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RESISTANCE DAMPING

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DESIGN AND TESTING OF A RESISTANCE LINEAR DAMPING DEVICE TO SUPPRESS FLUCTUATIONS IN VENTURI GAGES

Flow measurements in the Hydraulic Laboratory are made primarily with venturi tubes with mercury differential pot gages. It has been the accepted procedure in the past for the average of several mercury gage readings to be used for discharge determinations. Under certain conditions the fluctuations of the mercury column height was so severe that such manual reading was lengthy and difficult. It was felt that for these conditions a device which would damp the oscillations to the average value could be used to advantage.

There are three general types of damping: volume, inertia, and resistance. Volume damping occurs when the gage is so constructed that a large change of volume is necessary to indicate a small change in pressure. Thus, a pressure surge disappears before the gage can fully respond. Such damping is found in wells for hook or float gages. Inertia damping occurs when the gage embodies a large mass which must be moved to indicate a change in pressure. Thus, the inertia of the mass resists motion for rapid, short pulses. Although inertia damping is present to some extent in mercury gages, it is not always sufficient to quiet the level of the gage. Resistance damping occurs when a constriction is present in the gage line. Thus, the flow is limited so that the gage is unable to respond to rapid, short pulsations of pressure. It was felt that resistance damping offered the simplest method of damping the mercury column fluctuations.

Resistance type damping can be classified in two categories: nonlinear and linear. Nonlinear damping is that in which the action is not proportional to the velocity, linear damping is that in which the action is proportional to the velocity. Linear damping occurs only when the flow through the damping device is laminar.

An example of nonlinear damping is that which results from a small orifice in the instrument line. As the head loss is a function of the square of the rate of flow, the damping is nonlinear.

An example of linear damping occurs when a capillary tube is in the instrument line, where the flow in the capillary tube is laminar. Such damping is linear as the head loss is a linear function of the velocity.

It has been shown that if a nonsymmetrical pulsation is applied to a gaging system, the average reading is different for nonlinear than for linear damping 1/. For nonlinear damping the average reading resulting is quite different from the arithmetic average. For linear damping the average reading resulting should be the same as the arithmetic average of the undamped gage readings.

The system for which the damper was designed was considered as an open end mercury pot gage. Then the damping device was considered to be in the gage line to limit the flow to the gage. The device was

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1/ Addison, H., Hydraulic Measurements, John Wiley and Sons, New York, page 64.

expected to damp pressure fluctuations of 5 feet of water with an average pressure of 25 feet of water.

To accomplish linear damping, a capillary tube was chosen because of the simplicity of construction and design. A length of small diameter brass tubing was coiled with the ends attached to the opposite sides of the leaf in a small gate valve. This is shown in Figure 1. Such an arrangement made it possible, by opening the valve, to quickly bleed the major part of the system and to allow the level of the mercury column to attain its approximate steady level. Then when the valve was closed the damping was in effect. It was found to be good practice to also bleed the system with the valve closed to bleed and flush the damper tube.

Two conditions govern the length of the tube. First, it must be long enough to insure laminar flow; and, second, it must be long enough to give adequate damping.

For linear damping to occur, laminar flow must be present in the tube. For water it can be shown that the length of the tube, L, is given by

$$L = 31.2\, D / \left[(16.1)(10)^4 D^2 h - 1 \right]$$

where D is the diameter of the capillary tube, and h is the magnitude of the pressure fluctuations.

For the pulsations to be reduced to a fraction $(1 - x)$ of the original, it can be shown for water that the length of the tubing is given by

$$L = 31.2D \frac{x}{1 - x}$$

For both conditions to be met, the largest of the above two values must be taken as the length of the tube.

Preliminary tests were made with a pilot model using 1/32-inch inside diameter brass tubing with a pot gage where the mercury column was 3/16 inch in diameter. Some 200 readings were made with very frequent checks; in every case the damped gage gave the average of 10 readings from the undamped gage to within the accuracy of the readings.

Later the final model was made and installed. The form of the damper was a brass tube 68.9 inches long with an inside diameter of 1/16 inches. The mercury column is 1/2 inches in diameter. For this size tubing and with the original boundary conditions, the length to insure laminar flow was found to be 40.6 inches. For $x = 0.97$, L was found to be 64 inches.

To test the results of the final damper, flow conditions were set up in the laboratory so that the worst oscillation of the mercury level occurred. This was done so that the operation of the damping device could be easily seen. With conditions prevailing as described, a series of photographs were made of the mercury column and a stop watch. The time interval between exposures was about 0.2 to

0.3 seconds. Two sets of tests were made. One with the damping device not acting and another with the damping device acting. The data taken from these photographs is shown plotted in Figures 2 and 3. Figure 4 shows a typical set of exposures. As seen from the Figures 2 and 3, the damping device acted to materially reduce the fluctuations of the mercury column.

The average of the data for each test was found by a planimeter. The average with no damping is 26.25 inches of mercury. The average with damping is 26.08 inches of mercury. Thus, the damper gives a valve which is within 0.64 percent of the actual average.

It should be pointed out that the conditions as set for the test are much more severe than is usually encountered. Also,the fluctuations of the mercury column may not represent fluctuations in the rate of flow.

In general two methods are used to read the mercury gages, one to take ten readings at a comfortable rate, and two to take readings at a specific interval. Both systems were applied to the data for the undamped gage. Recorded was the time interval between successive readings of a venturi gage which were made by a man who was unaware of the observation. This series of time intervals was applied to the data and the corresponding points were averaged. Second, the points corresponding to taking data every 10 seconds were averaged.

A summary of the results is shown in Table 1.

Table 1

AVERAGE GAGE HEIGHTS FROM VARIOUS TECHNIQUES

Data	Average	% Error
Average of all undamped gage data (true value)	26.25 inches	-
Average of all damped gage data	26.08 inches	0.63
Random data at t = 193 to 301 seconds on undamped gage curve	26.14 inches	0.42
Random data at t = 202 to 310 seconds on undamped gage curve	26.18 inches	0.27
Data takes every 10 seconds starting at t = 190 seconds on undamped gage curve	26.10 inches	0.57

As can be seen from the results, the resistance linear damping device reduces the flustuations to a small value and to an average which is very close to the true average. Although the manual readings give very good results, there is some question as to whether or not unbiased readings can be taken or whether the operator is erroneously influenced by the history of the fluctuations. The damper not only removes this question but also makes the readings much easier to take.

The linear damping device, although introduced to aid in the taking of measurements from the gage, must be used with care as it represents an additional source of error. Errors can be easily

Caution

introduced if the damper is plugged completely. Errors can also be introduced if one end of the damper is plugged in such a manner that appreciable orifice losses occur, this would cause nonlinear damping. Also, if one end of the tube is plugged in such a manner as to cause the discharge coefficient to be different for flow in opposite directions. The latter condition will cause a climbing of the gage in the direction aided by flow in the direction with the smaller discharge coefficient. Even though leaks in the measuring system are always viewed with considerable suspicion; the use of a linear damper amplifies the adverse effects of leaks when they occur between the damper and the gage.

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APPENDIX

List of Symbols Used

D = Diameter of the damping tube

h = Change of head on the damper

L = Length of the damping tube

X = An attenuation factor

h_f = Head loss due to friction losses

h_v = Velocity head

V = Velocity of fluid in the damper

g = Acceleration due to gravity

f = Friction factor of the damping tube

N_R = Reynolds number

ν = Kinematic viscosity

Finding the length of a damping tube to insure laminar flow.

for the capillary tube, see Figure 5

$$h = h_f + h_v = f\frac{L}{D}\frac{V^2}{2g} + \frac{V^2}{2g}$$

$$h = \frac{V^2}{2g}\left(1 + f\frac{L}{D}\right)$$

for the flow to be laminar

$$N_R < 2000$$

taking $N_R = 2000$

As $\quad N_R = \frac{DV}{\nu}$

$$D\frac{V}{\nu} = 2000$$

or $\quad V = 2000\frac{\nu}{D}$

for laminar flow

$$f = \frac{64}{N_R}$$

then, letting $N_R = 2000$ for laminar flow

$$h = \left(\frac{2000\,\nu}{D}\right)^2 \frac{1}{2g}\left(1 + \frac{64}{2000}\frac{L}{D}\right)$$

solving for L

$$L = \frac{2000\ D}{64}\left(\frac{2gD^2h}{(4)(10)^6\,\nu^2} - 1\right)$$

for water letting $\nu = 10^{-5}$

$$L = 31.2\ D\left[(16.1)(10)^4 D^2 h - 1\right]$$

For the pulsations to be reduced, h_v must be small so that the gage cannot respond quickly.

Let $\frac{h_f}{h} = x$, an attenuation factor

then:

$$x = \frac{f\frac{L}{D}\frac{V^2}{2g}}{f\frac{L}{D}\frac{V^2}{2g} + \frac{V^2}{2g}}$$

or

$$x = \frac{f\frac{L}{D}}{(1 + \frac{fL}{D})}$$

solving for L

$$L = \frac{D}{f}\left(\frac{x}{1-x}\right)$$

for laminar flow

$$f = \frac{64}{N_R}$$

and $N_R = 2000$

Then

$$L = \frac{2000\ D}{64}\left(\frac{x}{1-x}\right)$$

or

$$L = 31.2D\left(\frac{x}{1-x}\right)$$

<u>Calculations:</u>

for $D = 1/16$ inch

$h = 5$ feet water

$$L = \frac{(2000)}{64}\left(\frac{1}{16}\,\frac{1}{12}\right)\left[(16.1)(10)^4\left(\frac{1}{16}\,\frac{1}{12}\right)^2 5 - 1\right]$$

$$L = \frac{10.4}{64}\left[21.8 - 1\right]$$

$$L = 3.38 \text{ ft}$$

for $x = 0.95$

$$L = (594)\left(\frac{1}{16}\right) = 37.1 \text{ inches}$$

for $x = 0.96$

$$L = \left(\frac{1}{16}\right)(31.2)\left(\frac{0.96}{0.04}\right) = 46.8 \text{ inches}$$

for

$x = 0.97$

$$L = \left(\frac{1}{16}\right)(31.2)\left(\frac{0.97}{0.03} = 64 \text{ inches}\right.$$

for $x = 0.98$

$$L = \left(\frac{1}{16}\right)(31.2)\left(\frac{0.98}{0.02}\right) = 95.5 \text{ inches}$$

for $x = 0.9721$, $L = 68$ inches

for $x = 0.9724$, $L = 68.9$ inches.

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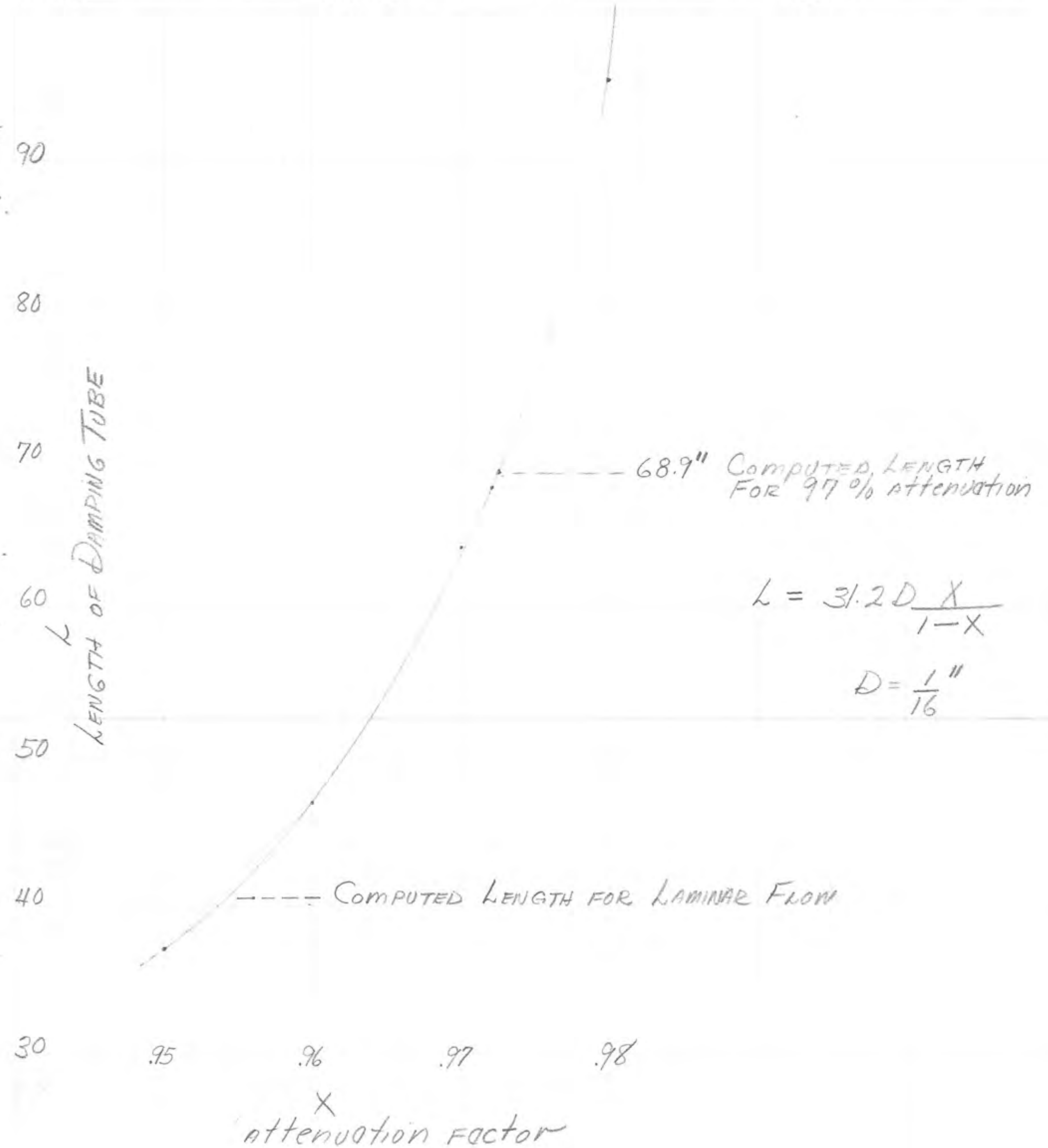

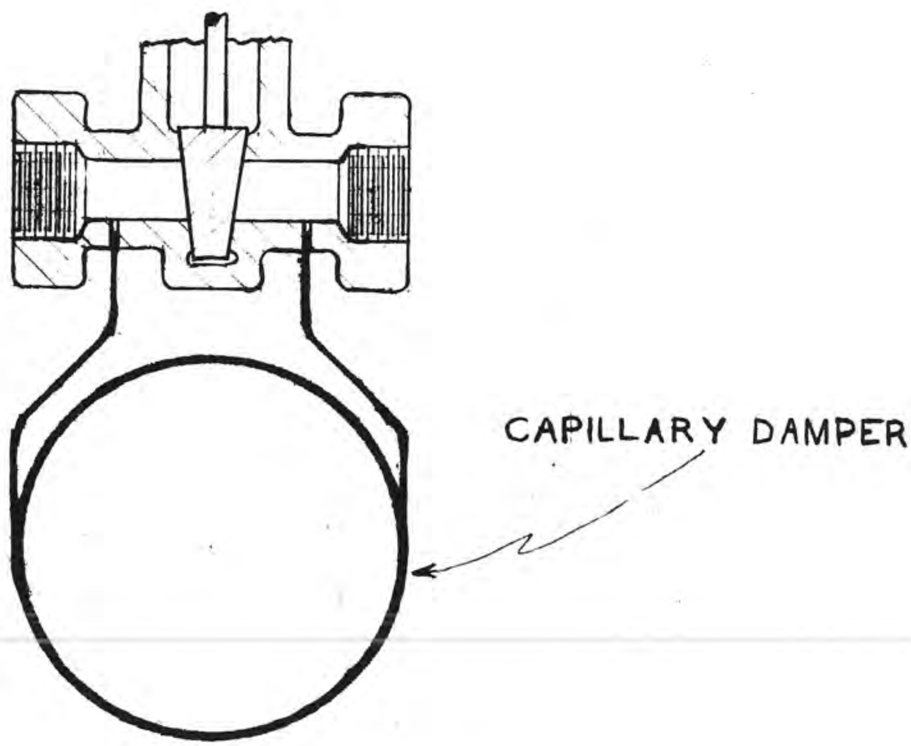

FIG. 1

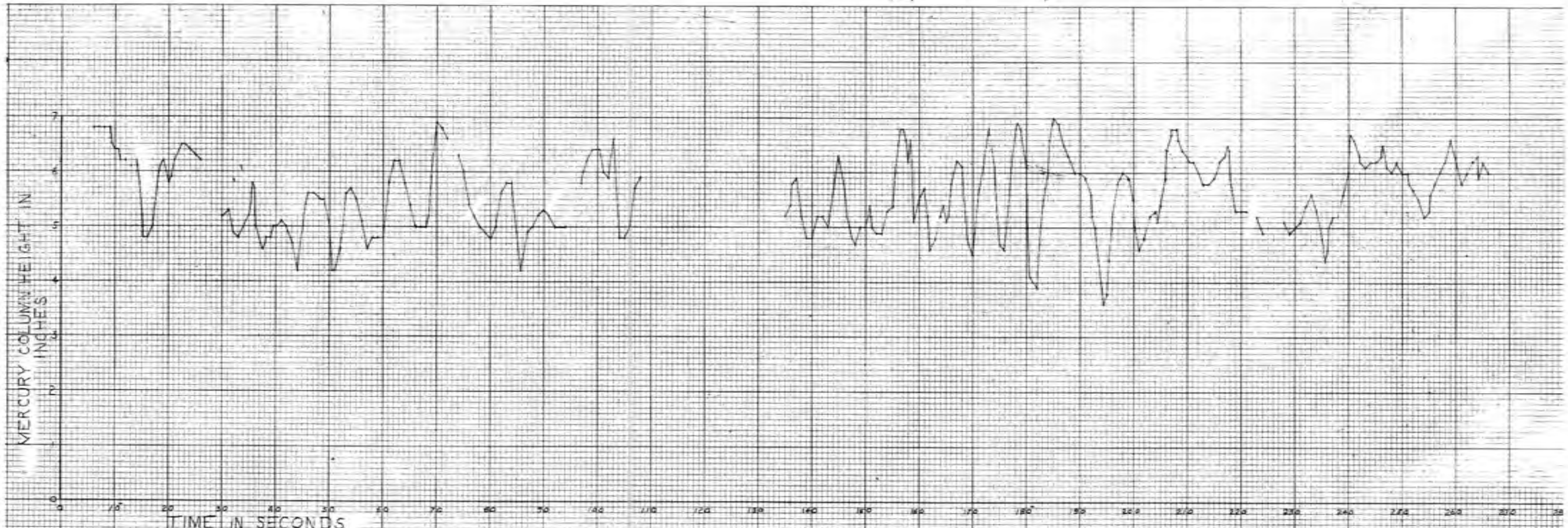

FIG. 2
UNDAMPED MERCURY GAGE HEIGHT VS. TIME

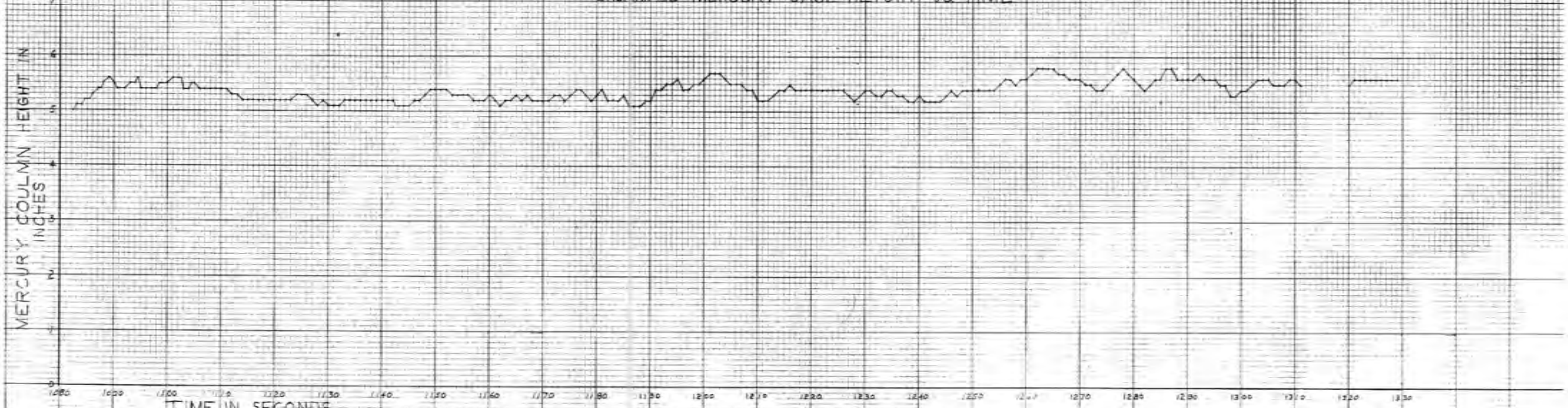

FIG. 3
DAMPED MERCURY GAGE HEIGHT VS. TIME

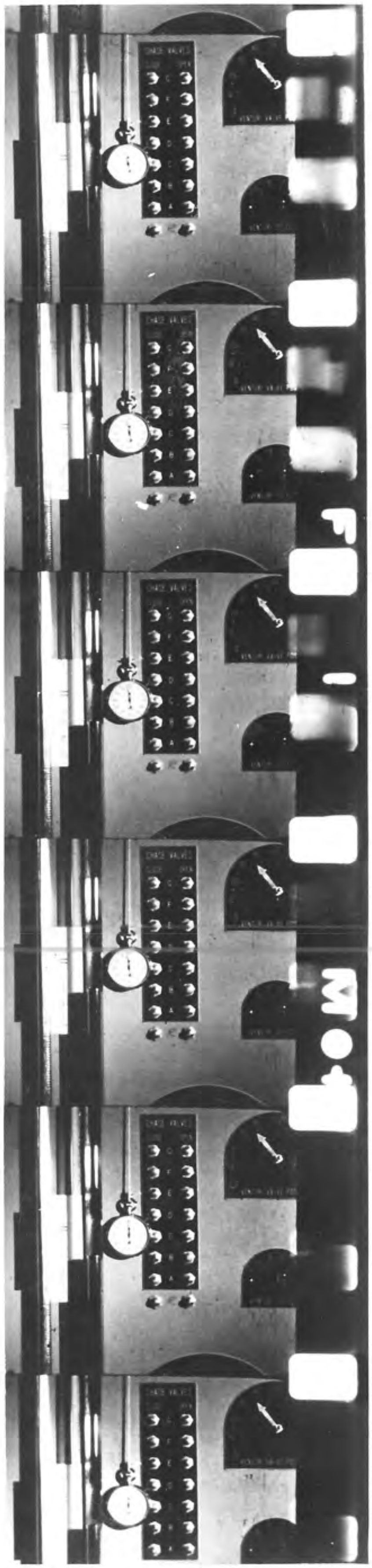

Figure 4

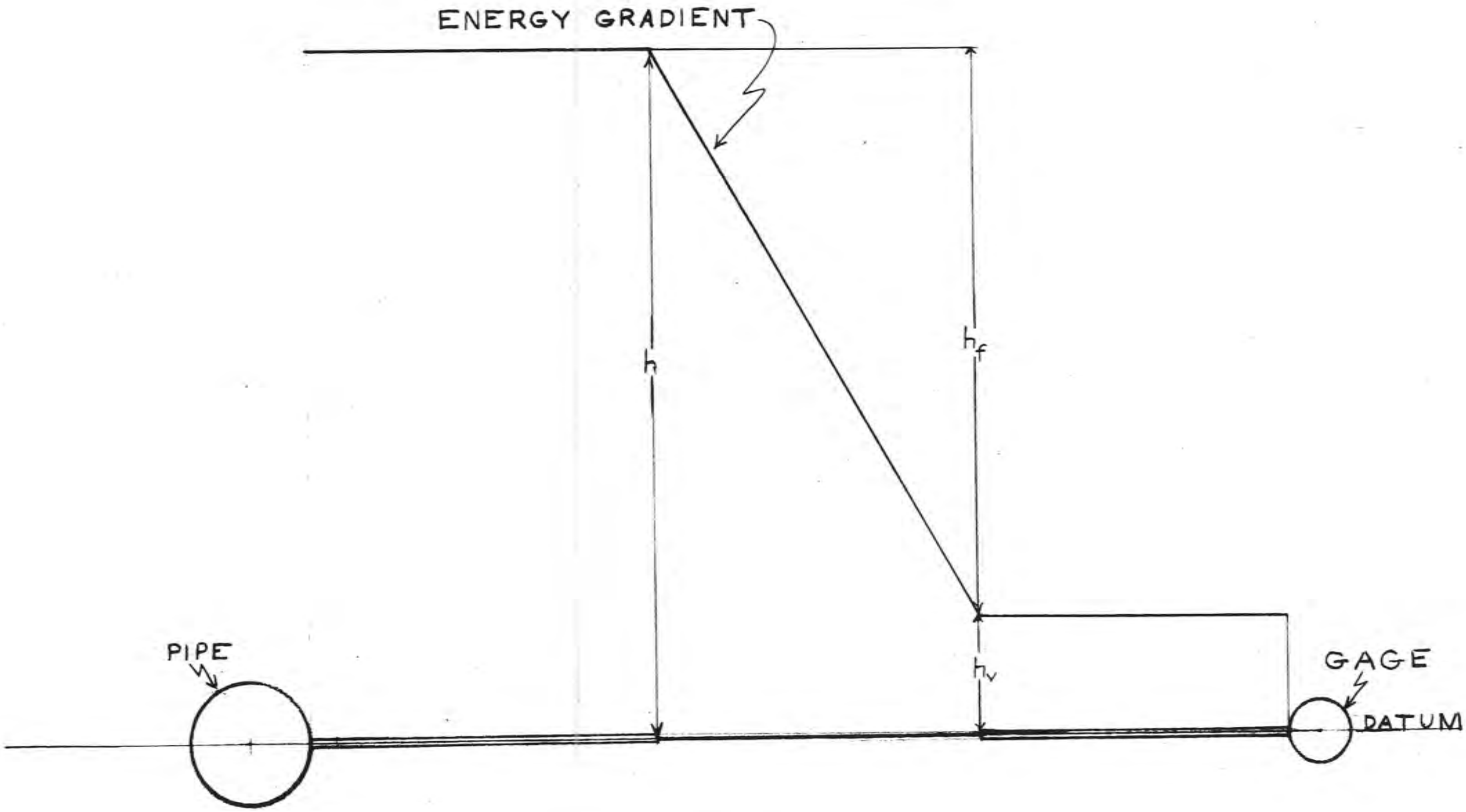

FIG. 5