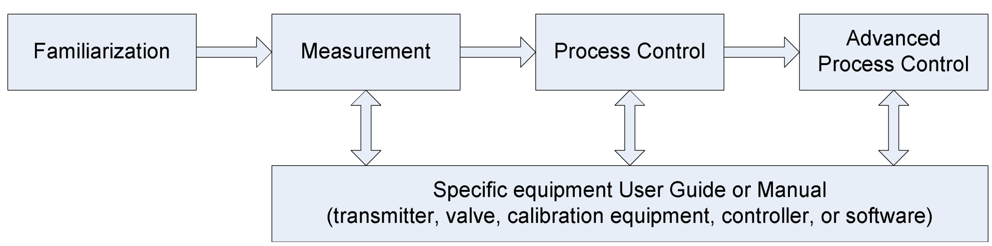
Automated process control offers so many advantages over manual control that the majority of today's industrial processes use it at least to some extent. Breweries, wastewater treatment plants, mining facilities, the automotive industry, and just about every other industry sector use it.

Maintaining process variables such as pressure, flow, level, temperature, and pH within a desired operating range is of the utmost importance to manufacturing products with a predictable composition and quality.

The Instrumentation and Process Control Training System, series 353X, is a state-of-the-art system that faithfully reproduces an industrial environment in which students can develop their skills in the installation and operation of equipment used in the process control field. The use of modern industrial-grade equipment is instrumental in teaching the theoretical and the hands-on knowledge that is required to work in the process control industry.

The modularity of the system allows the instructor to select the equipment required to meet the objectives of a specific course. Two versatile, mobile workstations on which all the equipment is installed forms the basis of the system. Several optional components used in pressure, flow, level, temperature and pH control loops are available as well as various valves, calibration equipment, controllers, and software.

Standard Learning Path



We hope that your learning experience with the Instrumentation and Process Control Training System will be the first step toward a successful career in the process control industry.

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Sample Exercise

Extracted from

Student Manual

Three-Element Control

EXERCISE OBJECTIVE

When you have completed this exercise, you will be familiar with a three-element control strategy to regulate the level of water in a boiler. You will have explored the limitations of the two-element scheme and used cascade control to improve the control scheme. You will have practical experience with the tuning and optimization of a cascade control loop which includes a feedforward component.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Shortcomings of the two-element control scheme
- Three-element level control

DISCUSSION

Shortcomings of the two-element control scheme

The previous exercise detailed a two-element level control scheme. While this scheme is good at controlling the level, you should have observed in the last manipulations of Exercise 2 that it was not optimal when sudden changes in the feedwater flow rate occur.

As shown on the typical experimental results of Figure 25, the controller does not react immediately to the large change in the input flow rate (about 30%). The controller monitors only the level to adjust the control valve. The error is quite small at first, so the control signal does not change very aggressively. The result is that the level keeps rising for a time until the flow rate is brought below its original value to let the level decrease.

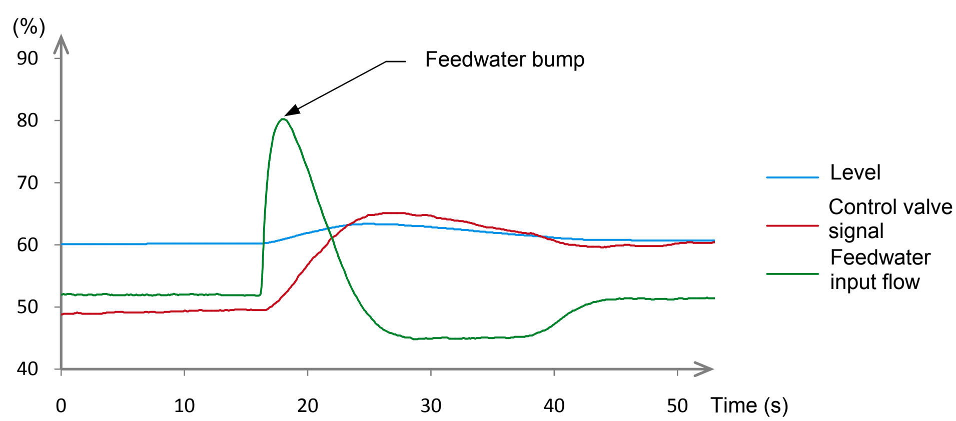

Figure 25. Experimental response to a sudden feedwater increase – Two-element control.

Intuitively, regulating the flow rate of the feedwater to minimize unexpected variations should appear as a promising way to alleviate the level fluctuations due to the feedwater changes. Cascade control, a scheme which you have encountered in the *Process Control* manual, should perform nicely in this case.

Three-element level control

Three-element level control makes use of the two-element scheme to which is added information about the flow rate of feedwater into the boiler. The added information given by the input flow rate of water helps to refine the control scheme and to mitigate the problem caused by a fluctuating water supply.

Different schemes can be devised to make use of the information given by the three measured variables (level, steam flow rate, feedwater flow rate). Of course, the best scheme to use for a particular process is the simplest one that can perform the control with the required precision and level of safety. Costs rise with increased complexity of the control scheme. The conditions of operation, safety considerations, and the size of a particular boiler dictate the necessary level of complexity of the control scheme.

Figure 26 illustrates the three-element control strategy retained for this exercise. The main idea is to use **cascade control**. The previously-studied two-element control scheme is used as the master control loop driving the set point of a slave loop that controls the flow rate of the feedwater. Consequently, the input flow rate is always controlled and steered toward a set point determined by both the actual level of water in the boiler and by the feedforward algorithm of the output flow rate of steam.

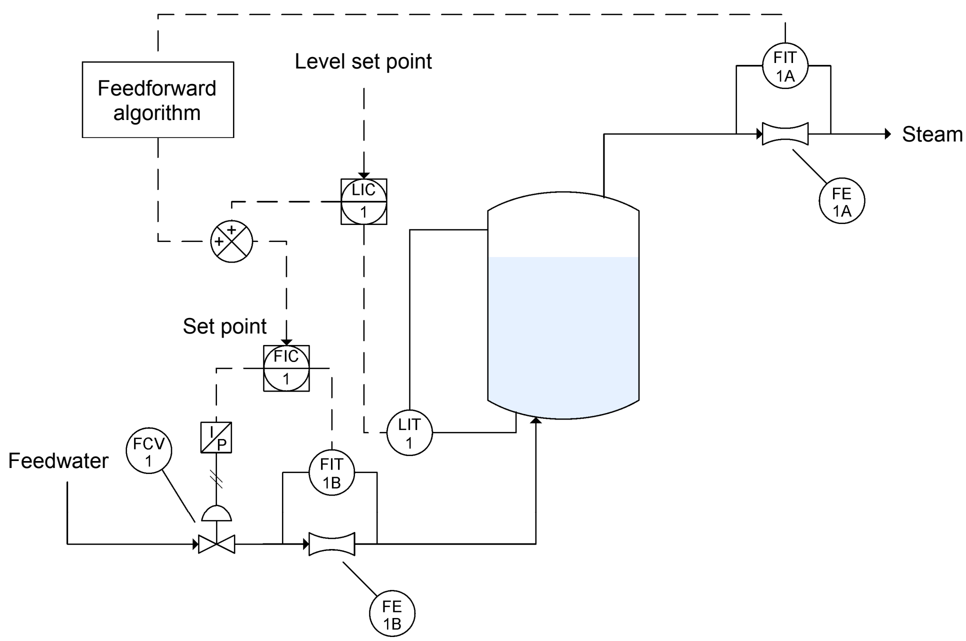

Figure 26. Three-element level control.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Setup and connections
- Adjusting the differential-pressure transmitters
- Controlling the three-element level process

PROCEDURE

Setup and connections

1. Connect the equipment according to the piping and instrumentation diagram (P&ID) shown in Figure 27 and use Figure 28 to position the equipment correctly on the frame of the training system.

   The setup is almost the same as the one in Exercise 2. You can start from that setup and simply modify it to add the necessary equipment. Note that the Venturi tube (FE 1) and the associated differential-pressure transmitter (FIT 1) are now identified as FE 1A and FIT 1A.

Table 4. Material to add to the setup of Exercise 2 for this exercise.

Name	Model	Identification
Differential-pressure transmitter (High-pressure range)	46920	FIT 1B
Orifice Plate	46912	FE 1B
Three-valve manifold	85813	-

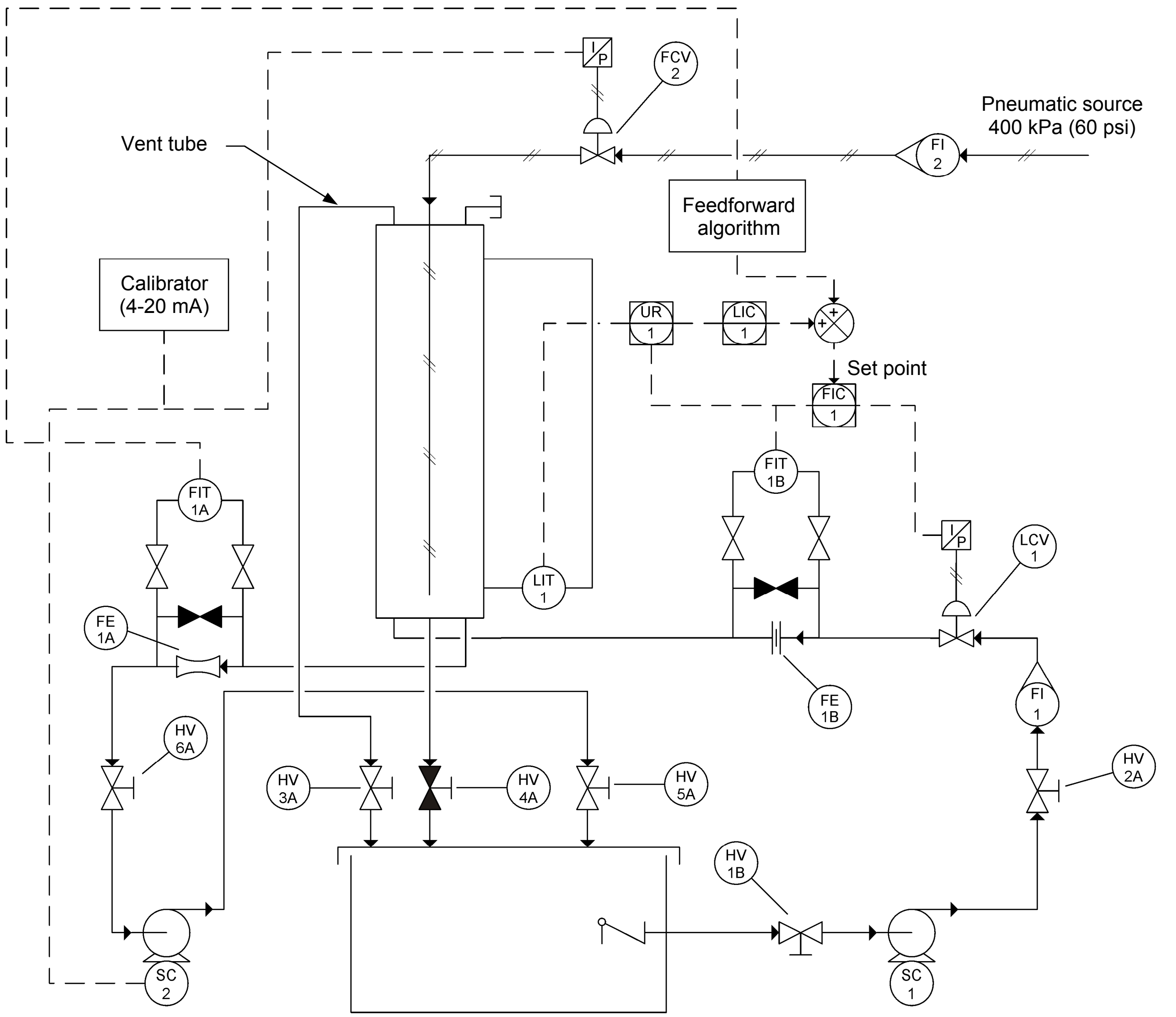

Figure 27. P&ID - Three-element level control.

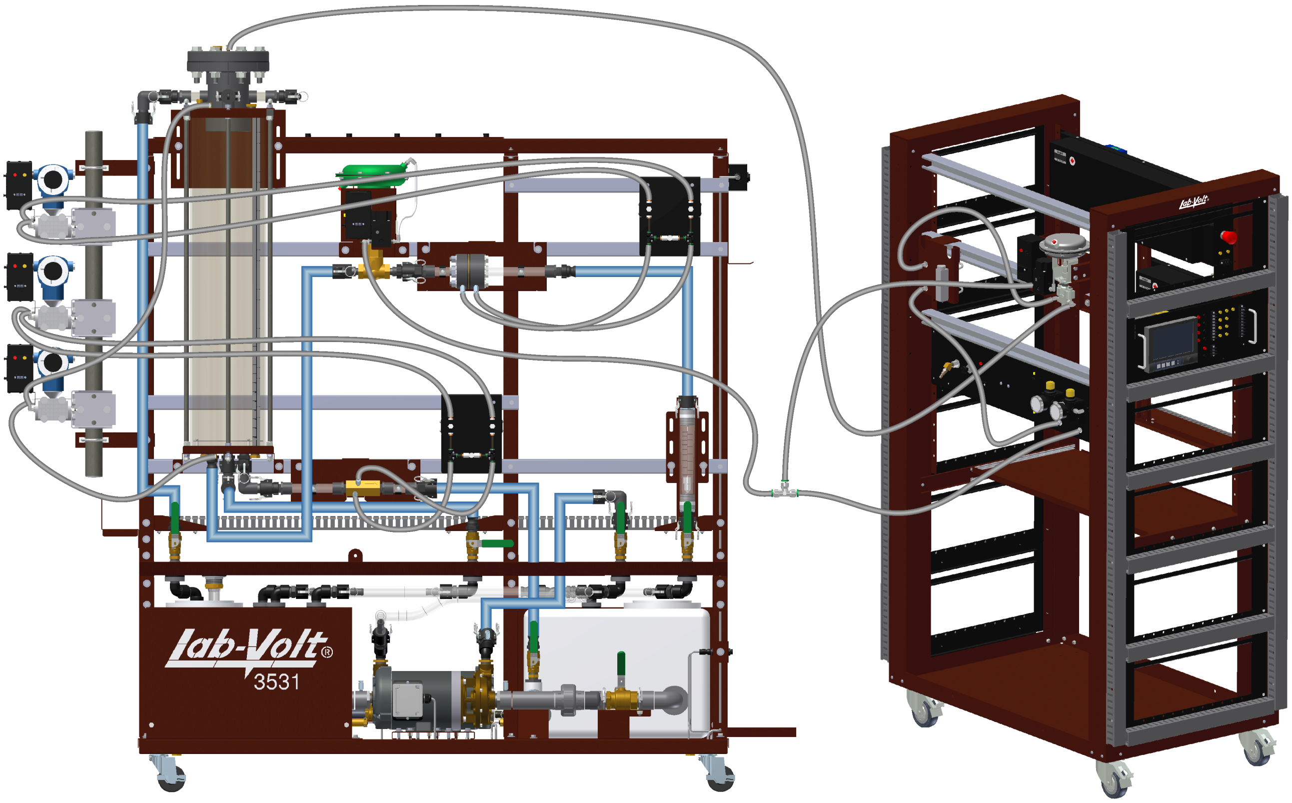

Figure 28. Setup - Three-element level control.

2. Wire the emergency push-button so that you can cut power to the drives and the pneumatic unit in case of emergency.

3. Connect the pneumatic unit to a dry-air source with an output pressure of at least 700 kPa (100 psi).

4. Connect the two control valves to the pneumatic unit in order to supply their I/P converter with a 175 kPa (25 psi) signal. To do so, connect an end of a pneumatic line to the low-pressure port of the pneumatic unit and connect the other end to a T-shaped connector. Connect separate pneumatic lines from the T-shaped connector to each of the two valves.

5. Do not power up the instrumentation workstation yet. Do not turn the electrical panel on before your instructor has validated your setup—that is not before step 9.

6. Connect the controller to the control valve and to the differential-pressure transmitters. You must also include the recorder in your connections. On channel 1 of the recorder, plot the output signal from the controller. On channel 2, plot the signal from the LIC 1 transmitter. Channel 3 is used to plot the signal from the FIT 1A transmitter and channel 4 is used for the

signal of the FIT 1B transmitter. Be sure to use the analog inputs of your controller to connect the differential-pressure transmitters.

Figure 29 shows how to connect the different devices together. The connections of Figure 14 are still needed.

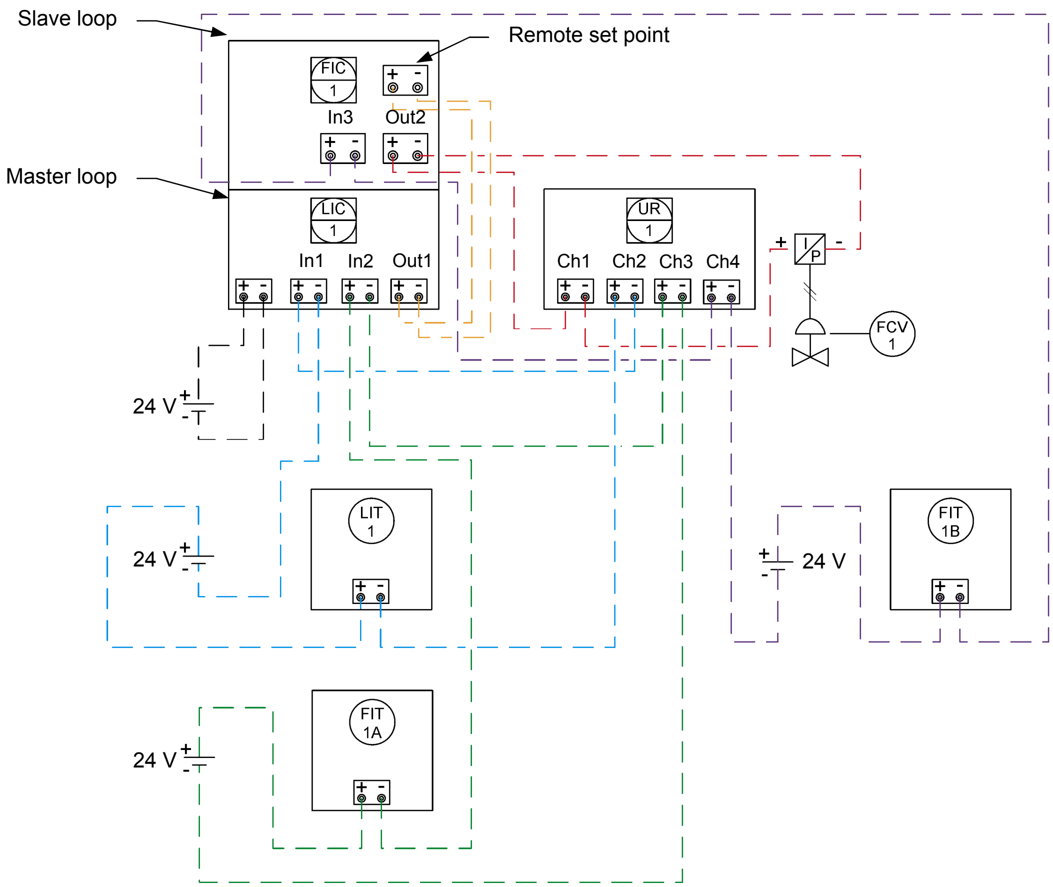

Figure 29. Electrical connections - Three-element level control.

The output of the master loop determines the set point of the slave loop in cascade control. This output is usually relayed internally to the slave loop when operating in cascade mode. However some controllers do require a physical connection from the output of the master loop to the remote set-point port of the slave loop. The corresponding electrical connections shown above (in orange) might or might not be required with your controller (consult the technical information related to your controller).

7. Before proceeding further, complete the following checklist to make sure you have set up the system properly. The points on this checklist are crucial elements to the proper completion of this exercise. This checklist is not exhaustive, so be sure to follow the instructions in the *Familiarization with the Instrumentation and Process Control Training System* manual as well.

☐ Every piece of equipment used is secured to the station with the appropriate bolt-and-nut mechanism.

☐ All unused ports of the column are closed with a cap.

☐ The ball valves are in the positions shown in the P&ID and listed below:

Open valves: HV1B, HV2A, HV3A, HV5A, HV6A, and HV7.
Closed valves: HV1A, HV2B, HV3B, HV4A, HV4B, HV5B, HV6B, HV8A and HV8B.
(HV8 valves may not be present on your system)

☐ Control valve LCV1 is fully open and control valve FCV2 is fully closed.

☐ The pneumatic connections are correct.

☐ The controller is properly connected to the differential-pressure transmitters and to the control valve.

☐ The paperless recorder is connected correctly to plot the appropriate signals on channel 1, channel 2, channel 3, and channel 4.

8. Ask your instructor to check and approve your setup.

9. Power up the electrical unit, this starts all electrical devices as well as the pneumatic unit. Activate the control valve of the pneumatic unit to power the devices requiring compressed air.

Adjust the pressure output so that a 400 kPa (60 psi) signal is sent to the bubbler pressure line while a 175 kPa (25 psi) signal is supplied to the I/P converter of both control valves.

Configure the paperless recorder to display the control signal sent to the valve (Channel 1), the level signal coming from the LIT 1 differential-pressure transmitter (Channel 2), the output flow rate signal coming from the FIT 1A differential-pressure transmitter (Channel 3), and the input flow rate signal coming from the FIT 1B differential-pressure transmitter (Channel 4).

10. With the controller in manual mode, set the output of the controller to 0% then to 100%. The LCV1 control valve should respectively be completely open and fully closed. If it is not, revise the electrical and pneumatic connections and be sure the calibration of the I/P converter is appropriate.

11. Test your system for leaks. Use the SC1 drive to make the P1 pump run at low speed to produce a small flow rate. Gradually increase the flow rate, up to 50 Hz. Fix any leaks and stop the pump when the column is about filled.

Press the start button on the drive SC2, turn on your calibrator and send a 4 mA signal to both the air control valve and the drive. Increase the signal up to 20 mA and make sure pump P2 draws water from the column and the flow of air sent to the column is regulated by the air control valve. Both processes should vary linearly with the signal. **Stop the drive whenever the level of water becomes low to avoid pumping air**.

Adjusting the differential-pressure transmitters

12. Connect the impulse line leading to the high-pressure port of the LIT 1 differential-pressure transmitter to the pressure port at the base of the column. Connect the low-pressure port open to the top of the column. Bleed the impulse line and configure the transmitter for level measurement. Adjust the zero of the differential-pressure transmitter.

Set the LIT 1 transmitter parameters so that a 4 mA signal is sent for a level of 5 cm (2 inches) and a 20 mA signal for a level of 75 cm (30 inches).

13. Connect an impulse line leading to the high-pressure port of the FIT 1A differential-pressure transmitter to the three-valve manifold and next to the high-pressure port of the Venturi tube. Make sure to use the three-valve manifold as explained in the *Familiarization* manual.

Connect the low-pressure port of the transmitter to the low-pressure port of the Venturi tube, passing through the three-valve manifold. Bleed the impulse lines and configure the transmitter for flow rate measurement. Adjust the zero of the differential-pressure transmitter.

Set the FIT 1A transmitter parameters so that a 4 mA signal is sent for a flow rate of 0 l/min (0 gal/min) and a 20 mA signal for a flow rate of 40 l/min (10 gal/min). Use a damping time of at least 1 second to avoid oscillations due to noise.

14. Connect an impulse line leading to the high-pressure port of the FIT 1B differential-pressure transmitter to a second three-valve manifold and next to the high-pressure port of the orifice plate. Make sure to use the three-valve manifold as explained in the *Familiarization* manual.

Connect the low-pressure port of the transmitter to the low-pressure port of the orifice plate, passing through the three-valve manifold. Bleed the impulse lines and configure the transmitter for flow rate measurement. Adjust the zero of the differential-pressure transmitter.

Set the FIT 1B transmitter parameters so that a 4 mA signal is sent for a flow rate of 0 l/min (0 gal/min) and a 20 mA signal for a flow rate of 40 l/min (10 gal/min). Use a damping time of at least 1 second to avoid oscillations due to noise.

Controlling the three-element level process

15. Set pump P1 to run at 50 Hz while pump P2 is powered by a drive receiving a 12 mA input signal (i.e., P2 should run at 15 Hz with the proper settings).

Tune the slave loop of your controller using the trial and error method. The slave loop must be set to control the input flow rate in PI mode. A suggested starting point for your search is $K_c = 0.5$ and $T_i = 8$ s.

Fine-tune the parameters until you are satisfied with the control. Test the control of the flow rate when the set point is at 50% by using valve HV 1 to create small perturbations. Write down the value of the parameters of your controller once optimized:

$K_c =$ ___________ and $T_i =$ ___________

Make sure valve HV 1 is fully open once you are done testing the response of the controller to flow perturbations.

16. Once the slave loop is properly tuned and set in auto mode, activate the cascade control mode. Tune the master loop using the parameters of Exercise 2 (including the feedforward component). The parameters should be appropriate, but could be adjusted if required.

Keep in mind to set the action of the master loop correctly. Changing the action of the PID also requires changing the sign of the feedforward function.

Once well adjusted, have the controller maintain a level set point of 60% in auto mode.

17. Decrease the speed of the SC 1 drive to 40 Hz. Let the level stabilize again to the set point of 60%.

Plot a graph of the level as it undergoes a feedwater perturbation. To do so, increase suddenly the speed of the SC 1 drive from 40 Hz to 60 Hz. How does the process react? How much time is required to stabilize the level at the 60% set point?

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18. Stop the two drives and turn off the pneumatic and electrical power. Empty the column using valve HV4 (close it afterwards).

Store the equipment and make sure the station is properly set for the next users.

CONCLUSION

In this exercise, you made use of a complete three-element control strategy for the control of the level in a simulated boiler. You tuned a three-element level control loop and observed its behavior as the boiler underwent changes in the flow of feedwater to the column.

The different exercises proposed in this manual made you explore the characteristics of control schemes ranging from the simple one-element strategy to the more complex three-element scheme. Even more complex control schemes are likely to be encountered in the industry. The skills obtained in this manual should allow you to approach different control designs with the tools required to understand their basic mode of operation.

REVIEW QUESTIONS

1. What is the difference between two-element and three-element level control?

2. What effect does three-element level control help to attenuate?

3. Briefly describe what cascade control is.

4. On the following P&ID, identify the master and the slave loops.

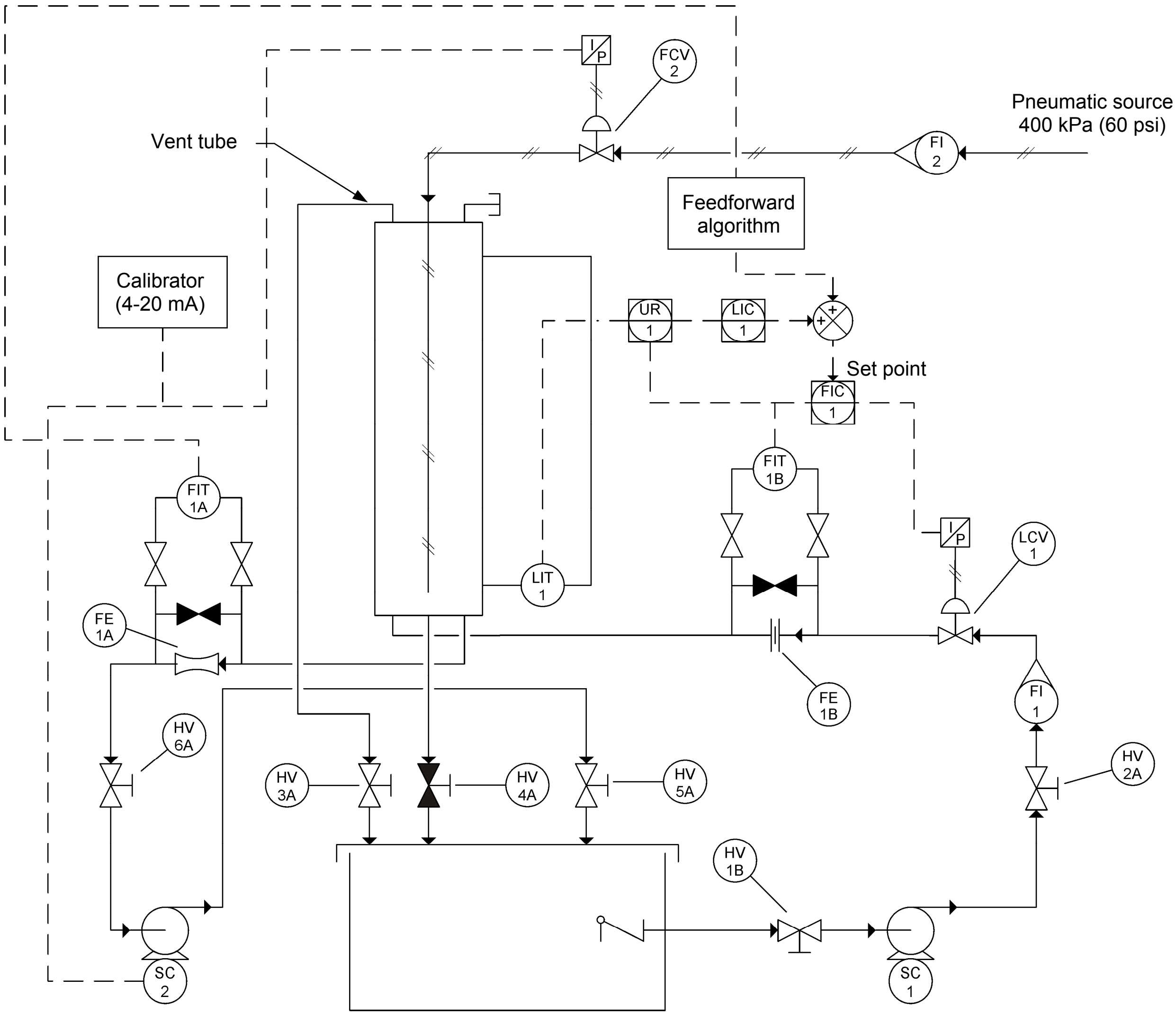


Figure 30. P&ID - Three-element level control.

5. Name five elements that should be considered when selecting the control scheme to regulate the level in a boiler?

Sample

Extracted from

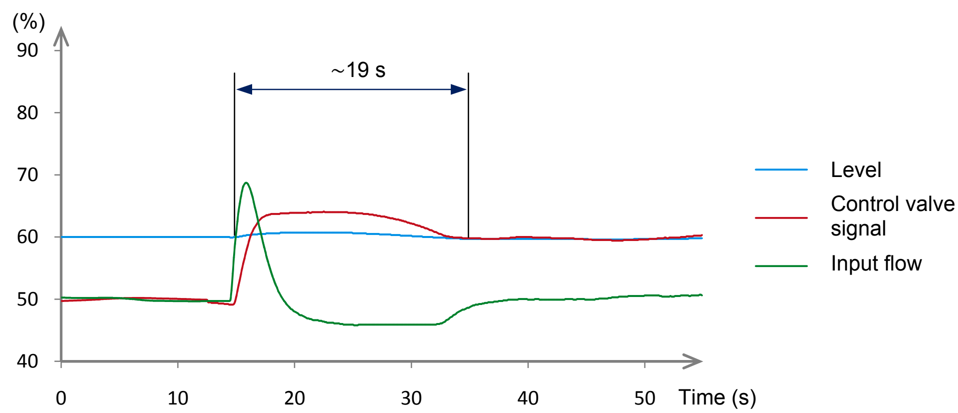
Instructor Guide

Exercise 3 Three-Element Control

Answers to Procedure Step Questions

15. The PID parameters used in our setup were $K_c = 0.3$ and $T_i = 1\ \mathrm{s}$. The PID parameters obtained on your setup may differ.

17. The process should react better with cascade control than before. Observe that the level does not change much compared to the case of the two-element scheme. The total time required for the level to return to the set point is about 19 s. The variation of the input flow rate is also much less pronounced than in the two-element case.



Response of the process to a sudden increase in feedwater supply – Three-element control.

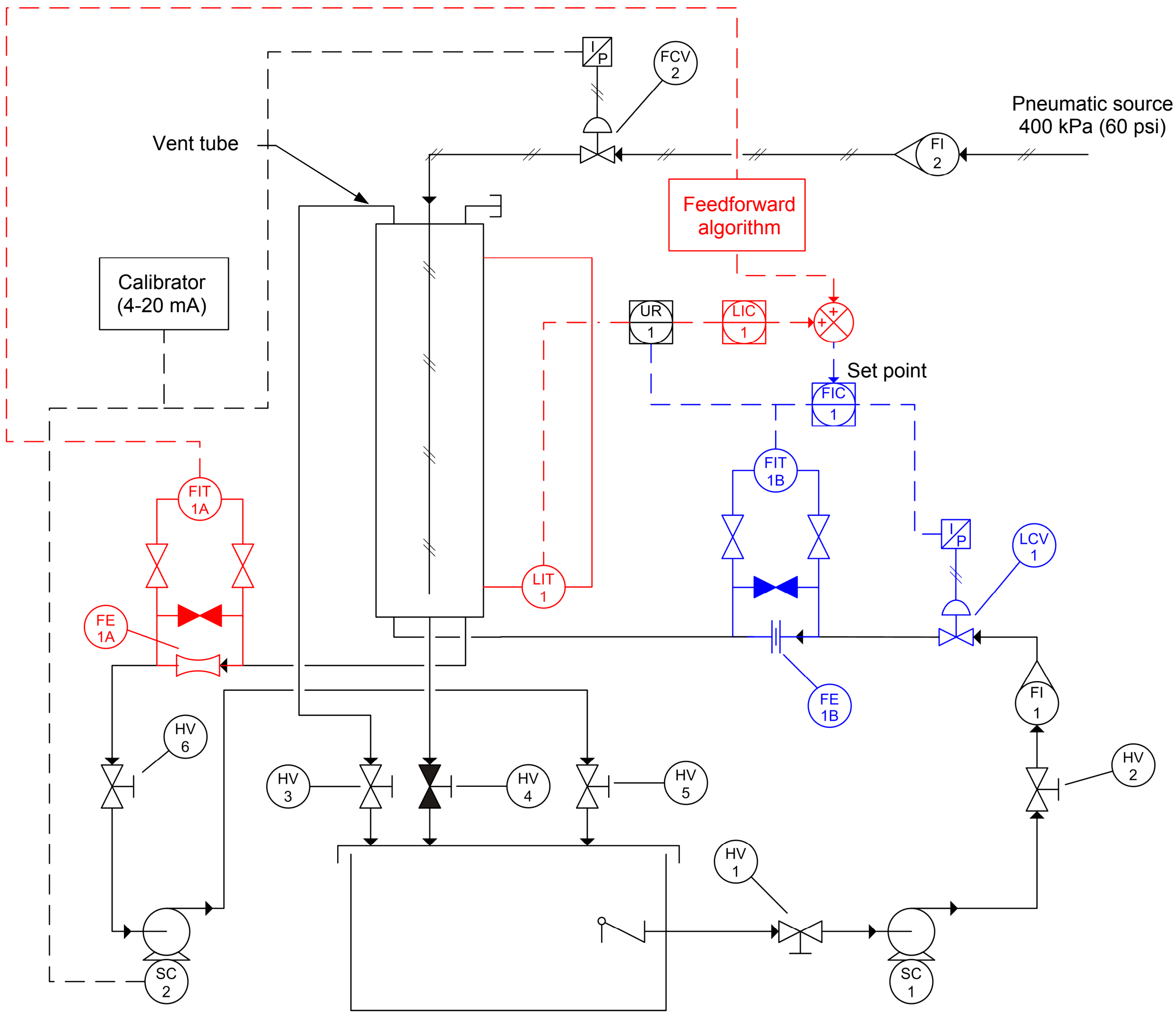
Answers to Review Questions

1. Three-element level control makes use of the two-element scheme to which is added information about the flow rate of feedwater into the boiler. All this is integrated in a cascade-based control scheme to achieve an efficient level control.

2. It helps to minimize the effects of fluctuating flow rate in the feedwater.

3. Cascade control utilizes two control loops: a master loop and a slave loop. The master loop monitors the primary variable. The slave loop monitors a second variable. The output of the master controller is connected to the set-point input of the slave controller, causing the two controllers to be cascaded.

4. The master loop is shown in red and the slave loop is shown in blue.



5. Simplicity, precision, safety, costs, conditions of operation, and the size of the boiler are all elements that should be considered when selecting the control scheme to regulate the level in a boiler.

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