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An Introduction to Boiler Control Systems

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1. INTRODUCTION

1.1 PURPOSE AND SCOPE. This course provides an introduction to criteria for the design of heating plant instrumentation. A heating plant contains one or more boilers. The plant may be an individual plant serving a single building or a compact group of buildings, or a central plant serving many buildings and facilities through an extensive distribution system. The heating plant instrumentation discussed is, in general, for a saturated steam power boiler heating plant. The typical saturated-steam power boiler heating plant discussed will operate at a design steam pressure of between 1.03 bar (15 psig) and 20.68 bar (300 psig), with a heating capacity of greater than 422 megajoule/h (400,000 Btu/h). The information provided may also be applicable to Low, Medium, and High Temperature Hot Water heating plants, but does not cover all of the requirements of those plants, such as control of water pressurization and circulation systems. The information may also be applicable to superheated-steam power plants, but does not cover the all of the requirements of those plants, such as steam extraction, reheating, steam turbine control, and cooling water controls. Instrumentation is a rapidly changing field. The options available in choosing and designing plant instrumentation are numerous. A boiler plant includes a large number of instrument items, all of which have to be specified in the procurement of a boiler plant. This course does not attempt to cover all details. Rather, its purpose is to present general guidelines for selecting and designing instrumentation for boiler plants.

1.2 DEFINITIONS.

Heating Boiler – A boiler operated at pressures not exceeding 1.03 bar (15 psig) for steam, or for Low Temperature Hot Water (LTW) at pressures not exceeding 10.98 bar (160 psig) and temperatures not exceeding 121.1 degrees C (250 degrees F) for water.

High Pressure Power Boiler – A power boiler operated at pressures exceeding 20.68 bar (300 psig) for steam, or for High Temperature Hot Water (HTW) at

pressures exceeding 10.98 bar (160 psig) and temperatures exceeding 176.6 degrees C (350 degrees F) (but not exceeding 215.5 degrees C (420 degrees F)) for water. HTW pressure must exceed saturation pressure plus 1.72 bar (25 psig) to avoid cavitation.

Power Boiler – A boiler operated at pressures more than 1.03 bar (15 psig) (but not more than 20.68 bar (300 psig)) for steam, or for Medium Temperature Hot Water (MTW) at pressures not exceeding 20.68 bar (300 psig) and temperatures not exceeding 176.6 degrees C (350 degrees F) for water. MTW pressure must exceed saturation pressure plus 1.72 bar (25 psig) to avoid cavitation.

2. TYPES OF CONTROLS

2.1 GENERAL. Control systems may be pneumatic, analog, digital, or a combination of the three. Older designs utilized pneumatic control for local control loops. Analog control systems were an industry standard for a short time before quickly being replaced by digital control systems. The present industry standard is for a distributed control system (DCS), a programmable logic controller (PLC), or a direct digital controller (DDC) to provide digital control logic based on information gathered from electronic sensor inputs and responding with electronic control of pneumatic or electric powered valves and dampers.

2.2 CONTROL SELECTION. Choose the type of control that will do the job most economically. This includes total cost over the lifetime of the equipment. Also consider compatibility with controls used in the existing plant, ease of operation and maintenance, and plant personnel familiarity and training. Consider unique situations such as a high EMF (electric magnetic field) where either EMF shielding, fiber optic data transmission, or pneumatic controls are required. Obtaining the latest technology should not be used as the main criteria in the selection of controls.

Use the following as a guideline in selecting the type of control.

- Microprocessor digital type of controls (e.g. PLC, DDC, or DCS) should be used for most new designs and in particular where a large number of control

loops are involved. Consideration should also be given to using microprocessor digital type controls to replace pneumatic control systems that have exceeded their life expectancy.

- Pneumatic control devices should be used in hazardous areas. They may also be used in the expansion of existing designs or as actuators for the final control elements in the design. In general, the pneumatic actuation of larger valves and large number of valves is more cost effective than using electric actuation.
- Analog logic devices (e.g. pneumatic receiver-controllers or electric potentiometer controllers) should not be considered for new designs.
- Consider the environmental conditions (e.g. temperature and humidity) in which the controls will be installed.

2.3 PNEUMATIC CHARACTERISTICS. Pneumatic characteristics are included primarily for the pneumatic power requirements of valves and dampers. In most cases, new designs should incorporate electronic control signals. Standard operating and supply pressures for pneumatic instruments are defined by ANSI/ISA-S7.0.01, *Quality Standard for Instrument Air*.

2.3.1 AIR SUPPLY PRESSURE. Plant and instrument air is typically available at 6.21 bar (90 psig) pressure. Instruments typically operate from a 1.38 bar (20 psig) supply. A standard pneumatic control signal is 0.21-1.03 bar (3-15 psig). Standard pressures for diaphragm actuators are 1.03 and 2.07 bar (15 and 30 psig). Standard pressure for piston operators is 6.21 bar (90 psig).

2.3.2 DESIGN CONSIDERATIONS. Piston operators are used for dampers and control valves. Size pneumatic devices operating on a nominal 6.21 bar (90 psig) air supply so that they will operate with a minimum pressure of 4.14 bar (60 psig) and will withstand a maximum pressure of 7.58 bar (110 psig).

2.3.3 SERVICE TUBING SIZE. Use 9.53 millimeter (3/8-inch) outside diameter (OD) copper or stainless steel tubing for signal transmissions of 60.96 meter (200 feet) and over. For shorter lines, use 6.35 millimeter (1/4 -inch) OD copper or stainless steel tubing.

2.3.4 CONTROL DISTANCE. Pneumatic control can be used for up to 60.96 meter (200 feet) without any special provisions and up to 91.44 meter (300 feet) if the valve has a positioner. A volume booster must be used for distances between 60.96 and 91.44 meters (200 and 300 feet) if the valve does not have a positioner. Use electronic signals for valve control in lieu of pneumatic for distances greater than 91.44 meter (300 feet).

2.3.5 INSTRUMENT AIR REGULATION. Furnish pneumatic instruments requiring an instrument air supply with individual combination filter-regulators and an output gauge. Instrument air should be supplied by an oilless compressor to help eliminate control instrument and device contamination.

2.4 ELECTRICAL CHARACTERISTICS.

2.4.1 ELECTRICAL INTERFACE. The electrical interface between instruments and a digital controller varies depending upon application. Typical analog signal ranges and levels include the following:

- mA direct current (DC) (4-20 mA, 10-50 mA, or 0-100 mA)
- volts DC (0-10 millivolts, 0 -100 millivolts, or 0-5 volts)
- temperature (thermocouple in millivolts, or RTD)
- volts alternating current (AC) (120 volts)

Transmitters and control valves commonly use a range of 4-20 mA DC. Switches and solenoid control commonly use a switched level of 120 volts AC. For signal

requirements for instrument loops refer to ANSI/ISA-S50.1, *Compatibility of Analog Signals for Electronic Industrial Process Instruments*.

2.4.2 COMMUNICATION DATA BUS. Complex boiler control systems may involve multiple digital control systems (e.g. DCS, PLC, or computer controlled smart instruments) linked together by a communication data bus. The communication data bus passes significant data between the digital control systems in a serial format. There are numerous bus architectures available. One commonly used is the RS-485 hardware bus with Modbus software protocol. Refer to TIA/EIA -485, *Characteristics of Generators & Receivers for Use in Balanced Digital Multipoint Systems* for a complete definition of the RS-485 bus. Modbus protocol is an open industry standard that was originally created and defined by the Modicon Company. Other industry communication bus standards include:

- **Fieldbus** -- A hardware and software protocol standard created and maintained by the Fieldbus Foundation. The Fieldbus Foundation is a not-for-profit organization that consists of more than 100 of the world's leading control and instrumentation suppliers and end users.
- **DeviceNet** -- A hardware and software protocol standard maintained by the Open DeviceNet Vender Association (ODVA). The ODVA is an independent organization that works closely with vender members, end users, and distributors to further establish DeviceNet as an open communications network in industry automation.
- **HART** -- An open hardware and software protocol standard that was originally created and defined by the Rosemount Company.
- **Honeywell** -- A family of proprietary hardware and software protocol standards (e.g. the D-E bus) that are licensed products of the Honeywell Company.
- **Allen-Bradley**-- A family of proprietary hardware and software protocol standards (e.g. the Data Highway + bus) that are licensed p roducts of the Allen-Bradley Company.

3. GENERAL REQUIREMENTS

3.1 GENERAL. Provide control systems in accordance with applicable codes. Design control systems so that the loss of the control medium (e.g. air, electricity, or other) will leave the controls in a fail-safe position.

3.2 CONTROL LOCATION. Locate instrument control in the control room as much as practical. Provide local control panels where they are required for equipment start-up and where constant attendance is not required.

3.3 TURNDOWN. Instruments have to cover normal operating as well as upset conditions. Several instruments might have to be provided to cover all of the ranges. It is important that all instruments be reviewed for covering all operating as well as upset conditions during the plant design stage.

3.4 INSTRUMENT RANGES. Size flow instruments based on a normal operating flow of approximately 70 percent of full scale. For all other instruments set the normal operating point at 50 percent of full scale. Use the following scales:

- Flow -- Direct reading
- Pressure -- Direct reading
- Temperature -- Direct reading
- Level -- 0-100% linear
- Analyzers -- Direct reading

Suppressed ranges for temperature and pressure may be used as long as they cover startup and upset conditions.

3.5 ALARMS AND SHUTDOWNS. Design the plant controls to avoid nuisance shutdowns. These can be caused by unnecessary items being interlocked into the shutdowns, bad design, or lack of provisions in the case of power or instrument air

failure. Also design for easy restart in the case of shutdown, especially when caused by non-process type failures such as interruption of power or instrument air.

3.5.1 DESIGN CRITERIA. Use contacts that open on abnormal conditions to alarm or shut down. For all shutdowns provide a pre-alarm that precedes the shutdown. Provide separate devices for alarms and shutdowns. Do not use the same device for an alarm or shutdown as used for control. An electrical power or instrument air failure must shut off all fuel and require operating personnel attention for a restart.

3.5.2 TESTING AND SERVICING. Include provisions for the testing and servicing of the shutdown device and related alarms without interfering with plant operation.

3.5.3 INTERLOCK AND SAFETY REQUIREMENTS. Safety controls are needed to protect against boiler explosions and implosions. Interlock and other safety requirements for boilers are given in the following American Society of Mechanical Engineers (ASME) and National Fire Protection Association (NFPA) standards. Where local or state code requirements differ from the ASME and NFPA codes, the more stringent code requirements must prevail.

- ASME CSD-1 *Controls and Safety Devices for Automatically Fired Boilers*
- NFPA-8501 *Standard for Single Burner Boiler Operation*
- NFPA-8502 *Standard for the Prevention of Furnace Explosions/Implosions in Multiple Burner Boilers*
- NFPA-8503 *Standard for Pulverized Fuel Systems*

3.5.3 1 SAFETY INTERLOCKS. Safety interlocks are required but not limited to those listed below. Additional safety interlocks may be required to fulfill applicable state and local codes for the boiler fuel type used.

- **Prepurge Interlock** – Prevents fuel from being admitted to a furnace until the furnace has been thoroughly air-purged to remove residual combustibles.

- **High Steam Pressure Interlock** – Fuel is shutoff upon abnormally high boiler steam pressure.
- **Low Airflow Interlock** – Fuel is shutoff upon loss of airflow from the combustion air fan or blower, the induced draft fan or the forced draft fan.
- **Low Fuel Supply Interlock** - Fuel is shut off upon loss of fuel supply pressure. The loss of fuel supply pressure would result in unstable flame conditions.
- **Loss of Flame Interlock** – All fuel is shut off upon loss of flame in the furnace or to an individual burner in the furnace.
- **Fan Interlock** – Stop forced draft upon loss of induced draft fan.
- **Low Water Interlock** – Shut off fuel on low water level in boiler drum.
- **High Combustibles Interlock (optional)** – Shut off fuel on highly combustible content in the flue gases.
- **Post Purge Interlock** – Continues fan operations to remove residual combustibles from the furnace prior to shutting down the fans.

3.5.3.2 SHUTDOWN VALVE RESET. Safety shutoff valves must be a manual reset type and shall not be operable until all limit controls are in the safe position. Sequence interlocks for start-up and stop must also be provided. Provide annunciator alarms to respond to any safety shutdown.

3.5.3.3 DEDICATED SAFETY SYSTEM. The safety shutdown system must be dedicated and independent of the one used for boiler control. For example, if PLC controllers are utilized, the design must contain a PLC for safety shutdown that is separate and independent of the one used for boiler control.

3-5.3.4 SPECIAL CONSIDERATIONS. Special attention should be maintained throughout the boiler design to prevent the following safety hazards.

- Equipment must be designed to protect against electrical shock from exposure to control power.
- Boiler control must assure a sufficient quantity and duration of pre-purge airflow through the boiler prior to ignition to prevent boiler explosions.

- Boiler control must assure a sufficient quantity and duration of post-purge airflow through the boiler during shutdown to prevent boiler explosions.
- Boiler control must assure a sufficient quantity of combustion air and prevent excessive fuel during boiler operation to prevent boiler explosions.
- Boiler control must limit the number of retries when igniting the boiler pilot. The industry standard is to allow three attempts at achieving pilot ignition prior to necessitating a boiler purge cycle.

3.6 HARDWARE. Hardware standards are defined by NEMA-ICS 2, *Standards for Industrial Control and System Controllers, Contractors, and Overload Relays Rated Not More Than 2000 Volts AC or 750 Volts DC.*

3.7 EQUIPMENT RATING AND CLASSIFICATION. Provide instruments that are rated for the environment. Electrical components must be designed for the anticipated temperature and humidity inside of the enclosure, fungus proofing where required, and vibration. Refer to NEMA-ICS 1.1, *Safety Guidelines for the Application, Installation, and Maintenance of Solid State Control* for additional information.

3.7.1 ENCLOSURES. Enclosures must be certified by the National Electrical Manufacturers Association (NEMA) for the environment where they will be used. NEMA 4 enclosures must be used for outdoor locations. Use NEMA 4X enclosures in corrosive environments. A space heater is required where condensation of moisture is a problem. Enclosure ratings are defined by NEMA-250, *Enclosures for Electrical Equipment (1000 Volts Maximum)*, and NEMA-ICS 6, *Enclosures for Industrial Controls and Systems.* Enclosure ratings are summarized in Table 3-1.

3-7.2 Hazardous Locations. Hazardous locations are defined by NFPA-70, *National Electric Code.* Enclosures must be rated for the location in which they will be installed. Cost savings may be achieved by relocating an enclosure from a hazardous location to a non-hazardous one. A summary of hazardous area classifications follows.

TYPE	LOCATION	PROTECTION AGAINST OR USE
1	Indoors	Dirt
2	Indoors	Same as above plus splashing water
3	Outdoors	Dust, rain
3R	Outdoors	Rain
3S	Outdoors	Dust, rain, sleet
4	Outdoors	Dust, rain, sleet, hosing down with water or indoors
4X	Outdoors	Same as above plus corrosion resistant or indoors
5	Indoors	Dirt, dust
6	Outdoors	Dust, rain, sleet, hosing down with water, or indoors temporary submersion in water
6P	Outdoors	Same as above plus corrosion resistant or indoors and prolonged submersion in water
7	Indoors	Hazardous locations. Available for Class I, Groups A, B, C, and D
8	Indoors	Same as above except arcing contacts immersed in oil
9	Indoors	Hazardous locations. Available for Class II, Groups E and G
10	Indoors	Hazardous locations. Non-ventilated. Meets Mine Safety and Health Administration requirements
11	Indoors	Dirt, splashing water, corrosion resistant Indoors Dirt, dust, splashing water, dripping non-corrosive liquids
12K	Indoors	Same as above except with knockouts. No protection at knockouts.
13	Indoors	Dirt, splashing water, oil, or coolant.

Table 3-1
Enclosure Ratings

3.7.2.1 CLASS DEFINITION

- Class I - Gases and Vapors
- Class II - Combustible Dusts
- Class III - Easily Ignitable Fibers or Flyings Classes I and II are applicable to boiler plants; class III is not.

3.7.2.2 DIVISION DEFINITION

- Division 1 - Normally hazardous
- Division 2 - Not normally hazardous

Division 1 is usually not applicable to boiler plants except for coal handling and fuel storage areas. Division 2 is often applicable.

3.7.2.3 GROUP DEFINITION

- Group A - Acetylene
- Group B - Hydrogen and other gases of equivalent hazard
- Group C - Ethylene and other gases and vapors of equivalent hazard
- Group D - Natural gas, gasoline, other gases and vapors of equivalent hazard
- Group E - Metal dusts
- Group F - Coal dust
- Group G - Agricultural and plastic dusts

Groups A, B, C, E, and G are not applicable to boiler plants. Groups D and F are applicable.

3.7.3 SPECIAL CONSIDERATIONS. When specifying enclosures note the following:

3.7.3 1 MAINTENANCE. Class I, Group D, Division 2 can be met by either providing an explosion proof enclosure or by providing a non-explosion proof enclosure and purging it with air. The non-explosion proof enclosure is less expensive (initial cost) but requires an air supply and more attention in that a constant air purge must be maintained. This long-term maintenance is expensive. Therefore, to keep maintenance to a minimum, specify the enclosure as explosion proof. Only exceptionally large equipment should be considered for a Class 1, Group D, Division 2 constant air-purge system, where the life cycle cost of the special enclosure will clearly exceed the life cycle cost of maintenance of the air purge and the effort to provide continuous assurance of safe operation.

3.7.3.2 SPECIFICATION COMPLETENESS. Include all requirements when specifying explosion-proof enclosures. For example, specify the enclosure as Class I, Group D explosion-proof, not just explosion-proof. An explosion proof enclosure is not necessarily dust tight or suited for an outdoor location. Therefore, both the explosionproof requirement and the weather or dust tight requirement must be specified to define the required enclosure.

3.8 POWER SUPPLIES. Furnish a power supply that provides clean power to the instruments. That is one that is free of disturbances and nuisance shutdowns. The manufacturer should be able to provide equipment specifications and recommend safeguards against severe power disturbances. Refer to NEMA ICS 1.1, *Safety Guidelines for the Application, Installation, and Maintenance of Solid State Control* for additional information. Include the following:

- Provide power supplies that enable the controls, including combustion safeguard systems and other control devices, to operate through an electric power interruption of 20 milliseconds without affecting the operation of the plant.
- Provide an uninterruptible power supply (UPS) system to keep the electronic instrumentation on line in case of a power interruption. The required time depends on the plant and instrumentation, but 30 minutes is often

specified. The UPS system must provide a safe plant shutdown in case of a longer power outage. Small UPSs located inside of control panels should be equipped with ventilation fans to remove unwanted heat.

- Connect all trip circuits to the UPS system.

UPS system standards are defined by NEMA-PE 1, *Uninterruptible Power Systems*.

3.9 INSTRUMENT AIR. Provide clean, dry instrument air as defined by ANSI/ISA-S7.0.01, *Quality Standard for Instrument Air*. Test that the instrument air control circuits are free of leaks per the same standard.

3.10 WIRING AND CONDUITS. Wiring must conform to NFPA 70, *National Electric Code*. Run signal, thermocouple, and power wiring in separate conduits. Wiring for alarm, shutdown, and interlock circuits of the same voltage as the power wiring may be run in the same conduit as the power wiring. Cable and thermocouple wire must conform to NEMA-WC55, *Instrumentation Cables and Thermocouple Wire*. Provide high point vents and low point drains for all conduits. Recommended practices for control centers are defined by ISA-RP60.8, *Electrical Guide for Control Centers*.

3.11 INSTRUMENT TUBING AND PIPING. Do not bring lines containing process fluids such as water and steam into the control room, control panels or control boards. Keep pneumatic signals in and out of the control room to a minimum. Use electronic signals instead. Avoid pneumatic signals in controlled pressure sensitive areas. Certain pneumatic local instruments "bleed" air to their environment. Use recommended practices for installation of piping and tubing in control centers as defined by ISA-RP60.9, *Piping for Control Centers*.

3.12 IDENTIFICATION. Identify all instruments and controls with a stainless steel metal tag permanently mounted on the instrument. Include the instrument number and service in the identification.

3.12.1 NAMEPLATES. Provide nameplates for all panel instruments on both the front and the rear of the panel. Minimum front panel information must include instrument number, service, scale factors, and units. The rear of panel only requires the instrument number. Use recommended practices on panel nameplates as defined by ISA-RP60.6, *Nameplates, Labels and Tags for Control Centers*.

3.12.2 TERMINATIONS. Identify each electrical and tubing terminal with the instrument item number to which it connects. Tag and number all terminals and the ends of all wires. Identify all electrical conduits as to type of wiring (power, thermocouple, DC signals, or other).

3.12.3 INSTRUMENTS. Identify all local instruments such as valves and switches with the item number of the instrument with which it operates.

3.13 INSTRUMENT SPECIFICATION FORMS. Use instrument specification forms when ordering instruments. Forms and specification checklists for a number of instruments are provided in ISA-S20, *Specification Forms for Process Measurement and Control Instruments, Primary Elements and Control Valves*. Obtain complete information on the instrument from the manufacturer before ordering. Sources of information include manufacturer catalogs, data sheets and other literature. Provide all data required for ordering the instrument. Specify all items including optional selections and deviations from the manufacturers standard.

3.14 DRAWINGS. Use standard symbols. For standard symbols, presentation, and terminology refer to the following industry standards.

- ANSI/ISA-S5.1, *Instrumentation Symbols and Identification*
- ISA-S5.3, *Graphic Symbols for Distributed Control/Shared Display Instrumentation, Logic and Computer Systems*
- ANSI/ISA-S5.4, *Instrument Loop Diagrams*

Provide control schematic diagrams, logic diagrams, and instrument loop diagrams.

3.15 CODE REQUIREMENTS. Where local or state code requirements differ from the ASME, ANSI, and NFPA codes, the more stringent code requirements shall prevail.

The following codes apply.

- ASME, *Boiler and Pressure Vessel Code, Section I, Rules for the Construction of Power Boilers, and Section IV, Rules for the Construction of Heating Boilers*
- ASME B16.5, *Pipe Flanges and Flanged Fittings*
- ASME B31.1, *ASME Code for Pressure Piping Power Piping*
- NFPA-70, National Electric Code
- NFPA-8501, *Standard for Single Burner Boiler Operation*
- NFPA-8502, *Standard for the Prevention of Furnace Explosions/Implosions in Multiple Burner Boilers*
- NFPA-8503, *Standard for Pulverized Fuel System*
- State, Local, and Utility Boiler Codes

3.16 STANDARDIZATION. Standardize all instrumentation in the boiler plant. Specify that all like instruments, such as all control valves, be provided from the same manufacturer. Avoid having two control valves in identical service from two different manufacturers or from the same manufacturer but of two different model numbers.

3.16.1 MULTIPLE MANUFACTURERS. Multiple manufacturers are acceptable for different types of instruments. Instruments of the same type, however, must be standardized. For example, controllers can be obtained from one manufacturer, control valves from a second manufacturer, and pressure gauges from a third manufacturer.

3.16.2 PACKAGED EQUIPMENT. Packaged equipment, which is often furnished with instrumentation included, does not always lead to standardization. Buying the package manufacturers standard, however, might result in considerable cost savings. Even with

packaged equipment, however, the instruments should conform to the plant standards whenever practical.

3.16.3 SPECIAL CONSIDERATIONS. Also standardize the following for the boiler plant.

3.16.3.1 SIGNAL AMPLITUDE. Use standard signals. These are 4 -20 mA DC for transmitters and control valves, 120 volts AC for switches, and 0.21-1.03 bar (3-15 psig) for pneumatic signals.

3.16.3.2 CONNECTIONS. Use standard types of connections and connection sizes. Avoid non-standard connections.

3.16.3.3 RECORDERS. Standardize on recording charts, recorder pens, lamps and similar items. Note that recorders from two different manufacturers most likely will require different chart paper and pens.

3.17 ENVIRONMENTAL CONCERNS. The Environmental Protection Agency (EPA) regulates the maximum allowed emissions from all external combustion sources including boilers. EPA-AP-42, *The Compilation of Air Pollutant Emission Factors* contains information associated with the types and quality of emissions and methods used to control them. Allowable emission limits varies by local and state regulations. Consult the Code of Federal Regulations, Title 40, *Protection of Environment* for regulated limitations and monitoring requirements. The following are the criteria pollutants associated with the burning of fuel for boilers.

- Particulate matter
- Sulfur Oxide
- Nitrogen Oxide
- Carbon Monoxide
- Organic Compounds

Some common methods of minimizing or reducing these emissions include:

- Flue Gas Recirculation
- Low No_x Burners
- Wet Scrubber
- Cyclone Separators
- Selective and Nonselective Catalytic Reduction (SCR and NSCR)
- Electrostatic Precipitator (ESP)
- Baghouse

3.18 SAFETY PLAN AND HAZOP STUDY. Boiler controls must be included in the Safety Plan and Hazardous Operations (HAZOP) Study submitted by the boiler designer.

4. CONTROL LOOPS

4.1 GENERAL. Provide controls in accordance with applicable codes. The codes take precedence over the control requirements shown in this COURSE. A typical control loop is shown in Figure 4-1.

4.2 CONTROL LOOP TYPES. A single control loop includes a controlled variable sensor, controlled variable transmitter, controller, automatic-manual control station, and final control element. Control loops used for boilers may be of the pressure, temperature, liquid level type, or flow type.

4.2.1 PRESSURE. Pressure control loops may be used for the control of boiler pressure or fuel oil pressure. For the control of boiler pressure, the final control element regulates fuel flow to the boiler in response to boiler drum steam pressure. For the control of fuel oil pressure, the final control element is usually a pressure reducing control valve that regulates in response to downstream pressure. A typical pressure control loop is shown in Figure 4-2.

4.2.2 TEMPERATURE. Temperature control loops may be used for the control of steam temperature from boilers or fuel oil temperature from fuel oil heaters. A typical temperature control loop is shown in Figure 4-3.

4.2.3 LEVEL. Liquid level control loops may be used for the control of boiler drum water level. A typical level control loop is shown in Figure 4-4.

4.2.4 FLOW. Flow control loops may be used for the control of fuel flow into the boiler burners, burner draft airflow, feed water into a boiler, or steam flow out of a boiler.

A typical flow control loop is shown in Figure 4-5.

4.3 AIR TO FUEL-RATIO. Furnish controls to automatically provide the proper fuel to air ratio over the entire boiler operating range from maximum turndown to Maximum Continuous Rating (MCR). Provide cross-limited (lead-lag) controls between air and fuel to increase airflow before increasing fuel flow and to decrease fuel flow before decreasing airflow. Consider full metering controls, which measure directly both airflow and fuel flow, for all boilers with capacities greater than 5.28 gigajoule/h (5,000,000 Btu/h). Consider an oxygen analyzer, for trim only, for all boilers with capacities greater than 25.32 gigajoule/h (24,000,000 Btu/h). Consider CO trim for all boilers with capacities greater than 52.75 gigajoule/h (50,000,000 Btu/h), especially coal fired boilers. Evaluate the energy savings of these measures and provide all those that are life cycle cost effective. A typical cross-limited (lead-lag) boiler control system with oxygen trim for a single fuel is shown in Figure 4-6.

4.3.1 CONTROL CONFIGURATION. Configure the controls so that the air to fuel ratio does not have to be manually reset or reprogrammed when switching from one fuel to another or from one combination of fuels to another. Provide an 8-point minimum fuel to air characterization curve for each fuel or combination of fuels.

Provide controls so that the air to fuel ratio is automatically adjusted to the proper proportions for all of the following:

- Load change (between minimum firing and MCR)
- Fuel change (either change in fuels or same fuel but different specifications)
- Fuel ratio change (more than one fuel firing)

4.3.2 FUEL CHANGEOVER. Accomplish the switch over from one fuel to another without shutting down the boiler. Configure the controls so that the changeover from one fuel to another can be made by either a selector switch, pushbuttons, or by entering commands on a keyboard.

4.3.3 SIMULTANEOUS FUEL FIRING. Provide automatic controls for maintaining the proper fuel ratio and fuel to air ratio to compensate for load changes when firing several fuels at the same time. Do not allow multiple attempts to switch fuels without a full postpurge and pre-purge after each unsuccessful fuel switch attempt.

4.3.4 ALARMS. Furnish alarms to announce the approach of unsafe conditions. Provide shutdowns to shut the equipment down under unsafe conditions.

4.4 BOILER DRUM LEVEL. Provide controls to always maintain the boiler drum level within the boiler manufacturer's specifications under all operating conditions. Three types of control systems used in boiler plants are single element, two element and three element. These are shown in Figures 4 -7, 4-8 and 4-9 respectively.

4.4.1 SINGLE ELEMENT CONTROL. A single element control system utilizes just a level transmitter to maintain control of the boiler drum water level. Use a single element control system only for boilers operating at steady loads.

4.4.2 TWO ELEMENT CONTROL. A two element control system utilizes a level transmitter and the amount of steam flow from the boiler to maintain control of the

boiler drum water level. A two element control system provides some compensation for variable loads. It does not adequately correct for the expansion of water within a boiler due to the decreased boiler pressure that occurs when a large amount of steam is required or the contraction of heated water in a boiler due to the addition of cold feedwater. Do not use two element controls.

4.4.3 THREE ELEMENT CONTROL. A three element control system utilizes a level transmitter, the amount of steam flow from the boiler and the amount of water into the boiler to maintain control of the boiler drum water level. Note that although not shown, the steam flow from the boiler is usually compensated for pressure and temperature. A three element control system corrects the problems associated with a two element control system and provides the best method of compensating for variable loads.

4.5 MULTIPLE BOILERS. The output of multiple boilers is accomplished by routing the steam from each individual boiler into a common plant output header. The pressure measured at this plant output header will be feed back into each individual boiler control loop. Control is maintained by the plant master cascading the output of the boiler masters to achieve the desired steam output. A typical multiple boiler control loop is shown in Figure 4-10. Dual Pressure Indicating Transmitters (PIT) and Pressure Indicating Controllers (PIC) are shown feeding their output signals into a High Select Relay. This redundancy may be provided for plants with three or more boilers to allow continued plant operations during maintenance or failure of one PIT or PIC.

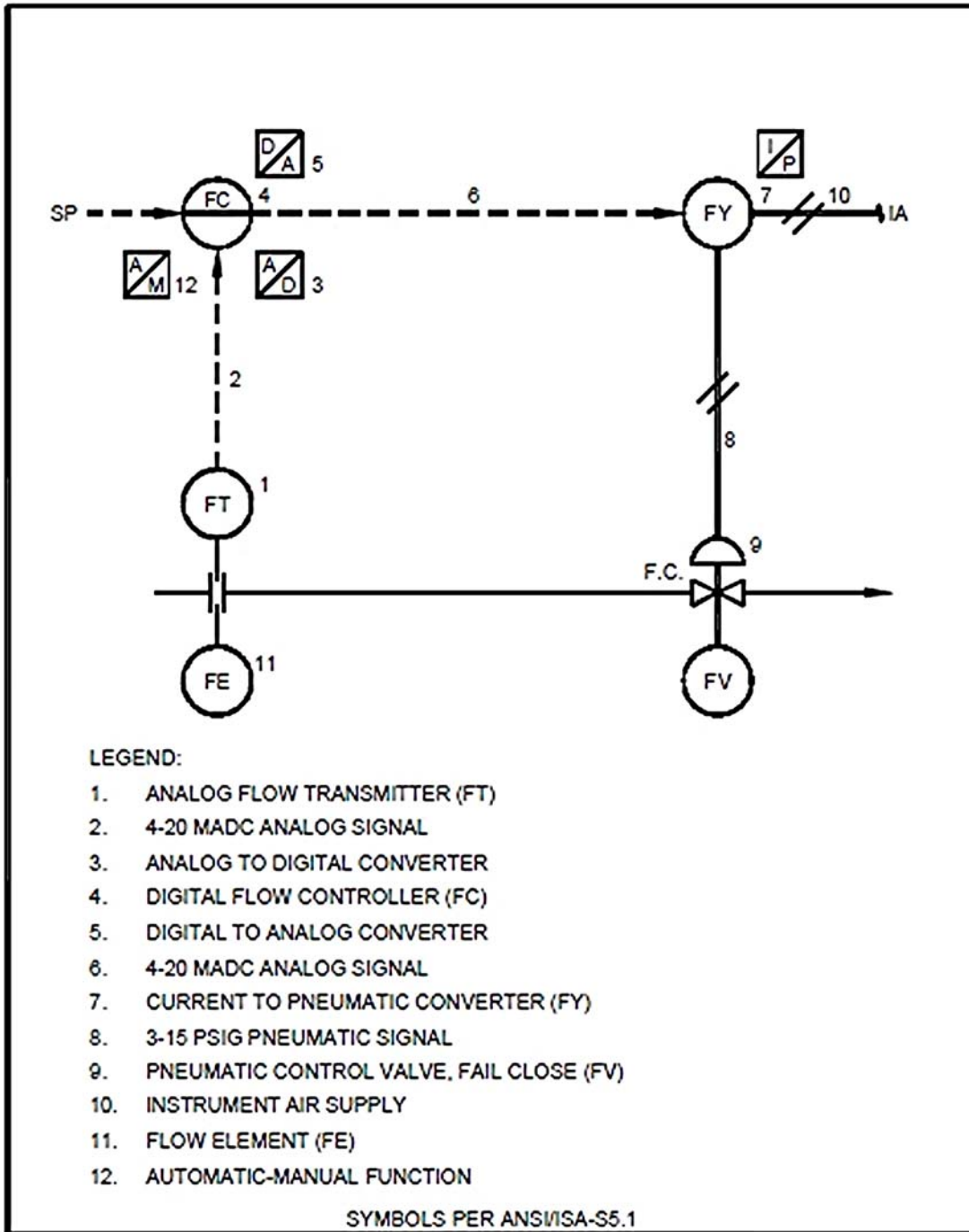


Figure 4-1
 Typical Control Loop
 (Symbols per ANSI/ISA -S5.1)

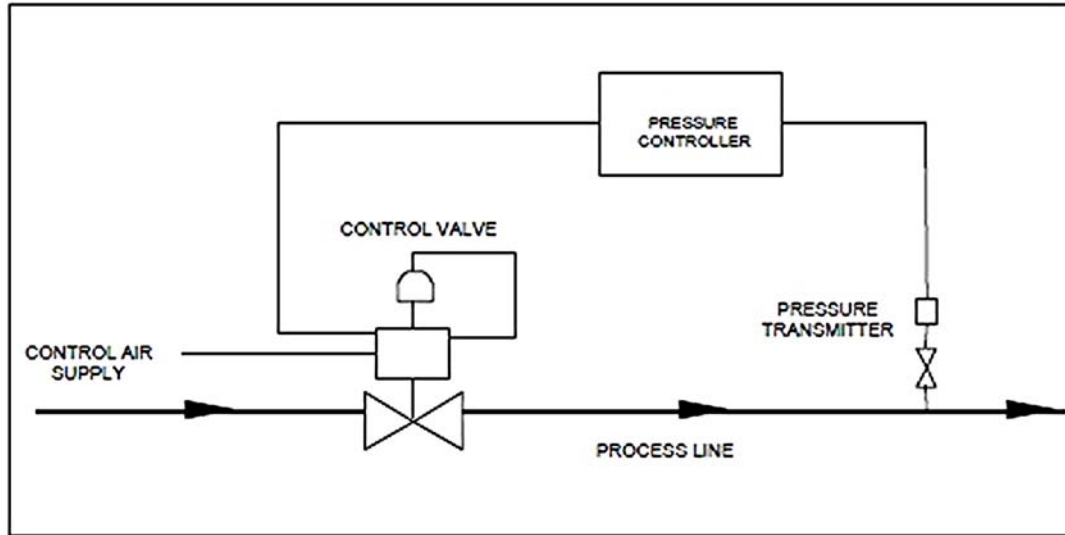


Figure 4-2
Typical Pressure Control Loop

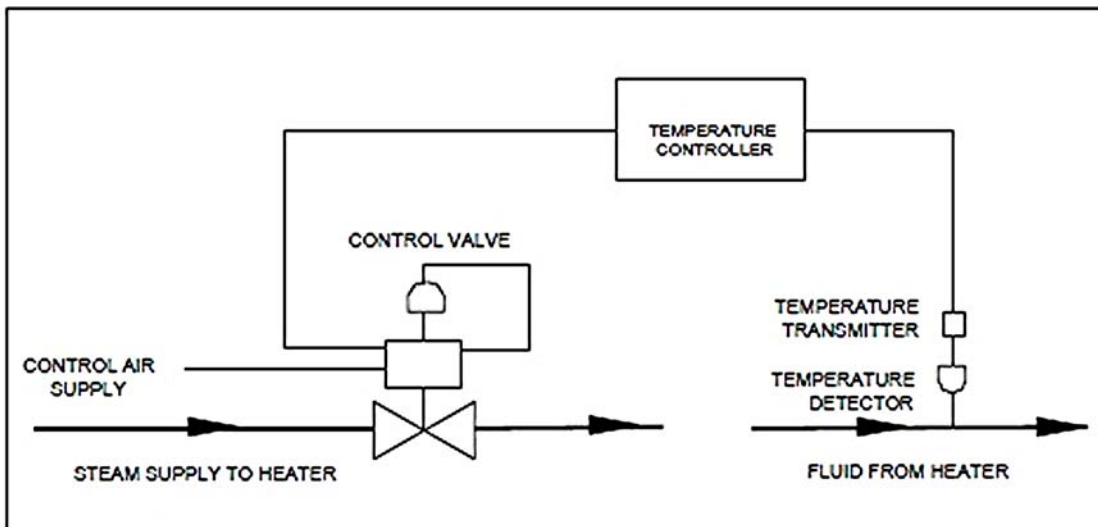


Figure 4-3
Typical Temperature Control Loop

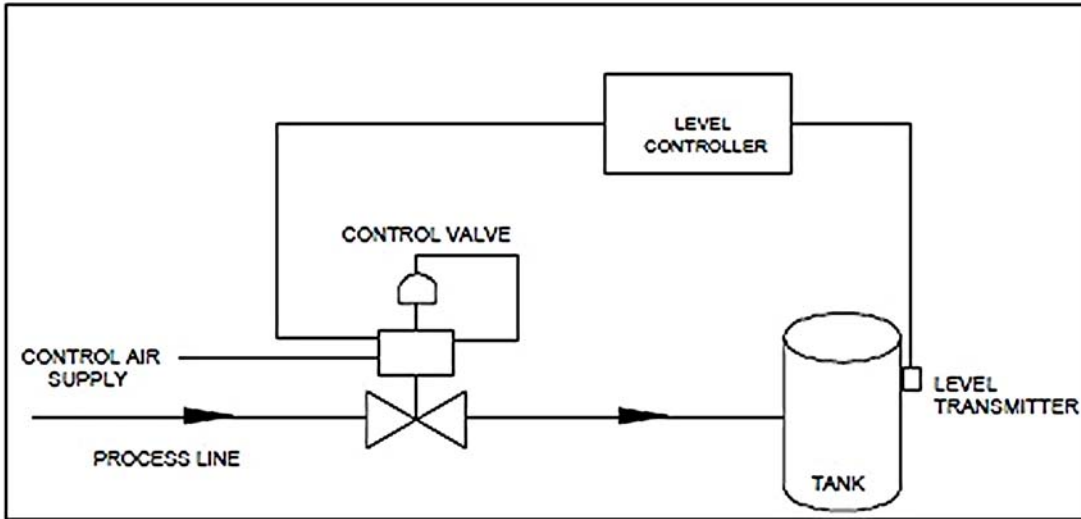


Figure 4-4
Typical Level Control Loop

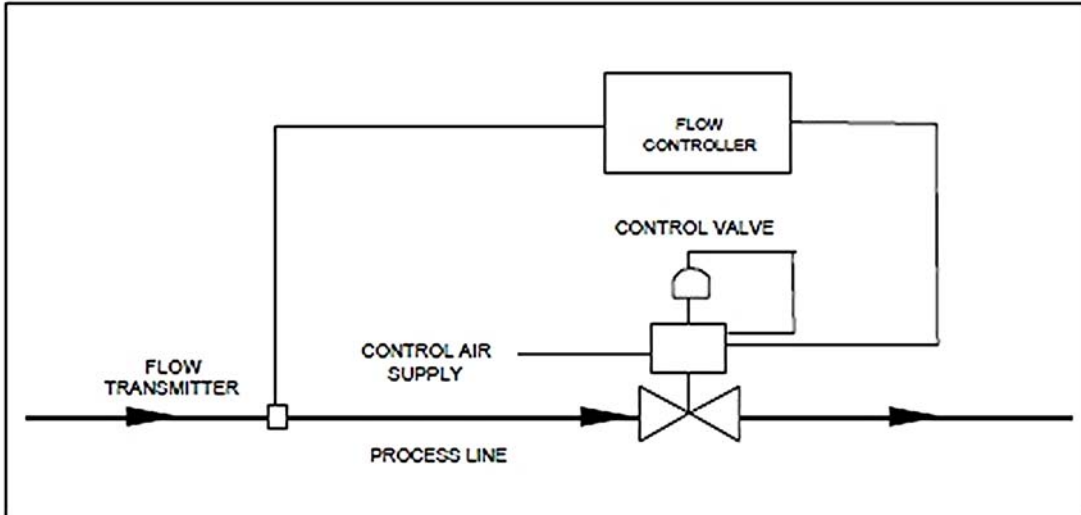


Figure 4-5
Typical Flow Control Loop

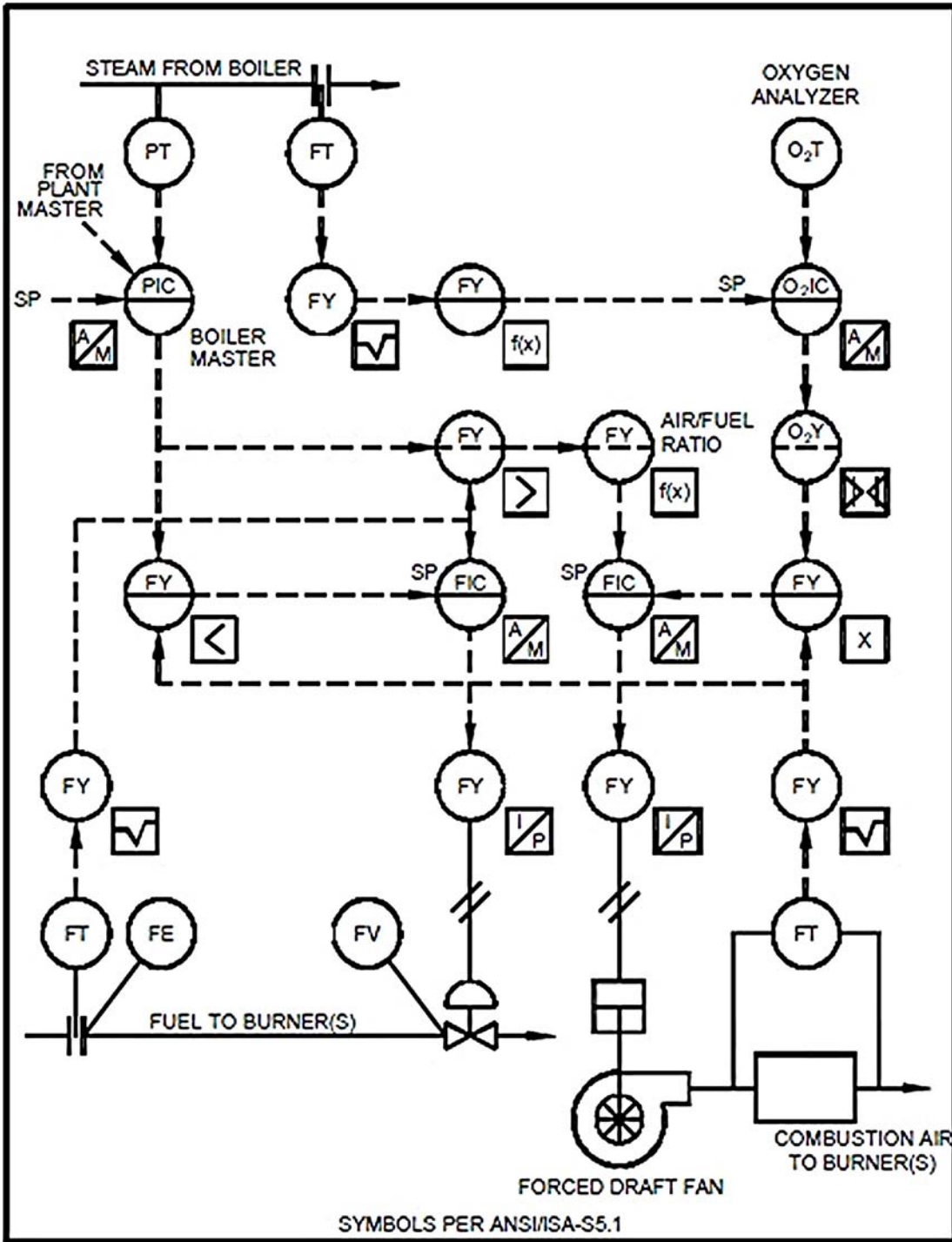


Figure 4-6

Typical Cross-Limited (Lead-Lag) Boiler Control System for a Single Fuel Using Full Metering with Oxygen Trim

(Symbols per ANSI/ISA-S5.1)

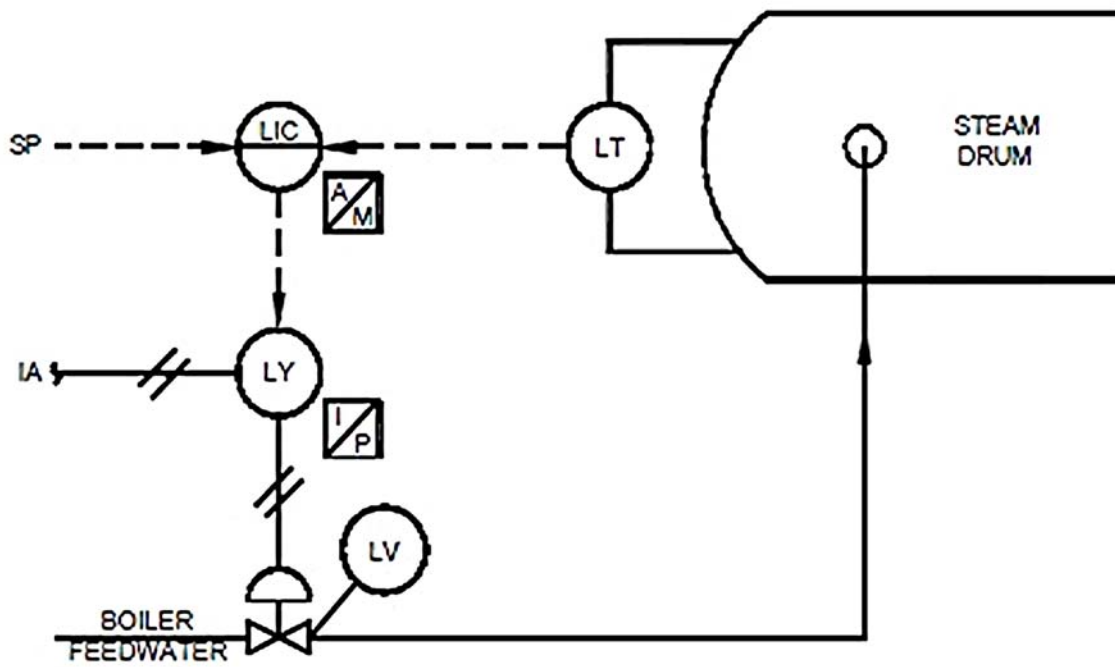


Figure 4-7
Single Element Drum Level Control System

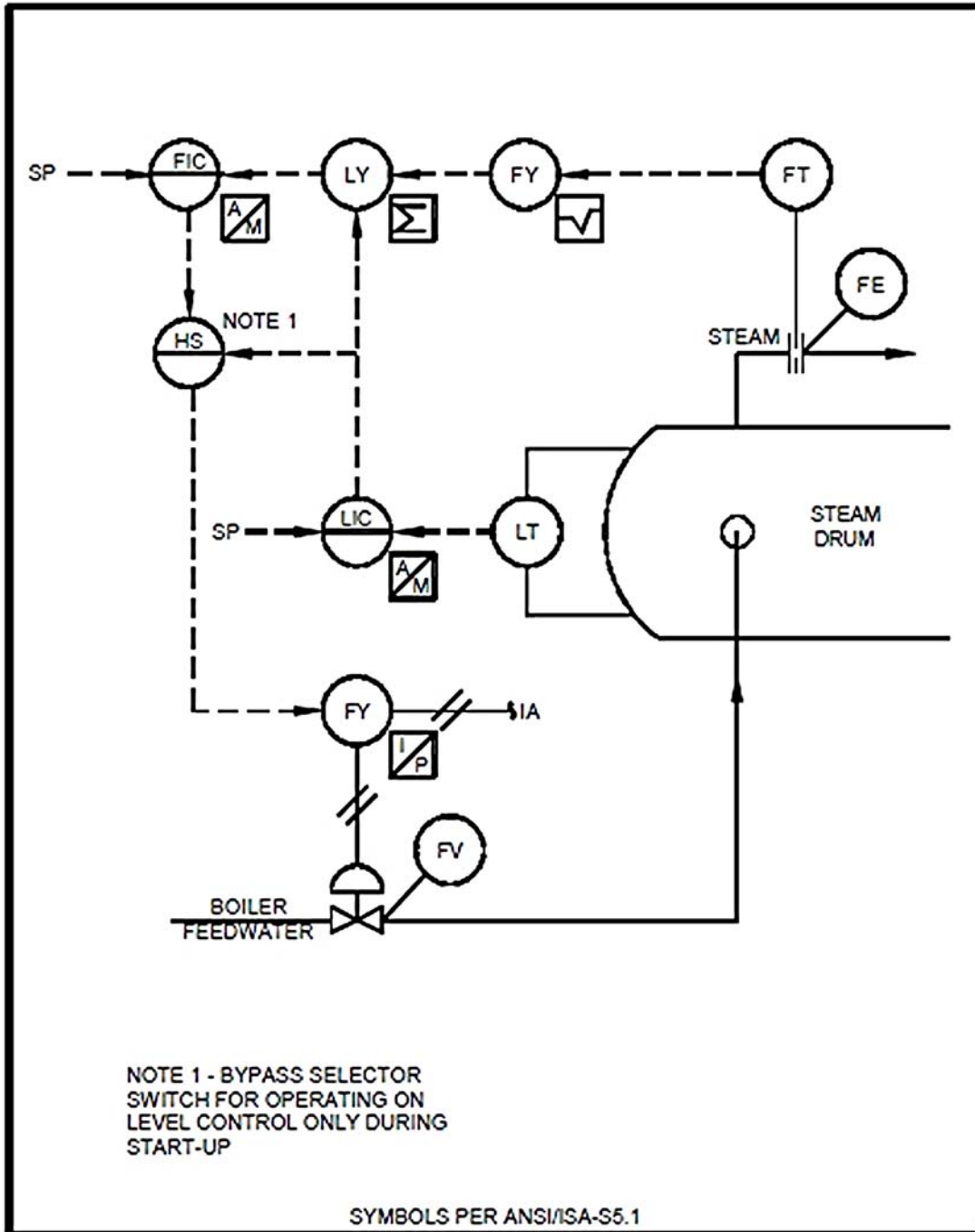


Figure 4-8
Two Element Drum Level Control System
(Symbols per ANSI/ISA-S5.1)

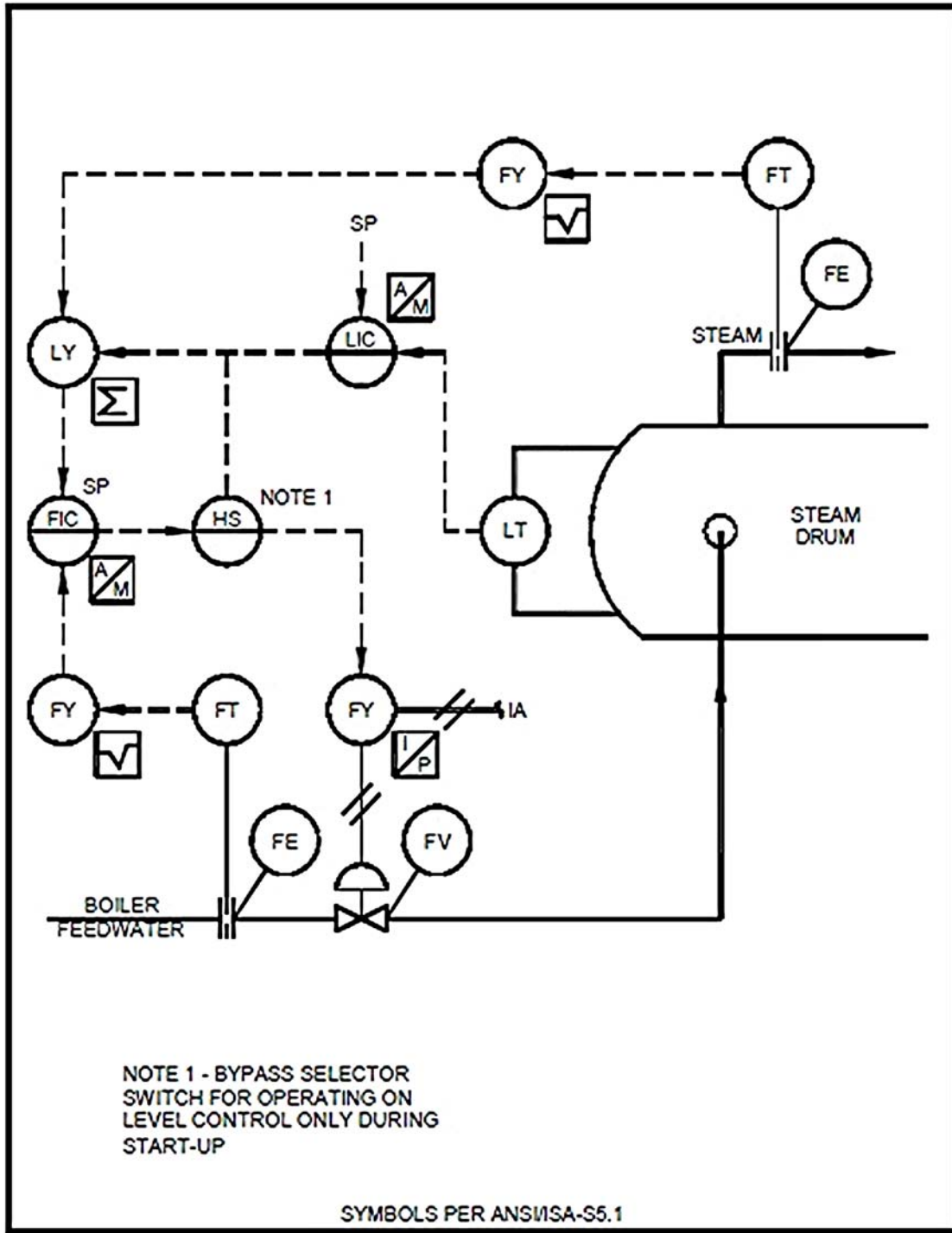


Figure 4-9
Three Element Drum Level Control System
(Symbols per ANSI/ISA-S5.1)

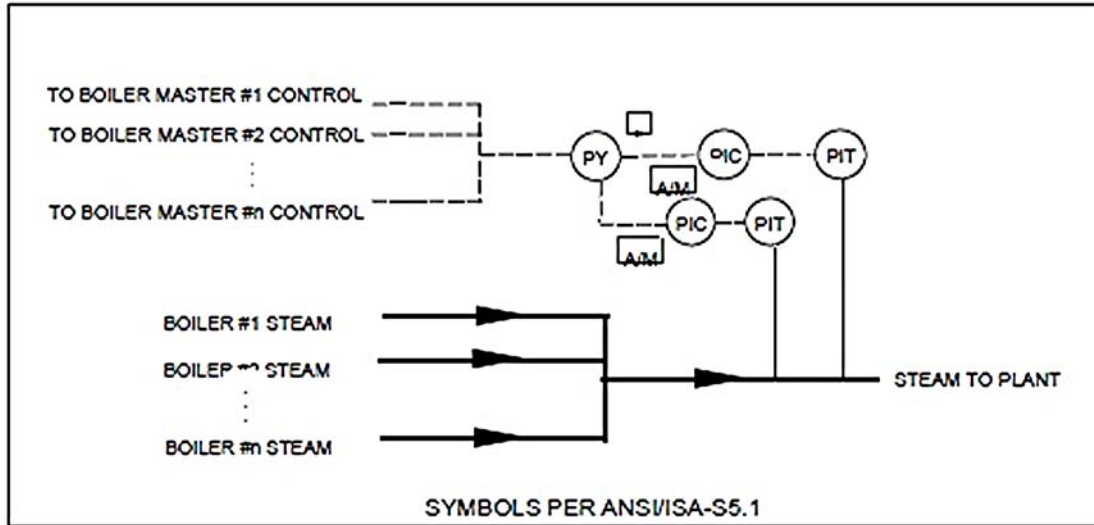


Figure 4-10
Multiple Boiler Control Loop – Plant Master
(Symbols per ANSI/ISA-S5.1)

4. APPENDIX: REFERENCES

1. U.S. GOVERNMENT PRINTING OFFICE

Superintendent of Documents
U.S. Government Printing Office
P.O. Box 371954
Pittsburgh, PA 15250-7954

Environmental Protection Agency, AP-42,
The Compilation of Air Pollutant Emission
Factors

Code of Federal Regulations, Title 40,
Protection of the Environment

2. AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)

American Society for Testing and
Materials
1916 Race Street
Philadelphia, PA 19103

ASME Boiler and Pressure Vessel Code,
Section I, Rules for the Construction of
Power Boilers and Section IV, Rules for
the Construction of Heating Plants

ASME B16.5, Pipe Flanges and Flanged
Fittings

ASME B16.36, Orifice Flanges

ASME B31.1, ASME Code for Pressure
Piping, Power Piping

ASME B40.100, Pressure Gauges and
Gauge Attachments

ASME CSD-1, Controls and Safety
Devices for Automatically Fired Boilers

3. INSTRUMENT SOCIETY OF AMERICA (ISA)

Instrument Society of America
P.O. Box 12277
Research Triangle Park, NC 27709

ANSI/ISA-S5.1, Instrumentation Symbols and Identification

ISA-S5.3, Graphic Symbols for Distributed Control/Shared Display Instrumentation, Logic and Computer Systems

ANSI/ISA-S5.4, Instrument Loop Diagrams

ANSI/ISA-S7.0.01, Quality Standard for Instrument Air

ISA-RP16.1,2,3, Terminology, Dimensions and Safety Practices for Indicating Variable Area Meters (Rotameters, Glass Tube, Metal Tube, Extension Type Glass Tube)

ISA-RP16.4, Nomenclature and Terminology for Extension Type Variable Area Meters (Rotameters)

ISA-RP16.5, Installation, Operation, Maintenance Instructions for Glass Tube Variable Area Meters (Rotameters)

ANSI/ISA-S18.1, Annunciator Sequences and Specifications

ISA-S20, Specification Forms for Process Measurement and Control Instruments, Primary Elements and Control Valves

ISA-RP31.1, Specification, Installation, and Calibration of Turbine Flowmeters

ANSI/ISA-S50.1, Compatibility of Analog Signals for Electronic Industrial Process Instruments

ISA-RP55.1, Hardware Testing of Digital Process Computers

ISA-RP60.3, Human Engineering for Control Centers

ISA-RP60.6, Nameplates, Labels and Tags for Control Centers

ISA-RP60.8, Electrical Guide for Control Centers

ISA-RP60.9, Piping Guide for Control Centers

ISA-S75.11, Inherent Flow Characteristic and Rangeability of Control Valves

ANSI/MC98.1, Temperature Measurement Thermocouples

4. NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION (NEMA)

National Electrical Manufacturers Association
2101 L Street, N.W
Washington, DC 20037

NEMA 250, Enclosures for Electrical Equipment (1000 Volts Maximum)

ICS 1.1, Safety Guidelines for the Application, Installation, and Maintenance of Solid State Control

ICS 2, Standards for Industrial Control and System Controllers, Contactors, and Overload Relays Rated Not More Than 2000 volts AC or 750 volts DC

ICS 8, Enclosures for Industrial Controls and Systems

PE 1, Uninterruptible Power Systems

WC 55, Instrumentation Cables and Thermocouple Wire

5. NATIONAL FIRE PROTECTION ASSOCIATION (NFPA)

National Fire Protection Association
Batterymarch Park
Quincy, MA 02269

NFPA-70, National Electrical Code

NFPA-8501, Standard for Single Burner
Boiler Operation

NFPA-8502, Standard for the Prevention
of Furnace Explosions/Implosions in
Multiple Burner Boilers

NFPA-8503, Standard for Pulverized Fuel
Systems

6. ELECTRONIC INDUSTRIES ALLIANCE (EIA)

Global Engineering Documents
15 Inverness Way East
Englewood, CO 80112

TIA/EIA-485, Characteristics of
Generators & Receivers for Use in
Balanced Digital Multipoint Systems