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(Quarterly Report No. 1)

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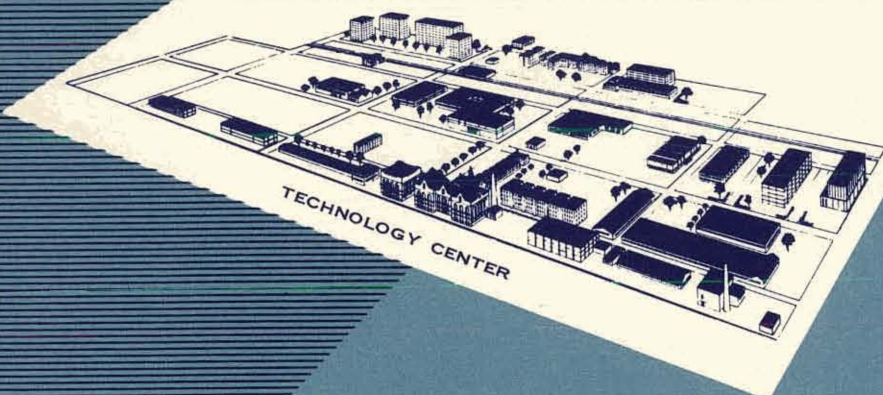

FEASIBILITY STUDY OF A NEW MASS FLOW SYSTEM

G. M. Burgwald

U. S. Atomic Energy Commission
Lemont, Illinois

Contract No. AT(11-1)-578
Project Agreement No. 5

"AEC Research and Development Report"

1-43 007

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of
Illinois Institute of Technology
Technology Center
Chicago 16, Illinois

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to

U. S. Atomic Energy Commission
Chicago Operations Office
P. O. Box 59
Lemont, Illinois

Attn: Steven V. White, Director
Research Contracts Division

(Covering the Period from June 1 to September 1, 1960)

September 21, 1960

143-02

FEASIBILITY STUDY OF A NEW MASS FLOW SYSTEM

I. INTRODUCTION

A number of mass flow devices are described in patent and periodical literature. However, existing devices are limited to specific applications, no general purpose unit being presently available. There are a number of desirable characteristics in mass flow systems, i.e., the ability to measure homogeneous flow, slurries, highly corrosive fluids and multiphase fluids. In addition, considerations such as pressure drop, ability to measure external to the flow, ruggedness and reliability are also important. A mass flow measurement technique capable in principle of meeting the above requirements has been devised, and is the basis of the present experimental investigation. Badger Meter Manufacturing Company, Milwaukee, Wisconsin, is a sub-contractor in this work and the evaluation is being performed on a joint basis.

II. TECHNICAL DISCUSSION

A. Measurement of Mass Flow

In the proposed system, the fluid is made to pass through a U-shaped tube wherein measurements of the angular momentum and density yield mass flow directly. As the fluid traverses the 180 degree bend, a radial force is generated and can be measured externally with a force transducer, such as a strain gauge. Density will be determined by measurement of the absorption of nuclear radiation in the fluid. A density measuring technique investigated on a previous AEC contract appears particularly well suited for this application and will be the basis of the instrumentation for density measurement. This approach uses radiation chopping in a manner to minimize variations in scintillation counter sensitivity. Mass flow is proportional to the square root of the product of force times density and a square root servo will be used to provide mass flow rate directly. Discussion of the bent flow element is included in Badger's quarterly report, which is included as an appendix to this report.

B. Measurement of Density by Absorption of Nuclear Radiation

Use of the absorption properties of nuclear radiation provides a convenient means of measuring either thickness or density of a material without making physical contact with the material. In the more common examples, thickness is measured for a material of fixed composition, or density is measured for a material confined to a fixed volume. Absorption follows predictable relationship, which can be written as

$$I = I_o e^{-\mu \rho x} \quad (1)$$

where

I = transmitted radiation intensity

I_o = unattenuated beam intensity

μ = mass absorption coefficient

ρ = density or specific gravity

x = thickness of material.

The mass absorption coefficient is energy dependent, so that the amount of absorption is very dependent on energy.

An effect which must be considered in the measurement of density is called "composition effect." The relationship in the equation above is true only if the value of the mass absorption coefficient remains constant as the density varies. At low energies, the composition effect can be extreme, since the mass absorption coefficient of a given element changes appreciably at its K-absorption edge. At an energy of one mev, the mass absorption coefficient is reasonably constant for most elements the most serious offender being hydrogen, which has a value approximately twice that of other elements. As a result, if a material contains an appreciable amount of hydrogen by weight, the average mass absorption coefficient will change with composition. Fortunately, in most practical situations, the hydrogen problem is not serious. In addition, if density is being controlled to a fixed value, calibration about a given point is not difficult.

A second effect which must be considered is that the absorption is dependent on the source-detector geometry. Handbook values are given in terms of narrow beam geometry, which implies that any photon scattered in the sample is not permitted to reach the detector. When measuring the density of a fluid flowing through a pipe, the geometry is necessarily of the open variety. This implies that a good deal of scattered radiation reaches the detector, so that the absorption is less than would be expected by narrow beam coefficients. Equation (1) is normal modified to make the expression fit the data. A "build-up" factor is included which may appear as a constant multiplier, or in the exponential term, or in both. In the case being considered, the build-up factor appears only in the exponential term, and it is convenient to use the experimentally determined mass absorption coefficient, rather than the narrow beam value multiplied by a build-up factor.

A parameter of interest is the change in transmitted intensity for a given change in density. Differentiating equation (1) with respect to density gives

$$dI = I_o(-\mu x)\, e^{-\mu \rho x}\, d\rho \qquad (2)$$

Dividing both sides of the equation by I gives

$$\frac{dI}{I} = \frac{I_o(-\mu x)\, e^{-\mu \rho x}\, d\rho}{I_o\, e^{-\mu \rho x}} = (-\mu x)\, d\rho \qquad (3)$$

It is convenient to rewrite the expression in the form

$$\frac{dI}{I} = -(\mu \rho x)\, \frac{d\rho}{\rho} \qquad (4)$$

It can be seen that the change in intensity for a given change in density is directly proportional to the value of the exponent. For example, if $\mu \rho x$ has a value of one, a one percent change in density would result in a one percent change in intensity. Since the value of density is normally defined by the problem, one can vary μx within certain limits to achieve a desired value. A value of $\mu \rho x = 1$ is usually considered desirable, since obtaining larger values normally requires a large source, or working with a smaller signal.

Equation (2) can be written in the form

$$\frac{dI}{d\rho/\rho} = I_o\, (-\mu \rho x)\, e^{-\mu \rho x} \qquad (5)$$

By differentiating equation (5) with respect to density, and setting the expression equal to zero, it is found a maximum is reached at $\mu \rho x = 1$.

C. Instrumental Considerations in the Measurement of Density

A density measuring technique investigated on AEC contract AT (11-1)-745 used a scintillation counter as the radiation sensitive element. The scintillation counter offers the advantage of high detection efficiency and rapid speed of response. However, when used in the normal fashion, the counter does not have the inherent stability necessary for industrial gauging applications. To achieve the desired stability, a double beam technique is utilized in which variations in detector sensitivity are cancelled. The detector alternately looks at radiation transmitted through the sample, and through a calibrated absorber. Any difference in signal causes a servo system to reposition the calibrated wedge such that the difference signal goes to zero.

The original system used dual rotating lead choppers to permit the detector to alternately sample the two radiation beams. Even for a low energy source such as thulium-170, the mass of the chopper was appreciable. In an attempt to minimize the amount of mass which must be moved, the approach being considered is that of moving the source with respect to a fixed lead shield. In this way, only the mass of the source and its protective cover need be moved. Two variations of this technique have been reported in the Russian literature, the first uses a source mounted on a vibrating reed, while the second positions the source on the edge of a rotating disc. Because of characteristics such as simplicity and long term reliability, the vibrating reed technique is being considered. In this system, the two sources are vibrated out of phase so that one is covered when the other is in the open position.

The previous contract further classified dual beam systems into non-commutating and commutating devices. In the non-commutating system, the radiation is chopped at 60 cps, and an error signal directly in the photomultiplier output is used to drive a servo system. In the commutating case, the detector current is commutated into two integrating networks, in sequence with the radiation chopping, the voltage developed across the networks being proportional to the intensity of the two radiation beams. Better results were achieved with the commutation system because it was possible to introduce electrical damping to smooth statistical variations in output. However, it now appears possible to introduce electrical damping in the servo of a non-commutating system, and the old experimental unit is being modified accordingly. Commutating systems are both mechanically and electrically more complicated than the non-commutating variety, so there is argument for the additional investigation.

III. EXPERIMENTAL RESULTS

Experimental measurements were made to determine absorption characteristics as a function of specific gravity and source energy. A range in specific gravity of 1.0 to 1.91 was covered, the 1.91 value representing a saturated solution of zinc chloride. Figure 1 shows the experimental arrangement that was used. The detector consists of a 1-3/4"D x 2" NaI(Tl) crystal coupled to a DuMont 6292 photomultiplier tube. Voltage for the photomultiplier tube was supplied from a Baird-Atomic Model 312 high voltage supply, and the signal was measured with a Keithley Model 410 micro-microammeter. Readings were corrected for dark-current and background radiation level, and all data were normalized to the readings obtained with no fluid in the measurement tube. The results obtained for cobalt-60, cesium-137 and iridium-192 are shown in Fig. 2.

Since the measurement tube is cylindrical, the absorber thickness is not well defined. An approximate average value of thickness was determined from the solid angle between source and detector. Using this thickness, a value of mass absorption coefficient was computed to give the required slope. The following table summarizes the results.

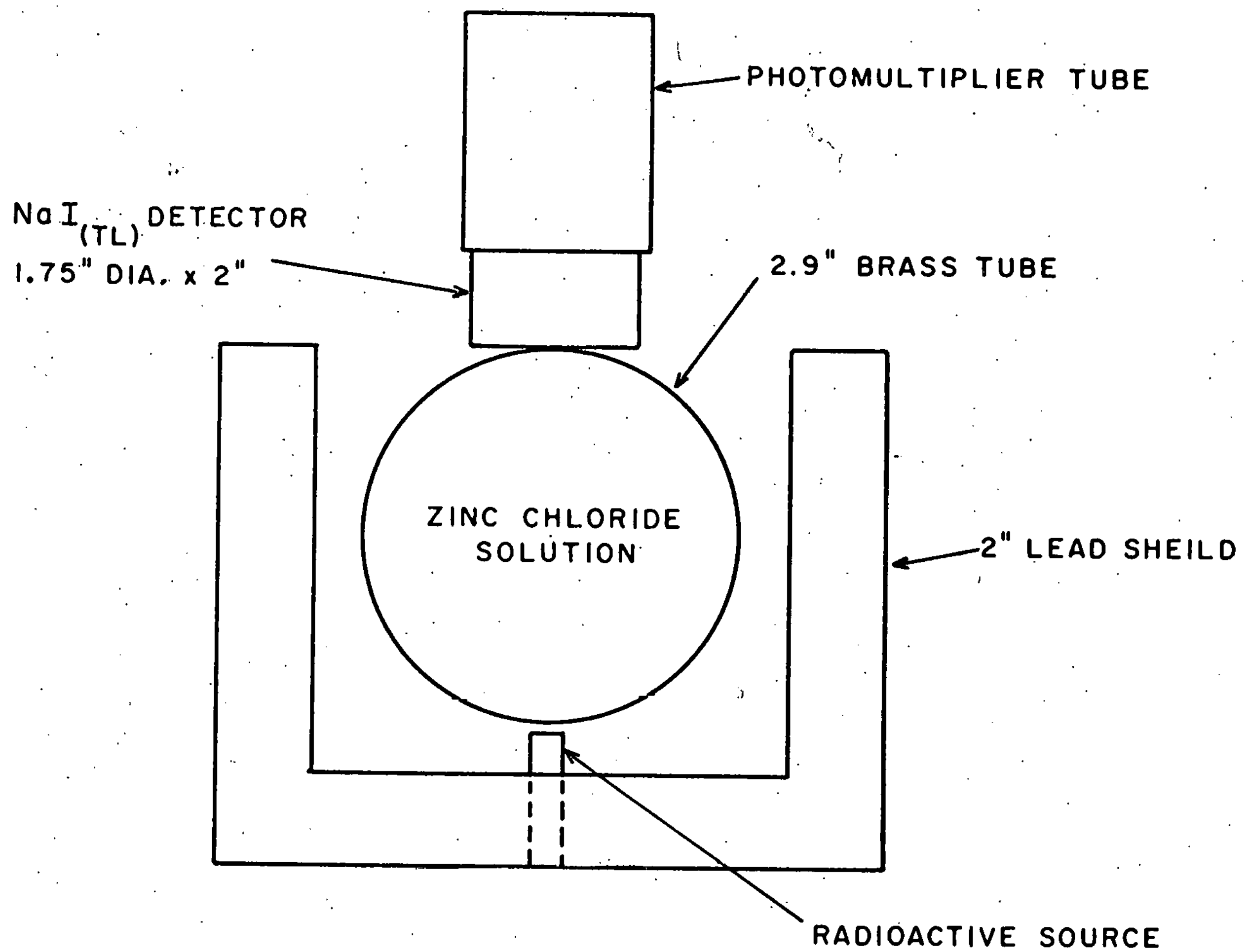

FIG. I - EXPERIMENTAL ARRANGEMENT.

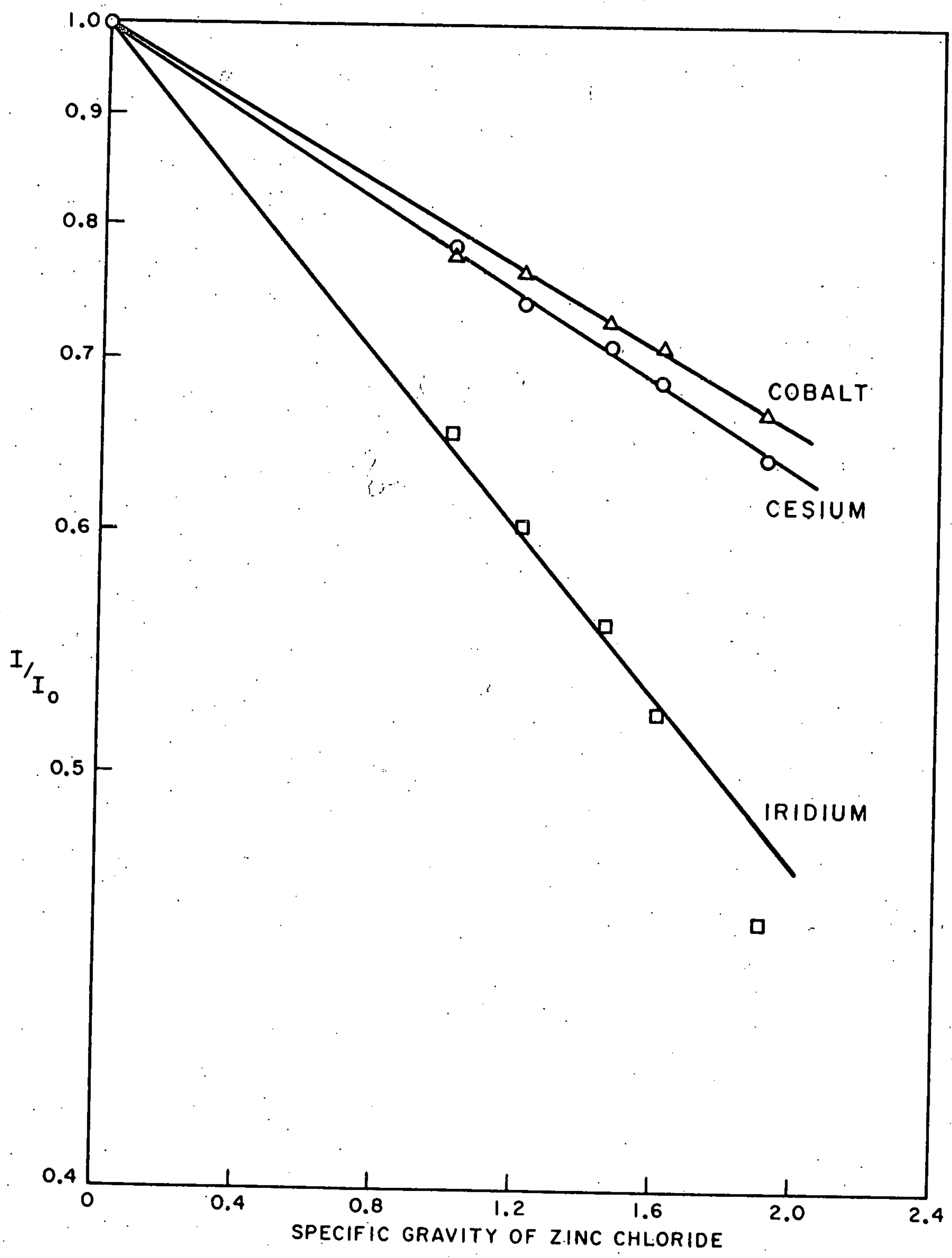

FIG. 2 - RELATIVE INTENSITY.

Isotope	μ (experimental)		$\mu \rho x$	
		$\rho = 1$	$\rho = 1.5$	$\rho = 1.91$
cobalt-60	$0.029\ cm^2/g$	0.21	0.31	0.40
cesium-137	0.032	0.23	0.35	0.44
iridium-192	0.056	0.41	0.61	0.78

It can be seen that for a density of one, the values of $\mu \rho x$ for cesium and cobalt are approximately 0.2, which is somewhat less than the desired value of one. Although iridium has a more favorable value, its short half-life precludes its use.

The data were normalized to the value obtained with only air in the measurement cylinder. This value is not exactly the same as the term I_o described in equation (1). This is because the radiation must pass through the walls of the brass cylinder twice before reaching the detector. However, since this loss is constant and small, the effect might be described as a loss in effective source strength. The experimental mass absorption coefficients are approximately half the "narrow-beam" values given in the literature. This implies that a build-up factor of approximately 0.5 is present due to scattering effects.

Information regarding expected detector signal and statistical fluctuation can also be obtained from the experimental data. For example, the cobalt-60 source had an activity of 34 millicuries, and an I_o detector current of 9 μa was measured with 770 volts across the detector. Actually, the detector voltage can be increased to 1200 volts, which would increase the current. The source used was an available one and the detector voltage was adjusted to limit the current to approximately 10 μa. For a fixed operating voltage, there is a fair variation in gain among photomultipliers of a given type, so that some means of gain adjustment is required in the system.

The current output of a photomultiplier tube is reasonably independent of load impedance so that output pulse height can be increased by selection of load resistor size. In pulse work, a limit is reached because of the effects of capacity across the load resistor. Since the modulation of interest will be at a 60 cps rate, the capacity effects are less serious permitting the use of a large load resistor. For example, if a 10 μa signal was collected across a 1 megohm load resistor, a voltage of 10 volts would be observed. At a density of one, a one percent change in density reflects as an 0.2 percent change in intensity, or a change in voltage of 20 millivolts. To achieve a measurement accuracy of 0.1 percent would imply that a 2 millivolt error signal would be available for a corresponding unbalance in density.

Another consideration is the statistical fluctuation in output signal. An approximate calculation indicates that for the geometry shown in Fig. 2, of the order of a million gamma rays per second are detected by the crystal. If a one second time constant were used at the indicated counting rate, a statistical accuracy of 0.1 percent would be achieved. As a result, it can be seen that selection of source intensity is dependent both on statistical considerations and on the amount of current available from the detector.

Results of vibrating reed tests, a description of the square root servo and a discussion of the test facility are included in the appendix of this report.

IV. SUMMARY

Calculations have been included to show the manner in which mass flow can be determined by measuring density and a radial force. Radial force in the U-tube is measured with a conventional strain gauge, while density is measured by the degree of absorption of nuclear radiation. The use of a double beam technique permits a scintillation counter to be used as the radiation detector. Radioactive sources mounted on vibrating reeds provide a very attractive means of performing the required radiation chopping. Calculations showing design considerations for the reed have been included, and an experimental reed is now operating. Experimental measurements have been made to determine the absorption characteristics for possible sources, and to determine the source intensity required. A square root servo has been assembled and is being tested, and will be used to provide mass flow information from force and density inputs.

Respectfully submitted,

ARMOUR RESEARCH FOUNDATION
of Illinois Institute of Technology

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Director of Physics Research

FEASIBILITY STUDY OF A NEW MASS FLOW SYSTEM

Quarterly Report No. 1

(Period from July 15 to September 1, 1960)

Prepared for Submittal to:

Armour Research Foundation

of

Illinois Institute of Technology
Technology Center
Chicago, Illinois

Contract No. AT (11-1)-578
Project Agreement No. 5
Armour - Badger Subcontract

BADGER METER MANUFACTURING COMPANY
4545 WEST BROWN DEER ROAD
MILWAUKEE 23, WISCONSIN

142 014

1.0 Description of the Mass Flow Rate Measurement Technique

Mass flow rate can be metered by measuring a component of the force necessary to change the direction of flow in a conduit, and the amount of gamma radiation emanating from a nuclide which is absorbed by the flow as the radiation traverses a diameter of the conduit. Signals proportional to force and absorbtion are multiplied and the square root of the product is extracted using conventional analog techniques. A shaft position proportional to this square root provides a read-out for mass flow rates. An essential requirement of this technique is that the force and radiation absorbtion be measured at the same point as shown in Figure 1. The axis of the force sensing element is perpendicular to the direction of the radiation beam. Both are perpendicular to the direction of the flow stream providing a symmetrical orthogonal system. Figure 3 is a block diagram of the complete system.

1.1 Passive Angular Momentum (Bent Tube) Flow Element

A fundamental advantage of density measurement using radiation techniques is that no contact with the fluid stream is required and as a result, the measurement involves no pressure drop and is "sanitary" in the commercial sense. This is also a desirable feature for a mass flow measurement. Shown in Figure 2 is a flow element that offers no appreciable restriction to the flow and relates the variables of density, volumetric flow, and mass flow. As the fluid stream traverses the 180 degree bend, a radially directed force is generated having a component F in the direction of the incoming flow derived as follows:

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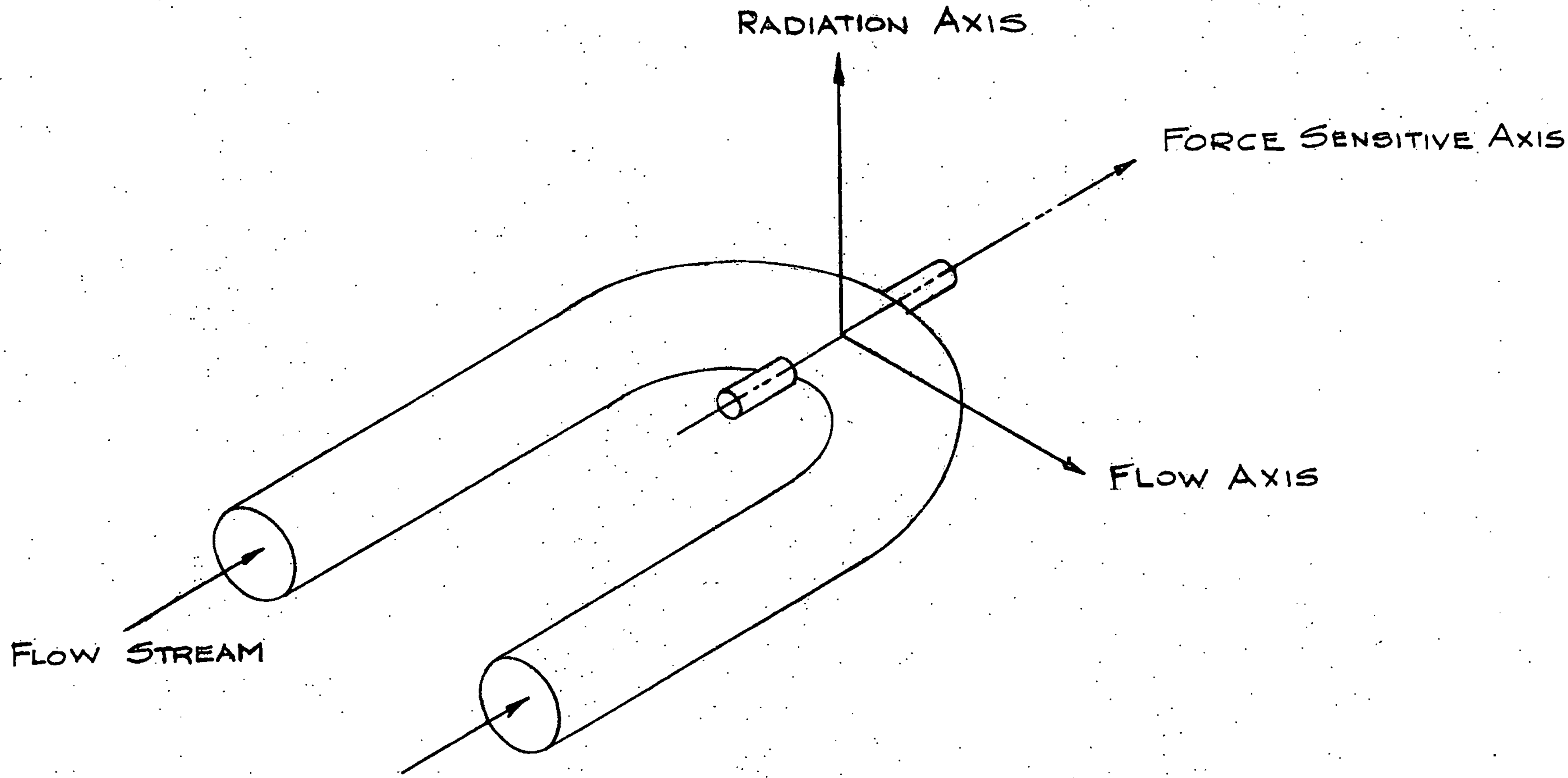

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FIGURE 1 — REV.

SIZE / MODEL / TYPE: ORTHOGONAL MEASUREMENT AXES

PART NAME

PATTERN NO.

REMARKS

MATERIAL

BMMCO CODE NO.

DRAWN: RHS DATE: 4-15-60

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APPROVED: [signature] DATE: 4/15/60

SCALE

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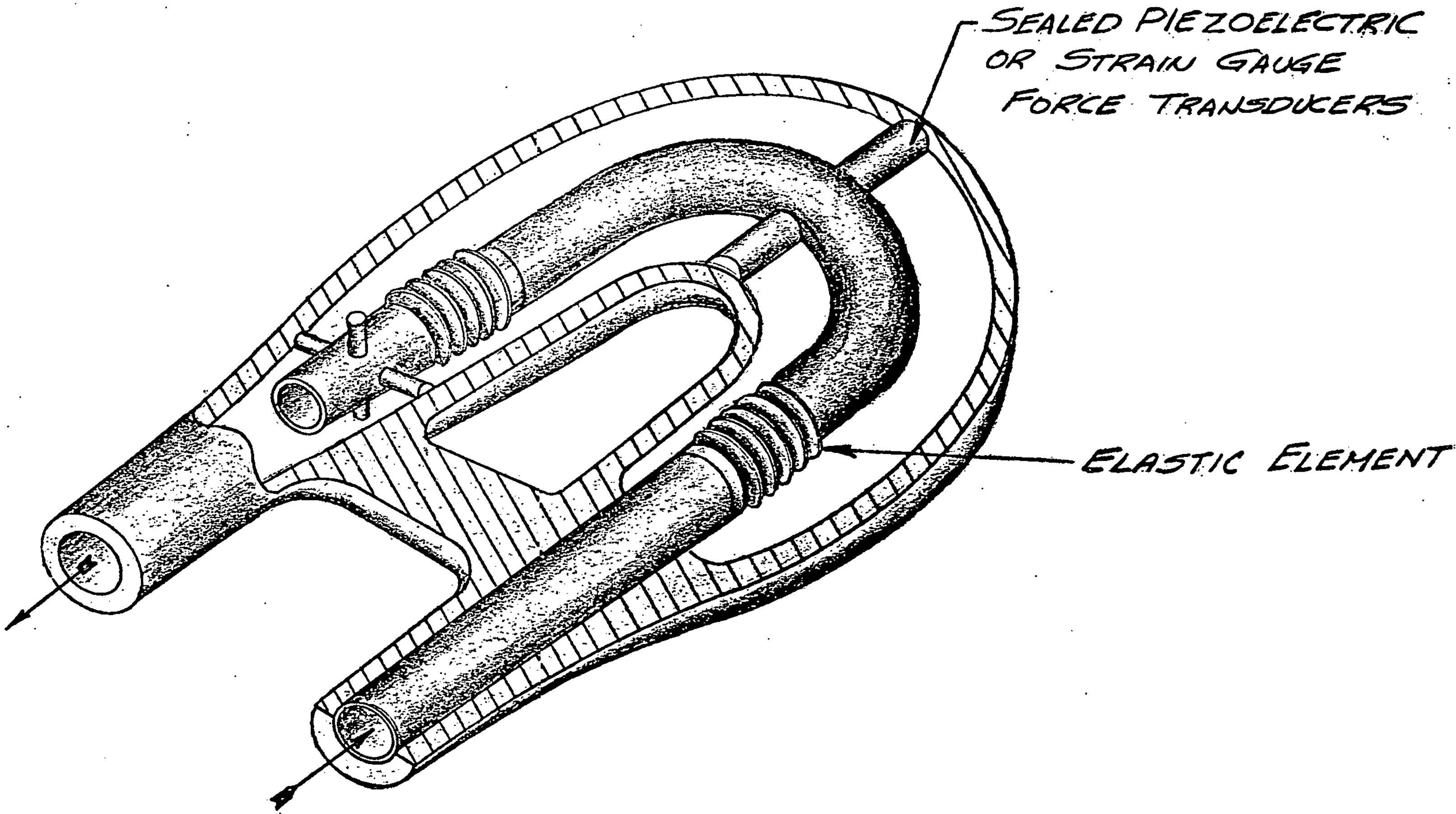

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FIGURE - 2 | REV.

BENT TUBE FLOW ELEMENT

SIZE | MODEL | TYPE

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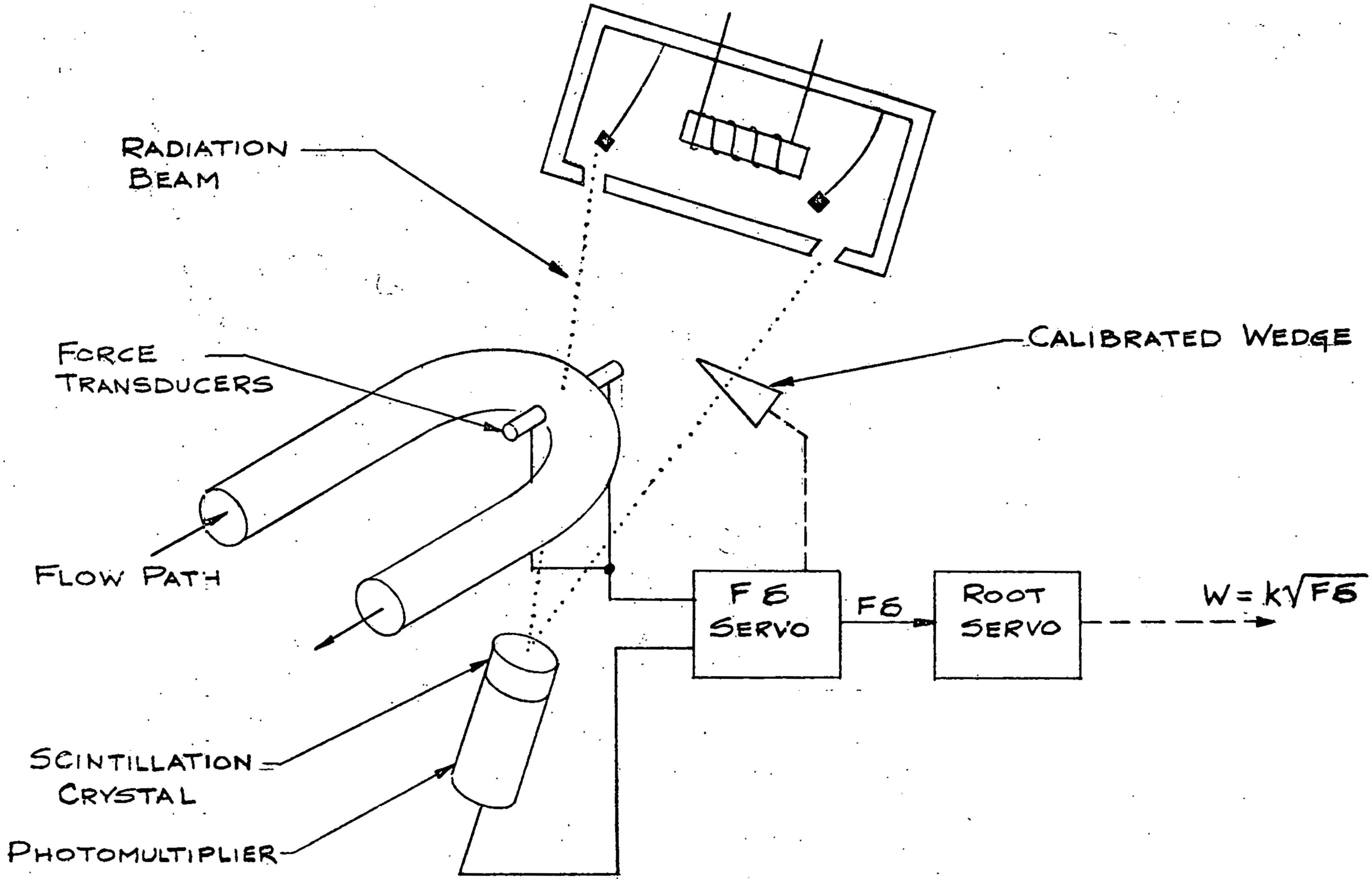

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FIGURE 3 | REV.

SIZE / MODEL / TYPE: SYSTEM MECHANIZATION

PART NAME

PATTERN NO. | REMARKS

MATERIAL | BMMCO CODE NO.

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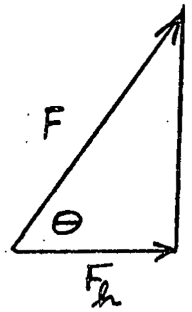
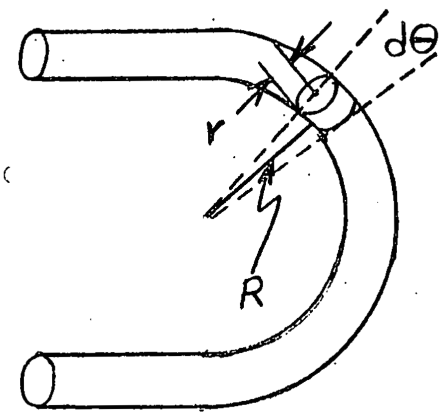
Consider dM to be one element of mass of the fluid traversing a U-tube:





$$dM = \text{(density) (volume)}$$

$$dM = \rho\,(\pi r^2 R d\theta) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

Centripetal force of a mass rotating in a plane about a point in the same plane is

$$F = \frac{M V^2}{R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (2)$$

where V is tangential velocity, R is the radial distance from the point to the mass, and M is mass.

From equations (1) and (2) the element of centripetal force is:

$$dF = \frac{V^2}{R}\, dM$$

$$= \frac{\rho \pi r^2 R V^2}{R}\, d\theta$$

$$dF = \rho \pi r^2 V^2 d\theta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (3)$$

The component of centripetal force in the direction of the incoming flow is $F_H = F \cos\theta$, and

$$F_h = \int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} \rho \pi r^2 V^2 \cos\theta\, d\theta \quad . \quad . \quad . \quad . \quad . \qquad (4)$$

$$F_h = \rho \pi r^2 V^2 \sin\theta \Big|_{-\frac{\pi}{2}}^{+\frac{\pi}{2}}$$

$$F_h = 2\rho \pi r^2 V^2$$

But $Q = V A$ and $V = \frac{Q}{A}$

where Q = volumetric flow rate
A = conduit cross section area

$$F_h = \frac{2\rho \pi r^2 Q^2}{\pi^2 r^4} = \frac{2\rho Q^2}{\pi r^2}$$

Mass flow rate $W = \rho Q$ and $Q = \frac{W}{\rho}$, so

$$F_h = \frac{2 W^2}{\pi r^2 \rho} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Solving for W, we have

$$W = k\sqrt{\rho F_h} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where $k = r\sqrt{\frac{\pi}{2}}$

A measurement of the square root of density times force yields mass flow rate. The analog device for extracting square root is shown in Figure 4. The input to the root servo $F\rho$ is the output voltage from a potentiometer which is excited with a voltage proportional to F and is driven by a shaft whose position is proportional to ρ. The shaft of the root servo is proportional to $\sqrt{F\rho}$ and mass flow rate.

1.2 Density Measurement

Figure 5 illustrates a density measurement technique which makes use of two vibrating reeds which carry sealed radi-

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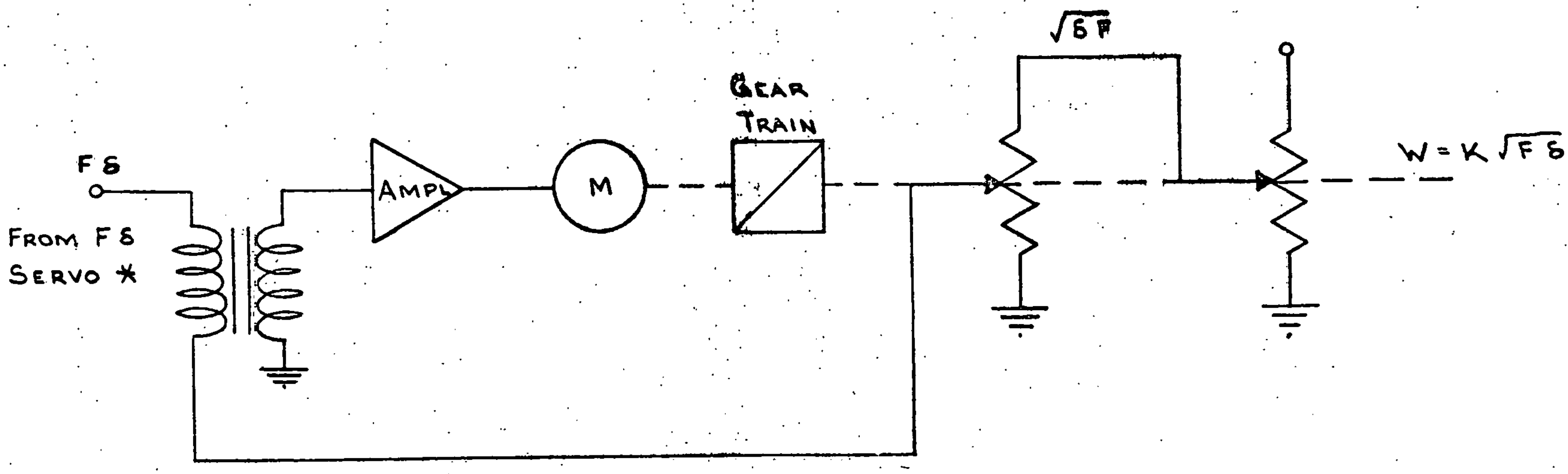

* SEVERAL VERSIONS OF THE Fδ SERVO ARE SHOWN IN FIGURES 5, 6, 7, & 8

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FIGURE 4 | REV.

SIZE | MODEL | TYPE

ROOT SERVO

PART NAME

PATTERN NO. | REMARKS

MATERIAL | BMMCO CODE NO.

DRAWN: DS 4-15-60 DATE

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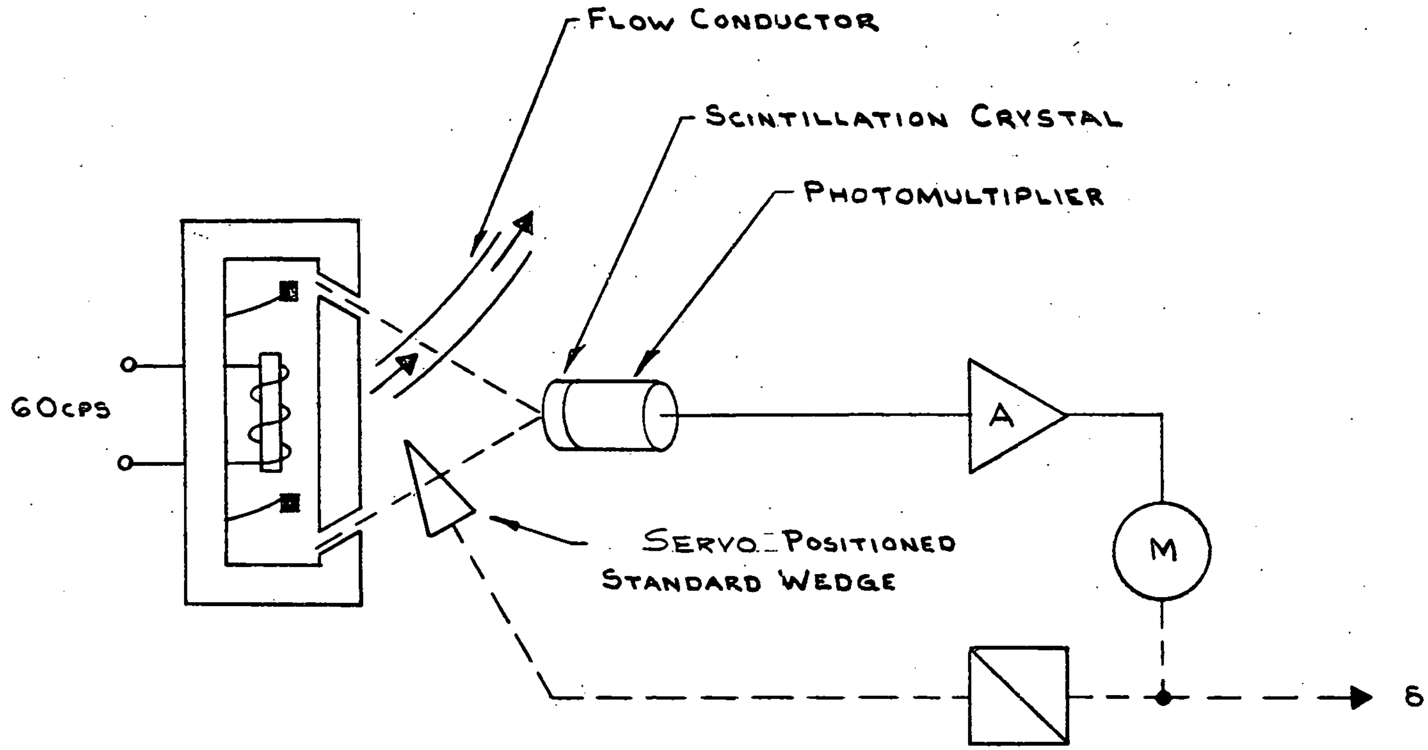

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FIGURE 5 — REV.

SIZE — MODEL — TYPE

DRIVEN REED DENSITY NULL 60CPS
PART NAME

PATTERN NO. — REMARKS

MATERIAL — BMMCO CODE NO.

DRAWN DS DATE 4-15-60
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APPROVED DATE
SCALE

DESIGN PRODUCTS CO.—1000H

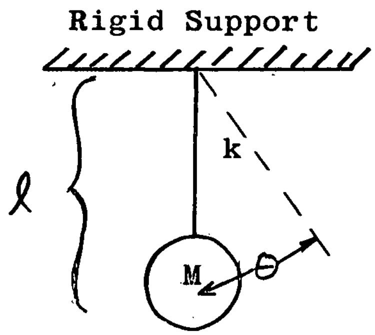
D4173

ation sources buried in their tips. Negotiations are under way with a supplier of radioisotopes to encapsulate sources within reeds supplied by Badger. Encapsulation will be in accordance with AEC sealing requirements.

The two sources vibrate out of phase with each other providing pulses of radiation in an alternative fashion, first through the servo positioned calibrated wedge and then through the U-tube flow conductor. Any difference in density between the wedge and U-tube plus fluid causes a net alternating voltage to appear at the output of the photomultiplier tube. This voltage is amplified and used to reposition the wedge so as to null out the error signal. If the calibration of the wedge is known, the position of the motor shaft driving the wedge is a known function of density.

Great care must be taken in the design of the vibrating reed to eliminate the possibility of reed fatigue and fracture. To this end materials have been selected such that the amplitude and frequency of vibration required bring about stresses which are well within the fatigue limits of the material. To demonstrate the reliability of the reed radiation chopper, a preliminary model was constructed and has been vibrating continuously since the first month of this program. The vibrating reed itself does not make contact with any other member, so wear problems do not exist. These facts combine to provide a radiation sampling technique which should be quite simple and very reliable.

Vibration is sustained by applying an alternating magnetic field to the ferromagnetic material of the reed. If the reed is to be vibrated at line frequency 60 cycles per second, the reed must have an undamped natural frequency equal to 60 cycles per second in order to minimize input power necessary to sustain the vibrations. The equations which describe the motion and the damped and undamped natural frequencies of the elastic reed are the basis of reed design and are derived as follows.



Let a force F be applied to the mass. This force will be resisted by a force:

$$F = k\,\theta + J\,\frac{d^2\theta}{dt^2} + B\,\frac{d\,\theta}{d\,t} \quad . \quad . \quad . \quad . \quad . \qquad (7)$$

where $J = M\,l^2$, the inertia of the mass

k = spring constant of reed

B = viscous damping coefficient of reed

In Laplace notation:

$$F(s) = k\,\theta(s) + J\,s^2\,\theta\,(s) + Bs\,\theta$$

$$\theta(s) = \frac{F(S)}{Js^2+Bs+k} = \frac{A/J}{s^2 + \frac{B}{J}s + \frac{k}{J}} \quad F(S)$$

The characteristic equation $s^2 + \frac{B}{J}s + \frac{k}{J}$ is of the form $s^2 + 2\zeta w_o s + w_o{}^2$ wherein ζ is the damping factor and w_o is the undamped natural frequency. The damping factor is given by

$$2\,\zeta\,w_o = \frac{B}{J}$$

$$w_o = \sqrt{\frac{k}{J}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (8)$$

$$\zeta = \frac{B}{2J} \sqrt{\frac{J}{k}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

In terms of ζ and w_o, the damped natural frequency is

$$w_d = \sqrt{1 - \zeta^2}\, w_o$$

$$w_d = \sqrt{1 - \frac{B^2}{4Jk}}\, w_o \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

The damped natural frequency is slightly lower than the undamped natural frequency. The energy absorbed by the damping restraint of the reed is supplied by the magnetic field. Therefore, the mechanical design frequency used for selection of M, k, and l, must be the damped natural frequency which will be several cycles per second higher than sixty.

The thickness and width of the reed for a given θ and l are selected on the basis of the stress - fatigue characteristics of the reed material.

2.0 Range and Flow Capacities of the Experimental Model

2.1 Flow Rate Range

A U-tube diameter of one inch was chosen to provide a representative flow rate capacity within the capabilites of Badger's hydraulic testing facilities. A tube of this diameter will provide a flow range from 5 to 100 gallons per minute or equivalently, from 40 to 800 pounds per minute. The following table gives U-tube forces and average stream velocities for this flow rate range.

Volumetric Flow Rate Q		Mass Flow Rate W		U-Tube Force F_h	Stream Average Velocity
gpm	ft^3/sec	lb/min	slug/sec.	lb.	ft/sec.
5	.0111	41.5	.0216	.0876	2.035
10	.0222	83.2	.0433	.352	4.07
25	.0555	208	.108	2.19	10.2
40	.0888	444	.231	10.0	16.2
75	.167	623	.324	19.7	30.6
100	.222	832	.433	35.2	40.7

Because mass flow rate is proportional to the square root of centripetal force, a 20:1 range on W requires that the force transducer be accurate over a 400:1 range. The mass flow rates given above are predicated upon the flow of water at 4° C.

2.2 Density Range

Addition of Potassium Carbonate to the water in the mass flow rate test facility will provide a 50 % density change. Potassium Carbonate was chosen on the basis of its chemical properties, cost, solubility, and the available density range. By incremental additions of the solute, known finite changes in density can be brought about ranging between 1 and 1.5 grams per cubic centimeter.

2.3 Square Root Servo Range

The square root servo shown in Figure 4 has been assembled and tested. The amplifier shown is a Kearfott #A3300-01 sixty cycle transistorized servo amplifier and the motor is a Kearfott R-160-5 servo motor. The accuracy and response of the servo over a 400:1 range of the input $F\rho$ is presently being evaluated. The nature of this loop is such that the closed loop gain and positioning accuracy is a function of the output. In order to establish uniform transient response and accuracy over the entire input range, it may be necessary to make the amplifier gain a function of output position.

3.0 Calibration and Test Facilities

Figure 6 illustrates the mass flow meter test bed which will be used to calibrate and test the experimental models. The air compressor, receiver, and pressure regulator provide a pressure head over the fluid in the pressure vessel adequate to sustain a flow of 100 gallons per minute for 1½ minutes down to 5 gallons per minute for 30 minutes. The heating system, cooling system, and associated thermostats maintain fluid temperature at preset settings between $0^{\circ}C$ and $65^{\circ}C$. The output rotation of a positive displacement flow meter drives a synchro transmitter which provides the input to a flow rate control servo. The output of this servo drives a servo controlled valve which maintains flow rate at a preselected setting. The rotameter is used to read coarse volumetric flow rate. The timer controlled valve* directs flow into the flow receiver or into the waste receiver. Load cells mounted below the flow

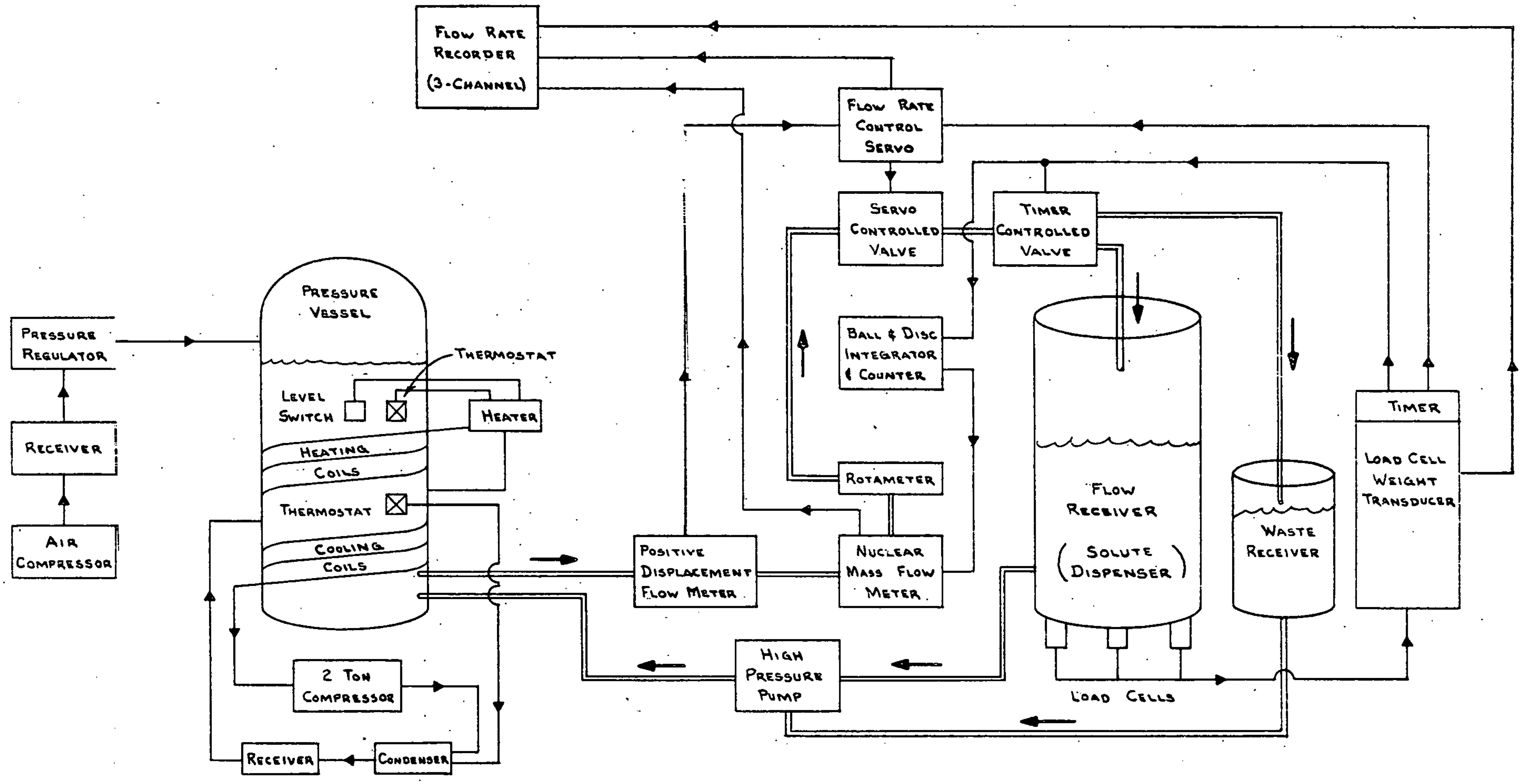
* This valve is a "diverter valve" designed in accordance with National Bureau of Standards procedures shown in "Liquid-Flowmeter Calibration Techniques". Transactions of the ASME, October 1958, Page 1369-1379.

REV.

UNLESS OTHERWISE SPECIFIED

TOLERANCE ON DECIMAL DIMENSIONS ± .005 | TOLERANCE ON ANGULAR DIMENSIONS ± 0° 30 MIN.

TOLERANCE ON FRACTIONAL DIMENSIONS ± .010 | REMOVE ALL BURRS .005 R. MAX. OR .005 MAX. X 45° CHFR.



NO.	CHANGE	BY	DATE

BADGER METER MFG. CO.

FIGURE 6 — REV.

DRAWN: DS 9-6-60

SIZE / MODEL / TYPE

MASS FLOW METER TEST BED

PART NAME

CHECKED: M. Guthe 9/6/60

APPROVED / DATE

PATTERN NO. — REMARKS

MATERIAL — BMMCO CODE NO. — SCALE

DESIGN PRODUCTS CO.—1000H 3M-1-57

receiver continuously weigh its contents and send a signal to the load cell weight transducer. This transducer provides a continuous display and constitutes the primary standard against which the nuclear mass flow meter will be calibrated.

3.1 Test Procedure

a) A flow rate is selected and set into the flow rate control servo.

b) A test time duration is selected and set into the timer.

c) Flow is started into the waste receiver and zero time weight is recorded from the load cell weight transducer and the mass flow meter counter.

d) The timer triggers the timer controlled valve and flow is directed into the flow receiver.

e) After a preset time, the timer redirects the flow into the waste receiver and the run is complete.

f) Comparison can now be made between total quantity which has flowed as measured by the load cell weight transducer and the nuclear mass flow meter.

g) If flow rate was maintained constant during the run (no artificially introduced transients) a very accurate average mass flow rate can be calculated using transducer weight divided by timer interval.

h) If flow rate transients had been introduced by manipulation of the flow rate control servo during the test run, the quality of the mass flow meters transient response can also be evaluated by reading the three tracks of the flow rate recorder.

Respectfully submitted

William K. Genthe
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Approved:

Clayton Fyfe
Chief Research and Development Engineer

M.E. Hartz
Director of Research and Engineering