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SUMMARY

A review of the criteria involved in the selection of primary sensing elements for the measurement of process variables in high-pressure, aqueous, nuclear reactors is presented. Some acceptable types of sensing elements now in use at ORNL are described.

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INSTRUMENT TRANSMITTERS FOR HIGH-PRESSURE, AQUEOUS, NUCLEAR REACTORS*

The design of primary "sensing" elements for use in the measurement of process variables in high-pressure, aqueous, nuclear reactors presents many problems not usually found in the design of primary elements for more conventional high-pressure systems.

Design Considerations

In addition to the usual problems of obtaining structural strength, accuracy, reliability, corrosion resistance, and freedom from temperature and pressure effects, the reactor applications may impose one or more of the following requirements:

- (1) Absolute containment of the process fluid.
- (2) Resistance to radiation damage.
- (3) Amenability to remote adjustment and removal.
- (4) Immunity to damage from immersion in water.
- (5) Drainability.
- (6) Small "liquid holdup" volume.

The requirement of containment is common to all reactor high-pressure instrumentation and is the primary consideration in the selection of acceptable types of sensing elements. Since absolute containment over long periods is required, pressure containing elements must be seal-welded or sealed with closures which present a suitably low probability of leakage. Also allowances must be made for corrosion in specifying the minimum thickness of pressure containing parts.

Resistance to radiation damage may be provided by the use of shielding or by the elimination of materials susceptible to radiation damage. In general, shielding of field mounted instruments is difficult and expensive, since such shields are usually large and heavy. A more desirable method is to locate the instruments in a shielded compartment and connect it to the process by small instrument lines. This method is feasible where transmissions lags may be tolerated, or where vapor space connections may be made in such a manner as to assure a low activity condensate fill of the instrument lines. It should be noted that an external

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shield is useless when the instrument contains a high activity process fluid.

If the instrument cannot be located in a shielded location, or is subject to internal contamination with radioactive fluids, then provisions must be made for remote adjustment and removal. Regardless of location, it is desirable that the instrument be drainable. This is particularly true if the instrument contains highly radioactive process fluids. Drainability simplifies the problems of removal and replacement, since the possibility of spills of radioactive material is eliminated, and since the activity of the instrument may be substantially reduced by flushing and acid rinses prior to removal.

In the case of instruments which contain uranium or other fuel solution, it is also desirable that the internal volume be small in order to minimize "holdup" of costly materials in areas external to the process.

Types of Instrumentation Encountered

Although a wide variety of types of instrumentation is required in the complete reactor system, the process instrumentation of the primary reactor system is usually limited to that required for measurement of temperature, pressure, differential pressure, flow, liquid level, and weight.

Temperature Measurement

The thermocouple is the most common element used for the measurement of reactor temperatures at ORNL. The simplicity, accuracy, flexibility, reliability, and the low susceptibility to radiation effects of the thermocouple makes it ideal for reactor services. Commercial grade thermocouples with silicone impregnated fiberglass insulation have been found to be quite satisfactory for reactor service in areas external to the reactor core. For service in areas having extremely high neutron and gamma flux or for prolonged service in areas of lower activity, the mineral insulated, sheathed thermocouple shows great promise. This type of thermocouple uses an inorganic material such as magnesium or aluminum oxide for insulation, and therefore, is practically immune to radiation damage. The insulation is contained by an outer metallic sheath which is swaged to pack the insulation. Since mineral insulation is hygroscopic, care must be exercised in the use of mineral insulated couples in order to insure that the sheath and the end closures are completely waterproof.

In areas where the flow rate approaches the critical corrosion velocity, it is recommended that thermocouples be spot welded to the outside of the pipe or vessel, since the installation of thermocouple wells may produce turbulence and result in acceleration of corrosion. Also the installation of thermocouple wells involves at least one reactor grade weld, and therefore, greatly increases the cost of the installation. In stagnant areas, or in areas of low flow, the use of thermocouple wells is permissible.

Where the thermocouple is to be attached to a pipe or vessel wall, the accuracy of measurement may be increased by laying the couple against the surface for the distance of several inches from the point of attachment and insulating.

In areas where the couples are subject to immersion in water, the use of chromel-alumel wire is recommended since it is less susceptible to corrosive attack by water than iron-constantan alloys and the signal is less affected by galvanic EMFs.

Pressure Transmitters

Several types of pressure elements suitable for use in reactor service are commercially available. Fig. 1 (ORNL Photo 27066) illustrates the Bourdon sensing-tube element of a 0-3000 psi pneumatic pressure transmitter supplied by The Taylor Instrument Company. Specifications provide for an overrange to 3750 psig, an operating temperature of 140°F, a hysteresis of ± 15 psi, a sensitivity of ± 3 psi, and a weld-sealed type 347 stainless steel element. Fig. 2 (ORNL LR-Dwg. 26382) shows a pressure transmitter manufactured by the Swartwout Instrument Company. This transmitter utilizes electric transmission and incorporates a secondary pressure housing for containment of fluid in case of rupture of the Bourdon tube. The motion of the bourdon is directly coupled to a magnetic core. The motion of the core is sensed through the pressure housing by means of a differential transformer.

Fig. 3 (ORNL LR-Dwg. 23538) shows a pressure transmitter, manufactured by the Callery Chemical Company, which may be mounted directly on a high-temperature, high-pressure system. A motion proportional to pressure is developed by the use of the range springs located in the upper body. This motion is sensed by a differential transformer. Temperature effects on the range are practically eliminated by the use of cooling fins. The pressure seal is provided by a bellows. A secondary bellows provides protection against the failure of the primary bellows. Bellows leakage may be detected by rise or drop of pressure in the chamber between the two bellows. The pressure drop method is preferable since it results in leakage into the system.

Fig. 4 (ORNL LR-Dwg. 10327) is a weld-sealed, electric-transmission, absolute-pressure transmitter with an operating range of 0-300 inches of water, which is capable of withstanding overranging to 2000 psi. Overrange protection is provided by the convoluted diaphragm backup flange which limits the diaphragm motion. The absolute pressure range is obtained by evacuation of the back side of the diaphragm. This instrument was designed and manufactured by The Foxboro Instrument Company.

The pressure instrument shown in Fig. 5 (ORNL LR-Dwg. 27605) was supplied by the Taylor Instrument Companies. It has a range of 0 to 30 psi absolute and may be completely weld sealed. The instrument will withstand overrange pressures to 500 psi without shift and will contain pressures to 1000 psi without rupture of the body or sealing bellows. The signal output is pneumatic. The sealing bellows serves as a vacuum seal and as a secondary pressure seal. Since it is not normally exposed to high pressure or process fluids, the use of a thin bellows section is not objectionable.

The Norwood Controls pressure transmitter shown in Fig. 6 (ORNL LR-Dwg. 32332) has many features desirable in reactor instrumentation. The twisted Bourdon element is weld-sealed and will withstand high overrange pressure. A secondary seal provides protection against bellows rupture. It is drainable, has a low holdup volume, and the housing may be sealed to provide protection against immersion in water. Units using Ni-Span C Bourdon elements have performed satisfactorily in high-pressure water service on the PWR.¹ A transmitter of this type, but with a 347 stainless steel Bourdon element, has been ordered for test and evaluation at ORNL.

Another type of high-pressure element which may be used is the Baldwin SR-4 strain gauge pressure cell shown in Fig. 7. It satisfies the requirements of containment, drainability and holdup volume, but must be shielded from radiation to prevent damage to the strain gauge bond. Care must be exercised in the installations to prevent errors due to moisture absorption in the cable and to prevent differential temperatures across the cell. Unbonded strain gauge devices show some promise for use in high radiation fields. However, more information is needed on the behavior of strain gauges in radiation fields.

Differential Pressure Transmitters

The design of differential pressure transmitters for reactor service is more difficult than that of pressure transmitters since the forces available for producing motion are much lower. Therefore, since thin flexure members present the possibility of rupture, the use of motion or force transmission through pressure containing flexure members is limited to high range applications. For low ranges, the use of the variable inductance or differential transformer techniques to detect the motion of an iron core inside a pressure containing tube is preferable.

Fig. 8 (ORNL LR-Dwg. 10328) illustrates a 3- to 15-psi output pneumatic-transmission differential-pressure cell which uses a bellows sensing element and an all-welded flexure tube seal. The range of the cell is ± 50 psi with an overrange rating of ± 100 psi. The housing design pressure of the cell is 4000 psi. The unit is completely weld-sealed and fabricated from type 347 stainless steel.

Fig. 9 (ORNL LR-Dwg. 21453) illustrates an electric-signal differential-pressure transmitter which uses a diaphragm or a spring reinforced diaphragm to cover differential ranges from 50 inches of H_2O to 50 psi. The static pressure rating of the transmitter is 4000 psi.

Fig. 10 (ORNL LR-Dwg. 25715) illustrates a differential pressure transmitter of a design similar to the above but utilizing a bellows sensing element which can be specified for differential ranges from 50 to 125 psi. This instrument, as well as the two preceding instruments, was supplied by the Foxboro Instrument Company.

Liquid Level Transmitters

The continuous measurement of liquid level in vessels at pressure has been successfully done by both displacement and differential pressure techniques. The displacement transmitters have been used with ranges as low as 0 to 5 inches of water. The minimum range of the differential pressure transmitters suitable for high-pressure service in reactor environments is about 25 inches of water. The use of differential pressure techniques has the disadvantage that, in order to avoid pressure effects, the differential pressure cell must be located below the lower level tap, and is, therefore, not drainable.

The ORNL developed displacement transmitter shown in Fig. 11 (ORNL LR-Dwg. 14045) consists of a 5-in. long displacer suspended by two helical springs. An extension rod above the springs positions an iron core in the center of a differential transformer. Since the instrument is inherently a spring-mass system, it is subject to oscillation at the natural frequency of the system. In order to prevent these oscillations from reaching an amplitude sufficient to impair the operation of the receiving equipment, eddy current damping is provided by the action of a permanent magnet field on a one-turn copper ring. The copper damping ring and the iron core are enclosed in a 347 stainless steel jacket. All materials in contact with the process fluid are 347 stainless steel, except for the springs which are gold plated. The pressure shell is of all-welded construction except for an ASA 2500 psi ring-joint-flange. The flange construction was provided to make the instrument amenable to remote replacement. The instrument was designed to operate at a pressure of 2500 psi and a temperature of 300°C. It will withstand a cold hydrostatic test of 3750 psi. The range of the instrument may be varied by changing the float length. The sensing coil is a special ORNL designed high-temperature differential transformer. Constant current excitation is provided to minimize temperature effects on the coil. The transmitted signal is 0-20 mv/v at 1000 cps.

It is to be noted that neither the displacement type transmitters or the differential pressure transmitters are compensated for span shifts due to fluid density changes. This can be done manually or automatically, in most cases, from a measurement of the fluid temperature. The displacement transmitters are also subject to zero shifts because of spring modulus changes with temperature. This effect is avoided in the differential pressure transmitters by not insulating long connecting lines to the transmitters.

A second displacement type level transmitter, also developed at ORNL, is shown in Fig. 12 (ORNL LR-Dwg. 14046). This unit has a 47-in. long displacer and is damped by the interaction of two moving vanes attached to the float and a baffle attached to the housing. This unit is rated for a 500 psi operating pressure.

Fig. 13 (ORNL LR-Dwg. 14062) is an all-weld sealed float switch of the type used for high or low liquid-level alarm or control. The mercury switch is tripped by the action of the moving magnetic piston on a permanent magnet. All parts exposed to the process fluid or its vapor are stainless steel. The device is supplied by Magnetrol, Inc., and is rated for 600 psi service.

Heated thermocouple probes of the type shown in Fig. 14 (Photo 30874) have been satisfactorily used for liquid level alarm or control. The thermocouple junction is normally held a few degrees above the vapor temperature; as the liquid level surrounds the probe, the increased heat transfer to the fluid from the probe lowers the thermocouple signal output.

The capacitance probe illustrated in Fig. 15 (Photo 30604), and manufactured by Fielden Instrument Division, has been recently received by ORNL but has not yet been evaluated. The ceramic-to-metal seal is rated at 2000 psi and 636°F.

Inventory Systems

In the operation of aqueous nuclear reactors, it is often necessary or desirable to obtain accurate, continuous inventories of the liquid within a high-pressure vessel. Such inventories may be made by measuring the level and correcting for density and vessel geometry or by weighing the vessel and subtracting the tare weight.

The choice of the system is strongly influenced by the geometry and weight of the vessel, by the accuracy and range of measurement required, and by environmental conditions of temperature, pressure, etc. In general, level systems lend themselves to high narrow vessels and the weigh systems lend themselves to low, wide vessels.

Fig. 16 (ORNL LR-Dwg. 6860) shows a system used for measurement of dump tank and condensate inventories in the HRT. Because of criticality considerations, the tanks were of long, small diameter, cylindrical configuration. The condensate tanks have two 1/2-in. Sch. 40 pipe connections. Piping connections to the dump tanks consisted of four 1/2-in., two 3/4-in., three 1-in., and one 3-in. Sch. 40 pipes. The system shown is used in the fuel low pressure system. A similar system is used in the blanket low pressure system. The condensate and dump tank live and tare weights are as follows:

	<u>Live Wt. (lbs)</u>	<u>Tare Wt. (lbs)</u>
Fuel Condensate Tank	0-500	500
Fuel Dump Tank	0-1600	4220
Blanket Condensate Tank	0-500	500
Blanket Dump Tank	0-2500	5800

An accuracy of ± 10 lbs was requested in the presence of system pressure variations from 0-500 psi, system temperature variations from 0-100°C, ambient pressure variations from 7-15 psia, and ambient temperature variations from 70-140°F.

After investigating several level detection systems, it was decided that the only feasible method of obtaining the desired accuracy was by weighing the tanks. The major problem in weighing was the elimination of the effects of thermal expansion and pressure on the pipe loading. This was accomplished by the use of long pipe runs in horizontal planes and by careful attention to support and anchor points. A suspension system incorporating beams and knife edge was designed so that a given weight at any point in the tank would be transmitted equally to a pneumatic load cell.

The pneumatic load cell, which was supplied by the A. H. Emery Corporation, is shown in Fig. 17 (ORNL LR-Dwg. 6874). This type of load cell was selected for the following reasons:

- (1) It is of all-metallic construction, and therefore, is immune to radiation effects or damage.
- (2) Tare load suppression may be accomplished remotely by adjustment of a pneumatic regulator.
- (3) It may be completely submerged in water without subsequent impairment of its operation.
- (4) The operation utilizes null balance principles and is, therefore, free from zero or range shifts.
- (5) Operation of the cell may be checked remotely.
- (6) Compensation for ambient pressure variations may be provided by the simple addition of a reference pressure connection on the tare regulator.

The load cell system is shown schematically in Fig. 18 (ORNL LR-Dwg. 6873). Air pressure in the weighing chamber is automatically adjusted to counter-balance the applied force minus the force supplied by the tare chamber. This adjustment is accomplished by means of an internal baffle-nozzle and a remote pilot relay.

The accuracy of the load cells is $\pm 1/2\%$. Accuracy of the system is approximately $\pm 1\%$ under quiescent conditions and is better than $\pm 2\%$ under operating conditions.

Flow Measurement

Flow may be measured in high pressure reactor systems by measurement of differential pressure across orifices or capillary tubes or by use of variable orifice or heat balance devices.

Suitable differential pressure transmitters have been described in a previous section.

A variable area device which may be seal welded is shown in Fig. 19 (ORNL LR-Dwg. 14061).

In the heat balance method of flow measurement the temperature difference across a heated or cooled section of pipe is measured. This method is valuable for measurement of erratic, pulsing flows and where restrictions in the pipe cannot be tolerated.

Slurry Instrumentation

The devices discussed were designed for high-pressure, aqueous reactor service. High pressure slurry reactors may be instrumented by using these devices and providing purge streams to prevent plugging and caking. However, in reactor systems, the purge water must be obtained from within

the reactor and equipment necessary to generate and circulate this purge water adds complexity and expense to the reactor system. A development program is underway at ORNL to develop instruments which do not require purging. A flush diaphragm differential pressure element is being designed; capacitance, heated thermocouple and differential expansion level devices are being evaluated, and the electromagnetic and heat balance methods of slurry flow detection are being investigated.

Pneumatic vs Electric Transmission

In a typical reactor system the primary and final control elements are in a radioactive area sealed from the control area by a vapor container and a concrete radiation shield.

Electric - Advantages for electric transmission under these conditions include the ease of readjusting systems zeros and spans from the control room and the ability to sense motion from weld sealed transmitters without the use of flexure seals. The speed of information transmission and the ease of switching signals may also be important. The major disadvantage in the use of electric transmitters in reactor systems is the possibility of radiation damage to the insulating materials.

Pneumatic - Advantages of a pneumatic system include the utilization of all-metallic radiation resistant construction for the transmitters. The advantages of the high state of commercial development, low cost, reliability, miniaturization, and ease of paralleling of receiving elements are also considerable. A great disadvantage of the pneumatic system is the tubing transmission line which affords a possible path out of the radiation enclosure for contaminated fluids or vapors in the event of an explosive rupture of the reactor pressure vessel.

Summary

A wide variety of primary elements suitable for use in high-pressure, aqueous, nuclear reactors is presently available. These instruments are accurate and reliable and satisfy the primary requirement of containment. However, many of the instruments described do not have all the features which are desirable in reactor instrumentation.

The instrumentation described could be adapted to a slurry reactor system; however, it is desirable to develop new instrumentation to eliminate the need for purge streams.

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Figure 1

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ORNL-LR-DWG 26382

PRESSURE TRANSMITTER WITH SAFETY HOUSING

Figure 2

UNCLASSIFIED
ORNL-LR-DWG 23538

Figure 3

UNCLASSIFIED
ORNL-LR-DWG 10327

MATERIAL: STAINLESS STEEL, TYPE 347
RANGE: 0 - 300 in. H₂O
OVER-RANGE: 2000 psi
DESIGN TEMPERATURE: 70 °F
MAXIMUM ALLOWABLE TEMPERATURE: 140 °F
CALIBRATION ACCURACY: 3 %
MAXIMUM HYSTERESIS: 1 %
BODY RATING:
DESIGN PRESSURE: 4000 psi
TEST PRESSURE: 6000 psi
OUTPUT: 1 mv/volt input OVER FULL RANGE

Figure 4

Absolute Pressure Transmitter.

Figure 5

NOTES:

PROCESS CONTAINING PARTS—347 SS
 RANGE—0-2500 psig
 OUTPUT SIGNAL—0 TO 8.5 volts, 60 cps OPEN CIRCUIT
 ERROR— $\pm 1\%$
 TEST PRESSURE—5000 psig
 PRESSURE RATING WITHOUT RUPTURE—12,500 psig
 MAX.—ENVIRONMENTAL TEMP.—200°F
 VENDOR—NORWOOD CONTROLS DIV

Pressure Transmitter.

Figure 6

NOTES:

TYPE—"SR-4" RESISTIVE STRAIN GAGE

RANGE—0 TO 5000 psi

MATERIAL IN CONTACT WITH PROCESS FLUID—NO. 410 S.S.

ACCURACY— $\pm 1/4\%$ OF RANGE

OUTPUT SIGNAL—1.000 mv/v

BRIDGE RESISTANCE—120 Ω

MAX. OPERATING TEMPERATURE—150°F

OVERPRESSURE TEST—200% OF RANGE

VENDOR: BALDWIN-LIMA-HAMILTON CORP.

Fluid Pressure Transmitter.

Figure 7

MATERIAL: STAINLESS STEEL, TYPE 347
RANGE: ± 50 psi
OVER-RANGE: ± 100 psi
DESIGN TEMPERATURE: 70°F
MAXIMUM ALLOWABLE TEMPERATURE: 140°F
CALIBRATION ACCURACY: 2 %
MAXIMUM HYSTERESIS: 1 %
BODY RATING :
 DESIGN PRESSURE : 4000 psi
 TEST PRESSURE : 6000 psi
OUTPUT : 3-15 psi AIR

Figure 8

UNCLASSIFIED
ORNL-LR-DWG 21453

TYPE—INDUCTIVE BRIDGE FOR 1000 cps EXCITATION
RANGE—50 in. H₂O TO 50 psi BY CHANGE OF RANGE SPRING
OVER-RANGE—TO 2000psi WITHOUT DAMAGE
MAXIMUM TEMPERATURE—140°F
ACCURACY—3%
BODY RATING—4000psi DESIGN, 6000psi TEST
OUTPUT—1mv per volt INPUT FOR FULL RANGE
MATERIAL—TYPE 347 STAINLESS STEEL.

Figure 9

DIFFERENTIAL-PRESSURE TRANSMITTER
 TYPE: INDUCTIVE BRIDGE FOR 1000 cps EXCITATION
 RANGE: 0-50 psi TO 0-125 psi BY CHANGE OF RANGE BELLOWS
 OVER-RANGE: HIGH SIDE-2000 psi, LOW SIDE-500 psi
 ACCURACY: 3 %
 BODY RATING: 4000 psi DESIGN, 6000 psi TEST
 MATERIAL: 347 STAINLESS STEEL
 VENDOR: THE FOXBORO CO.

Figure 10

Figure 11

Figure 12

Figure 13

UNCLASSIFIED
PHOTO 30874

Figure 14

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PHOTO 30604

Figure 15

Figure 16

Figure 17

Figure 18

Figure 19