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A DISPLACEMENT TECHNIQUE FOR CALIBRATION OF SPECIAL NUCLEAR MATERIAL TANKAGE VOLUMES

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ABSTRACT

A liquid volume calibration instrument using a nonconventional technique was needed for the sophisticated plutonium processing facility nearing completion at the Rocky Flats Plant of Rockwell International. It features displacement pistons standardized by dimensional inspection and uses automatic microprocessor control to provide validity checks and a complete data record. The instrument calibrates remote Special Nuclear Material (SNM) tankage of special design under program control but retains alternate operation modes and the ability to operate in general environments. Calibration data produced on punched paper tape is directly entered into an associated data base which provides analytical treatment in accordance with ANSI N15.19-1975, "Volume Calibration Techniques for Nuclear Material Control."

Design considerations, operation, and the results of experiments are discussed. Some error sources are evaluated and composite advantages in the calibration of process tankage are given with emphasis on tank volume reliability for SNM measurements.

INTRODUCTION

A new instrument was developed to improve calibration capability for Special Nuclear Material (SNM) tankage at the Rocky Flats Plant (RFP) operated for the Energy Research and Development Administration by Rockwell International's Atomics International Division. This instrument, the Positive Displacement Piston Prover (PDPP), utilizes microprocessor control of directly determined volume standards to provide the sophistication and flexibility required by the new plutonium processing and waste treatment facility it will serve. This processing facility had its origin early in this decade when the then United States Atomic Energy Commission approved and obtained funding for a design answering to rigid requirements for plutonium handling. As the sophisticated design of the facility, and more especially the tankage, progressed, it became apparent that the classical methods of calibrating SNM tankage using open volumetric prover vessels or weigh tanks were not acceptable. Therefore, one of the authors of this paper, Mr. L. H. Morrow, designed the PDPP to deliver precisely known volumes of liquid to the specially designed tankage for calibration in accordance with ANSI N15.19-1975, "Volume Calibration Techniques for Nuclear Materials Control." Development criteria and advantages obtained are discussed below.

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DESIGN CONSIDERATIONS

The primal need in SNM tank calibration is the accurate determination of tank capacity as a function of liquid height and knowledge of the precision of that measurement. This is simplified when short path traceability to the National Bureau of Standards (NBS) exists. Calibration efforts at the RFP also are required to be in accord with the well known NBS philosophy that accurate measurement is a dynamic process requiring periodic confirmation. This reliable measurement of SNM liquids is necessary to fulfill accountability goals which are an integral part of ERDA/contractor security and safeguards programs, and accurate calibration of process tankage is a vital part of the reliability program. SNM process volumes are involved in each inventory accounting and in every internal transfer of process liquids. In addition, nuclear safety engineering personnel are interested in volume changes which might indicate irregularities in the system. Such changes might be caused by sludge buildup or by plating or leaching of the tank interior or its components including the substantial surface area of the borosilicate Raschig ring nuclear poison. Complete and adequately random fill with the Raschig rings also needs to be assured. In addition to these somewhat periodic needs, process engineering personnel are interested in the continuous indication of tank content.

Accurate SNM measurement data from tank calibration is needed in diverse forms for chemical operations, SNM control, and nuclear safety engineering. The PDPP was designed to aid in the convenient production of documented certification for these users as well as for future needs which may have not been completely anticipated. All data from each successful calibration is entered into computer data base where it may be accessed as required. The data base system processes the calibration data and produces certificates on demand.

Since tankage is frequently calibrated efficiency, expressed in minimum man/machine dollars per calibration, becomes an important criterion. The total cost includes the obvious direct costs of calibration services and calibration downtime. Because safety considerations normally require tanks and equipment associated in the module of the tank under calibration to also be held inactive during calibration, there is a large potential economic penalty. Lost time for a typical processing module is estimated to cost two thousand dollars per hour. In recognition of this cost, calibrations are coordinated with required inspections, routine maintenance, and inventory intervals.

Because of differing data needs, two liquid level sensor systems were provided in each tank to be calibrated. One system uses a level transmitter (LT) to provide a continuous analog signal corresponding to the liquid mass in the tank. When the temperature and chemistry of the process liquid are known, its density may be determined. Thus, the differential pressure sensed by the LT corresponds to the liquid height, and through calibration, to the volume content of the tank. The second system gives a digital indication of liquid height at several selected points. Tuned pairs of sealed piezoelectric crystals sense the presence of a liquid bridge when the ultrasonic output of the driver is transmitted to the driven crystal. In addition to the desirable redundancy, this system is less subject to drift and is essentially independent of liquid density. This provides an accurate set of two or four reference points according to tank design. Process liquids having a density different than the calibration liquid, can be referenced this way if necessary.

Personnel access in proximity to the tankage was restricted by design to reduce exposure and enhance safety considerations. Thus, the system design required a calibration fluid line and an electrical panel connection for each tank to be serviced. The panel connection provides a control path to the calibration valve and access to the sensor signals conveniently away from the tankage areas. Another constraint on the calibration system was the decision to transfer liquid process material under positive pressure rather than by gravity or the vacuum techniques previously in use at the RFP.

DESIGN DECISIONS

In consideration of the above needs and constraints, Mr. Morrow elected to design the PDPP rather than use the more conventional techniques of rotameters and volume provers. Piston volume may be determined by direct comparison to dimensional standards with a short traceability path to the NBS. Volume provers calibrated by weighing methods have a derived value, and rotometers usually have the even longer and even more tortuous path through derived volumes. Through his considerable experience using positive displacement pistons to calibrate gas container volumes and to accurately mix gas samples, Mr. Morrow conceptualized a system to deliver precisely known volume increments with insignificant uncertainties to remote tankage. He also mandated the use of a microprocessor to provide the advantages of efficiency, accuracy, simplicity, and safety. System elements are sketched in Figure 1.

While the processing facility has many interesting and advanced safety features, only those influencing the calibration system design are discussed. Obviously, if the SNM tankage were not located in remote, shielded enclosures primarily for personnel safety considerations, a remote calibration system would not be required. Personnel safety also is involved in the mounting of all moving parts inboard or under covers, the use of program control of the calibration system to free the calibrator from tedious or complex routines, and the limitation or fluid pressure to a maximum of 85 psi by using a relief valve. System safety also benefitted from several of these design decisions. Further, in consideration of improbably severe fault conditions, the entire delivery system was designed and dimensioned for critically safe containment. Parts which would be exposed to process solutions if backflow occurred are fabricated from stainless steel, Monel ®, or Teflon ®, so they are resistant to chemical attack, and are in a critically safe array. In addition, the valves were specified to be fail-safe and the PDPP system was made multi-interruptable. Operation can be halted by an emergency button or by error routines in the control program if unsafe or indeterminate conditions are sensed. Interruption can also be initiated from the module control panel by either the process operator or by the fault sensors which monitor the entire module operation. Separate and functionally independent microswitches are used to limit the piston movement if program control fails.

Simplicity, in comparison to alternative systems, is found in verification of the volume elements, data handling, and control. Program control of the system offers essentially one-button calibration although alternate control modes are available. Since the microprocessor gathers and outputs data on punched paper tape, the calibrator need only tear it off and feed it to a data terminal. Thus, since there is no human interpretation of the data between the calibration and the data base, the fidelity of the transfer is assured, and since the devices which provide the data are certified, accuracy is unequivocal. The efficiency gains are those expected in automation for uninterrupted task performance on demand. A typical process tank can be calibrated in less than four hours. The volume elements, the pistons, are easily demounted for dimensional inspection when verification is required, and wheel mounting makes the system conveniently portable. Not only can it serve its intended process tankage, but it can be used to deliver to almost any applicable liquid container in a nonspecialized environment. During verification, it was used with open containers without any external control signals.

OPERATOR CONTROLS

Four connections, two for fluid and two for electrical service, are required to the PDPP in its intended environment. The electrical connections are to a 110 volt power receptacle and to a multipin connector for information and control signals. The fluid connections are a filtered and backchecked inlet and an outlet for the calibration fluid. Manual valves are provided for air bleed from the cylinders if required. Controls are 1) a toggle switch for power, 2) flagged pushbuttons for function selections, and 3) a thumbwheel for use in entering control values and identification data (date, tank number operator number, and time intervals). There are dedicated displays for time-of-day, system pressure, and piston position (distance). Light emitting diodes (LED's) are used to indicate tank fill (low, 1/2, 2/3, high) sensed by the acoustic sensors, and some of the microprocessor control points and signals. A selectable display is used to monitor water temperature, pressure limit value, delay time, or identification values. Input values are received through the multipin cable from the acoustic sensors and the LT, and a valve control signal is sent through the multipin connector to direct flow into the tank under calibration. Incoming data is processed under program control and output in two forms at the end of each piston stroke. A ticket printer outputs a numeric form for human convenience and a puched paper tape is produced for transfer to the data base.

OPERATION

Precisely known volume displacement into the tank under calibration occurs when the microprocessor opens the tank calibration valve and initiates the drive motor. This motor, through a variable speed transmission, turns the drive screw which lowers the pistons into their cylinders. The pistons displace liquid equal to their volume into the tank. A microswitch signals the end of the downstroke to the microprocessor, causing it to close the tank calibration valve. Pressure in the PDPP rises quickly to the cutoff value, signalling for the motor to be stopped. There is a program controlled delay interval for testing pressure drop and, unless an error is sensed, the data for that stroke is printed on the ticket printer and punched in paper tape. When the data output is complete, the microprocessor opens the inlet valve and starts the motor in the reverse direction to raise the piston head, refilling the cylinders with fluid. At the top of the stroke, another microswitch signals the microprocessor to stop the motor and close the inlet valve. After a short interval for motor inertia decay, downward motion is used to again trigger the pressure cutoff routine and pressure drop is sensed as it was at the bottom of the previous stroke. If the pressure drop is within the limits given in the program, initial values for the stroke are sensed and recorded in random access memory (RAM), and a new cycle is begun.

A full stroke requires about six minutes and delivers approximately forty litres; therefore, about four hundred litres per hour can be delivered. About eighty-five percent of the cycle time is used for piston movement, and the balance is used to check pressure drop, allow the motor inertia to decay, and output the data. While these overhead times could be reduced (shorter delay times, data output during piston motion) to slightly increase delivery rate, these modifications were judged not economically justified for current use. In addition to the run time, about fifteen minutes is required to transport the PDPP to location, connect the electric and fluid fittings, input identification values, check and bleed the system, and initiate operation. About five minutes is needed to break connections and restore the system. A data port in the building is used to access the data base. After data transmission and the remote job initiation of data processing, a certificate is returned via electronic printout within fifteen minutes.

ERROR ESTIMATION

The precision expected if the only uncertainty was that associated with piston measurement was calculated using Equation C2 of Appendix C3 of ANSI N15.19-1975. For an average stroke (693 mm, 36.557 ℓ) the volume uncertainty was 0.165 cc, yielding a relative uncertainty of 4.5×10^{-4}% for that stroke. This is approximately the same as the 4.3×1^{-4}% change in the volume of the Monel pistons associated with temperature uncertainty of 0.1°C, and substantially less than the 1.98×10^{-3}% volume uncertainty of water for the same thermal error. Since temperature resolution of 0.1°C is the required resolution and also the design practical limit for the PDPP, the uncertainty due to the coefficient of thermal expansions of the pistons is negligible and their volumes can be considered absolute for this system.

Rocky Flats process water, the calibration fluid, contains less than 800 ppm cation impurities and is considered the density equivalent of distilled water for ordinary tankage calibration.

Another limiting condition is the resolution of the acoustic sensors. In experimental trials they were found to repeat individually to about 45 micrometers (< 0.002 inch) at the ninety-five percent confidence level. Pairs can be expected to differentiate about 64 micrometers at the same confidence level. In the experimental arrangement the pairs were spaced about 456.2 mm (18 in.) apart, producing a relative uncertainty of 1.4×10^{-2}%. In process tankage the lowest and highest sensing points are specified to be just inside the lower and upper tangent lines. While this distance varies from tank to tank, it is normally greater than 18 inches so this error margin is less than 1×10^{-2}%.

Delivery volumes from the PDPP were verified by substitution weighing. The small necked delivery vessels were capped after each delivery and the weight difference was determined using certified laboratory weights. This was corrected for air buoyancy and converted to volume by using standard temperature/density tables. These comparisons were made with fractional strokes and with three-quarter length strokes (called "full" strokes for convenience in the following discussion) of the PDPP. When bias was found in the deliveries which used the pressure set point to stop the motor as described above, a "soft" stop comparison data set was gathered as shown in Table I. A "soft" stop was made by closing the tank valve after the motor is halted. Table I shows that bias was substantially reduced when soft stops were used, but that variability was not.

TABLE I

Stroke Length	Full		Fractional	
Valve Closure Mode	Pressure	Soft	Pressure	Soft
Average Error*	38	9	32	3
Standard Deviation of Error*	12	35	21	15
Average Delivery*	25226	27690	2492	2603
Number of Determinations	9	8	8	11

* Volume in cubic centimeters.

Some caution must be used in interpreting this data of Table I since some conditions other than the stroke length and stop mode were not closely controlled. An example is flexing of the distance readout due to pressure.

The pressure trapped in the PDPP by the pressure check routine varied without apparent pattern within the range of 15 psi to 70 psi for successive checks. Since the position readout system is essentially on a lever arm, small movements of the head biased the position reading and introduced most of the observed error. The system operation was designed to eliminate lash, and since no significant losses of fluid occurred, no other source of bias was found. Fluid losses at pipe joints connections, and the backcheck valve were an order of magnitude smaller than required to explain the error. Measurable leakage did occur at the Teflon chevron stack seals. They are subject to cold creep under the prolonged loading due to slight piston misalignment. However, losses could be measured conveniently and reduced by increasing the compression, and are accounted in the data.

CORRECTIVE ACTIONS

The operating program has been changed to delay the pressure check routine until after the position is read. Data subsequent to the modification is not available for this report. A new style of seal has been ordered to stop the fluid losses. These have some lateral float and will be less subject to creep.

DESIGN RECOMMENDATIONS

Future design should include at least two items to reduce position reading error. Addition of a third guide pin in a triangle configuration would stabilize head motion. Either additionally or independently, mounting the position sensor in the center of the head would average out-of-plane motion to zero.

It is also noted that the microprocessor has capabilities not being used at present. It can, for example, gather data at millisecond or multi-microsecond intervals from existing sensors or from devices which may be added to provide a dynamic record. Although the operating instruction are now stored in a read-only-memory (ROM) by design to prevent unauthorized changes, communication devices and RAM may be added at will to augment the current uses.

CONCLUSIONS

The PDPP is a highly satisfactory instrument for the automatic calibration of remote SNM tankage at the RFP. It provides economical and accurate results and quick return of the calibration certificate. Microprocessor control makes it simple to adapt the PDPP to a general environment or to special tank calibration needs. The design considers the rigid safety responsibilities for plutonium processing plants and the volume calibration techniques specified by ANSI N15.19-1975. Minor design modifications are planned and new experiments will be conducted to evaluate the accuracy and precision which can then be achieved.

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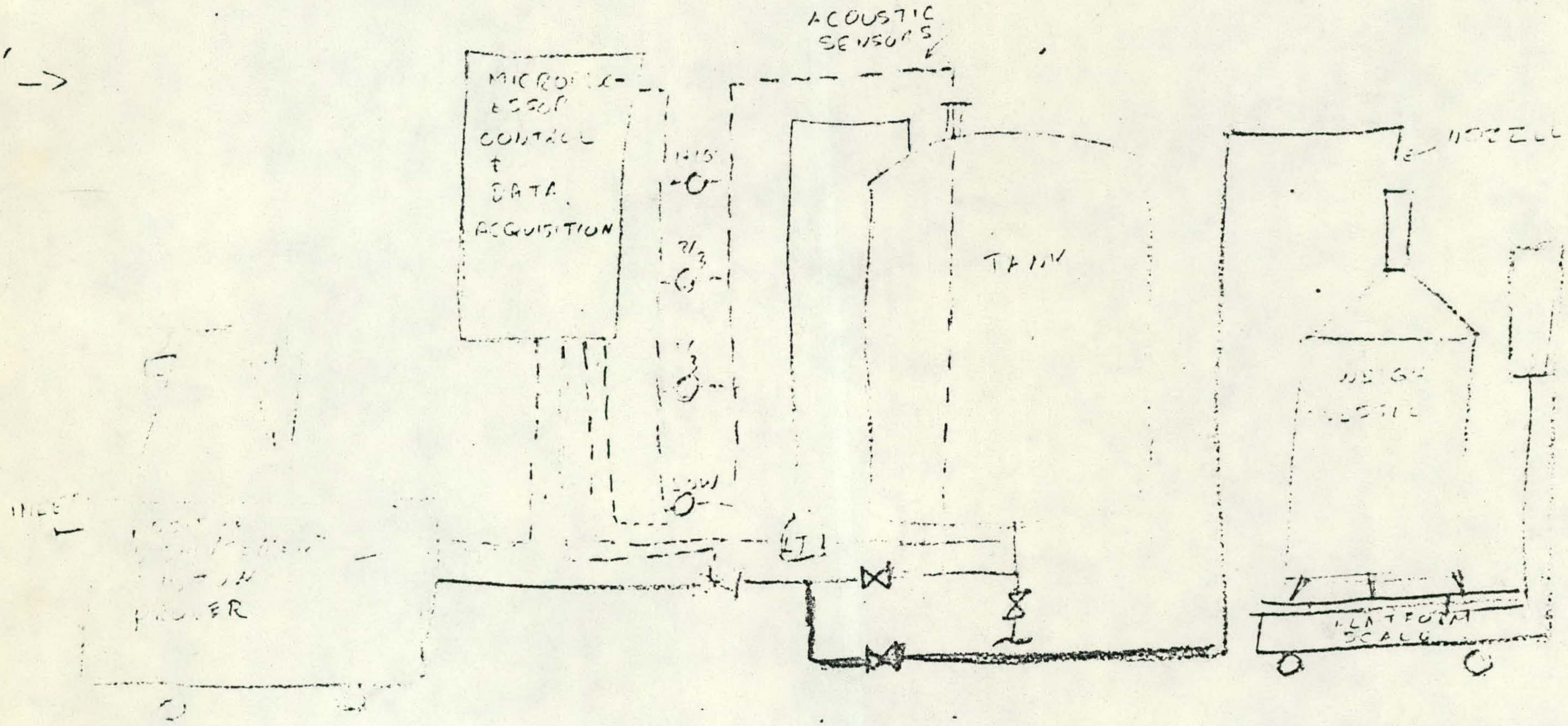

Fig 1. EXPERIMENTAL ARRANGEMENT FOR PDPD

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