MASTER

ARF 1167-8

ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

FEASIBILITY STUDY OF A NEW MASS
FLOW SYSTEM

G. M. Burgwald

U. S. Atomic Energy Commission
Argonne, Illinois

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

"AEC Research and Development Report."

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ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY

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February 15, 1961

U. S. Atomic Energy Commission
Chicago Operations Office
9800 South Cass Avenue
Argonne, Illinois

Attention: Steven V. White, Director
Research Contracts Division

Subject: ARF 1167-8 (Contract No. AT(11-1)-578, Project Agreement No. 5) entitled, "Feasibility Study of a New Mass Flow System," covering the period from January 1 to January 31, 1961.

Gentlemen:

A mass flow measurement technique is being investigated which has a number of advantages not found in available methods. In the proposed system, the fluid is made to flow through a curved pipe, wherein measurement of the angular momentum and density yield mass flow directly. As the fluid traverses a radial bend, a radial force is generated and can be measured externally with a force transducer. Density is determined by measurement of the absorption of gamma radiation in the fluid. Badger Meter Manufacturing Company is a subcontractor in this work and the evaluation is being performed on a joint basis.

Machining of the castings for the experimental unit has been completed, and it is now expected that assembly of the unit will be completed by the end of February. Because of the time delay expected before promethium sources will be available for use in the unit, two cobalt-60 sources have been ordered from Nuclear-Chicago. The cobalt wire will be encapsulated directly in the stainless steel reed assemblies. Although absorption of this radiation is not optimum for the effective mass being gauged, it will permit evaluation of the vibrating reed techniques and its associated servo system. With regard to the servo system for the density gauge, a d-c tachometer is being installed on the rotating chopper unit at ARF to further evaluate the use of tachometer feedback for damping statistical fluctuations. The use of a d-c tachometer with a suitable d-c - a-c converter offers much lower noise levels than is possible using an a-c tachometer directly.

Interval review of the progress reports within the Foundation has suggested possible sources of error in the mass gauge system, and part of Badger's report is devoted to a discussion of these errors. It appears that proper design of the S-tube assembly will minimize the effects of the errors.

Respectfully submitted,

ARMOUR RESEARCH FOUNDATION
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BADGER METER MFG. COMPANY

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February 6, 1961

Armour Research Foundation
Technology Center
10 West 35th Street
Chicago 16, Illinois

Attention: Mr. C.A. Stone, Supervisor,
Nuclear Physics Section.

Subject: Contract AT(11-1)-578, Badger Subcontract,
"Feasibility Study of a New Mass Flow System",
report #8 covering the period from
January 1st through January 31st, 1961.

Gentlemen:

Progress during this month is reported in the following paragraphs. Also, consideration is given to possible sources of error in the measurement of flow rate using the S-tube configuration.

a) S-Tube Flow Element.

Machining has been completed and all parts for the S-tube flow element are on hand with the exception of the SC R amplifier. Mechanical assembly of the experimental model should be complete by the end of February and the amplifier added shortly thereafter. Difficulty was encountered in obtaining a calibrated spring of proper characteristics and dimensions for the flow element. However, a suitable spring has been constructed for use at a constant known temperature. This spring will be used in the experimental model. A second spring which is self-compensated for temperature variations is being designed to replace it at a later date.

b) Reed Densitometer.

All parts are on hand except the calibrated wedge, drive motor-tachometer, scintillation crystal, and reed radiation sources. These are scheduled for completion or delivery before March 15th. In the meantime, the completed portions such as the gear heads, readout dial assemblies, and reed shields are being assembled and tested.

Calculations for geometry factor, detector efficiency, and effective absorption along the useful radiation path have been completed. Using these calculations, the reeds are being charged with 100 millicuries of Cobalt-60 to provide counting rates of the order of 10^6 counts per second.

c) Test Equipment.

Load cell equipment has been delivered and calibration checking is proceeding. The flow rate control has been calibrated and performs satisfactorily. Flow rate is maintained constant in the test stand in the presence of long term (30 psia per minute) pressure changes. Response to step transient changes occurs with a damping constant of about 0.6 and an effective response time of 10 seconds (95 % of ultimate reading). Static accuracy is approximately 0.5 % and 0.25 % should be possible.

d) Source of Error in the S-Tube Flow Rate Measurement.

Considering the attached diagram, it has been suggested that several possible sources of error exist which can not be easily compensated. Investigation has shown that some of these errors do not in fact appear to exist, and that other possible sources of error can be avoided by proper design.

1. Due to pressure loss around the two 90° bends in the S-tube, the pressure at the inlet P_1 does not equal the pressure P_2 at the outlet. It was therefore suggested that an error torque would exist equal to:

$$E_{T1} = R A (P_1 - P_2) \dots \dots \dots (1)$$

where A : Effective area over which the total pressure differential acts
 R : Effective bend radius.

However, P_1 and P_2 are conversant with the oil bath surrounding the S-tube through flexible couplings C_1 and C_2 . Therefore a pressure P_3 exists in the oil bath equal to

$$P_3 = \frac{P_1 + P_2}{2} \dots \dots \dots (2)$$

which is the arithmetic average of P_1 and P_2 . For our purposes, the casting which forms the outer container for the oil bath is rigid, and the oil is virtually incompressible (0.1% volume reduction at 100 psi).

Equation (2) holds regardless of the magnitude of P_3 if the radial elastic properties of C_1 and C_2 are the same and flexible relative to the compressibility of the oil and expansion of the housing under pressure. Therefore:

$$\Delta P = P_1 - P_3 = P_3 - P_2 \dots \dots \dots (3)$$

The force due to P_1 is $P_1 A$. It is resisted by a force $P_3 A$. The force due to P_2 is $P_2 A$, resisted by the same counter force $P_3 A$.

Torque about O = $P_1 A R - P_3 A R + P_2 A R - P_3 A R$

$$= A R (P_1 - P_3 + P_2 - P_3) \dots \dots \dots (4)$$

But equation (3) states that: $P_1 - P_3 - P_3 + P_2 = 0$

Therefore the torque about 0 is zero and equation (1) is not valid.

2. Differences in the velocity profile across the pipe at the entrances to the two 90° bends of the S-tube may cause differences between the mean radii R_1 and R_2 . For all flow rates under consideration, flow will be turbulent. Additional eddies and recirculations can be expected to form as the flow passes over the elastic couplings and around the bends. Accordingly it is difficult to predict what the effective flow profile across any pipe section will look like. For any one configuration it would be expected that the effective radii differences would be independent of pressure and would vary repeatably with flow rate, if at all. In this event the flow rate output signal of the meter would depart from a perfect square function in a repeatable fashion and could be compensated. Pressure differences caused by losses due to this local secondary flow produce a torque reaction which is negated exactly as in 1.) above.

3. Unequal pressures P_1 and P_2 will cause unequal areas at the couplings as C_1 expands and C_2 contracts radially. A twofold error is possible as a result.

a) An error torque can arise due to unequal pressure-area products across boundaries 1 and 2.

$$\frac{\Delta P}{2} A \frac{P_1}{P_3} \neq \frac{\Delta P}{2} A \frac{P_2}{P_3} \quad \dots \quad (5)$$

where $A_1 = A \frac{P_1}{P_3}$ and $A_2 = A \frac{P_2}{P_3}$

b) An error torque can also arise due to forces transmitted to the S-tube due to axial stressing of the coupling in both compression and tension.

Neither of these error torques are compensated by the oil bath. These possible errors can be minimized however, by proper selection of coupling characteristics. The coupling must have the following elastic properties:

1) Radial spring constant stiff enough that a 1 psi pressure will cause only negligible radial strain; but flexible relative to the stiffness of the container casting.

2) Axial spring constant very flexible so as to minimize (b).

The pressure drop along the S-tube at 10 gpm is about 0.02 psi, at 100 gpm it is 2.0 psi. A flexible coupling having these characteristics is readily available and is similar to the plastic type used for vacuum cleaner hoses.

e) Percentage Completion.

It is estimated that 48 percent of Badger's work on this program has been completed.

Respectfully submitted,

BADGER METER MFG. COMPANY

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$$P_3 = \frac{P_1 + P_2}{2}$$

$$P_1 - P_2 = \Delta P$$

$$P_3 - P_2 = P_1 - P_3 = \frac{\Delta P}{2}$$

$$\text{For } A = A_1 = A_2 : \text{Error torque} = \frac{\Delta P}{2} A - \frac{\Delta P}{2} A = 0$$

$$\text{For } A_1 \neq A_2 : \text{Error torque} = \frac{\Delta P}{2} A \frac{P_1}{P_3} - \frac{\Delta P}{2} A \frac{P_2}{P_3} \neq 0$$

S-TUBE DIAGRAM