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DEFENSE RESEARCH LABORATORY

THE UNIVERSITY OF TEXAS · AUSTIN 12, TEXAS

PROGRESS REPORT NO. 2

ON

CONTRACT NObs-88181

1 JANUARY - 31 MARCH 1963

31 March 1963   Copy No. _10_

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         Applied Research Division Ship Silencing Branch

         Project S-F-013-11-01, Task 1359

DEFENSE RESEARCH LABORATORY
THE UNIVERSITY OF TEXAS
AUSTIN 12, TEXAS

ABSTRACT

Printing and binding work on the acoustic filter design manual, prepared
under Contract NObs-86165, has been completed and copies have been mailed to
activities designated on the initial distribution supplied by the Bureau of
Ships. Additional copies are on hand at this Laboratory. Construction of the
automatic plotting impedance computer is approximately 80% complete. Progress
in making admittance measurement for use in filter calculations has been slowed
because of an apparent change in characteristics of the acoustic impedance head.
This change was discovered while measuring the impedance of a unit built to
offer a predominantly resistive impedance equal to the characteristic impedance
of water-filled copper nickel pipe of 2.73-in. inside diameter. The measure-
ments indicated that the unit exhibited the desired impedance magnitude of

+70 dB re 1 gm/sec cm^4 at only two frequencies in the range $25 \leq f \leq 2500$ cps;
these were near 37 cps and 1200 cps. However, since the impedance head may
not have been operating properly when these data were taken, the results
obtained may be invalid. Sound transmission characteristics of piping system
and filter elements are discussed from the acoustic admittance parameter
standpoint.

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I. ADMINISTRATION

A. Introduction

This report covers technical work performed under Contract NObs-88181 during the months of January, February, and March, 1963.

On 25 February 1963 Dr. E. L. Hixson visited the Bureau of Ships, Code 345, and conferred with Dr. R. M. Sherwood on technical work being performed under this contract.

B. **Research Staff**

Name	Degree	Position	Time
Cousins, E. L.	B.S.	Research Engineer	1.00
Galloway, D. G.*	B.S.	Research Engineer	0.50
Hixson, E..L.	Ph.D.	Research Engineer	0.38
Kahlbau, J. V.	M.A.	Supervisor, Noise and Vibration Section	1.00
McKinney, C. M.	Ph.D.	Head, Acoustics Division	0.05

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*Terminated 31 January 1963

II. SUMMARY OF TECHNICAL WORK

A. Acoustic Filter Design Manual

The filter design manual, Guide to the Selection of Acoustic Filters for Liquid-Filled Systems, written under Contract NObs-86165, has been completed. Copies of this report were mailed on 29 March 1963, to activities specified by the Bureau of Ships.

Six hundred and seventy-nine (679) copies are still on hand to fill requests as may be authorized by the Bureau of Ships.
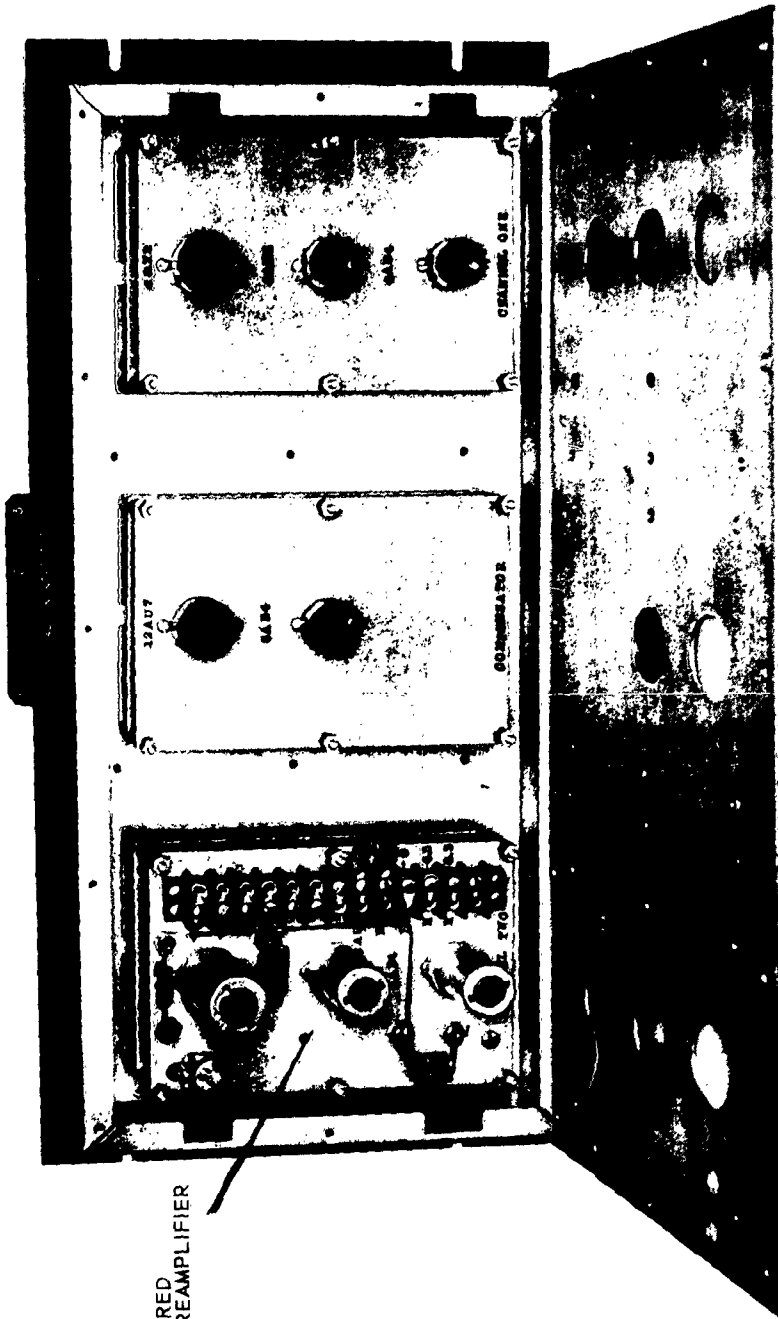
B. Impedance Computer

Parts for the impedance analog computer are under construction. The main assembly is to be mounted in a 47-1/2 x 22 x 17-in. rack supported on casters. Subassemblies of this unit will be (1) the main power supply, (2) power amplifier, (3) signal preamplifiers, and (4) the control and signal processing chassis. The master oscillator, phase meter, plotter, and impedance head will be separate units.

Photograph 88181-5 shows the main assembly rack with the power supply and power amplifier in place. Other units to be placed in this enclosure are approximately 80% complete, as shown in Photographs 88181-6 and 88181-7; these are respectively the signal preamplifiers and control panel. An auxiliary input jack has been provided on the control panel to simplify use of the computer for measuring transfer impedances and admittances.

Two of the units of the computer external to the main rack, the phase meter and plotter, are pieces of commercial equipment. The impedance head is an assembly of a small magnetic shaker with acceleration and pressure transducers; it was on hand and in general use before construction of this computer was begun. The master oscillator is a commercial unit modified by the addition of a nonlinear mechanical drive. The purpose of this modification is to render the shaft position versus frequency characteristic of the oscillator logarithmic over the range 10-20,000 cps. Photograph 88181-8 shows a rear view of the oscillator with the drive unit in place.
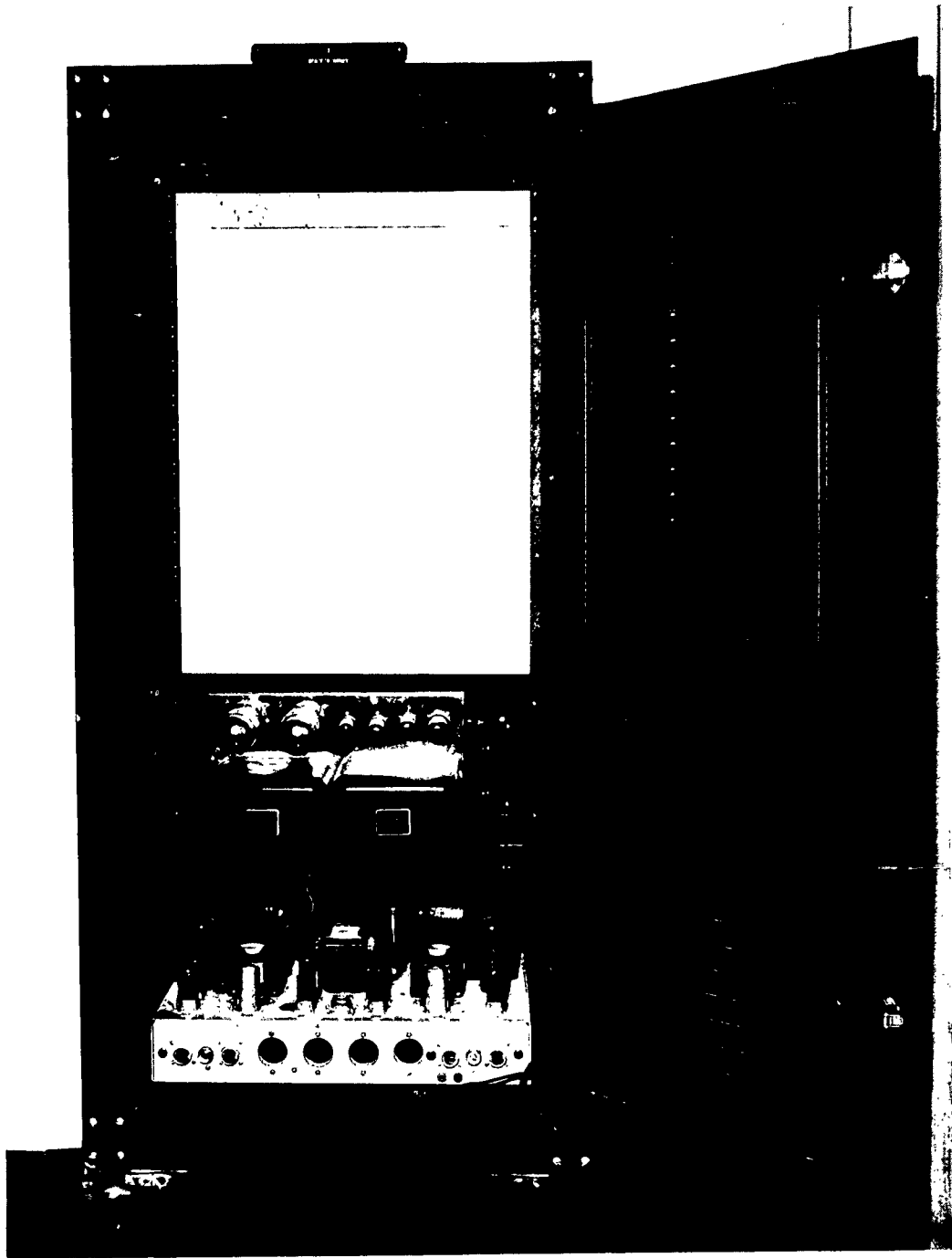
COMPUTER MAIN ASSEMBLY RACK

WIRED
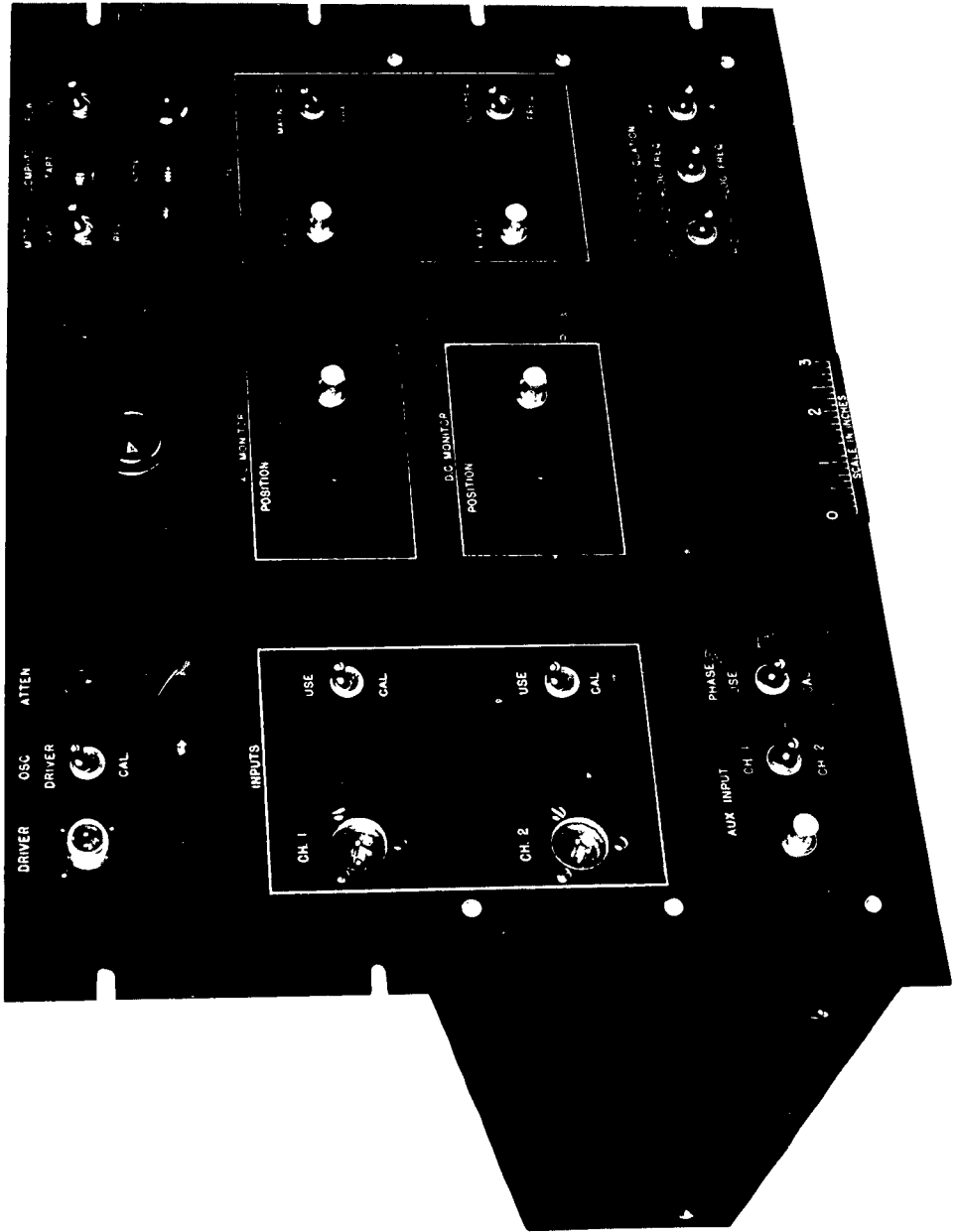PREAMPLIFIER

SIGNAL PREAMPLIFIER ASSEMBLY

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IMPEDANCE PLOTTING COMPUTER CONTROL PANEL

LIMIT SWITCHES

FREQUENCY
POTENTIOMETER

DRIVE MOTOR

SLIP CLUTCH

GEAR BOX

MECHANICAL DRIVE UNIT MOUNTED
ON BEAT FREQUENCY OSCILLATOR

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C. Filter Calculations with Measured Admittances

In Progress Report No. 1, steps for investigating a particular combination of acoustic filter, source, and load were described. The investigation entailed measurements of acoustic admittances of the filter branch element, the load, and the source. Progress in making the needed measurements has been retarded by erratic behavior of the impedance head. Difficulties with this unit are discussed in the following section of this report.

The computer program for calculating the filter output-input sound pressure ratio magnitude; however, has been completed and checked using assumed admittance values.

D. <u>Resistive Acoustic Termination</u>

      Work toward devising a simple means of terminating water-filled copper-nickel pipe, in an acoustic impedance predominantly resistive over at least a limited frequency range, has been continued. The liquid flow resistance unit, previously reported[1], has been assembled and subjected to some acoustic impedance measurements.

      The resistance unit was coupled to the impedance measuring head through a length of water-filled pipe (Dwg. AS-7834). On the basis of previous measurements[2] the characteristic impedance of water-filled pipe of this type is taken as 70 dB re 1 $gm/sec\ cm^4$. For any frequencies at which the impedance of the termination unit is real and equal to this value, the input impedance at the point of attachment of the measuring head should also assume this value. One test run produced the impedance magnitude curve shown in Dwg. AS-7835. It is noted that the desired condition with regard to impedance magnitudes is indicated at only two frequencies, 44 and 600 cps; data for an open-end water column are also given for purposes of comparison.

      Further impedance measurements were made on the resistance unit. It was coupled directly to the impedance head as shown in Dwg. AS-7836. Curves 1 and 2, Dwg. AS-7837, were plotted from measurement runs made on two different days. Results of the two runs are in close agreement over the entire range of measurement.

      The resistance unit was then disassembled from the top and the input impedance was measured after each part was removed. Curves 1-6, Dwg. AS-7838, show impedance magnitude vs. frequency for the top rubber diaphragm removed, the silicon fluid level lowered to the top of the perforated plate, the fluid level lowered to the bottom of the perforated plate, the plate removed, all

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[1] Progress Report No. 1 on Contract NObs-88181, Defense Research Laboratory, The University of Texas, 1 October - 31 December 1962, p. 12.

[2] Progress Report No. 20 on Contract NObs-77033, Defense Research Laboratory, The University of Texas, 1 July - 30 September 1961, p. 10.

RESISTIVE ACOUSTIC
TERMINATION UNIT

WATER COLUMN
12 INCHES LONG
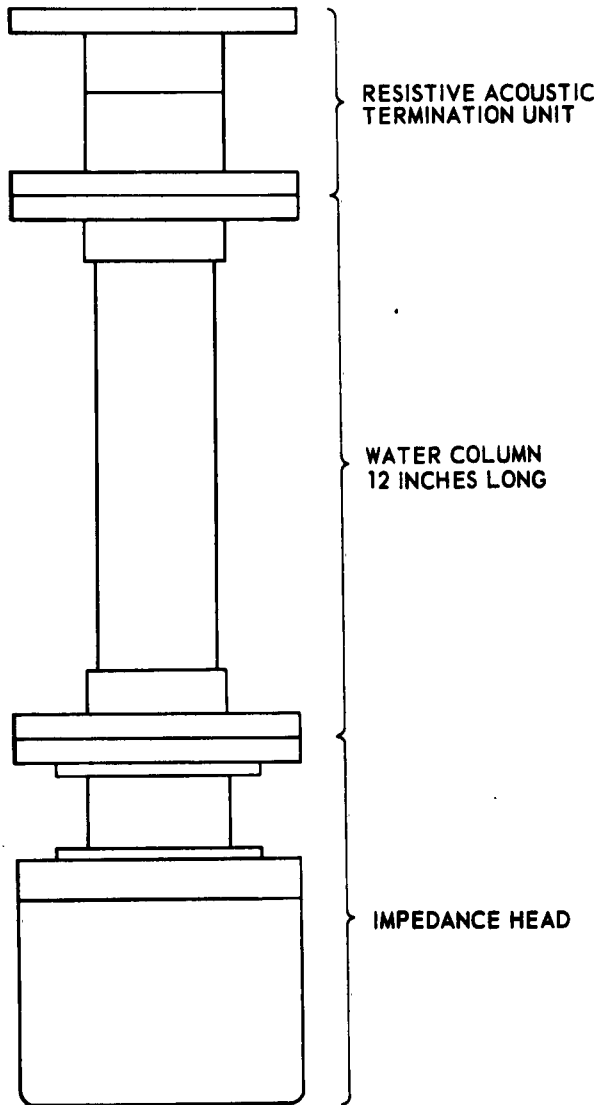
IMPEDANCE HEAD

ARRANGEMENT OF IMPEDANCE HEAD,
WATER COLUMN, AND TERMINATION UNIT

INPUT ACOUSTIC IMPEDANCE MAGNITUDE VS FREQUENCY

GASKETS
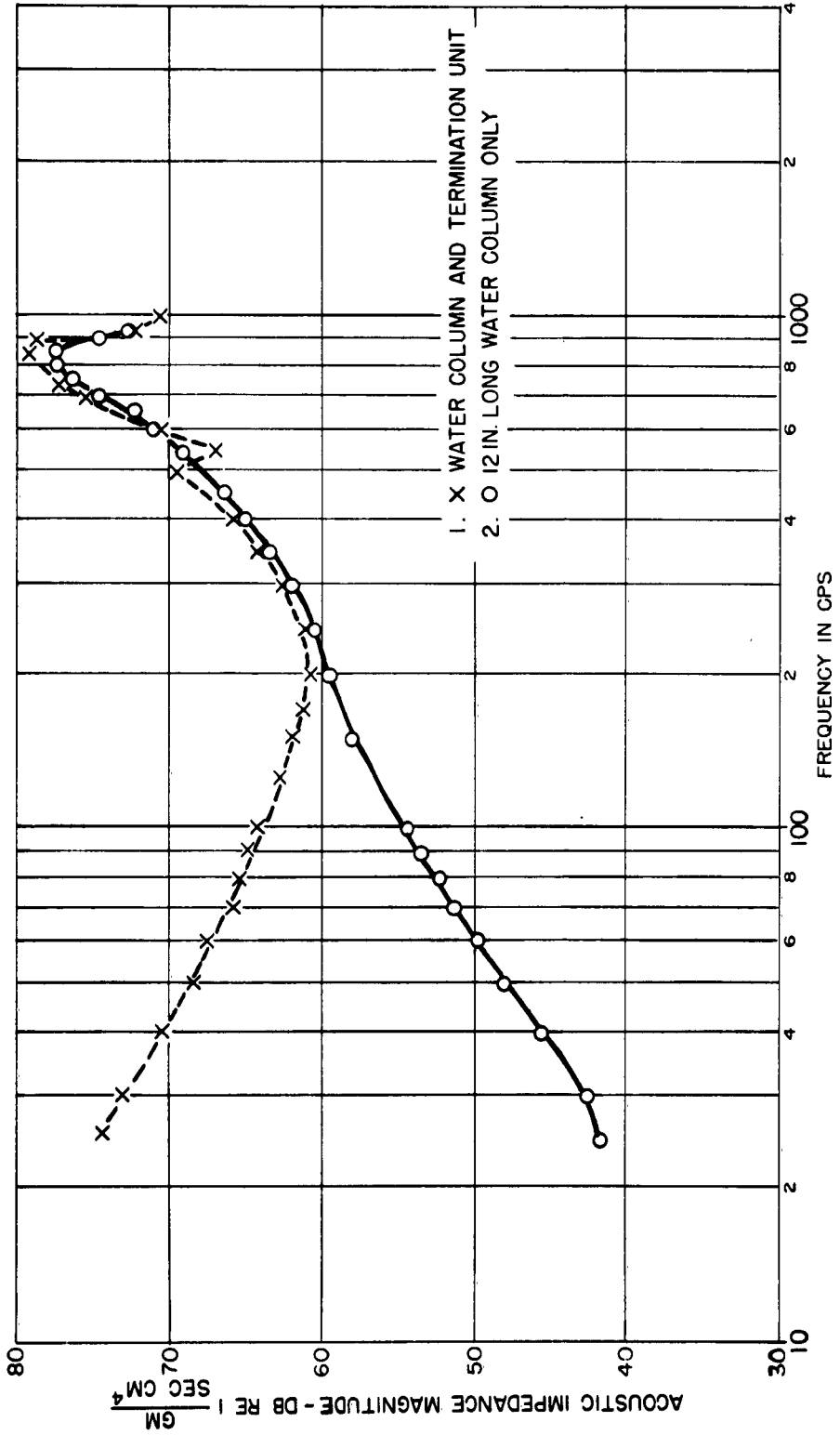
RESISTIVE ACOUSTIC
TERMINATION UNIT
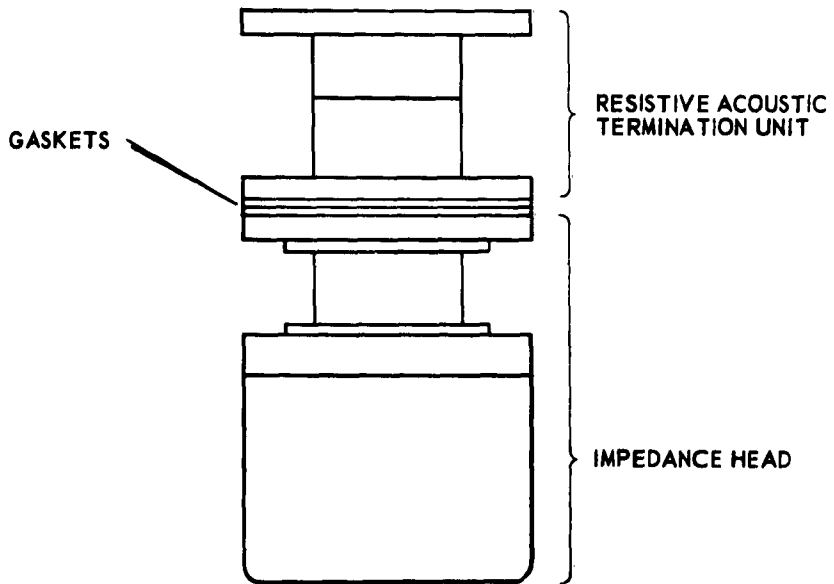
IMPEDANCE HEAD

IMPEDANCE HEAD AND TERMINATION UNIT DIRECTLY COUPLED
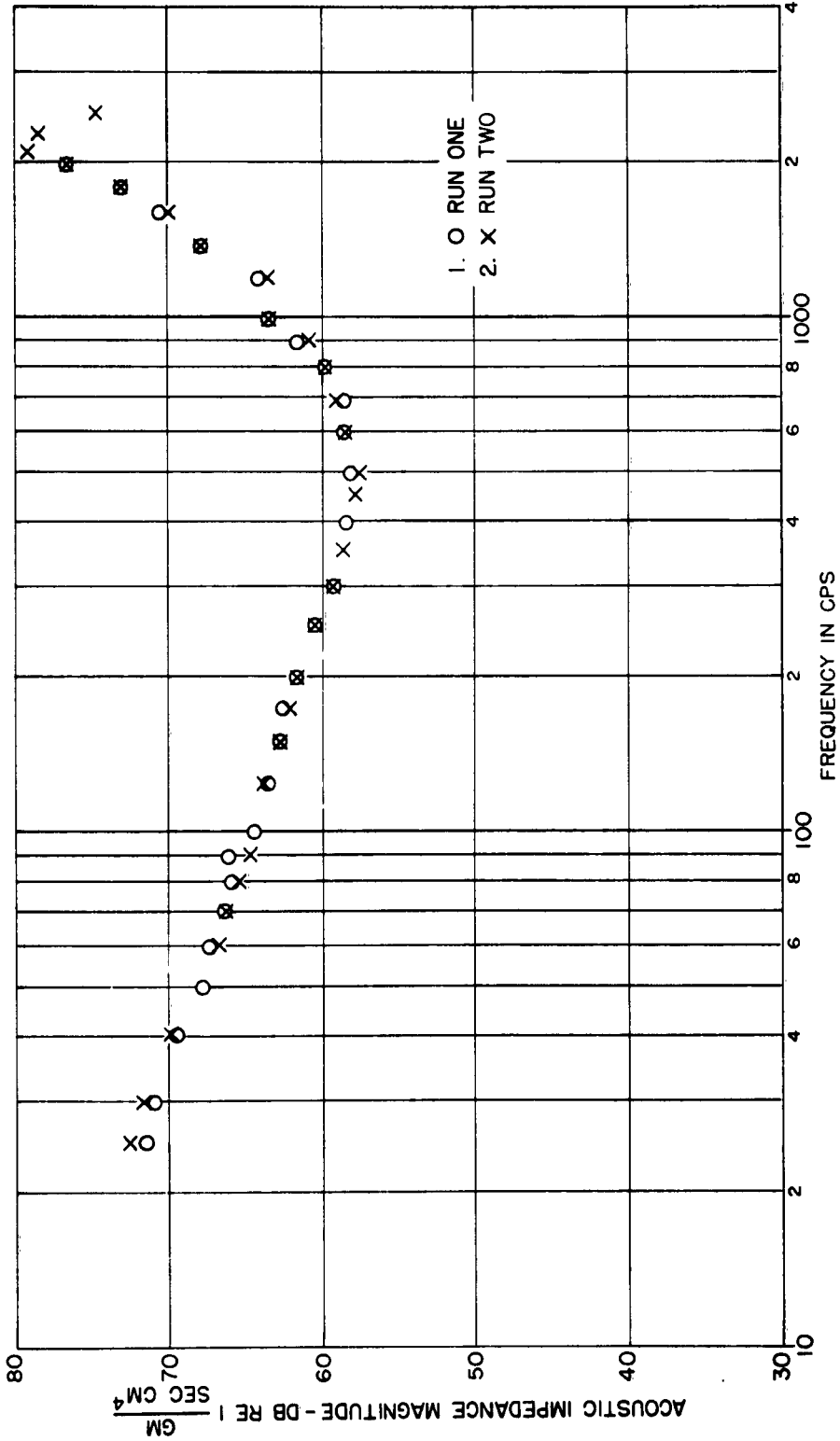
RESISTIVE TERMINATION UNIT
ACOUSTIC IMPEDANCE MAGNITUDE VS FREQUENCY

FREQUENCY IN CPS

ACOUSTIC IMPEDANCE MAGNITUDE - DB RE 1 $\frac{GM}{SEC\ CM^4}$

1. O RUN ONE
2. X RUN TWO
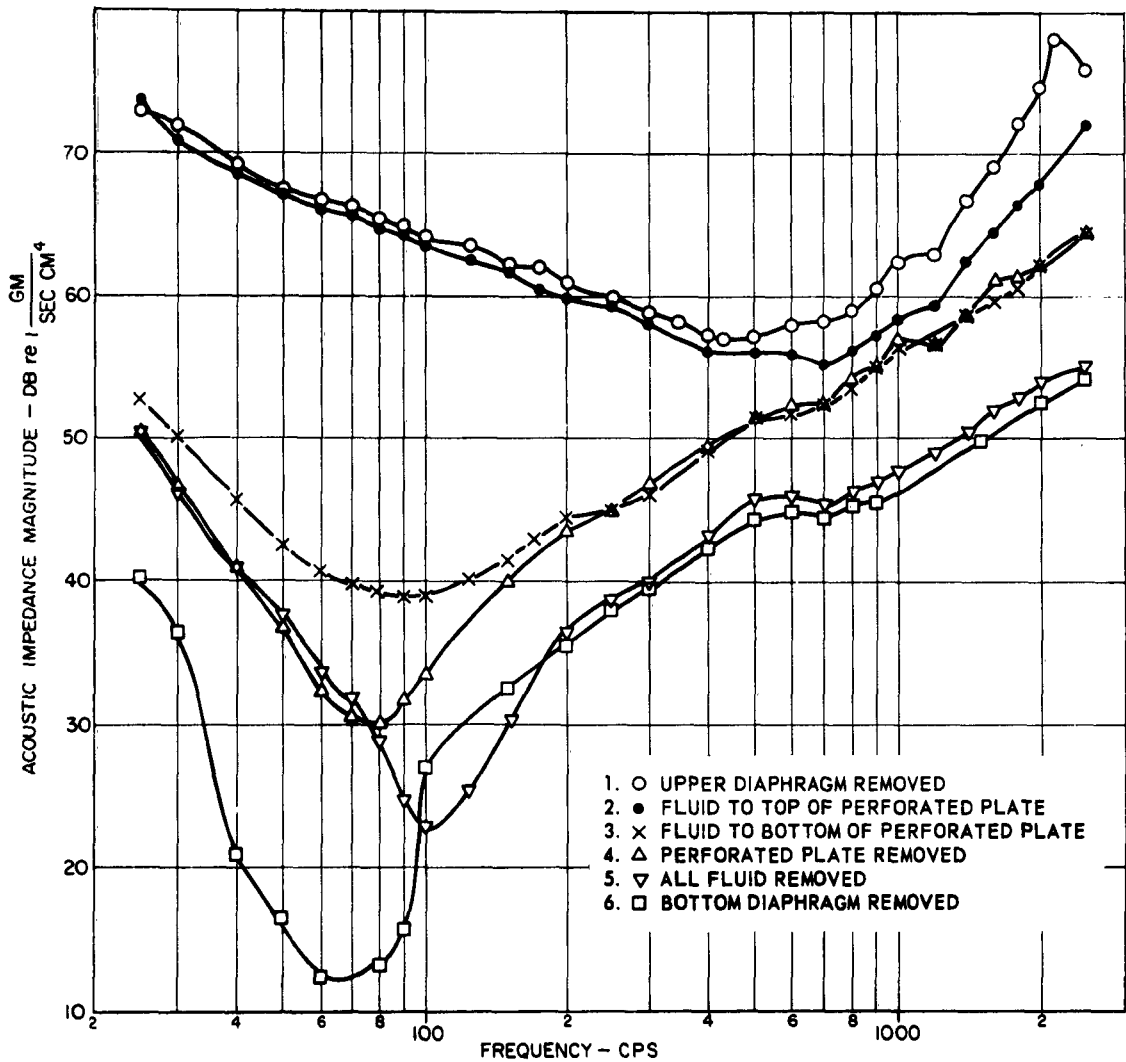
IMPEDANCE OF TERMINATION UNIT
FOR VARIOUS STAGES OF DISASSEMBLY

The figure plots ACOUSTIC IMPEDANCE MAGNITUDE – DB re 1 $\frac{GM}{SEC\ CM^4}$ versus FREQUENCY – CPS.

Legend:
1. ○ UPPER DIAPHRAGM REMOVED
2. ● FLUID TO TOP OF PERFORATED PLATE
3. ✕ FLUID TO BOTTOM OF PERFORATED PLATE
4. △ PERFORATED PLATE REMOVED
5. ▽ ALL FLUID REMOVED
6. ☐ BOTTOM DIAPHRAGM REMOVED

the fluid removed, and finally even the bottom diaphragm removed. All these curves appear credible except the one for the impedance head alone; it has an unusual shape for frequencies below 200 cps. The impedance head would be expected to exhibit an almost pure inertance, so the impedance should change with a uniform, positive slope of 20 dB per decade. These unexpected results led to checking the instruments by repeating measurements previously made on 13-in. water columns. The recently obtained results are plotted along with the older data on Dwg. AS-7839. Comparison of these and similar curves indicate a change in low frequency characteristics of the impedance head. The unit was disassembled and inspected. No cause for the apparent changes in characteristics was found. The accelerometer was recalibrated; its sensitivity was found unchanged. The hydrophone was checked by a low-frequency calibration technique reported by Schloss and Strasberg.[3] A sensitivity of -116 dB re 1 volt/μbar was found; this agrees with previously obtained values within 1 dB.

Another check of the hydrophone calibration was made by a related method. Acoustic impedance of a water column above the hydrophone was measured by two different methods, one utilizing the hydrophone signal, the other only signals from a mechanical impedance head. Details of the experimental arrangement are shown in Dwg. AS-7840. A column of water contained in a metal pipe in which the hydrophone was suspended was driven from below through a mechanical impedance head by a magnetic shaker. Electrical compensation was made for the mass of the pipe and the water below the center of the hydrophone. Thus the mechanical impedance of only the column of water above the hydrophone Z_m was measured. This value of Z_m was divided by the square of the column section area S to give acoustic impedance Z_α.

$$Z_\alpha = \frac{Z_m}{S^2} \quad .$$

Values of Z_α measured in this way are compared with calculated values and values

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[3]F. Schloss and M. Strasberg, "Hydrophone Calibration in a Vibrating Column of Liquid," The Journal of the Acoustical Society of America 34, No. 7, pp. 958-960 (1962).
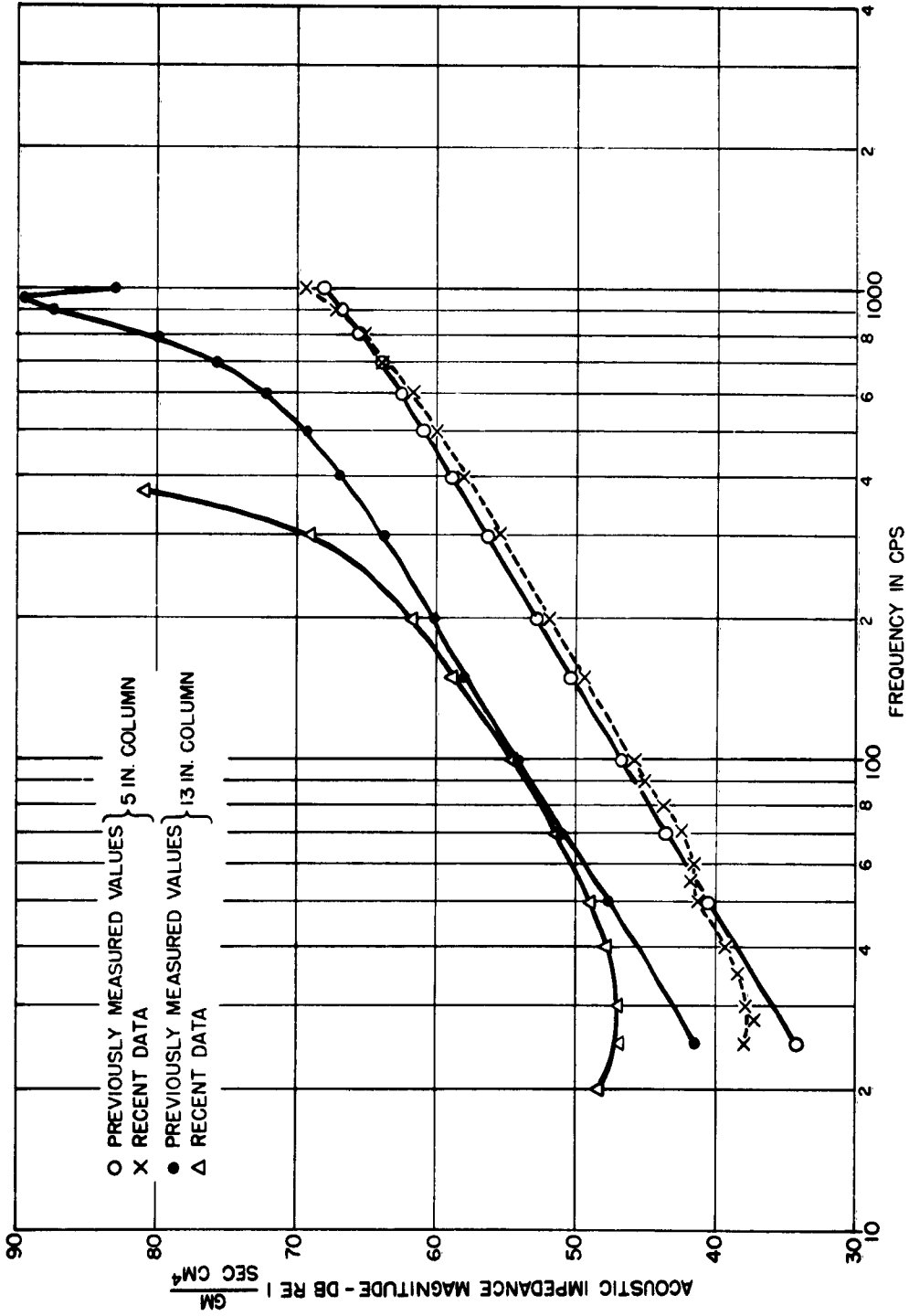
OPEN END WATER COLUMN
ACOUSTIC IMPEDANCE MAGNITUDE VS FREQUENCY

WATER COLUMN

EFFECTIVE DEPTH OF HYDROPHONE

PIPE

HYDROPHONE

MECHANICAL IMPEDANCE HEAD

MAGNETIC SHAKER
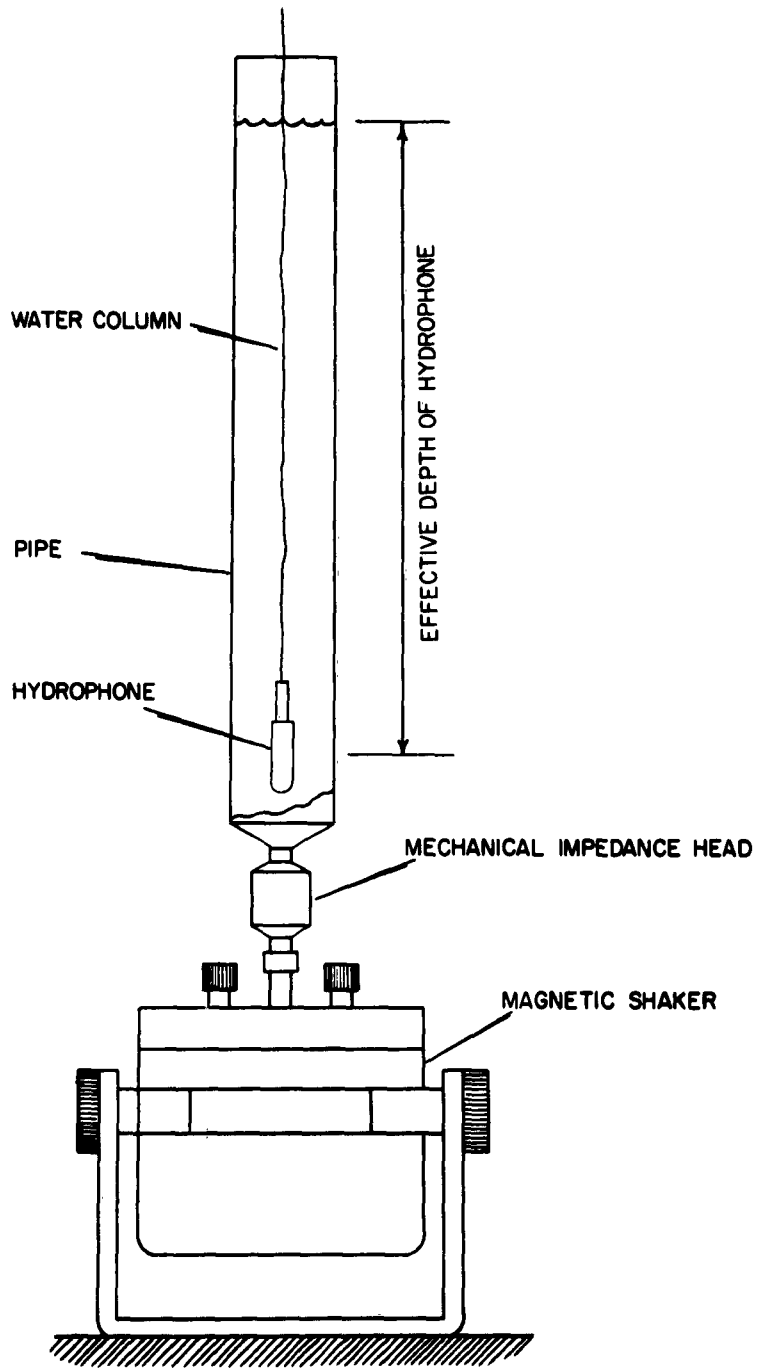
SETUP FOR LOW FREQUENCY CALIBRATION OF HYDROPHONE
BY MECHANICAL IMPEDANCE MEASUREMENT

found using the hydrophone and mechanical impedance head accelerometer signals, Dwg. AS-7847. It is seen that slopes of the three sets of data are in close agreement in the frequency range 10-200 cps. The displacement of the curve obtained using the hydrophone signal by approximately -3 dB suggests that the hydrophone may have lost sensitivity. However, such a loss does not explain the peculiar low frequency characteristics of the impedance head, the cause of which remains an unresolved question.

ACOUSTIC IMPEDANCE MAGNITUDE DB RE I $\frac{GM}{SEC \, CM^4}$

FREQUENCY IN CPS
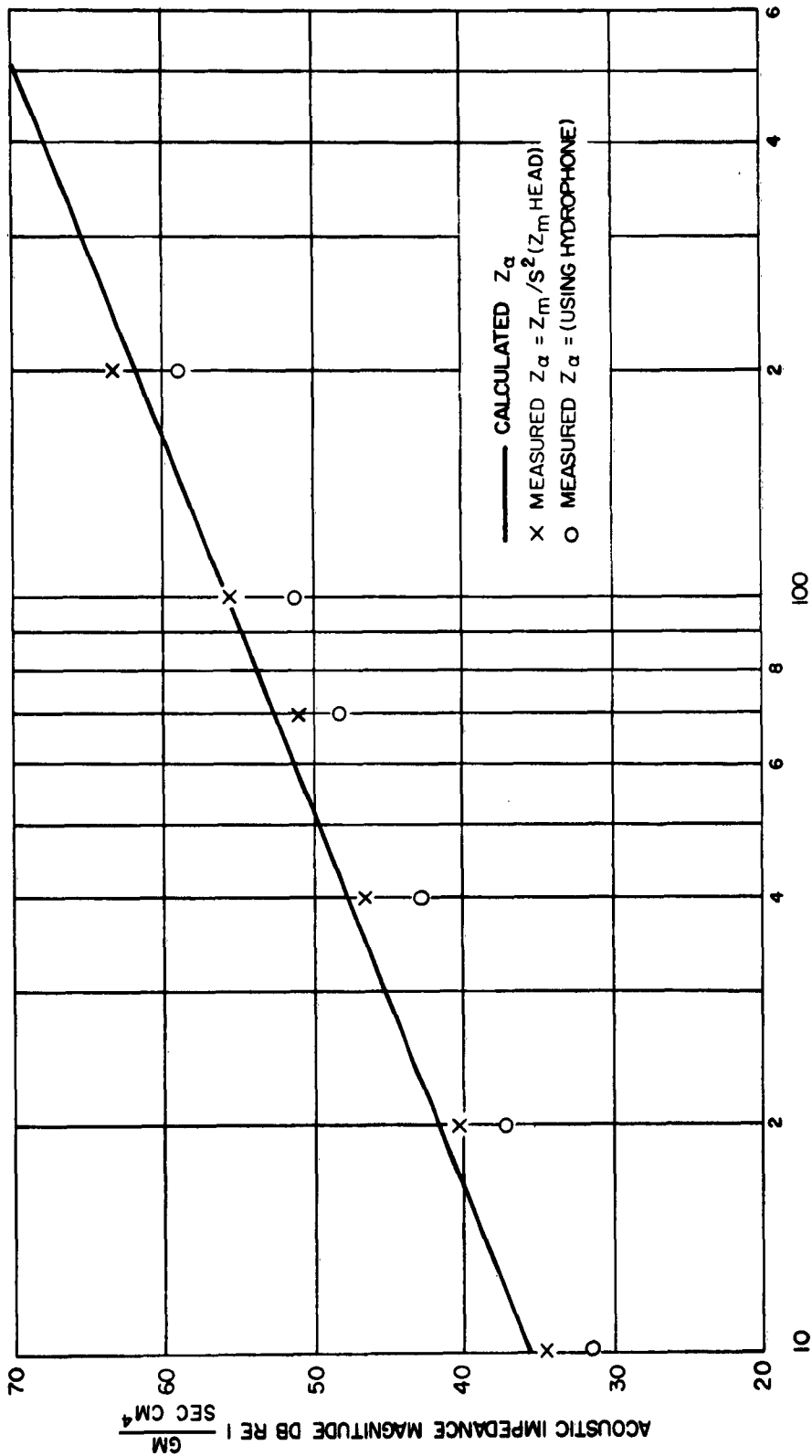
IMPEDANCE MEASUREMENTS ON 14 INCH WATER COLUMN

—— CALCULATED Z_a

X MEASURED $Z_a = Z_m/S^2$ (Z_m HEAD)

O MEASURED Z_a = (USING HYDROPHONE)

E.   Sound Transmission Characteristics of Piping System and Filter Elements

The acoustical transmission characteristics of piping system components such as valves, bends, "tees", manifolds, etc., are not readily calculated from theoretical considerations.   However, certain characteristics of these elements can be measured which allow the calculation of the ratio of sound pressure levels across the element and the admittance presented by it.   Acoustic filter calculation methods can then be used to determine the transmission loss from the input to any part of a piping system.   With a known sound pressure level at the input, the levels at various places in the system may be determined.

Any section of pipe that contains a valve, bend, strainer plate, or other discontinuity can be considered a two-port element.   If the acoustic pressures at and the volume velocities into each port are considered, a set of two port equations may be written:

$$P_1 = Z_{11} \bar{V}_1 + Z_{12} \bar{V}_2 \quad,$$

$$P_2 = Z_{21} \bar{V}_1 + Z_{22} \bar{V}_2 \quad. \tag{1}$$

Here subscripts "1" refer to port 1 and subscripts "2" refer to port 2.   The "Z" parameters are measurable quantities defined as follows:

$$Z_{11} = \left. \frac{P_1}{\bar{V}_1} \right|_{\bar{V}_2 = 0} \quad,$$

the imput impedance at port 1 with port 2 blocked;

$$Z_{21} = \left. \frac{P_2}{\bar{V}_1} \right|_{\bar{V}_2 = 0} \quad,$$

the transfer impedance between ports 2 and 1 with port 2 blocked;

$$Z_{22} = \left.\frac{P_2}{\overline{V}_2}\right|_{\overline{V}_1\,=\,0}$$, the input impedance at port 2 with port 1 blocked; and

$$Z_{12} = \left.\frac{P_1}{\overline{V}_2}\right|_{\overline{V}_1\,=\,0}$$, the transfer impedance between ports 1 and 2 with port 1 blocked.

These parameters can be measured with an acoustic impedance device at one port and a hydrophone at the blocked port.

If the pressure P_1 at port 1 is known and port 2 is terminated in some impedance Z_ℓ, equations (1) become

$$P_1 = Z_{11}\,\overline{V}_1 + Z_{12}\,\overline{V}_2$$

$$0 = Z_{21}\,\overline{V}_1 + (Z_{22} + Z_\ell)\,\overline{V}_2 \qquad (2)$$

where
$$P_2 = -Z_\ell \overline{V}_2 \quad .$$

From equations (2) the transfer function becomes

$$\frac{P_2}{P_1} = \frac{Z_\ell Z_{21}}{Z_{11}\,(Z_{22} + Z_\ell) - Z_{12}\,Z_{21}} \quad . \qquad (3)$$

The input impedance is then

$$Z_{in} = Z_{11} - \frac{Z_{12}\,Z_{21}}{Z_{22} + Z_\ell} \quad . \qquad (4)$$

This is then an impedance transformation equation that relates Z_{in} to Z_ℓ. Admittance methods are more convenient than impedance for acoustic filter

calculations.[4] Equation (4) can be expressed as an admittance transformation
equation:

$$Y_{in} = \frac{1 + Z_{22} Y_\ell}{(Z_{11}Z_{22} - Z_{12}Z_{21}) Y_\ell + Z_{11}} \quad . \tag{5}$$

It is therefore recommended that the characteristics of side branch
elements for acoustic filters as well as other discontinuities be measured and
characterized this way, since it is very difficult to measure the shunt admittance
presented by these elements at the pipe wall. The transmission loss or sound
pressure level differences between two points in a system require input admittance
calculations:

$$TL = -20 \log \frac{2}{\lceil 1 + Y_1/Y_0 \rceil} \left(\frac{Re \cdot Y_1}{Y_0} \right)^{1/2}$$

$$\left| \frac{P_0}{P_1} \right| (dB) = 20 \log \left(\frac{Re \ Y_1}{\overline{Re} \ Y_\ell} \right)^{1/2} \quad .$$

To calculate the input admittance of a system as required above, one
starts from the termination, Y_ℓ or Y_0, and proceeds through the filter elements,
other discontinuities, and lengths of system piping. The admittance is trans-
formed by each section to finally present a value, Y_{in}, at the input. Only two
equations are required for these calculations: Equation (5) above can be used
to calculate the input admittance of any discontinuity or side branch element
in terms of its termination and the transmission line transformation equation,

$$Y_{in} = Y_0 \left[\frac{Y_\ell + jY_0 \ \tan \ 2\pi \ell_1 f/v_1}{Y_0 + jY_\ell \ \tan \ 2\pi \ell_1 f/v_1} \right] \quad ,$$

[4]E. L. Hixson, J. V. Kahlbau, and D. G. Galloway, "Guide to the Selection of
 Acoustic Filters for Liquid-Filled Systems," Defense Research Laboratory
 Acoustical Report No. 202 (September, 1962)

can be used for lengths of pipe and expansion chambers. Here Y_0, ℓ, and v_1 are characteristic of the section considered.

Any branching of the liquid flow in a piping system by a "tee" or manifold will also divide the acoustic energy. The division will depend on characteristics of the manifold and the impedance presented at each port. This situation can be analyzed by considering the device an n-port element. Again, sets of equations involving measurable parameters can be written:

$$P_1 = Z_{11} \bar{V}_1 + Z_{12} \bar{V}_2 + Z_{13} \bar{V}_3 + \cdots$$

$$P_2 = Z_{21} \bar{V}_1 + Z_{22} \bar{V}_2 + Z_{23} \bar{V}_3 + \cdots$$

$$P_3 = Z_{31} \bar{V}_1 + Z_{32} \bar{V}_2 + Z_{33} \bar{V}_3 + \cdots \qquad (6)$$

$$\cdots$$

$$\cdots$$

or, in compact matrix form,

$$\left[P_i \right] = \left[Z_{ij} \right] \left[\bar{V}_j \right] \, . \qquad (6a)$$

The subscripts refer to each port. The impedance parameters are the input impedance $Z_{ij} (i = j)$ at each port measured with all other ports blocked, and the transfer impedance Z_{ij} $(i \neq j)$ between each port and all other ports with all other ports blocked. When each port is terminated in some impedance, the input admittance and pressure transfer ratio to each port can be calculated.

To illustrate, consider a "tee" with ports 1, 2, and 3. Port 1 has an acoustic pressure P_1, port 2 is terminated in Z_2, and port 3 is terminated in

Z_3. Equations 6 become

$$P_1 = Z_{11} \bar{V}_1 + Z_{12} \bar{V}_2 + Z_{13} \bar{V}_3$$

$$0 = Z_{21} \bar{V}_1 + (Z_{22} + Z_2)\bar{V}_2 + Z_{23} \bar{V}_3$$

$$0 = Z_{31} \bar{V}_1 + Z_{32} \bar{V}_2 + (Z_{33} + Z_3)\bar{V}_3$$

where $P_2 = -Z_2 \bar{V}_2$ and $P_3 = -Z_3 \bar{V}_3$. The input admittance is then

$$Y_{in} = \frac{\bar{V}_1}{P_1} = \frac{\begin{vmatrix} (Z_{22} + Z_2) & Z_{23} \\ Z_{32} & (Z_{33} + Z_3) \end{vmatrix}}{\Delta}$$

where Δ is the determinant of the Z's. It should be noted here that input admittance depends on the termination of both ports 2 and 3.

The ratio of P_2 to P_1 is then

$$\frac{P_2}{P_1} = \frac{+Z_2 \begin{vmatrix} Z_{21} & Z_{23} \\ Z_{31} & (Z_{33} + Z_3) \end{vmatrix}}{\Delta}$$

and the ratio of P_3 to P_1

$$\frac{P_3}{P_1} = \frac{-Z_3 \begin{vmatrix} Z_{21} & (Z_{22} + Z_2) \\ Z_{31} & Z_{32} \end{vmatrix}}{\Delta} .$$

It is evident that a multiport device will require many impedance measurements and tedious calculations. However, these methods become practical

with the impedance computer-plotter presently under construction and the
availability of high speed computers programmed to handle matrix operations.

DISTRIBUTION LIST

DISTRIBUTION LIST (Cont'd)

Defense Research Laboratory, The University of Texas, Austin, Texas.
PROGRESS REPORT NO. 2 ON CONTRACT NObs-88181, 1 JANUARY-- 31 MARCH 1963, by J. V. Kahlbau and E. L. Hixson. 31 March 1963, 31 p. incl. illus.   Unclassified report (Contract NObs-88181)

Progress in the construction of an electrical analog device to plot automatically acoustical and mechanical impedances is reported. Measured values of acoustic impedance of a resistive acoustic termination unit are given for the complete unit and for the unit in various stages of disassembly. The desired impedance magnitude for the complete unit prevailed at only two frequencies within the range of measurement. Findings of tests to check an impedance head hydrophone are reported. Results of two different, but related, hydrophone calibration methods were in disagreement by about 3 dB. Use of acoustic admittance parameters of pipe fittings, flow line irregularities, and acoustic filter branch elements in transforming acoustic load admittances toward the source past lossless elements is discussed.

1. Acoustic filters
2. Admittance, Acoustical and mechanical
3. Impedance, Acoustical and mechanical
4. Resistance, Acoustical
I. Kahlbau, J. V.
II. Hixson, E. L.
III. Contract NObs-88181