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# Introduction to Instruments and Devices for Boiler Control Systems

Course No: E04-022

Credit: 4 PDH

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# An Introduction to Instruments and Devices for Boiler Control Systems



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The Figures, Tables and Symbols in this document are in some cases a little difficult to read, but they are the best available. **DO NOT PURCHASE THIS COURSE IF THE FIGURES, TABLES AND SYMBOLS ARE NOT ACCEPTABLE TO YOU.**

## 1. INTRODUCTION

**1.1 PURPOSE AND SCOPE.** This course provides an introduction to instruments and devices for steam and hot water boilers and their control systems. This is not a design manual; it is an introduction to the technology, instruments and devices for boiler operation and control only.

## **2. PANEL INSTRUMENTS**

**2.1 GENERAL.** This section covers instruments usually located on panels.

**2.1.1 TYPES OF CONTROL PANELS.** Boiler plant panels include panels for boiler control, combustion safeguards, and the control of special equipment such as electrostatic precipitators.

**2.1.2 PANEL LOCATION.** Panels may be located either in a control room or locally. Both types of panels are covered in this section and are discussed below.

**2.1.2.1 CONTROL ROOM PANELS.** The control room is the preferred location for panels. Locate as much of the plant instrumentation in the control room as practical. The central location of panels will simplify both operation and maintenance. The control room is also usually cleaner, has better temperature and humidity control, and has less vibration than other plant locations. These conditions necessitate less stringent instrument enclosure requirements and the instruments will last longer.

**2.1.2.2 LOCAL PANELS.** Local panels are located in the vicinity of the equipment that they control. This can be either indoors or outdoors. The atmosphere can vary from clean to dusty or corrosive. Local panels should be minimized since more time and effort is required to access and monitor a large number of local panels than a centrally located one. Restrict local panels to instrumentation that does not require continuous attention and is used extensively for start-up and shutdown of the local equipment. Locate the panel as close to the equipment as practical. Do not locate local panels in front of any access panels or inspection plates where an operator may interfere with boiler inspections or where an explosion may injure an operator. Provide a panel designed for the environment. Furnish the panel with a rain hood for outdoor locations. Avoid local wall mounted panels which are mounted flush with the wall. These panels may allow wall condensate to enter. The panel should be a self-supporting box type if it is not mounted integrally with the local equipment.

**2.1.3 LAYOUT.** Good panel layout requires experienced personnel in panel design and user drawing review. The layout depends on the type of instrumentation to be placed on the panel and how it will be operated. For best results both the user and the designer should agree on instrumentation arrangement on the various panels prior to start of panel fabrication. Once the panel is in fabrication changes are expensive and should be kept to a minimum. Provide a minimum of 10 percent spare panel space for the future expansion of control room panels. Provide 1.52 to 1.83 meters (5 to 6 feet) access clearance between the panel and the wall behind it when possible. Recommended practices on control room and panel layout are defined by ISA-RP60.3, *Human Engineering for Control Centers*.

**2.1.4 CONSTRUCTION.** The following applies to both control room and local panels.

**2.1.4.1 ELECTRICAL COMPONENTS.** Use solid state logic. Do not use relay logic except where only a few logic steps are involved. Use items that have a long life and do not have to be frequently replaced. A typical example is the use of neon bulbs instead of incandescent bulbs for indicator lights. The neon bulbs have a longer life.

**2.1.4.2 DISPLAYS.** Use displays that are readily visible to the operator. This might entail specifying LED instead of LCD, although LCD consumes less power.

**2.1.4.3 LIGHTING.** Provide switched vapor tight lights to illuminate the front of the panel. Provide additional switched lights to illuminate the inside of the panel enclosure.

**2.1.4.4 SERVICE OUTLETS.** Provide ground fault interrupt (GFI) protected 120 VAC duplex outlets within each panel enclosure section. Locate outlets not more than 6 feet apart within each section.

**2.1.4.5 STEELWORK.** Fabricate enclosure panels from 3.04 millimeter (11 gauge (0.1196-inch)) or 3.18 millimeter (1/8-inch) steel plate. Reinforce the panels as required for stiffness. Use 1.52 millimeter (16 gauge (0.0598-inch)) minimum steel plate for doors. Slightly bevel or round all exposed edges. Larger panels are usually fabricated in 3.05 to 3.66 meter (10 to 12 foot) long sections. Make all joints vertical. Horizontal panel joints are not acceptable. Use angle iron at each end of a section to make up vertical butt joints. Preassemble the complete panel in the shop to check for accurate alignment and surface matching. Panel joints passing through an instrument are not acceptable.

**2.1.4.6 PREFABRICATION.** Specify panels to be complete with all instruments installed, piped, and wired. The only actions that should be necessary to place the panel in service are to connect power, instrument signals, and instrument air supply.

## **2.2 INDIVIDUAL ITEM REQUIREMENTS**

**2.2.1 CONTROLLERS.** Boilers use three types of controllers. These are digital (e.g. microprocessor or computer based), analog, and pneumatic. Use the following guidelines in selecting the type of controller to be used:

- Use the type of controller that is the most economical and reliable.
- For plants with many control loops use digital type of controllers.
- For the expansion of existing controls within a plant use the existing technology. This may be either digital, analog electronic, or pneumatic controllers.
- Use pneumatic controllers in hazardous areas.
- Avoid use of pneumatic controllers in the control room.
- When using digital control avoid depending on a single or a few control devices for the entire plant without having a backup. A redundant controller might not be required if only a single controller controls one loop. However, if a single controller controls a large number of loops then provide redundancy so that if the controller fails another controller will automatically take over.

**2.2.1.1 Process Controllers.** Process controllers use one or several of the following control modes:

- On-off
- Proportional
- Integral (also called reset)
- Derivative (also called rate)

Most digital controllers have all of the above control modes included. They are also usually provided with anti-reset windup. Analog and pneumatic controllers often do not include all three control modes or anti-reset windup.

**2.2.1.1.1 CONTROL MODES.** In general, use the following control modes for the indicated control loop.

- Flow -- Use proportional plus integral.
- Level -- Use proportional plus integral.
- Pressure and Temperature -- Use proportional plus integral. Use proportional plus integral plus rate when the application requires a quick response time.

**2.2.1.1.2 TESTING.** Recommended practices on tests to be conducted on digital controllers are defined by ISA-RP55.1, *Hardware Testing of Digital Process Computers*.

**2.2.1.1.3 CONTROLS.** Provide a separate control station for each control loop when using digital controls. Locate critical controls on the front of the panel. Provide the following minimum controls.

- Automatic/manual selection
- Set point adjustment

- Output signal adjustment when on manual control
- Alarm setting

**2.2.1.1.4 ALARMS.** Provide the following minimum alarms.

- Controller failure
- High-high alarm
- High alarm
- Low alarm
- Low-low alarm

**2.2.1.1.5 DISPLAYS.** Provide each control station with the following minimum displays.

- Process reading
- Set point
- Output signal
- Input signal
- Automatic/Manual indication
- Controller failure indication
- High-high alarm
- High alarm
- Low alarm
- Low-low alarm

**2.2.1.1.6 FEATURES.** Provide the following features as a minimum.

- Proportional, integral and derivative control modes
- Anti-reset windup
- Automatic/manual and manual/automatic bumpless transfer

- Change configuration without shutting down the control loop
- Display configuration data without interfering with the operation of the controller

**2.2.1.1.7 Failure Response.** Provide the following minimum actions on controller failure.

- The controller should switch to manual operation, hold its last output signal, and send out an alarm showing controller failure if a backup controller is not provided.
- The control should automatically switch over to the backup controller and send out an alarm showing controller failure if a backup controller is provided.

**2.2.1.1.8 SIGNAL INTERFACE.** Digital controllers do not always have dedicated contacts for alarms and shutdowns. If the contacts are not provided, specify a controller where dedicated contacts for each alarm and shutdown condition can be easily added using hardware obtainable from the controller manufacturer. Provide one set of single pole double throw (SPDT) contacts as a minimum.

**2.2.1.2 PROGRAMMABLE LOGIC CONTROLLERS.** Programmable logic controllers (PLCs) are usually programmed in the electrical ladder diagram format. Other formats are also used. When specifying PLCs include the following features:

- Provide a controller that can be programmed in the electrical ladder diagram format when many logic steps are involved.
- Include provisions so that the controller can be programmed and the program read without disturbing its operation.

**2.2.1.3 CONTROLLER CONFIGURATION.** Provide a controller that can be programmed in any of the following ways at the programmer's option:

- From the front of the controller if a separate controller is provided

- From a manual control station if a separate controller is not provided
- From a configuration device manually
- From a configuration device using stored information from a tape, computer disk, or other data storage device; provide either a non-volatile memory or battery back-up for the controller so that the controller configuration memory is not lost due to a power outage.

**2.2.2 RECORDERS.** Keep recorders to a minimum. They constitute considerable expense in paper and pen replacement costs. If recorders are required then standardize them so as to keep paper and pen inventory costs to a minimum. Note that recorders from different manufacturers usually require different paper and pens. The preferred method of recording data is on computer disks, tapes, or other data storage device. This data can later be viewed on a monitor, printed, or plotted.

**2.2.3 TOTALIZERS.** Provide an 8-digit minimum totalizer. Provide a lock to inhibit the reset function of reset type totalizers. Whenever practical, record the data on a computer disk, tape, or other permanent data storage device and use a computer program to add up the totals.

**2.2.4 INDICATORS.** Dedicated indicators are commonly used with pneumatic and analog type of control systems. Do not specify a dedicated indicator except for critical items when using digital type control systems. Obtain non-critical information from a control station readout or from a monitor.

**2.2.5 STATUS LIGHTS.** When dedicated status lights are required, use neon rather than incandescent lights as much as practical. Neon lights have lower power consumption and longer life. Use "Push to Test" indicating/status lights to ensure lights are functioning properly. Obtain the information from a control station read-out or from a monitor whenever practical instead of using status lights for digital type control systems.

**2.2.6 ANNUNCIATORS.** Annunciator standards are defined by ANSI/ISA-S18.1, *Annunciator Sequences and Specifications*. Use common trouble alarms instead of dedicated alarms as much as practical. Provide both visual and audible alarms. Provide a dedicated alarm for critical items.

**2.2.6.1 COMMON ALARMS.** Provide a dedicated window to contain the common trouble alarms. When possible, include on this display the specific item within the group that caused the alarm.

**2.2.6.2 DEDICATED ALARMS.** Provide a separate window that includes all dedicated alarms associated with an area. Typical dedicated alarms are summarized in Table 4-2.

**2.2.6.3 ANNUNCIATOR SYSTEMS.** Include the following minimum items in an annunciator system:

- Solid-state electronic system with first-out sequence
- Back-lighted windows
- Acknowledge, test, and reset pushbuttons. Locate the pushbuttons outside of the annunciator cabinet so that the cabinet door does not have to be opened to depress the pushbuttons. Provide a separate audible signal device and separate pushbuttons for each annunciator system.

**2.2.6.4 ALARM INDICATIONS.** The alarm indication is controlled by the annunciator manufacturer. Typical indications for various fault conditions are as follows:

- Normal - Light off and audible alarm off
- Abnormal - Light flashing, audible alarm on
- Abnormal First Out - Same as above except flashing pattern is different to distinguish it as a first out.
- Acknowledge - Audible alarm off
- Other than first-out - Light steady

- First-out - Light flashing but pattern is different from prior to acknowledgment
- Return to Normal - Light off and audible alarm off

**2.2.7 SELECTOR SWITCHES.** Provide a minimum of SPDT contacts for selector switches. Clearly label all switch positions. Label unused positions as such. Use backlighted switches for critical items in areas that are not well lit. Momentary selector switches may be required to electrically sequence equipment to start on emergency diesel generator power following the loss of normal power. This is necessary so as not to overload the emergency power circuit with equipment that has selector switches maintained in the "Run" mode.

**2.2.8 PUSHBUTTONS.** Use SPDT contacts as a minimum. Provide recessed or covered pushbuttons for shutdowns to guard against nuisance trips.

**2.2.9 PLANT CONTROL STATIONS.** Plant control stations, like panels, can be located either in a main control room or locally. The main control room is the preferred location. Restrict local plant control stations to equipment that require them for start-up or shutdown. In this case locate the control station as close to the equipment as practical. A typical control station consists of a computer for processing and storing data, a monitor, a keyboard, and a printer. Each of these items is discussed below.

**2.2.9.1 COMPUTERS.** Furnish the computer with a power supply that provides power that is free of disturbances. The manufacturer should be able to provide power supply specifications and recommend safeguards against severe power disturbances.

**2.2.9.1.1 CONTROL LIMITS.** Limit the ability of the computer to control the plant to those functions that can be safely controlled from the computer and in compliance with applicable codes. Provide an alarm connected to an annunciator to show computer malfunction.

**2.2.9.1.2 DATA OVERFLOW ALARM.** Provide computers that are used for logging data with an alarm connected to an annunciator to show the following:

- Data storage capacity is approaching full.
- Data storage capacity has been exceeded.

**2.2.9.1.3 REDUNDANCY.** Provide a spare computer to automatically take over the logging of critical data in the event of primary computer malfunction.

**2.2.9.2 MONITORS.** Cathode-ray tube (CRT) monitors are the most commonly used type. Others include LCD type and luminous gas plasma screen type. Provide a spare monitor that can be readily switched over to display critical data in the event that the primary monitor malfunctions.

**2.2.9.3 KEYBOARDS.** Provide sealed-type keyboards to resist liquid spills. Keyboards can be either a standard type or a non-standard with specialized keys. Standard keyboards should be used as much as practical. Mistakes are more likely to be made using a non-standard keyboard than using a standard keyboard. Keyboard replacement is also more difficult with a non-standard type.

**2.2.9.4 PRINTERS AND PLOTTERS.** Provide an alarm connected to an annunciator to show printer failure for printers receiving critical on-line data. Also provide a back-up printer to take over if the primary printer malfunctions.

**2.2.10 DATA LOGGING.** Provide the following minimum data logging for digital type control systems. Print out this information automatically on a dedicated printer.

- Date, time and device alarmed or shut down
- Identify first out
- Time alarm acknowledged
- Time for return to normal

Include year, day, hours, minutes, and seconds in the date and time. On the first out, show the device to alarm first, then show the device to shut down the equipment.

**2.2.11 RECEIVER INSTRUMENTS.** These instruments include recorders, indicators, controllers and totalizers (also known as integrators). Each is covered separately in preceding paragraphs.

**2.2.12 POTENTIOMETER INSTRUMENTS.** These instruments include recorders, indicators, controllers and transmitters.

### 3. LOCAL DEVICES AND INSTRUMENTATION

**3.1 GENERAL.** This discussion covers local instruments. Panel instruments are not included. Instruments that are usually located on panels, such as controllers, are covered above. Instruments should be located where they are accessible. Instruments that must be operated during the start-up or shutdown of equipment should be located as close to the equipment as practical. Some instruments must be accessed continuously for operation, others only during startup and shutdown. All instruments must be accessible for calibration and maintenance. Locate instruments using the following order of access preference.

- Grade
- Platform
- Stairs
- Ladder
- Portable ladder

### 3.2 INDIVIDUAL ITEM REQUIREMENTS

**3.2.1 VALVES.** This paragraph covers control valves, pressure regulators and solenoid valves. Each type is discussed below.

**3.2.1.1 CONTROL VALVES.** Common types of flow characteristics for control valves include quick opening, linear, and equal percentage. Control valves with equal percentage flow characteristics are specified for most applications. Control valves with linear flow characteristics are hard to tune at low flow and should be avoided. Select the flow characteristic to suit the application. Tolerance criteria for control valves are defined by ISA-S75.11, *Inherent Flow Characteristics and Rangeability of Control Valves*.

**3.2.1.1.1 DESIGN CHECKLIST.** There are many items to be considered in control valve selection. Checklists are provided in most manufacturer catalogs. Critical items that are sometimes overlooked include type of shutoff, shutoff pressure, line hydrotest pressure and controllability at turndown conditions. Review all pertinent sizing and selection information including accessories when selecting a control valve.

**3.2.1.1.2 CONSTRUCTION.** Use carbon steel body with stainless steel trim. Other materials may be specified when required by unique conditions.

**3.2.1.1.3 SIZING.** Size control valves to absorb 30 to 50 percent of the total system pressure drop.

**3.2.1.1.4 MAINTENANCE.** Provide manual block and bypass valves around control valves where practical to allow for control valve removal and servicing while the system is operational. If a manual bypass is not provided then furnish the valve with a hand wheel.

**3.2.1.1.5 LOCATION.** Locate control valves at grade where practical. Install the control valve near the operating equipment that has to be observed while in local manual control.

**3.2.1.2 PRESSURE REGULATORS.** Use self-actuated regulators only where the operating pressure is below 10.34 bar (150 psig) and where variations from the control point are acceptable. Use pilot-operated pressure regulators where the operating pressure is equal to or above 10.34 bar (150 psig), or where minimal variations from the control setpoint are acceptable.

**3.2.1.3 SOLENOID VALVES.** Common uses for solenoid valves in a boiler plant include the routing of instrument air to control devices and shutoff service. Verify solenoid valve sizing to ensure that the valve or damper will open or close within the specified amount of time. Port size might have to be increased to ensure the proper

actuation time. Verify that the proper solenoid valve is used for the intended service. An example of a critical service application is a pilot gas shutoff solenoid valve. Most manufacturer catalogs include checklists on items to be specified. Critical items sometimes overlooked include type of fluid, shutoff and opening pressures, and line test pressure.

**3.2.2 ACTUATORS.** Use spring-loaded diaphragm type actuators where practical. Springless operators and cylinder operators are acceptable only when spring-loaded diaphragm type actuators cannot provide the desired performance. Select the actuator so that the valve or damper that it controls will fail safe. Fail safe is defined as lock in position or take a position (either open or closed) that will result in the least upset. Furnish a pressure gauge to show diaphragm loading pressure on actuators that do not have a positioner. Furnish positioners for all automatically operated dampers. Furnish positioners for all control valves in critical service and where the variable, such as flow, has to be closely controlled. Specify that the positioner be furnished with the control valve or damper instead of separate procurement. Provide bypass switches and three (3) pressure gauges (air supply, instrument loading, and diaphragm pressure) for all positioners.

**3.2.3 CURRENT TO PNEUMATIC CONVERTERS.** Control valves and dampers require current to pneumatic converters (I/Ps) for pneumatic actuators with electronic control signals. It is important that the I/P be matched to the valve or damper, as applicable. To avoid possible mismatch have the I/P furnished with the valve or damper instead of separate procurement.

**3.2.4 DAMPERS.** Dampers can be operated either manually or by means of an actuator. This paragraph covers only actuator-operated dampers. Manually operated dampers are not included in this document. Specify temperature, pressure, pressure drop, type of shutoff, materials, damper bearings, linkages, damper bearing and linkage lubrication, and other applicable data when selecting dampers. Provide a hand wheel

or lever so that the damper can be manually operated in case of damper actuator failure.

**3.2.5 PRESSURE RELIEF VALVES.** Provide pressure relief valves in accordance with the applicable codes.

**3.2.6 RUPTURE DISKS.** Use reverse buckling type rupture disks at the inlet of the relief valve in corrosive services.

**3.2.7 LEVEL INSTRUMENTS.** Provide level instruments in accordance with applicable codes. In general, provide separate vessel connections for each level instrument. Provide 12.7 millimeter ( $\frac{1}{2}$  -inch) minimum vent and drain valves with plugs for all level instruments.

**3.2.7.1 GAUGE GLASSES.** Complete coverage of total liquid range is not always required. Consult the applicable codes for requirements. Also consider all operating conditions and upsets. Provide gauge glasses to cover and overlap a minimum of 5.08 centimeters (2 inches) beyond the ranges of displacers and switches. Gauge glasses should only cover the critical range zone such as high, low, and normal levels when the range is also covered by differential pressure type level transmitters. Provide illuminators for transparent gauge glasses.

**3.2.7.2 DISPLACER.** Displacer type level instruments can be used for level ranges up to 1.52 meters (60 inches) of fluid height. Avoid use of internal displacers except for open tanks and sumps. Provide carbon steel body material with stainless steel trim as a minimum.

**3.2.7.3 DIFFERENTIAL PRESSURE.** Use differential pressure type level instruments instead of displacer type level instruments for ranges over 1.52 meters (60 inches) of fluid height. They may also be used for ranges under 1.52 meters (60 inches).

**3.2.7.4 CAPACITANCE LEVEL.** Avoid the use of capacitance type level instruments in boiler plants.

**3.2.8 FLOW INSTRUMENTS.** The most commonly used flow element in boiler plants is the orifice plate. There are numerous other flow measuring devices that can be used depending on the application. In alphabetical order these include annubar flowmeters, coriolis type mass flowmeters, elbow meters, flow nozzles, magnetic flowmeters, pitot tubes, pitot-venturi tubes, positive displacement meters, rotameters, target meters, thermal-loss meters (also known as heat-loss meters), turbine meters, ultrasonic flowmeters, venturi tubes, vortex flowmeters, and wedge elements. Use an orifice plate for most flow measurement applications unless a different type of flow element, such as a flow nozzle or a pitot tube, offers specific advantages. Reasons for using flow elements other than orifice plates include higher accuracy, shorter meter run, lower pressure drop and large line size.

**3.2.8.1 METER RUNS.** Flow disturbances as much as 100 pipe diameters upstream of the flow measuring element can affect the accuracy of the flow measurement. Meter run requirements, including pressure tap locations, depend on a number of items. These include type of flow element, beta ratio, and flow disturbances upstream and downstream of the flow element. Flow disturbances result from valves, elbows, enlargers, reducers, and other pipe fittings.

**3.2.8.1.1 REQUIREMENTS.** Obtain complete meter run requirements from the flow measuring device manufacturer to ensure accurate measurements. This includes pressure tap locations and other details such as pressure tap size.

**3.2.8.1.2 STRAIGHTENING VANES.** Avoid the use of straightening vanes due to their cost. Use them only when meter runs without them are not practical.

**3.2.8.1.3 FABRICATION.** Do not fabricate meter runs in the field. Fabricate them in a shop qualified in that type of work. Include in the shop fabricated meter run at least 10

pipe diameters of upstream piping and 5 pipe diameters of down stream piping. Straight runs of piping required in addition to the above can be fabricated in the field.

**3.2.8.2 ORIFICE PLATES.** Orifice plate types include concentric and eccentric, square edge, quadrant edge, segmental and annular. In general, use concentric, square-edge orifice plates except for the following.

- Use quadrant edge for orifice plates with a Reynolds number of less than 10,000 (based on pipe diameter).
- Do not use concentric orifice plates for horizontal runs flowing wet steam or gas, liquids containing solids, or liquids containing gas or vapor. All of the above will result in inaccurate measurements.
- Water in the wet steam and liquid in the wet gas can cause damming of the liquid. Solids in the liquid can settle out upstream of the orifice plate. As a first solution use a concentric, square-edge orifice plate but locate it in a vertical run with flow in the downward direction. If locating the orifice plate in a horizontal run cannot be avoided then use a segmental or eccentric orifice plate.
- Use a concentric, square-edge orifice plate located in a vertical run with flow in the upward direction for liquids containing gas or vapor. Use a segmental or eccentric orifice plate with the opening at the top if locating the orifice plate in a horizontal run cannot be avoided.

**3.2.8.2.1 DESIGN.** Meter runs should be a minimum pipe diameter of 5.08 centimeters (2 inches). Do not use an orifice bore diameter of less than 12.7 millimeters (0.5 inch) due to the possibility of plugging. Do not locate orifices where a liquid is subject to flashing. Select the orifice plate maximum design flow and meter differential to give a scale reading of approximately 70 percent at normal flow. Use a meter differential of 2.54 meters (100 inches) of water unless not practical. The orifice plate beta ratio should be between 0.25 and 0.70 and preferably between 0.4 and 0.6. The beta ratio

must never be less than 0.20. Do not exceed a beta ratio of 0.70 for gases or steam and 0.75 for liquids.

**3.2.8.2.2 MOUNTING.** Mount the transmitter near the orifice flanges. Use flange taps whenever practical. Specify orifice flange and taps in accordance with ASME B16.36, *Orifice Flanges*. Flange taps are well suited for pipe sizes of 5.08 centimeters (2 inches) and larger. Provide meter taps at the top of the flange for gas service in horizontal lines. Provide meter taps on the sides of the flange for steam, vapor and liquid service in horizontal lines. Mount the meter below the orifice taps for liquid and steam service and above the orifice taps for gas service. Provide a separate three valve type manifold for each meter. Provide condensate traps for both the high and low pressure sensing lines for steam and condensate service lines.

**3.2.8.2.3 CONSTRUCTION.** Use 304SS material as a minimum for the orifice plate. Provide an identification tab projecting beyond the orifice flange. Show the following minimum information on the tab:

- Actual measured orifice bore
- Pipe inside diameter
- Orifice plate material
- Orifice plate orientation to flow
- Type of fluid

**3.2.8.3 FLOW NOZZLES.** Use flow nozzles for applications where a higher accuracy is required than using orifice plates.

**3.2.8.4 VENTURI TUBES.** Use venturi tubes for applications where higher accuracy, lower pressure drop and shorter meter run are required than using orifice plates or flow.

**3.2.8.5 ELBOW METERS.** Elbow meters may be used for measuring relative flow rates and where absolute readings are not required. Elbow meters provide good repeatability and can be installed using an elbow in the regular piping.

**3.2.8.6 PITOT TUBES.** Use pitot tubes for large ducts where high accuracy and rangeability are not required and where pressure drops must be kept low.

**3.2.8.7 ROTAMETERS.** Rotameters are used for flow measurement in small lines such as fuel oil and purge air. Use glass tube rotameters only for purge air. Otherwise use armored type rotameters. Recommended practices on rotameters are defined by 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)*, and ISA-RP16.5, *Installation, Operation, Maintenance Instructions for Glass Tube Variable Area Meters (Rotameters)*.

**3.2.8.8 MAGNETIC FLOWMETERS.** Magnetic flowmeters provide obstructionless flow, good accuracy, and a good turndown ratio. However, they have the disadvantage of being costly, large and heavy.

**3.2.8.9 POSITIVE DISPLACEMENT METERS.** Use positive displacement meters only for high accuracy totalizing where measurement of flow rate is not required. These meters would typically be used for the measurement of fuel oil, fuel gas, and feedwater flow. Furnish a removable strainer installed upstream of the displacement meter.

**3.2.8.10 TURBINE METERS.** Turbine meters are extremely accurate and have a high turndown ratio. They do, however, present a high pressure loss to the system. Refer to ISA-RP31.1, *Specification, Installation, and Calibration of Turbine Flowmeters for additional information on turbine meters*.

**3.2.8.11 VORTEX METERS.** Vortex meters are extremely accurate, have a high turndown ratio, and present a low permanent pressure loss to the system.

**3.2.8.12 ANNUBAR METERS.** An annubar meter is a rigid tube device that measures flow by producing a pressure drop signal that is proportional to the square of the flow rate. Multiple sensing ports along the tube average the velocity profile of the fluid. Meters of this type provide less permanent system pressure drop than orifice plates and can be used for all applications that involve clean fluids. Measurement accuracy and repeatability is good and turndown ratios of 4:1 to 11:1 can be achieved depending on meter tube design.

**3.2.9 TEMPERATURE MEASUREMENTS.** Temperature instruments include thermocouples, resistance-temperature detectors (RTDs), filled bulb systems, and bimetallic thermometers.

**3.2.9.1 THERMOWELLS.** Thermowells are used to protect the temperature element from the environment and for personnel protection. Thermowell design varies depending on the application. Items affecting design include temperature, pressure, type of fluid and fluid velocity. In general, thermowells can be classified into two types: these are pressure service and non-pressure service. Thermowells used in nonpressure service are commonly referred to as protective tubes.

Provide thermowells for all temperature elements in pressure service. Use 304 SS material as a minimum. Use the material best suited for the application of protective tubes.

**3.2.9.2 THERMOCOUPLES.** In general, use the following thermocouples for the different temperature ranges:

- Type T, Copper constantan -- Below  $-17.77$  to  $371$  degrees C (0 to 700 degrees F)
- Type J, Iron constantan --  $-17.77$  to  $593$  degrees C (0 to  $1,100$  degrees F)

- Type K, Chromel alumel -- 315 to 1093 degrees C (600 to 2,000 degrees F)

Thermocouple assemblies can be single (one thermocouple) or duplex (two thermocouples). Provide duplex thermocouples for all temperature control loops. Use one thermocouple for control and the other for indication. Thermocouple and thermocouple extension wire specifications are defined in ANSI/ISA-MC96.1, *Temperature Measurement Thermocouples*, and NEMA-WC55, *Instrumentation Cable and Thermocouple Wire*.

**3.2.9.3 RESISTANCE-TEMPERATURE DETECTORS.** Resistance-temperature detectors (RTDs) are used where accurate temperature or temperature difference measurements are required.

**3.2.9.4 FILLED BULB SYSTEMS.** Filled bulb systems are used for local temperature indicators, recorders, and controllers in services where the fluid temperature is below 426 degrees C (800 degrees F). Mercury filled bulb systems are not allowed. Provide armored capillary tubing for all filled bulb systems. Limit capillary length to 15.24 meters (50 feet) maximum. In all cases provide a thermowell where the filled bulb system is used in pressure service.

**3.2.9.5 BIMETALLIC THERMOMETERS.** Bimetallic thermometers are mostly dial type thermometers used for local temperature indication. In all cases provide a thermowell where the bimetallic thermometer is used in pressure service.

**3.2.10 PRESSURE MEASUREMENTS.** Pressure instruments include gauges, switches, and transmitters. In general pressure gauges use bourdon tubes to measure pressure greater than 1.03 bar (15 psig), and bellows to measure pressure less than 1.03 bar (15 psig) or differential pressure. Transmitters and switches use diaphragms to measure pressure. Use snubbers where pulsation dampening is required.

**3.2.10.1 GAUGES.** Provide blowout discs for pressure gauges in services with pressures greater than 1.03 bar (15 psig). Provide a safety wall between the dial and the bourdon for service pressures above 68.9 bar (1000 psig). Provide pigtail siphons for all gauges in steam service. Pigtail siphons should be installed perpendicular to the gauge. Provide pulsation dampers and diaphragm seals where required by service conditions and for all gauges in steam and condensate service. Provide a gauge isolation valve for each gauge. Pressure gauges are usually direct connected and field mounted. The size and range is specified by the user. Locate local gauges so that they are visible from the operating area and are readable from grade or a platform. Local mounted gauges give a “backup” reading and also help operators in determining if equipment or pressure systems are working satisfactorily. Pressure gauges should conform to ASME B40.100, *Pressure Gauges and Gauge Attachments*.

**3.2.10.2 SWITCHES.** Pressure switches are used for monitoring alarm conditions and providing safety shutdowns. They are typically mounted directly to the process pipe.

**3.2.10.3 TRANSMITTERS.** Pressure transmitters convert the measured pressure to an analog or digital signal that is monitored by the control system (e.g. PLC). Provide a three-valve manifold to accomplish block, drain, and test functions for all pressure transmitters. Provide a five-valve manifold to accomplish block, equalize, drain, and test functions for all differential-pressure transmitters. Refer to Paragraph 5-2.11 for additional transmitter requirements.

**3.2.10.4 DRAFT.** Pressure instruments for the measurement of draft in furnaces require careful attention as to range and sizing. Note that the draft in a balanced draft boiler furnace is slightly negative, around -2.54 millimeter (-0.1 inch) WC, at the top of the furnace. Too wide of an instrument range will result in the loss of accuracy. Too narrow of a range will not cover all operating conditions. Verify that the connections and sensing lines are adequately sized for the low negative pressures. Use larger sizes than for lines sensing positive and high pressures.

**3.2.11 ELECTRONIC TRANSMITTERS.** Electronic transmitters are used to transmit an electronic signal from a local measuring device to a remotely located device such as a panel mounted controller. Typical transmitters include flow, level, pressure and flue gas oxygen. A typical electronic signal is 4-20 mA DC. Use stainless steel material for all transmitter components in contact with the stream. Provide local indicators for all electronic transmitters. Locate the local indicator at the transmitter for non-controlling loops such as a signal to an indicator or recorder. Locate the local indicator at the controlling device for controlling loops such as diaphragm-operated valves. Provide an integrally mounted junction box with a metal cover and a terminal block for blind electronic transmitters to allow for the connection of a plug-in ammeter. Electronic transmitters with internal microprocessors are known as “smart transmitters”. These transmitters provide on-board sensor linearization, data correction coefficients, measurement ranging, system diagnostics, and instrument configuration. These transmitters communicate to the control system via a communication bus (e.g. HART or Fieldbus).

**3.2.12 ELECTRICAL INSTRUMENT SWITCHES.** Typical applications for electrical instrument switches are alarms and shutdowns. Contacts should open to alarm or shut down for fail safe operation. Provide switches that are suited for the environment. Provide switches that are dust tight and vibration proof for all locations. Provide NEMA 4 rated switches for outdoor locations with non-corrosive atmospheres and NEMA 4X rated switches for corrosive atmospheres. Provide SPDT contacts as a minimum.

**3.2.13 ANALYZERS.** Include all analyzers necessary to meet federal, state and local environmental monitoring requirements. Analyzers used in a boiler plant include the following:

- In-line
- Sample diverted from the stream to the analyzer and then returned to the stream

- Sample diverted from the stream to the analyzer and then discharged to the atmosphere or a drain

**3.2.13.1 GENERAL GUIDELINES.** Use in-line analyzers where practical. As a second choice, use an analyzer where the sample is diverted to the analyzer and then returned to the stream. Use an analyzer where the sample is discharged to the atmosphere or drain as a last choice. Provide a relatively constant differential pressure device, such as a pump, as a bypass to divert a sample that is to be returned to the stream. Avoid bypassing around a control valve.

**3.2.13.1.1 CALIBRATION.** Where practical use a self-calibrating analyzer that provides zero and full span in the range in which the analyzer will be operating. Provide automatic calibration at power-up, at manual command, and at preprogrammed intervals.

**3.2.13.1.2 APPLICATION.** When to use analyzers and what type of analyzer to use, depends upon environmental and value engineering concerns for a given boiler size. Analyzers should be used for trim or alarms. Avoid using analyzers as a sole means of control or shutdown.

**3.2.13.1.3 PACKAGING.** It is possible to obtain multiple analyzers packaged in one system. For example, flue gas analyzers are available that combine oxygen, combustibles and methane measurement in one package. This packaging concept would reduce installation complexity and may provide cost savings. When practical obtain the analyzer from the manufacturer completely packaged in a housing, wired, piped and with the sample system installed. Specify the analyzer to be free standing unless it is mounted on the equipment.

**3.2.13.2 OXYGEN ANALYZER.** Oxygen analyzers in a boiler plant are used for oxygen measurement to provide an indication of excess air in the flue gas. Use the analyzer for alarms and trim. Do not use it as the sole instrument for the control of

combustion air. Probe location is not critical for forced draft type or pressurized boilers since leakage is flue gas out of the boiler. Probe location is critical, however, for balanced draft boilers (which have induced draft fans), since leakage is typically tramp air into the boiler from flue ductwork. Locate the oxygen probe so as to keep the effect of tramp air on the oxygen reading at a minimum. This usually entails locating the probe as close to the furnace as practical.

**3.2.13.3 COMBUSTIBLES ANALYZER.** Combustibles analyzers in a boiler plant are used for carbon monoxide measurement, hydrogen measurement or both to provide an indication of incomplete combustion in the flue gas. Use the analyzer for alarms and trim. Do not use it as the sole instrument for the control of combustion air.

**3.2.13.3.1 CARBON MONOXIDE ANALYZER.** Carbon monoxide (CO) analyzers used in a boiler plant may utilize a catalytic element, wet electrochemical cell, or non-dispersive infrared absorption. Install the CO analyzer in a clean gas stream that is downstream of the particulate removal system. A CO analyzer permits firing at lower oxygen levels than without it. A minimum air requirement is established by decreasing oxygen in the stack gas until a large increase in the CO reading occurs. A CO analyzer is also useful in boiler startup. During start-up, monitor the CO analyzer closely for unsafe firing conditions. High CO readings indicate incomplete combustion, which implies potentially unsafe conditions in the furnace.

**3.2.13.3.2 HYDROGEN ANALYZER.** Hydrogen (H<sub>2</sub>) analyzers used in a boiler plant are on line monitors that employ a catalytic element. Like the CO analyzer, a Hydrogen analyzer permits firing at lower oxygen levels than without it. A minimum air requirement is established by decreasing oxygen in the stack gas until a large increase in the H<sub>2</sub> reading occurs. A H<sub>2</sub> analyzer is also useful in boiler start-up. During start-up, monitor the H<sub>2</sub> analyzer closely for unsafe firing conditions. High H<sub>2</sub> readings indicate incomplete combustion, which implies potentially unsafe conditions in the furnace.

**3.2.13.4 STACK OPACITY ANALYZER.** Stack opacity analyzers are used in a boiler plant to monitor particulate emissions. Their main use is in coal and heavy oil fired boilers. Stack opacity monitors are generally not required for gas fired boilers; however, state and federal regulations should be consulted. Also, most large boilers are dual fuel which may be a combination of gas and oil.

**3.2.13.5 CONDUCTIVITY ANALYZERS.** Conductivity analyzers are used in boiler plants to monitor dissolved solids in the boiler drum. Use a conductivity analyzer for adjusting boiler blowdown. Do not use it as the sole device for boiler blowdown control.

**3.2.13.6 METHANE ANALYZERS.** Methane analyzers in a boiler plant are used for methane measurement to provide an indication of a completed purge cycle prior to boiler ignition or during boiler shutdown. Note that this analyzer must be used in conjunction with and not as a substitute for the minimum purge time requirements stated in the applicable codes.

**3.2.14 FLAME DETECTORS.** Provide the flame detector best suited for the fuel and flame. For gas fired boilers always use an ultraviolet (UV) self-checking flame scanner. Do not use a flame detector that is activated by hot refractory. Provide a separate flame detector for each burner. Locate the flame detector so that it will be activated only by its own burner and not by an adjacent burner or hot refractory.

**3.2.15 CONTINUOUS EMISSION MONITORING (CEM).** Provide all necessary equipment to meet federal, state, and local environmental analysis and documentation requirements.

## 4. RECOMMENDED BOILER INSTRUMENTATION

### 4.1 BOILER CONTROL PANEL INDICATORS, RECORDERS AND TOTALIZERS.

The instrumentation in Table 4-1 represents the minimum recommended requirements for a boiler plant. This instrumentation selection is based primarily on boiler operation safety concerns. Refer to NFPA 8502, *Standard for the Prevention of Furnace Explosions/Implosions in Multiple Burner Boilers* for further instrumentation concerns for boiler plants in the 13.18 gigajoule/h (12,500,000 Btu/h) or above range and ASME CSD-1, *Controls and Safety Devices for Automatically Fired Boilers* for boiler plants below 13.18 gigajoule/h (12,500,000 Btu/h). The indicators and recorders can be either dedicated or shared devices. Totalizers must be dedicated devices. Shared device selection may be either by means of push-buttons, a selector switch, or by entering commands on a keyboard. Provide the following in the display of information associated with a shared device.

- Name of process variable
- Instrument number
- Units
- Process variable value

Store the process data in a storage device such as a computer disk or tape if a dedicated recorder or totalizer is not provided. Label the computer disk or tape as to process variable, instrument number, date, time, and units. The time label must include hours, minutes, and seconds. Store the data so that it can be retrieved selectively. In selective retrieval as a minimum include the name of process variable, instrument number, date and desired time interval. Include maximum and minimum points and alarms with the data to be recorded. Provide a dedicated printer or printer/plotter on which the recorded and totalized data can be presented on paper on demand. Data storage, retrieval, and printing must meet federal, state, and local environmental documentation requirements. An instrumentation item is not applicable if the equipment

INSTRUMENT	INDICATOR	RECORDER	TOTALIZER
Levels			
Boiler drum water <sup>1</sup>	X	X	
Flows			
Boiler steam <sup>1</sup>	X	X	X
Boiler feedwater <sup>1</sup>	X	X	X
Combustion air <sup>1</sup>	X	X	
Fuel gas <sup>1</sup>	X	X	X
Fuel oil <sup>1</sup>	X	X	X
Pressures			
Boiler steam drum	X		
Steam outlet header	X	X	
Boiler feedwater	X		
FD fan outlet	X		
Pilot gas	X		
Fuel gas	X		
Fuel oil	X		
Atomizing steam	X		
Draft			
Boiler furnace	X	X	
ID fan inlet	X		
Differential pressures			
Air preheater air	X		
Air preheater flue gas	X		
Temperatures			
Steam			
Steam drum	X		
Superheater inlet	X	X	
Superheater outlet	X	X	
Steam header	X	X	
Feedwater			
Supply header	X	X	
Economizer inlet	X	X	
Economizer outlet	X	X	
Fuel oil	X	X	
Combustion air			
Air preheater inlet	X	X	
Air preheater outlet	X	X	
Flue gas			
Superheater outlet	X		
Boiler outlet	X		
Economizer inlet	X	X	

Table 4-1

Boiler Control Panel Indicators, Recorders and Totalizers  
(X shows instrumentation item required)

INSTRUMENT	INDICATOR	RECORDER	TOTALIZER
Economizer outlet	X	X	
Air preheater inlet	X	X	
Air preheater outlet	X	X	
ID fan inlet	X	X	
Flue gas stack	X	X	
Viscosity			
Fuel oil	X	X	
Flue gas oxygen <sup>1</sup>	X	X	
Stack opacity <sup>1</sup>	X	X	
Current in amps			
ID fan	X		
FD fan	X		

1. These records shall be maintained separately and not shared in storage.

Table 4-1 (continued)

Boiler Control Panel Indicators, Recorders and Totalizers  
(X shows instrumentation item required)

that it services is not included in the plant. For example, if an air preheater is not provided then an air preheater outlet temperature indicator does not have to be furnished.

**4.2 BOILER CONTROL PANEL ALARMS AND SHUTDOWNS.** The alarms and shutdowns in Table 4-2 represent the minimum recommended requirements for a boiler plant. These were selected based primarily on boiler operation safety concerns. Refer to NFPA 8502, Standard for the *Prevention of Furnace Explosions/Implosions in Multiple Burner Boilers* for further information for boiler plants in the 13.18 gigajoule/h (12,500,000 Btu/h) or above range and ASME CSD-1, *Controls and Safety Devices for Automatically Fired Boilers* for boiler plants below 13.18 gigajoule/h (12,500,000 Btu/h). Provide a separate window in an annunciator system for each dedicated alarm. Provide a dedicated common trouble alarm window to which the non-dedicated alarms are wired. Include a first-out listing to show which device connected to the common trouble

<b>INSTRUMENT</b>	<b>ALARMS</b>	<b>SHUTDOWNS</b>
Levels		
Boiler drum water		
Low	X	
Low-low	X	X
High	X	
High-high	X	X
Flows		
Combustion air		
Low	X	
Low-low	X	X
Pressures		
Boiler feedwater header		
Low	X	
Boiler steam drum		
Low	X	
Low-low	X	X
High	X	
High-high	X	X
Steam header		
Low	X	
High	X	
Pilot gas		
Low	X	
Low-low	X	X
High	X	
High-high	X	X
Fuel gas		
Low	X	
Low-low	X	X
High	X	
High-high	X	X
Fuel oil		
Low	X	
Low-low	X	X
High	X	
High-high	X	X
Atomizing steam		
Low	X	
Low-low	X	X

Table 4-2

Boiler Control Panel Alarms and Shutdowns  
(X shows alarm or shutdown item required)

INSTRUMENT	ALARMS	SHUTDOWNS
High	X	
High-high	X	X
Atomizing air		
Low	X	
Low-low	X	X
High	X	
High-high	X	X
Instrument air		
Low	X	
Low-low	X	X
Scanner air		
Low	X	
Boiler furnace	X	
High	X	
High-high	X	X
Draft		
Boiler furnace		
High	X	
High-high	X	X
Differential pressure		
Atomizing steam to oil		
Low	X	
Low-low	X	X
Temperatures		
Boiler feedwater		
Low	X	
Fuel oil		
Low	X	
Low-low	X	X
High	X	
High-high	X	X
Flue gas		
Economizer outlet		
Low	X	
High	X	
Stack	X	
High	X	
High-high	X	X
Fan bearings		
High <sup>1</sup>	X	
Boiler water solids		
High	X	
Oxygen		
Low	X	

Table 4-2 (continued)

Boiler Control Panel Alarms and Shutdowns  
(X shows alarm or shutdown item required)

INSTRUMENT	ALARMS	SHUTDOWNS
High	X	
Smoke		
High	X	
Flame scanner failure	X	X
Failure to establish flame	X	X
Flame failure	X	X
Burner valves not closed		
Following trip	X	X
Equipment failure		
FD fan	X	X
ID fan	X	X
Oxygen analyzer	X	
Power failure		
Control	X	X
Equipment	X	X
Boiler shutdown		
Automatic	X	X
Manual	X	X

1. Provide one thermocouple at each bearing.

Table 4-2 (continued)

Boiler Control Panel Alarms and Shutdowns  
(X shows alarm or shutdown item required)

alarm tripped first. Provide instrumentation to show which device shut the equipment down first during a system shutdown. An alarm or shutdown is not applicable if the equipment that it services is not included in the plant. For example, if the boiler is gas fired only, a low fuel oil pressure alarm is not required.

**4.3 BOILER CONTROL PANEL CONTROLLERS.** Provide controllers as required for the proper operation of the boiler plant. Controllers required for a typical boiler plant

include steam header pressure (plant master and boiler master), boiler drum water level (feedwater flow), fuel flow, combustion air flow, and boiler furnace draft.

**4.4 VALUE ENGINEERING.** There are many cost tradeoffs associated with the design of a boiler. The use of an oxygen trim system is one example. The installation of an oxygen trim system in a boiler design will provide fuel savings. The analyzer that provides this function, however, is costly to buy and maintain. Therefore, oxygen trim systems should only be used on large boilers where the cost of fuel savings outweighs the cost of the analyzer.

## 5. REFERENCES

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

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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  
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ASME B16.36, Orifice Flanges

ASME B31.1, ASME Code for Pressure  
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ASME CSD-1, Controls and Safety  
Devices for Automatically Fired Boilers

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

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ANSI/ISA-S5.4, Instrument Loop Diagrams

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

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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

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WC 55, Instrumentation Cables and Thermocouple Wire

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Batterymarch Park  
Quincy, MA 02269

NFPA-70, National Electrical Code

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NFPA-8502, Standard for the Prevention  
of Furnace Explosions/Implosions in  
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NFPA-8503, Standard for Pulverized Fuel  
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15 Inverness Way East  
Englewood, CO 80112

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