TM-69-5

FLUERIC SENSOR FOR RF-INDUCED CURRENTS IN BRIDGE WIRES

U.S. ARMY MATERIEL COMMAND
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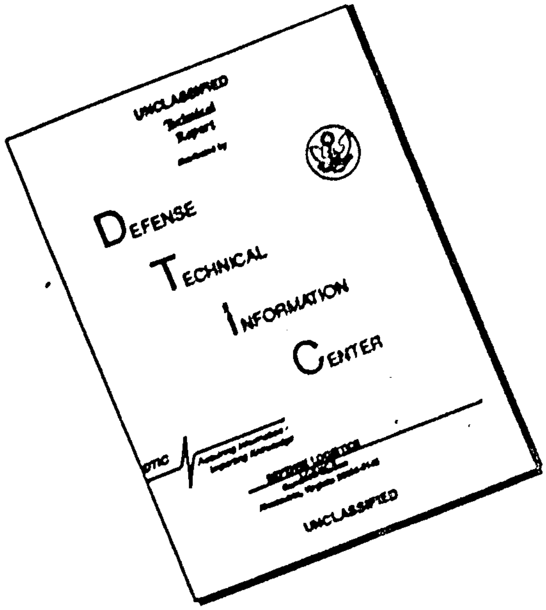

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by

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ABSTRACT

A simple system that employs the nonlinear fluid resistance of an orifice to detect the heat generated by small currents in bridge wires has been tested. The system utilizes the dependence of the orifice flow resistance on temperature to indicate the current through a bridge wire and produces an analog pressure readout. The system has a threshold of about 15 mA (for an 8.5-Ω bridge wire) and a thermal time constant of 3.5 sec. Suggestions are given for possible ways of improving both sensitivity and response time.

FOREWORD

Since electroexplosive devices (EED) containing bridge wires are affected by intense rf fields (e.g., radar), the military is deeply concerned with methods of measuring the induced currents in these wires. In an effort to obtain measurements that are not distorted by the radar fields, the Navy and the RAFRE (Radio-Frequency Effects) committee of AMC agreed with a Harry Diamond Laboratories suggestion to attempt to apply flueric technology to this problem. No exact specifications were established, but it was generally felt that a threshold of less than 10 mA, a response time of less than 50 msec, and a 10-m transmission line would make the flueric system competitive with the already established measurement systems employing thermocouples or other temperature-sensitive electronic devices.

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CONTENTS

1. INTRODUCTION

The bridge wire has been widely used in initiators of explosive charges, explosive bolts, etc. Unfortunately, the lead wires for these bridges can act as antennas in rf fields and have led to premature detonation of charges. Premature detonation constitutes a safety hazard and can lead to aborted missions. To understand and avoid these problems, an extensive series of tests is generally performed to determine the critical radio frequencies and field intensities that are hazardous for the bridge wires in a given military system. Having these data, it is possible to establish realistic criteria for the safe handling of these weapons.

Presently, the data are obtained by using thermocouples or other electronic sensors to detect the heat generated by the induced currents in the bridge wires (ref 1). However, this technique involves an electrical system that is also sensitive to the rf field. It has been suggested that a flueric temperature sensitive system might be used to obtain data that are not altered by the rf field.

Two flueric systems have been proposed for this purpose. The first employs the temperature-sensitive flueric oscillator developed at the Harry Diamond Laboratories. The performance of this sytem is described in reference 2. The second method uses the temperature sensitivity of an orifice and is the topic of the present report.

2. THEORETICAL DESIGN CONCEPTS

It is known that the flow resistance of an orifice is a function of the temperature of the air passing through it. Based on this phenomenon, a system has been devised and tested that attempts to measure the current in a bridge wire. Figure 1 indicates the main features of this system. The system develops a pressure output that is proportional to the square of the current in the wire. The linear resistors are long capillary tubes that have a much greater resistance than the orifices. For a constant temperature and pressure supply, a nearly constant flow passes through each orifice regardless of the small changes in resistance of the orifice as the bridge wire heats the air. The effect of applied heat is to increase the pressure P_1. Unfortunately, spurious changes in the supply temperature or pressure also affect P_1. To eliminate (or at least reduce) the effect of these changes on the output, the upper line has been added, so that the difference $P_1 - P_2$ will depend almost entirely upon the heating of the bridge wire. This requires the two orifices and two linear resistors shown in figure 1 to be identical, so that both P_1 and P_2 will be equally sensitive to supply temperature or pressure.

2.1 Thermal Characteristics

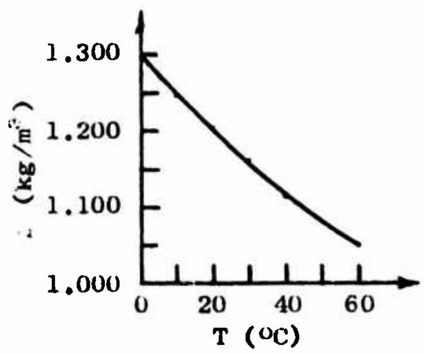
The small size and relatively low resistance (<10 Ω) of the bridge wire make the thermal properties of the measuring system of utmost importance.

The pressure-flow relationship for an orifice is given by the equation

$$P = \frac{\dot{m}^2}{2\rho A^2 C^2} \quad (1)$$

where
P = pressure drop across the orifice
ρ = density of the fluid
C = orifice coefficient
A = cross-sectional area of the orifice
$\dot{m}$ = mass flow through the orifice (held essentially constant)

The inset shows the manner in which the density of air depends on the temperature. A 1-percent change in the orifice resistance* will require that the bridge wire produce a temperature change of 2.5°C. Because very little heat is generated by the bridge wire, such a temperature change is difficult to obtain.



To produce an optimum temperature change, it is necessary to place the bridge wire as near the orifice as possible and to have very little flow in the system. The first of these conditions is needed to prevent the heat that is being generated by the wire from being lost to the surrounding walls.** The second condition follows from a heat balance. The heat generated by the wire H_{wire} is

$$H_{wire} = I^2 R \quad (2)$$

where
I = current through the wire
R = resistance of the wire

Assuming that all of this heat is given off to the gas or air stream, the temperature rise in the gas becomes

$$T = \frac{H_{wire}}{\rho Q C_p} \quad (3)$$

where
T = temperature change in the gas
Q = volume flow rate
C_p = specific heat at constant pressure

From equation (3) it can be seen that the change in temperature increases as the flow rate decreases.

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* Corresponds to a 1-percent change in the density.
**The next section shows why it is impractical to insulate the walls.

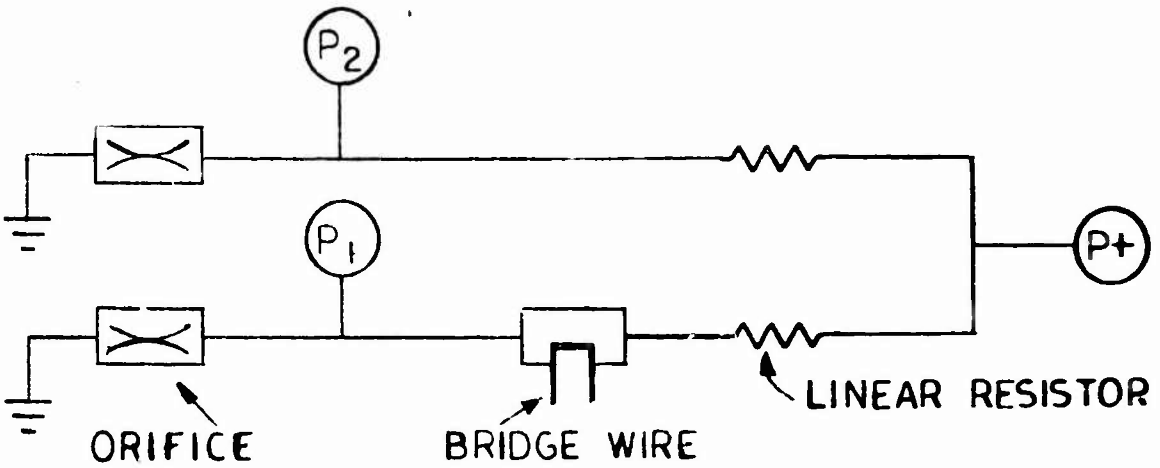

Figure 1. Basic system.

2.2 Thermal Time Constants

An obvious design approach is to place the bridge wire and the orifice in an insulated casing as shown in figure 2. The orifice could be drilled in a thin sheet (of steel) and placed about 2 to 3 mm downstream from the bridge wire. The typical response to a step increase in current through the bridge wire is indicated by the solid line in figure 3. The rapid, initial response corresponds to the thermal time constant of the thin steel sheet. Although the air is heated very rapidly, most of this initial heat will be lost into the cooler metal of the orifice and effectively delay the resulting pressure change until the metal orifice sheet is heated. Because it is impossible to obtain a perfect insulator, the walls will tend to heat up at a slower rate than the orifice sheet and produce the slower of the two time constants shown in figure 3. For the better insulators, it was empirically found that the second time constant approached 1 min.

A better design than the one just mentioned consists in housing the bridge wire and orifice in a copper casing, which acts as a virtual heat sink that tends to eliminate the second time constant. Because of the high heat capacitance and conductivity of the casing, any heat that escapes through the boundary layer and into the casing will be absorbed without a detectable change in the temperature of the casing. In fact, the change will occur so slowly that the dashed line in figure 3 will appear to be followed. By assuming a boundary layer conductivity of 1.75 joules/(m^2-°C-sec) and infinite conductivity in the copper, the thermal time constant for the casing is found to be about 100 hr. Such a large time constant can hardly be detected over a 1- or 2-hr span so that the magnitude of the output signal is effectively decreased slightly while the overall time constant is greatly improved.

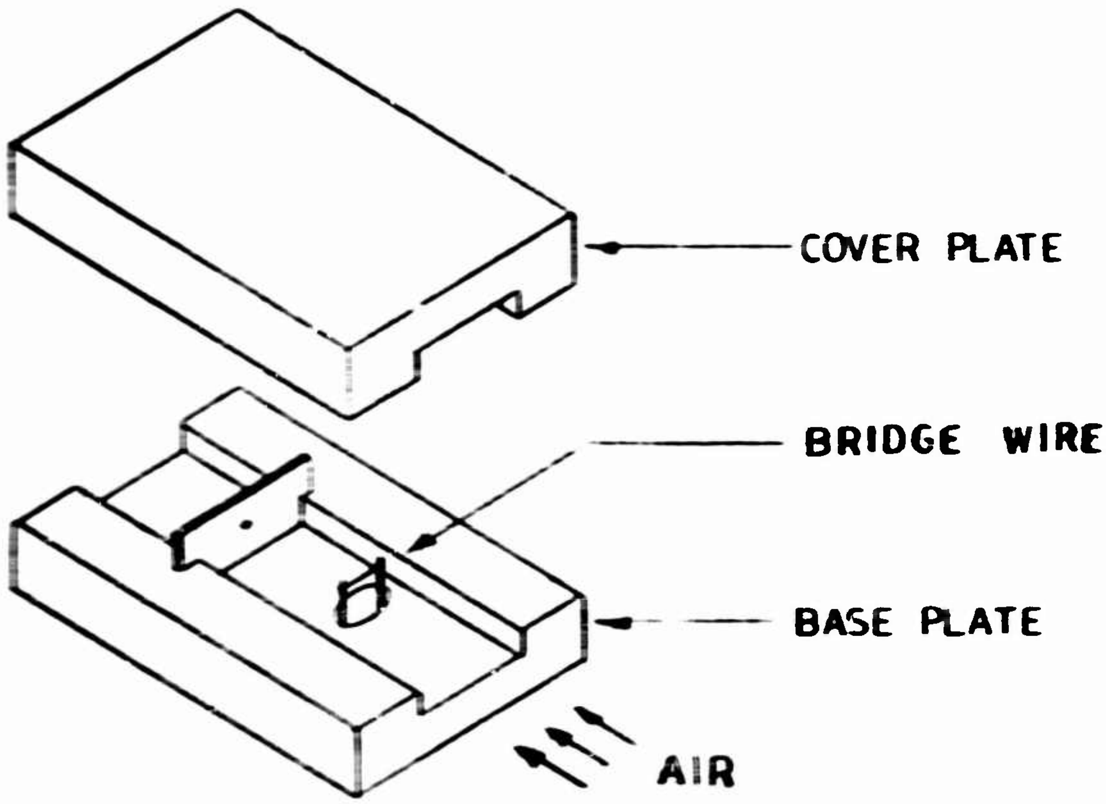

Figure 2. Simplified design.

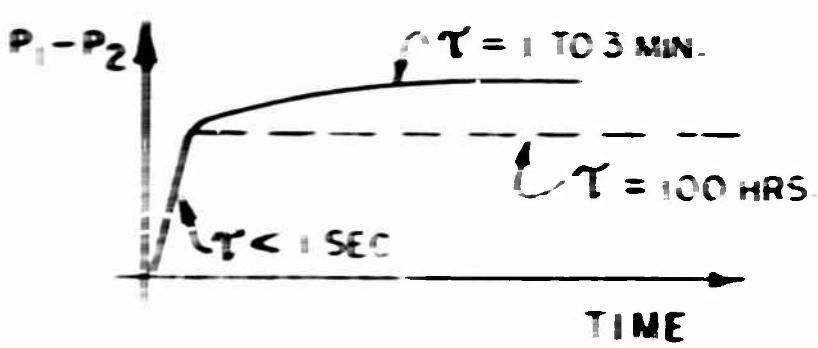

Figure 3. Step responses.

It should be noted that the metal casing enclosing the bridge wire will alter the currents induced in the bridge wire due to its shielding effect. It is hoped that this effect can be neglected. If it can not be neglected, then it is suggested that either a different material be used for the casing or a portion of the canister that houses the explosive charge associated with the EED be used as the casing for the fluid channels.

2.3 Transmission Line and Electronic Compensation

To transmit the pressure signal away from the rf environment, approximately a 10-m line is needed. Due to the distributed resistance and capacitance in this flexible line, the pressure measured at the end will lag the pressure developed due to the heated wire by about 5 sec. It is possible to treat the transmission line as a first-order system having the transfer function

$$G_{\text{transmission line}} = \frac{1}{\tau s + 1} \qquad (4)$$

The expression for the output of a rapidly responding differential electrical pressure transducer placed at the end of this transmission line would become

$$V = \frac{P_1 - P_2}{\tau s + 1} \qquad (5)$$

This electrical signal V will lag the actual pressure signal being generated at the other end of the transmission line by the time constant τ. The electrical signal V can be fed into the network shown in figure 4. This electronic circuit multiplies V by $\tau s + 1$, and the original signal is returned. Although the transmission line time constant is unchanged, the combination of the fluid transmission line and the electronic circuitry produce a signal as if there was no delay in the fluid line.

It should be noted that such a method is reasonable for a known time constant on the order of 5 sec but not for a time constant of 1 min or greater because in the latter case the noise problems due to

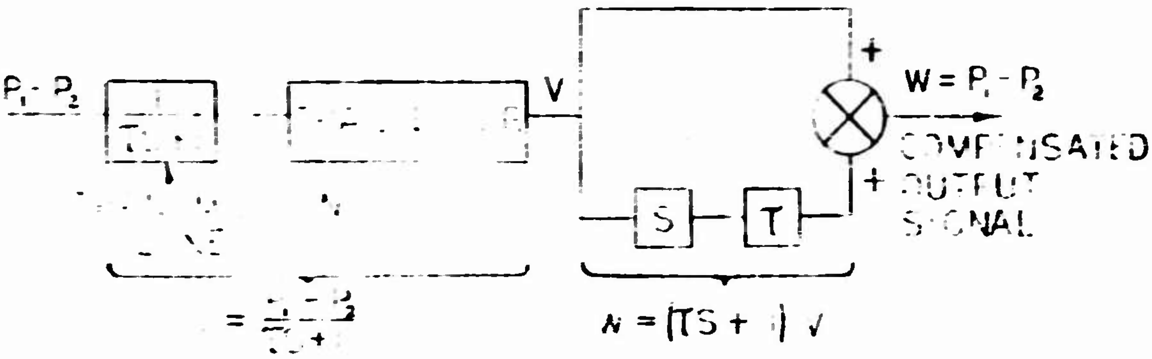

Figure 4. Electronic compensation.

the differentiator are magnified. Even with a 5-sec time constant the basic signal must be relatively noise free to make the compensation scheme useful. Also, the longer the transmission line, the greater the time constant will become, so there will be a practical limit to the distance that the pressure transducers can be removed from the wire that is being tested.

3. SYSTEM DESIGN AND PERFORMANCE

The actual bridge-wire current detector system consisted of two copper plates having two 0.25- by 1.01-mm slots as shown in figure 5. Holes were drilled to allow tubes capped with 0.076-mm diameter orifices to be inserted in the block and positioned near the bridge wire. Clippard fittings were used for the air inputs and to record the output pressures just upstream of the orifices. Figure 6 shows an external view of the entire system. The two slender brass tubes house the capillary resistors. Because of the small diameter of the orifices and the capillary tubes, bottled nitrogen was used instead of compressed air to insure that no dirt particles would clog the lines. The thermal characteristics of nitrogen are very close to those of air.

Figures 7 and 8 show the response of the system to various input currents. The bridge wire used in the system had a resistance of 8.5 Ω. The signal was transmitted through 7.5 m of a 0.6-mm i.d. flexible line. The base lines for the various plots have been separated so that several curves can be shown simultaneously. However, there is a slight amount of d-c drift shown in both figures. In figure 7, the quality of the signals seems fairly good, but in figure 8 the low-level noise becomes apparent as the gain on the x-y recorder is increased by a factor of five. From these figures, a system threshold of about 15 mA seems reasonable. The time constants are about 3.5 sec. No effort was made to compensate these signals electronically, but the relative lack of noise in the basic signal indicates that the compensation scheme should work above the 15-mA threshold.

Although a reasonable degree of success is indicated in figure 7 (i.e., little drift, low noise, a time constant that can be electrically compensated), it must be mentioned that it took a great deal of effort to achieve these results. The system was not entirely insensitive to external temperature and pressure fluctuations because it was impossible to match the two lines indicated in figure 1 to better than within 2 to 3 percent due to the small sizes involved. Also, there seemed to be a small amount of sporadic leakage between the two copper plates that at times became rather severe. While the system output was not too sensitive to reasonable vibrations such as striking the table on which it rested, it was sensitive to changes in position. In general, there is uncertainty about the confidence one could place in the system in a severe field test environment.

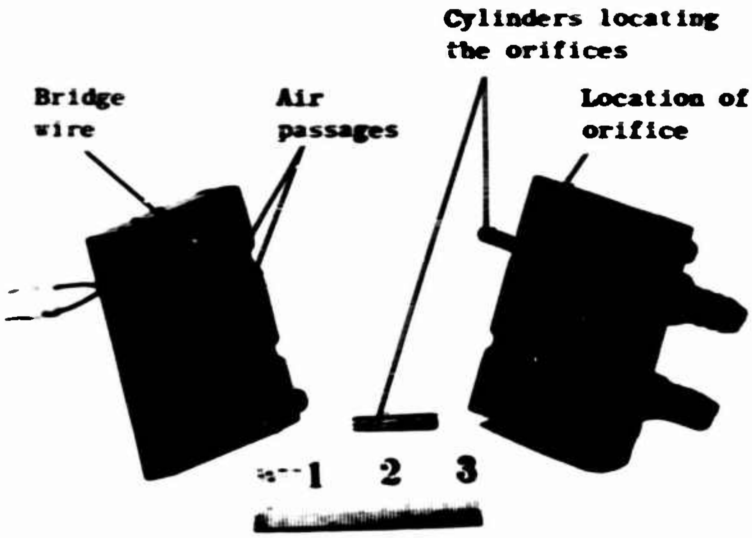

Figure 5. Internal view of bridge-wire sensor system.

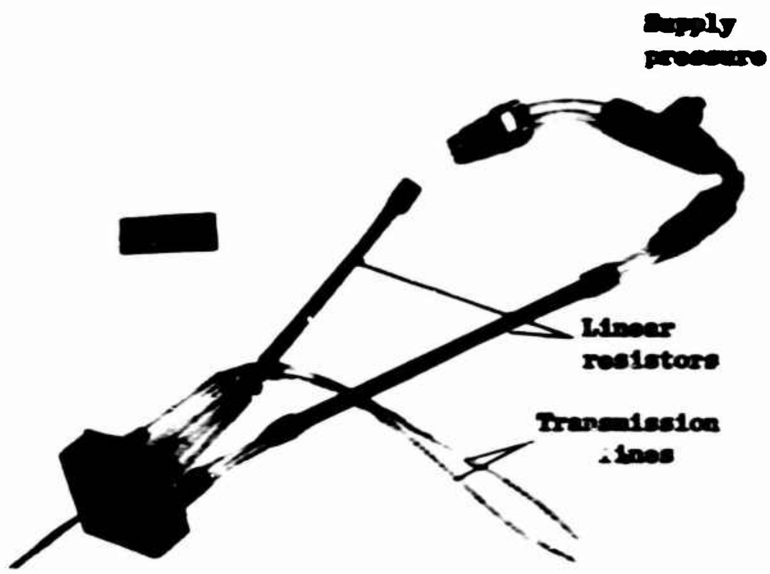

Figure 6. External view of bridge-wire sensor system.

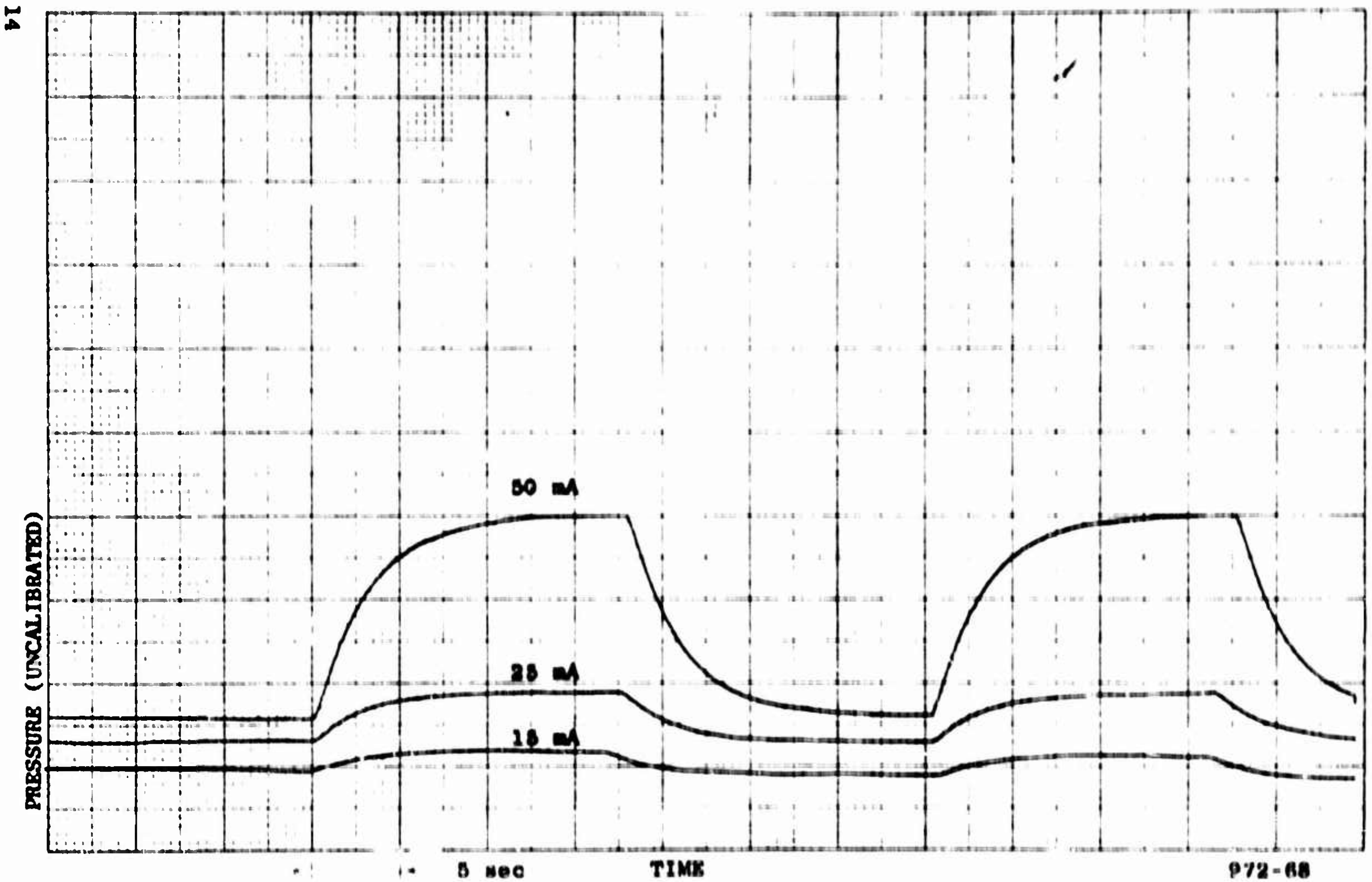

Figure 7. Response to current steps.

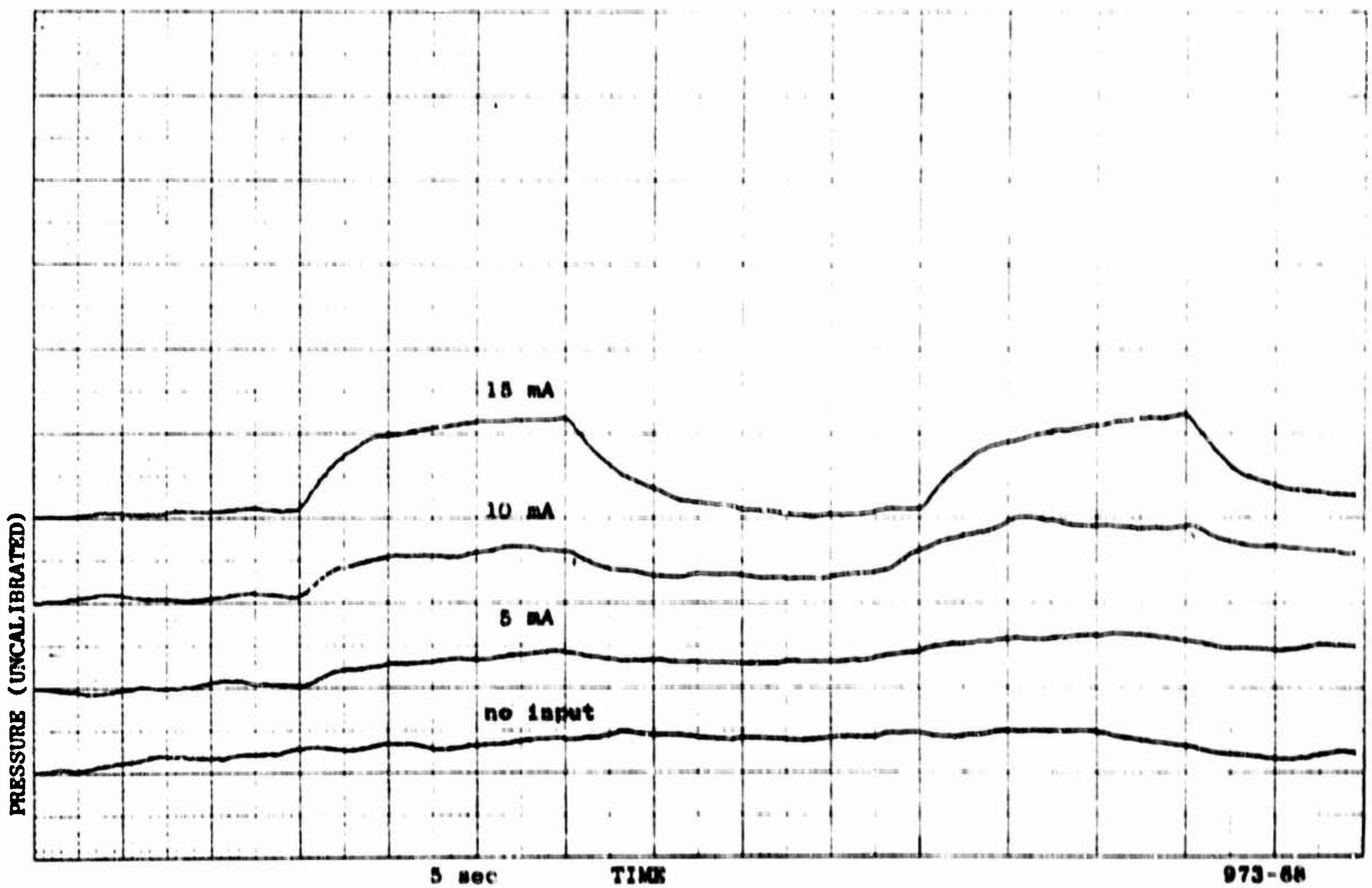

Figure 8. Response to current steps with increased gain.

4. CONCLUSIONS

It has been shown that a constant flow through an orifice can be used to determine the currents in a bridge wire. Because the transmission lines cannot be eliminated, electronic compensation will be required for an improved time response. Due to problems associated with constructing the system, improved designs and fabrication techniques are needed. A better understanding of the causes of the low-level noise in the systems should be sought before attempting to push the threshold lower than its present 15-mA value. Clearly, the sensitivity could be improved by matching the two lines even better than the 2 to 3 percent reported here because any external disturbances causing random noise in the system would have a proportionally smaller effect. Although little heat is being generated by the bridge wire, the heat that is available is probably not being fully recovered. Some heat is surely being conducted down the bridge-wire leads. The use of a colder gas (i.e., below room temperature) would establish a more favorable temperature gradient from the wire to the gas so that a greater percentage of the heat would flow into the gas. Also, the density variations become greater at the lower temperatures. Both a reduction of the noise and an increase in the thermal sensitivity would permit the measurement of smaller currents.

In summary, the present system is fairly simple even with the electronic compensation. The slight amount of d-c drift can be detected (and therefore eliminated) by checking the zero line from time to time during a test. Except for the time constant due to the transmission line, the general requirements for the system have been approximated. The above suggestions to improve the sensitivity were not implemented because the feasibility could be shown without them. Their inclusion might allow a two- to five-fold increase in the system sensitivity.

5. REFERENCES

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Bridge wires	8	3				
Flueric current sensor	8	3				