CHAPTER 17

Documentation and P&ID

17.1 Introduction

A vast amount of documentation is required for the design and construction of a process facility, which are front-end and detailed engineering drawings. The main engineering documents used on a regular basis by the engineering staff for smooth and efficient running, maintenance, and upgrading of the facility are Alarm and Trip Systems, PLC documentation, and Pipe and Instrumentation Diagrams (P&ID). As in all engineering disciplines, the initial accuracy of these documents, and the regular updating of them when changes are made, is critical, and one of the most important aspects of engineering. For this reason, documentation is discussed in this chapter. Documentation standards and symbols for all aspects of process control have been set up and standardized by the ISA, in conjunction with the ANSI [1].

17.2 Alarm and Trip Systems

The purpose of an alarm system is to bring a malfunction to the attention of operators and maintenance personnel, whereas the purpose of a trip system is to shut down a system in an orderly fashion when a malfunction occurs, or to switch failed units over to standby units. The elements used in the process control system are the first warnings of a failure. This could show up as an inconsistency in a process parameter, or as a parameter going out of its set limits. The sensors and instruments used in the alarm and trip system are the second line of defense, and must be totally separate from those used in the process control system. Alarm and trip system information and its implementation are given in ANSI/ISA-84.01-1996—Application of Safety Instrumented Systems for the Process Control Industry.

17.2.1 Safety Instrumented Systems

The alarm and trip system, or Safety Instrumented System (SIS), has its own sensors, logic, and control elements, so that under failure conditions, it will take the process to a safe state to protect the personnel, facility, and environment. To ensure full functionality of the SIS, it must be regularly tested. In an extreme situation, such as with deadly chemicals, a second or third SIS system with redundancy can be used in conjunction with the first SIS system, to ensure as close to 100% protection as possible. The sensors in the SIS usually will be of a different type than those used for process control. The control devices are used to accurately sense varying levels in the measured variable, whereas the SIS sensor is used to sense a trip point, and will be a much more reliable, rugged, and high-reliability device. The use of redundancy in a system cannot be used as a justification for low reliability and inexpensive components. The most commonly used high performance SIS system is the dual redundancy system, which consists of the main SIS with two redundant systems. In this case, a two-out-of-three logic monitoring system determines if a single monitor or the entire system has failed. If a single failure is detected, then the probability is that a sensor, its associated wiring, or logic has failed. If more than one failure is detected, then the indication is a system failure. A two-out-of-three logic circuit is shown in Figure 17.1(a), and the truth table is shown in Figure 17.1(b). With correct operation, the inputs are normally low (0). If one input goes high (1), it would indicate a sensor failure, and the sensor failure output would go from 0 to 1 to give warning of a sensor failure, but the system failure output would remain at 0. If two or more inputs go high, it would indicate a system failure, and the system failure output would go from 0 to 1, as shown.

In SIS systems failure analysis, the rate of component failure is as follows:

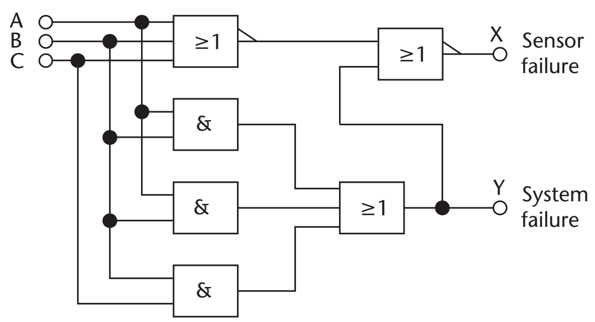
- Logic, 8%;
- Sensors, 42%;
- Control devices, 50%.

17.2.2 Safe Failure of Alarm and Trip

No system is infallible, and failures are going to occur. A good philosophy is the fail-safe approach, where each valve will trip to a predetermined fail position when they are deenergized. Even with an uninterruptible power system, power wires can get cut, fuses can blow, or cables can break, cutting off power. In some cases, this approach is not feasible, and extra safeguards are necessary to maintain safety when the SIS fails.

There are typically three levels of safety, and the systems normally associated with the safety levels are:

- Level 1—Single sensor with a one-out-of-one logic detection and single final control.



(a)

Inputs			Outputs	
A	B	C	X	Y
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	0	1

Truth table

(b)

Figure 17.1 (a) Monitor and two-out-of-three failure indicator, and (b) truth table.

- Level 2—More diagnostics than Level 1, plus redundancy for each stage.
- Level 3—Minimum of two systems with redundancy, or a two-out-of-three sensing system.

Components in an SIS system should be high-grade, with a high mean time between failures (MTBF). Relays were the preferred choice due to the capability of multiple contacts and isolation. However, semiconductor devices have an excellent MTBF, and they are replacing relay logic. A good design will take into account the integrity of all the components in an alarm system, as well as interactions between the components.

Testing of the alarm system is required on a regular basis to uncover faults or potential failures, which require corrective action. Testing is of prime importance in SIS applications. An SIS is designed to detect hazardous conditions, so it must be able to sense a malfunction of the logic, measuring device, and final alarms during testing. The requirements and testability of the SIS must be factored in at the system design stage.

17.2.3 Alarm and Trip Documentation

Good, up-to-date documentation is a prerequisite in alarm and trip systems, and must be initiated at the design stage. Hazard analysis must be performed on the facility to determine all areas that require alarms or trips. The SIS devices should be clearly marked and numbered. System drawings must show all SIS devices using standard symbols, their locations, functions, and set limits. Drawings must include lock and logic diagrams [2].

The types of information required in Alarm and Trip documentation are:

1. Safety requirement specifications;
2. Logic diagram with functional description;
3. Functional test procedures and required maintenance;
4. Process monitoring points and trip levels;
5. Description of SIS action if tripped;
6. Action to be taken if SIS power is lost;
7. Manual shutdown procedures;
8. Time requirements to reach safe status;
9. Restarting procedures after SIS shutdown.

Test procedures are needed to verify operation of the total SIS. These procedures must not pose any hazards or cause spurious trips, and must have the ability to detect wear, slow operation, leaking shutoffs, and sticking devices. A test procedure is necessary for an SIS, and should be available for all alarm and trip devices. The test procedure should contain the following information:

1. Frequency of testing;
2. Hazards that may be encountered;
3. Drawing and specification information;
4. Test equipment;

5. Performance limits;
6. Test procedure.

The results of the system testing must record any problem areas found, and the corrective action taken. Typical SIS test results will have the following information:

1. Time and date of test;
2. Test personnel;
3. System identification;
4. Test procedure;
5. Results of test;
6. Corrective action taken;
7. Follow-up required;
8. SIS operational.

17.3 PLC Documentation

The PLC documentation is a very important engineering record of the process control steps, and, as with all technical descriptions, accurate detailed engineering records are essential. Without accurate drawings, changes and modifications needed for upgrading and diagnostics are extremely difficult or impossible. Every wire from the PLC to the monitoring and control equipment must be clearly marked and numbered at both ends, and recorded on the wiring diagram. The PLC must have complete up-to-date ladder diagrams (or other approved language), and every rung must be labeled with a complete description of its function [3].

The essential documents in a PLC package are:

1. System overview and complete description of control operation;
2. Block diagram of the units in the system;
3. Complete list of every input and output, destination, and number;
4. Wiring diagram of I/O modules, address identification for each I/O point, and rack locations;
5. Ladder diagram with rung description, number, and function.

It is also necessary to have the ability to simulate the ladder program off-line on a personal computer, or in a background mode in the PLC, so that changes, upgrades, and fault simulations can be performed without interrupting the normal operation of the PLC, and the effects of changes and upgrades can be evaluated before they are incorporated [4].

17.4 Pipe and Instrumentation Symbols

The electronics industry has developed standard symbols to represent circuit components for use in circuit schematics, and, similarly, the processing industry has developed standard symbols to represent the elements in a process control system.

Instead of a circuit schematic, the processing industrial drawings are known as P&ID (not to be confused with PID), which represent how the components and elements in the processing plant are interconnected. Symbols have been developed to represent all of the components used in industrial processing, and have been standardized by ANSI and ISA. The P&ID document is the ANSI/ISA 5.1—1984 (R 1992)—Instrumentation Symbols and Identification Standards. An overview of the symbols used is given in this chapter, but the list is not complete. The ISA should be contacted for a complete list of standard symbols.

17.4.1 Interconnect Symbols

The standard on interconnections specifies the type of symbols to be used to represent the various types of connections in a processing plant. The list of assigned symbols for instrument line connections is given in Figure 17.2. Interconnect lines can be solid bold lines, which are used to represent the primary lines used for process product flow, and solid narrow lines, which are used to represent secondary flows, such as steam for heating or electrical supplies. One signal line symbol is undefined, and can be assigned at the user's discretion for a special connection not covered by any of the assigned interconnection symbols. The binary signal lines can be used for digital signals or pulse signals. The pneumatic signal lines can represent any gas used for signal transmission, and the gas may be specified next to the line. Electromagnetic lines can be any EM waves, such as light, nuclear, or radio frequencies [5].

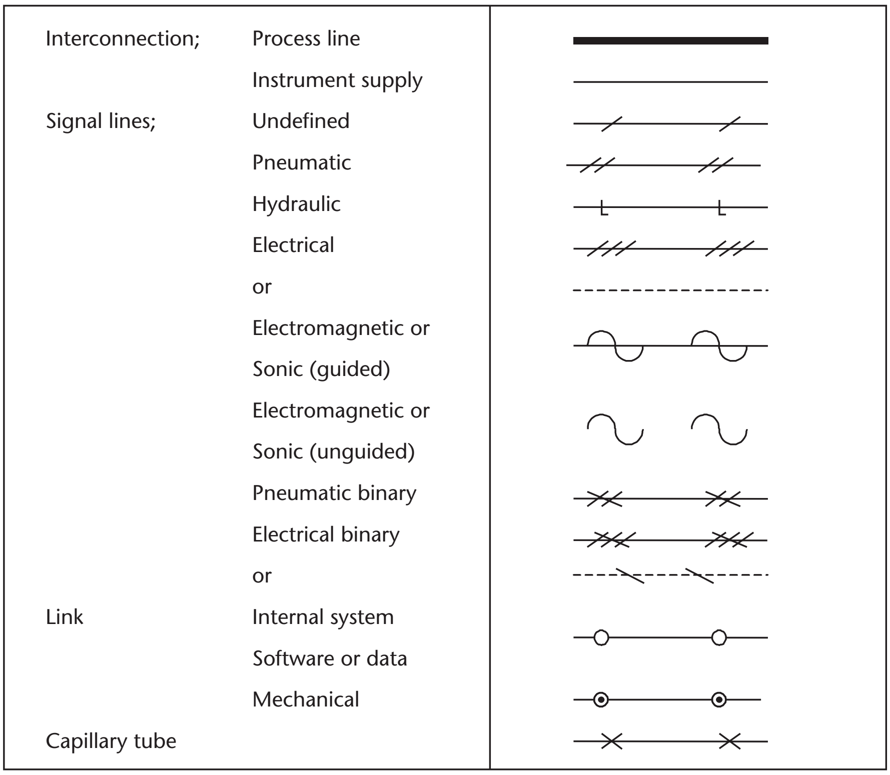


Figure 17.2 Symbols for instrument line interconnection.

Abbreviations to define the type of interconnect secondary flow lines are given in Table 17.1. The abbreviations are placed adjacent to the lines. Descriptive information can be added to signal lines to show on the P&ID, such as the signal's content and range. Electrical signals can be either current or voltage signals, and would be marked as such. Examples of signal lines with the signal's content and range marking are shown in Figure 17.3. The first two lines are supply lines. The first line is a 48V ac line, and the second a 60-psi nitrogen supply line. Lines 3 and 4 are signal lines. The third line carries an analog signal that ranges from 1V to 10V, and the fourth line carries a binary signal with 0 = 0V and 1 = 5V.

17.4.2 Instrument Symbols

Figure 17.4 shows the symbols designated for instruments. Discrete instruments are represented by circles, shared instruments by a circle in a rectangle, computer functions by hexagons, and PLC functions by a diamond in a rectangle. A single horizontal line, no line, dashed line, or double line through the display is used to differentiate between location and accessibility to an operator. A line through an instrument may indicate that the instrument is in a panel in the control room giving full access; no line could mean that the instrument is in the process area and inaccessible to the operator; and a double line could indicate that the instrument is in a remote location, but accessible to the operator. An instrument symbol with a dashed horizontal line means that it is not available, by virtue of being located in a totally inaccessible location [6].

17.4.3 Functional Identification

All instruments and elements will be identified according to function, and should contain the loop numbers. The letters are a shorthand way of indicating the type of instrument and its function in the system. Typically, two or three letters are used. The first letter identifies the measured or initiating variable, the second letter is a modifier, and the remaining letters identify the function. Table 17.2 defines some of the meanings of the assigned instrument letters.

Table 17.1 Abbreviations for Secondary Flow Lines

AS	Air Supply	HS	Hydraulic Supply
IA	Instrument Air	NS	Nitrogen Supply
PA	Plant Air	SS	Steam Supply
ES	Electric Supply	WS	Water Supply
GS	Gas Supply		

Figure 17.3 Method of indicating the content of a line.

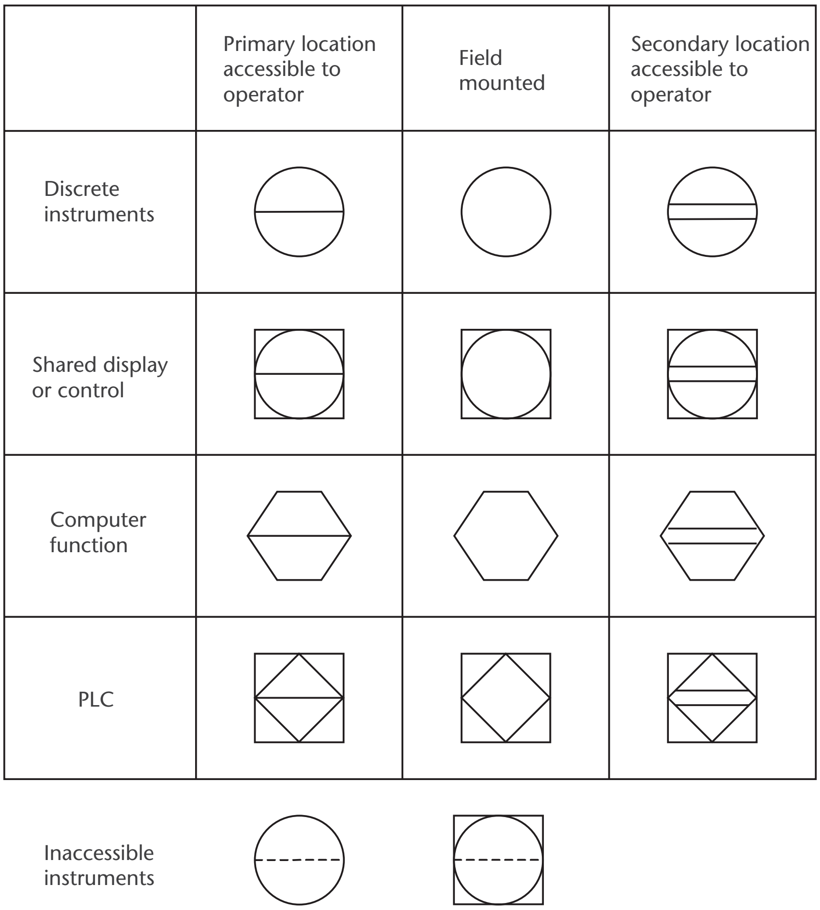


Figure 17.4 Standardized instrument symbols.

Examples of the use of instrument identification letters and numbers are shown in Figure 17.5. The instrument identification can be determined as follows:

(a) The flow control loop number 14 is shown. an orifice plate that has an electrical transmitter (FT14) measures the flow. The first letter, F, denotes that the function is flow, the second letter, T, denotes transmitter, and the dashed line is an electrical signal ranging from 0V to 10V. The output goes to a PLC (FC14) denoting flow control. The output is a current signal ranging from 4 to 20 mA, and this signal goes to a signal converter FY14, which converts the signal into a pressure signal ranging from 3 to 15 psi to drive the control valve FV14.

(b) The tank has a direct reading level indicator LI17, a high-level detector LSH17, and a low-level detector LSL17, where the first L denotes level, S denotes switch, H denotes high, and the subsequent L denotes low. The output from the level switch goes to an alarm (note the shared instrument symbol) LAHL 17, where A denotes alarm, H is high and L is low, showing that the alarm will be activated if the fluid level is above the set high level or below the low set level.

Table 17.2 Instrument Identification Letters

	First Letter + Modifier			*Succeeding Letters*	
	Initiating or Measured Variable	*Modifier*	*Readout or Passive Function*	*Output Function*	*Modifier*
A	Analysis		Alarm		
B	Burner, combustion		User's choice	User's choice	User's choice
C	User's choice			Control	
D	User's choice	Differential			
E	Voltage		Sensor		
F	Flow rate	Ratio			
G	User's choice		Glass, viewing device		
H	Hand				High
I	Current		Indicate		
J	Power	Scan			
K	Time	Time rate of change		Control station	
L	Level		Light		Low
M	User's choice	Momentary			Middle
N	User's choice		User's choice	User's choice	User's choice
O	User's choice		Orifice		
P	Pressure		Test point		
Q	Quantity	Integrate, totalize			
R	Radiation		Record		
S	Speed, frequency	Safety		Switch	
T	Temperature			Transmit	
U	Multivariable		Multifunction	Multifunction	Multifunction
V	Vibration, mechanical analysis			Valve, damper, louver	
W	Weight, force		Well		
X	Unclassified	x-axis	Unclassified	Unclassified	Unclassified
Y	Event, state, or presence	y-axis		Ready, compute, convert	
Z	Position, dimension	z-axis		Driver, actuator	

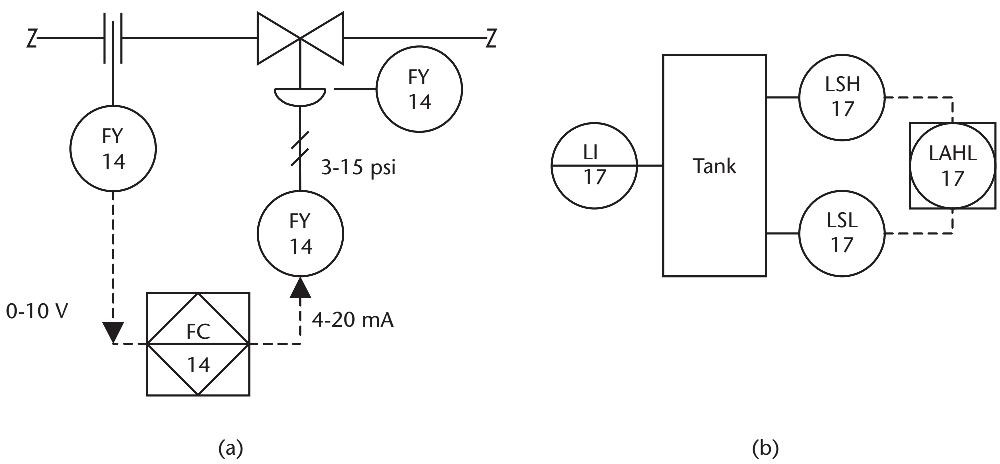


Figure 17.5 Examples of the letter and numbering codes.

17.4.4 Functional Symbols

A number of functional symbols or pictorial drawings are available for most P&ID elements. A few examples are given here to acquaint the reader with these elements. They have been divided into valves, actuators, temperatures, pressures, flows, levels, math functions, and others. The list is by no means complete, and a complete list of symbols can be obtained from the ISA—ISA-5.1-1984 (R1992).

Valve symbol examples are shown in Figure 17.6. Each type of valve has its own symbol. The first row shows a control valve, an angle valve, a three-way valve, and a four-way valve. The three-way valve has an arrow indicating that if power is lost, the fail-safe position is an open path between A and C ports. The second row of valves shows the fail-safe indication used for control valves, a globe valve, and a butterfly valve symbol. The last row shows other types of valves. In practice, each valve will have a balloon with functional information and loop numbers [7].

Actuator symbols are shown in Figure 17.7. Examples of eight types of valve actuators are shown. These actuators control the valves directly. The first row shows hand and electrical actuators, and the second row shows examples of pneumatic and hydraulic actuators.

Temperature symbol examples are shown in Figure 17.8, with six temperature functions shown: basic thermometer, thermometer in a well, capillary symbol, transmitter, radiation device, and high-level switch. Note the changes in symbols for different types of thermometer, letters for device functions, and loop numbers.

Pressure symbol examples are given in Figure 17.9, with six pressure sensors and regulators shown: basic pressure symbol, diaphragm isolated pressure symbol, pressure transmitter, two regulators, and pressure release rupture disk. Note the use of function indicators and loop numbers.

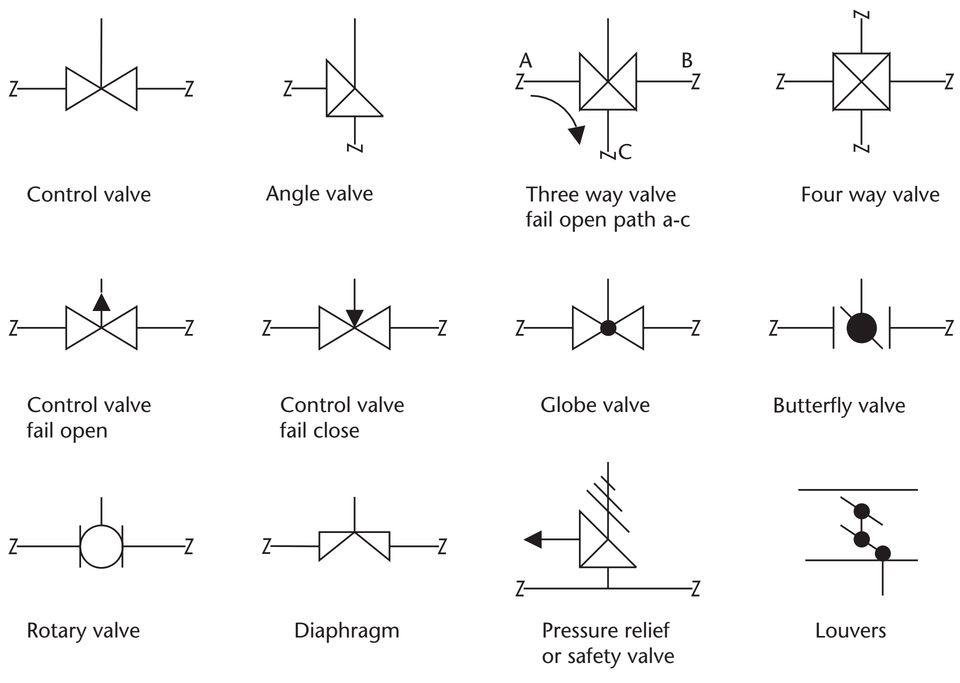


Figure 17.6 Examples of valve symbols used in P&ID.

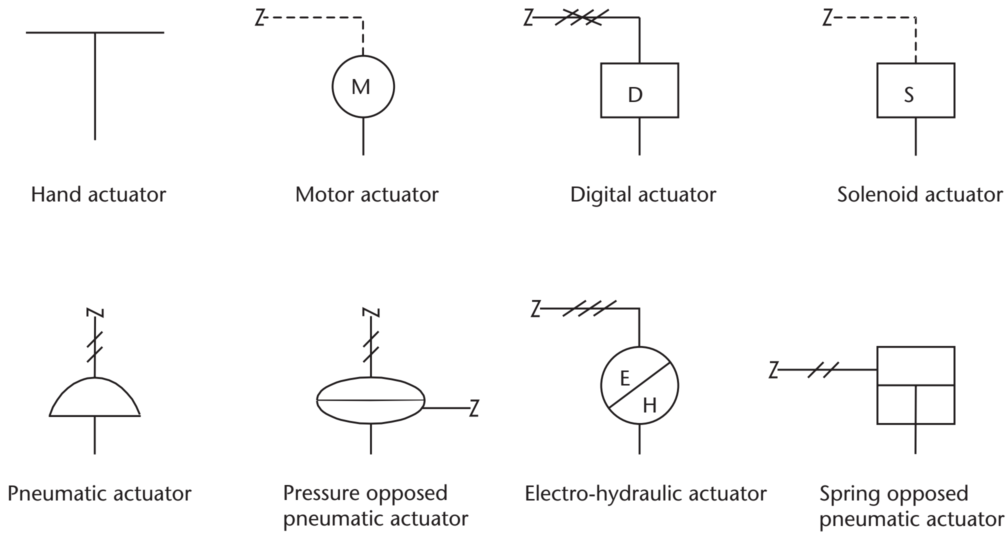


Figure 17.7 Examples of basic actuator symbols.

Flow symbol examples are given in Figure 17.10, with six flow measuring devices shown: orifice, internal flow instrument, venture tube, turbine, variable area, and magnetic instrument with transmitter. Functional letters and loop numbers are shown.

Level symbol examples are given in Figure 17.11, with three level measuring devices shown: basic two-connection level instrument with electrical output, single-connect instrument with electrical output, and float instrument. Letters are used for function and numbers for the loop.

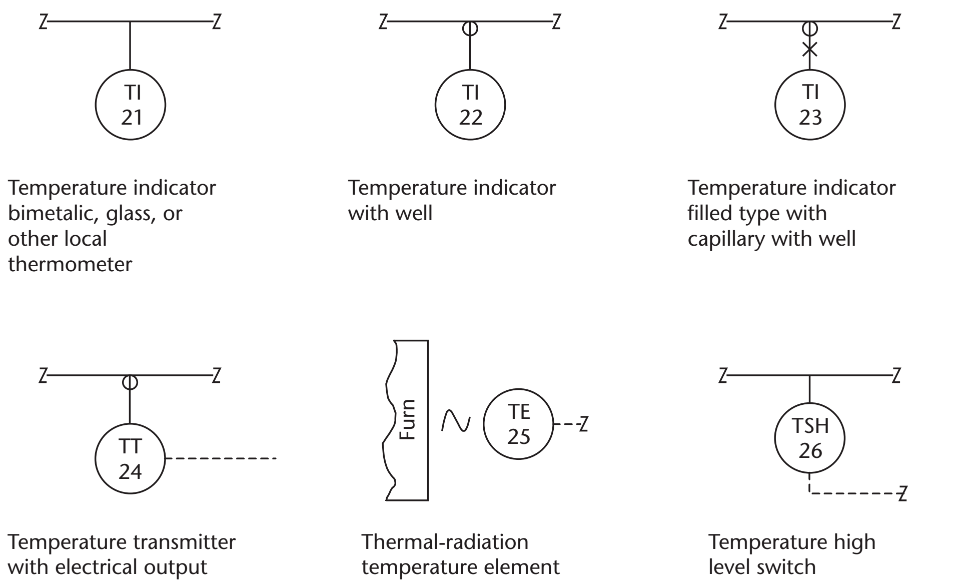


Figure 17.8 Examples of temperature symbols.

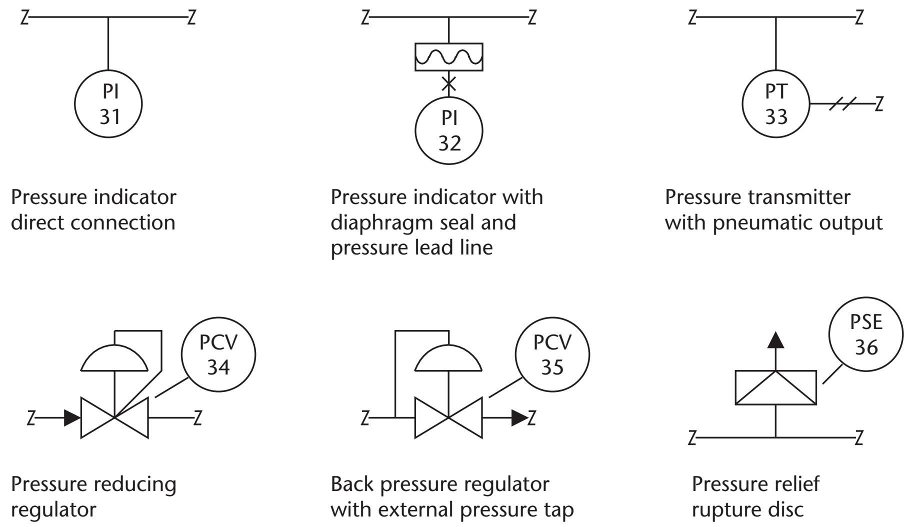


Figure 17.9 Examples of pressure symbols used in P&ID.

Other symbols are given in Figure 17.12, with six instruments shown: counting devices using a light source and detector, conveyer thickness measuring instrument, weight measurement, vibration, heat exchanger, and speed sensor. In loop 54, the QQS represents quantity, totalize, switch, or totalize or count number of switch operations.

Math functions can be performed digitally in PLCs using software. However, these functions were performed using hardware or analog devices (e.g., use of a square root to convert a pressure measurement to flow data). These functions have been symbolized. Some examples of these math symbols are shown in Figure 17.13: root, multiplication, division, derivative function, and subtraction.

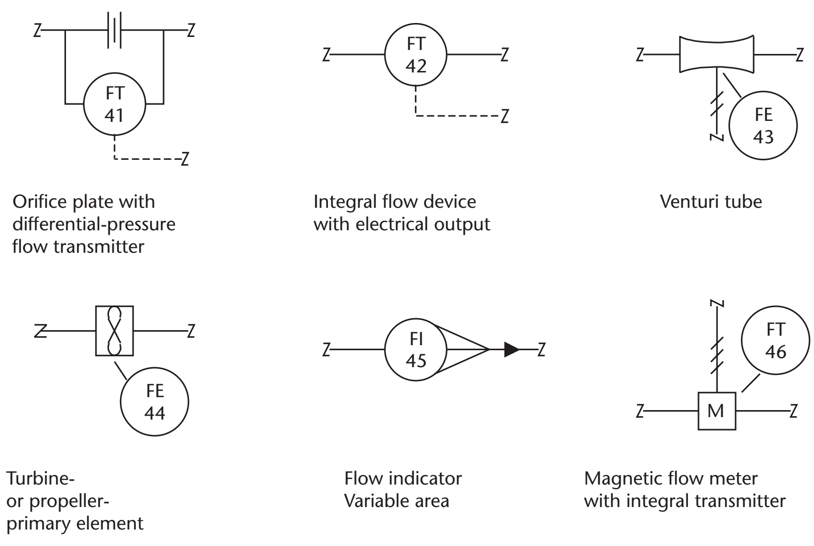


Figure 17.10 Examples of flow symbols used in P&ID.

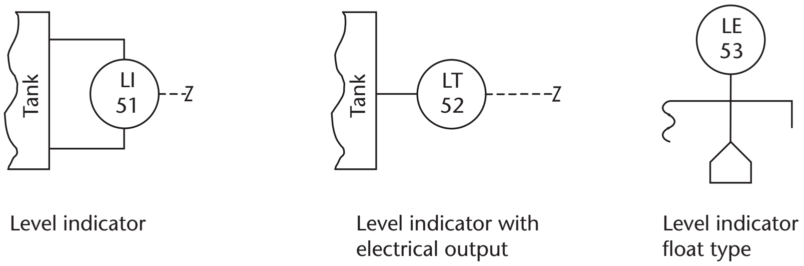


Figure 17.11 Examples of level symbols used in P&ID.

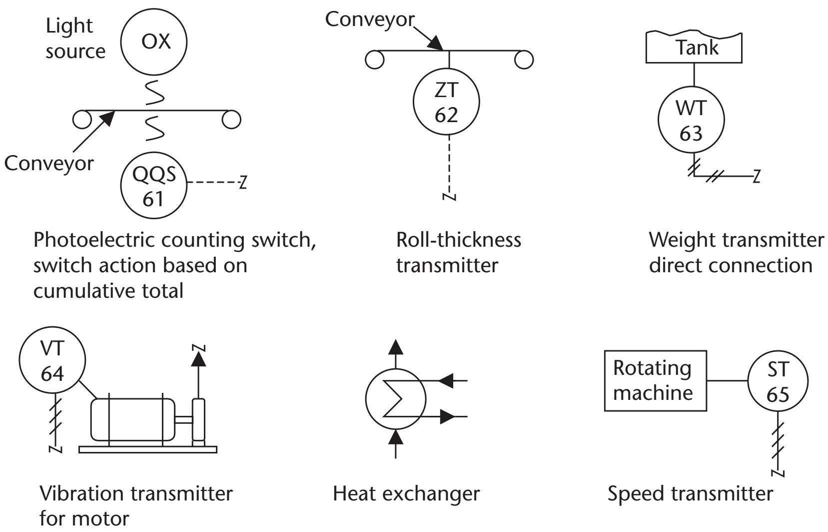


Figure 17.12 Examples of other useful P&ID symbols.

17.5 P&ID Drawings

All processing facilities will have a complete set of drawings using the standardized ISA symbols. These are the P&IDs or engineering flow diagrams that were developed for the detailed design of the processing plant. The diagrams show complete details and locations of all the required plumbing, instruments, signal lines, control loops, control systems, and equipment in the facility. The drawings normally consist of one or more main drawings depicting the facility on a function basis, along with support drawings showing details of the individual functions. In a large processing plant, these could run into many tens of drawings. Each drawing should be numbered, have a parts list, and have an area for revisions, notes, and approval signatures [8]. The process flow diagrams and plant control requirements are generated by a team from process engineering and control engineering. Process engineering normally has the responsibility for approving changes to the P&ID. These engineering drawings must be correct, current, and rigorously maintained. A few minutes taken to update a drawing can save many hours at a later date, trying to figure out a problem on equipment that has been modified, but whose drawings have not been updated. Every P&ID change must be approved and recorded. If not, time

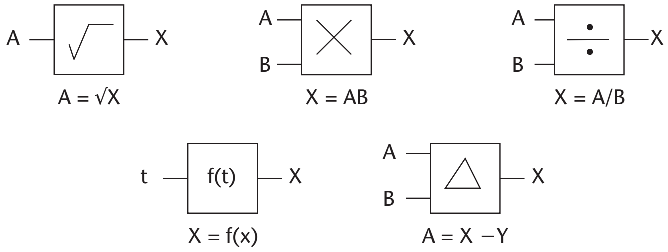


Figure 17.13 Examples of Math symbols used in P&ID.

is lost in maintenance, repair, and modifications. Using obsolete drawings can result in catastrophic errors.

P&IDs typically show the following types of information:

1. All plant equipment and vessels, showing location, capacity, pressure, liquid level operating range, usage, and so forth;
2. All interconnection signal lines, distinguishing between the types of interconnection (e.g., gas or electrical), and the operating range of the signal in the line;
3. All motors, giving voltage, power, and other relevant information;
4. All instrumentation, showing location of instrument, its major function, process control loop number, and range;
5. All control valves, giving type of control, type of valve, type of valve action, fail-save features, and flow and pressure information;
6. All safety valves and pressure regulators, giving temperature and operating ranges;
7. All sensing devices, recorders, and transmitters, with control loop numbers.

Figure 17.14 shows an example of a function block. The interconnection lines and instruments are clearly marked, and control loops are numbered.

Figure 17.15 shows the typical information that appears on each sheet of the P&ID. The information should contain a parts list with an area for notes, a sign-off sheet for revision changes, and the diagram name and original drafter, with approval signatures.

17.6 Summary

This chapter introduced the documentation for alarm and trip systems, PLCs, and P&IDs, and the standards developed for the symbols used in PID drawings. Alarm and trip systems were discussed. Alarm systems bring malfunctions to the attention of operators and maintenance personnel, whereas trip systems shutdown a system in an orderly fashion, if necessary. Such systems trip to a safe mode with loss of power, and are designed for high reliability using reliable components, redundancy, and regular testing. Alarm and trip documentation covers safety requirement specifications, a full system description, actions to be taken if the SIS shuts down, test equipment, test procedures, recordings of failures, and test results.

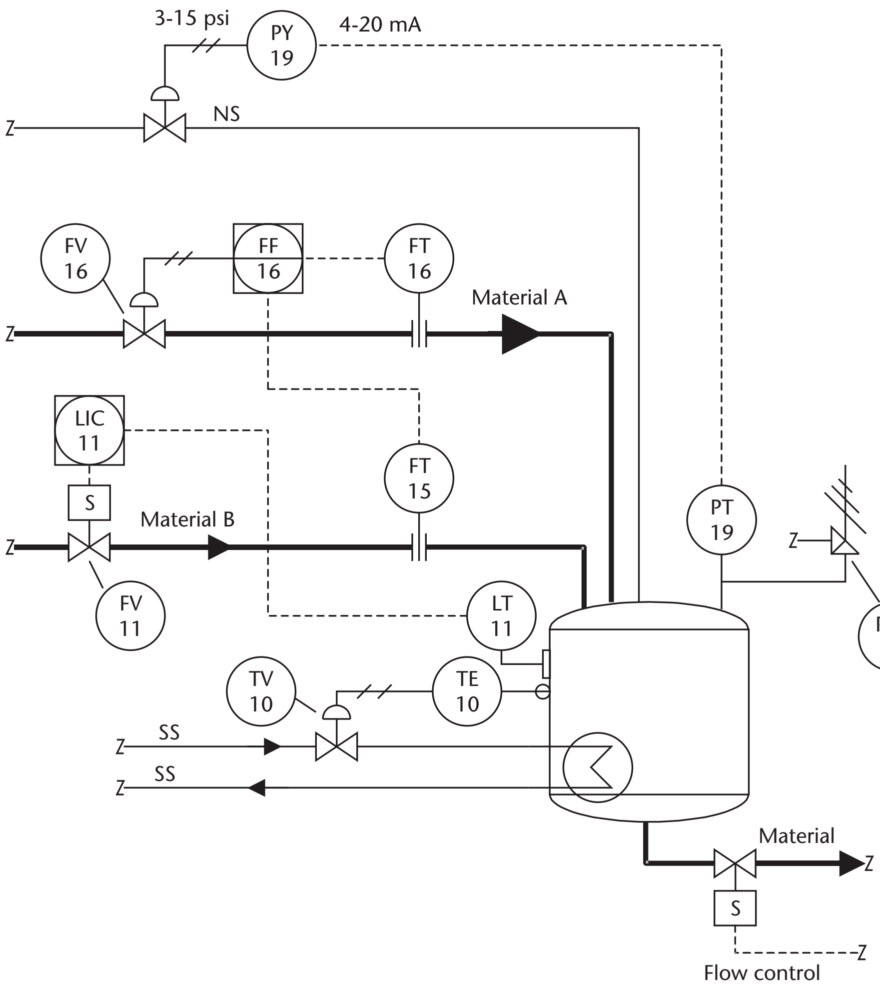


Figure 17.14 Illustration of a P&ID for a mixing station.

PLC documentation needs to be up-to-date, in order to have an accurate record of the programming used in the control of the process. Updates and changes are virtually impossible without accurate records.

The plumbing and signal lines in a process facility are shown in the P&ID. Standard symbols developed by the ISA for all of the various instruments, types of interconnections, actuator valves, and instrument functions are shown, together with an example of a facility P&ID.

References

[1] Mulley, R. M., *Control System Documentation*, Research Triangle Park, NC: ISA, 1998.

[2] Battikha, N. E., *The Condensed Handbook of Measurement and Control*, 2nd ed., ISA, 2004, pp. 241–263.

[3] Jones, C. T., *Programmable Logic Controllers*, 1st ed., Patrick-Turner Publishing Co., 1996, pp. 344–351.

Materials list			
Tag #	Manufacturer	Model	Part #
XV-213	Galant IND.	425 CV	66742-07

Notes

Revisions					
Rev #	Date	Description	By	Chk	Aprv

Industrial fuel processing			
Mixing station			
Dwn #		Sheet #	
Dwn by		Date	
Chq by		Date	
Aprv by		Date	

Figure 17.15 Typical information that appears on each sheet of the P&ID, such as drawing parts lists, notes, revisions, and sign-offs.

[4] Dunning, G., *Introduction to Programmable Logic Controllers*, 2nd ed., Delmar, 2002, pp. 387–397.

[5] Battikha, N. E., *The Condensed Handbook of Measurement and Control*, 2nd ed., ISA, 2004, pp. 9–18.

[6] Johnson, C. D., *Process Control Instrumentation Technology*, 7th ed., Prentice Hall, 2003, pp. 619–625.

[7] Stuko, A., and J. D. Faulk, *Industrial Instrumentation*, 1st ed., Delmar Publishers, 1996, pp. 305–308.

[8] Johnson, C. D., *Process Control Instrumentation Technology*, 7th ed., Prentice Hall, 2003, pp. 33–36.