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Development of a Dynamic Pressure Calibration Technique A Progress Report

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Electronic Technology Division
Institute for Applied Technology
National Bureau of Standards
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June 15, 1974

Progress Report Covering Period 9–15–73 to 2–15–74

Prepared for
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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

Development of a Dynamic Pressure Calibration Technique

A Progress Report

by: C. F. Vezzetti, P. S. Lederer, and J. S. Hilten

The objective of this task is to develop a dynamic pressure calibration technique yielding a flat frequency response to 2000 Hz or greater and amplitude capability of at least 3.4×10^4 Pa (5.0 psi) zero-to-peak. Equipment was set up, a universal test fixture fabricated, and testing was initiated of various liquids and damping schemes for a hydraulic sinusoidal pressure generator consisting of a vibrating liquid column. Two liquids of density greater than water, tetrabromoethane and fluorcarbon, were tested. As was expected from the densities and bulk moduli, improved frequency response could be accomplished only with the tetrabromoethane. Very little improvement of damping has been obtained by using tubes with large wetting surface area. Although tests using filters are only in early stages, indications are that the proper combination of liquid viscosity and filter porosity may result in improved damping.

Key Words: Calibration; dynamic; liquid column; pressure; sinusoidal.

DEVELOPMENT OF A DYNAMIC PRESSURE CALIBRATION TECHNIQUE

Progress Report for the Period
September 15, 1973 to February 15, 1974

to the

NASA Langley Research Center
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Prepared by

C. F. Vezzetti, P. S. Lederer and J. S. Hilten

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1. Introduction

This is the second progress report (1) on a study to develop a source of dynamic pressure signals constant in amplitude within ±5% to 2000 Hz or greater, and capable of amplitudes of at least 3.4×10^4 Pa (5.0 psi) zero-to-peak. The approach being used is based on a hydraulic sinusoidal pressure generator developed by the National Bureau of Standards Instrumentation Applications Section (2). The frequency range of this system is 15 Hz to 2000 Hz with a maximum pressure amplitude of 6.7×10^4 Pa (9.8 psi) zero-to-peak between about 100 Hz to 300 Hz and pressure amplitudes constant within ±5% to about 1000 Hz. Means of improving the frequency response characteristics of the pressure generator are being investigated.

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(1) First Progress Report: NBSIR 73-290, P. S. Lederer, Oct. 19, 1973.
(2) NBS Technical Note 720, "A Simple Hydraulic Sinusoidal Pressure Calibrator", J. S. Hilten, P. S. Lederer, and J. Sethian, April 1972.

1.1. The Basic Technique

The transducer to be calibrated is mounted near the base of a liquid-filled tube. The tube is vibrated by an electrodynamic vibration exciter, generating a sinusoidal pressure at the transducer. The natural frequency of the liquid-column-transducer structure determines the upper frequency limit in this method.

1.2. Methods of Obtaining Desired Frequency Response

Two approaches are available for extending the useful frequency range of the pressure generating system. One is to optimize the damping of the vibrating liquid column; the second is to increase the natural frequency. Both are being investigated.

An undamped system has a useful frequency range, amplitude constant within ±5%, up to about 20% of the natural frequency, while a suitably damped system (damping ratio about 0.6) has a useful frequency range to about 80% of the natural frequency. The methods for improving the damping of the generator that have been or will be evaluated in this study include: use of tubes with large wetting surface area to increase friction; use of pressure snubbers as "filters" to impede the flow of the liquid in the column; use of high viscosity liquid; adjustment of viscosity by controlling the temperature of the liquid; and use of magnetic fluids with electromagnetic control of damping.

The natural frequency of a liquid column open to air at one end is given by the relation $f_n = v_s/(4h)$, where h is the height of the column and v_s is the velocity of sound in the liquid. Thus, the natural frequency can be raised by shortening the column height and also by using a fluid in which the velocity of sound is greater. For a given acceleration, a shorter column produces a lower pressure; to compensate, a greater acceleration or use of a liquid of greater density is required.

Use of greater acceleration is limited by the output capabilities of the vibration exciter and splashing of the liquid that occurs, especially at low frequencies, when the pressure at the surface due to the acceleration exceeds the effects of surface tension of the liquid. Splashing can be reduced by floating a thin disc of cork or other light material on top of the liquid.

Greater acceleration without splashing and doubling of the natural frequency can be accomplished by using a closed tube. However, the pressure amplitude at a given acceleration of a closed tube system is half that of one that is open at one end. Other disadvantages of the closed tube system, such as increased temperature sensitivity, difficulty of filling and greater complexity, make this approach less attractive.

The column height required to obtain a given pressure amplitude at a given acceleration is inversely proportional to the density of the liquid. However the velocity of sound in a liquid, and therefore the natural frequency, is proportional to $(B/\rho)^{1/2}$, where B is the bulk modulus and ρ the density. To obtain the desired pressure amplitude and higher natural frequency at a given acceleration by using a shorter column of denser liquid, $\rho(B/\rho)^{1/2}$ should be greater for the denser liquid than for the original liquid (water). To verify this analysis, two liquids of density greater than water, one for which $\rho(B/\rho)^{1/2}$ is greater and one for which it is less than that of water, were tested: tetrabromoethane (density 2.95gm/cm^3, bulk modulus 2.99 x 10^9 Pa), and the fluorocarbon (density 1.88 gm/cm^3, bulk modulus 1.00 x 10^9 Pa).

2. Progress During This Reporting Period

In the period covered by this report, the components and tubes for the universal test fixture designed to facilitate testing of different types of pressure transducers and damping schemes were fabricated and the test equipment set up. The system was tested and the repeatability was found to be satisfactory for this phase of the study. Tests with the two liquids of density greater than water were conducted. Tests evaluating the use of tubes with large wetting surface area are nearly complete, and tests using the filters (pressure snubbers) are in early stages.

2.1. The Vibration Exciter Equipment

Two vibration exciter facilities are available for this study. One, a large electrodynamic vibration exciter used in a previous study (2), is available part time and is used to check out the equipment, to compare tube performance on the two vibration exciters, and for tests where the larger force capability of this facility is required.

The other, a small electrodynamic vibration exciter purchased for this study with NBS funds, is shown in Figure 1 with power supply and readout equipment. The vibration exciter (K) and trunnion (L) are securely attached to a sturdy metal stand (a section of a shock tube) which is fastened to the floor. The power supply (M), a variable oscillator (N), charge amplifier (O) for the monitoring accelerometer, the various amplifiers and power supplies (not shown) for the pressure transducers, a frequency counter (P), and a digital voltmeter (S) are housed in a relay rack. An oscilloscope (T) is used to monitor the signals. A three-position selector switch (R) permits connecting the output of any of three transducers to the voltmeter, frequency meter, and oscilloscope.

2.2. The Universal Test Fixture

A universal test fixture with provisions for changing liquid-column tubes and mounting pressure transducers of various sizes was fabricated. The components of the test fixture are shown in Figures 2 and 3.

The 5.1 cm (2.0 in.) diameter by 7.5 cm (3.0 in.) aluminum chamber section (A) has two flat surfaces for mounting the 4.8 cm (1.9 in.) square transducer plates (B). These plates contain threaded holes to receive the transducers (C) being tested and are attached to the chamber section with four screws. Rubber O-rings (D) seal the two surfaces. 1.6 cm (0.6 in.) diameter ports (E) lead to the 2.2 cm (0.9 in.) diameter chamber (F). The 30.5 cm (12.0 in.) long tubes (G) (see also Figure 4) are connected to the top of the chamber with six screws. The seal is made with a paper gasket (H).

This assembly is mounted on the top of a 5.1 cm (2.0 in.) diameter by 3.3 cm (1.3 in.) aluminum cup-like component (I) containing the accelerometer (J). The accelerometer is mounted on the bottom of the cup with a screw and the cup is connected to the vibration exciter table with three screws.

The tubes (Figure 4) range from 1.3 cm (0.5 in.) inside diameter (Tubes 1, 6, and 7) to 2.5 cm (1.0 in.) inside diameter (Tube 4). Some have smooth inner walls (Tubes 5, 6, and 7); one has 51 separate channels (Tube 3); one has spiral flutes (Tube 1); and one has a flat cross section with intersecting diagonal flutes (Tube 2). Tubes 1-3 are copper; tubes 4-7 are brass. Tube 4 is a soldered-together test fixture that was used in comparing the performance stability of the demountable test fixture with a one-piece fixture.

2.3. The Filters Used

The filters (Figure 4: 8-10) are commercially available porous-element pressure snubbers. Filter "C" (8) is the most porous (recommended by the manufacturer for use with highly viscous fluids) and is made of woven stainless steel strands. Filter "E" (9) is less porous (recommended for use with water and light oils). Filter "HX" (10) is the type recommended for use with mercury. The filter discs of "E" and "HX" are of sintered stainless steel. The housings of all the filters are stainless steel.

2.4. The Liquids Used

The liquids used in the test fixture during this period were water (specific gravity 1.00, bulk modulus 2.14×10^9 Pa), a fluorocarbon inert liquid (specific gravity 1.88, bulk modulus 1.00×10^9 Pa), tetrabromoethane (specific gravity 2.95, bulk modulus 2.99×10^9 Pa), and a light petroleum oil (specific gravity 0.86, bulk modulus 1.55×10^9 Pa) that was used in the tests with the filters.

2.5. System Performance Tests

Two pressure transducers, from our own stock, were selected for preliminary tests to check out the system and determine the performance of the system using the various liquids and damping methods. One transducer (A) is a piezoelectric type with integral solid state amplifier and the other (B) is a bonded straingage type with response to DC.

The accelerometer to be used in the test fixture was calibrated using the large vibration exciter. The test fixture accelerometer was attached directly to the vibration exciter table and known accelerations were applied at frequencies from 10 Hz to 3000 Hz. Table 1 shows that the acceleration indicated by the test fixture accelerometer agreed with the acceleration indication of the vibration exciter accelerometer within -3% to +6%. The calibration uncertainties (Table 2-A) were estimated to be ±2.3%.

To ascertain the reliability of the demountable universal test fixture, the fixture, with a 2.3 cm (0.9 in.) inside diameter tube (Tube 5 in Figure 4) attached, was filled with water to a height of 33.3 cm (13.1 in.) above the center of the pressure transducer diaphragm. The maximum pressure signal frequency and the transducer response at several frequencies were determined. The fixture was emptied, refilled and tested. This was done four times. The same test procedure also was performed on a one-piece fixture consisting of a 2.5 cm (1.0 in.) inside diameter tube soldered into a brass block with a threaded hole for attaching a pressure transducer (Tube 4 in Figure 4).

The data shown in Table 3 indicate that the universal test fixture is sufficiently stable over the flat part of the frequency response (up to roughly 100 Hz) to continue this phase of the testing program. The repeatability of the transducer response was within 3.6% and that of the maximum-pressure signal frequency was within 1.8%. The estimated uncertainty of the measurements was ±3.3 (Table 2-C).

The transducer response measured with the universal test fixture agreed very closely with the response measured with the one-piece fixture. The maximum-pressure signal frequency of the universal test fixture was about 40 Hz lower than that of the one-piece fixture, consistent with the additional elastic surface (the second transducer) present in the former. Some reduction in the maximum-pressure signal frequency could also result from the fact that in the universal test fixture the transducer diaphragms are recessed slightly from the main column chamber (they are flush with the transducer plate surfaces). The effect of this chamber geometry on the maximum pressure signal is being investigated.

2.6. Preliminary Test Procedure

The procedure followed was to assemble the fixture, attach the tube and transducers to be used in the test, fill the tube and chamber with the test liquid, evacuate the filled assembly for at least 15 minutes to remove entrapped and dissolved gas, and mount the assembly on the vibration exciter table. The height of the liquid column was measured with a depth micrometer and adjusted to the desired height by adding or removing a few drops of liquid. Usually the top of the liquid column was 1.3 cm (0.5 in.) from the top of the tube, producing a column height of 33.3 cm (13.1 in.) measured from the center of the pressure transducer diaphragm, or 34.9 cm (13.7 in.) from the bottom of the column to reduce splashing at low frequencies.

The frequency was then determined for the maximum pressure signal observed on the oscilloscope while sweeping the frequency at which the column was vibrated. The excitation power to the vibration exciter was set at a very low level to prevent overranging the pressure transducers and was maintained at that setting. It should be noted that, because the acceleration does not remain constant as the natural frequency of the liquid column is approached, the frequency of the maximum pressure signal is close to but not the same as the natural frequency of the liquid column. However, the maximum pressure signal frequency can be simply and rapidly determined in this way with sufficient repeatability (see Table 3) for the purposes of this phase of the study. It is usually necessary to vibrate the column for about 15 minutes before the maximum pressure signal reaches a stable value to remove any possible remaining adsorbed gas.

Readings of the output of the pressure transducers were taken at known accelerations at 18 different frequencies, from 10 Hz to above the maximum pressure signal frequency, and frequency response curves were plotted from the data (See Figures 5-9). When the large vibration exciter facility, which has an accelerometer integral with the exciter table, was used, readings of the output of the accelerometer in the test fixture were taken as an additional check on system performance.

Static calibrations also were made on the DC responding pressure transducer (B), by applying pneumatic pressures to the top of the liquid-filled tube. Gage pressures of $\pm 1.0 \times 10^4$ Pa (±40 in. of water) were generated with a bellows and measured with a precision gage. The static response was determined from the change in transducer output caused by the known pressure difference, 2.0×10^4 Pa (80 in. of water). The calibration uncertainty as shown in Table 2-B was ±0.7%.

2.7. Test Results

A summary of the test results is given in Tables 4 and 5, and representative frequency response curves are given in Figures 5-9. The maximum pressure signal frequency for the 34.9 cm (13.7 in.), total height, column of water was around 950 Hz, which is consistent with the approximately 1350 Hz resonance observed in the initial study (2) with a 22.8 cm (9.0 in.) column of water. The static calibrations of transducer response agreed within 3% with the dynamic transducer response (Table 5).

Using the water, tubes with large surface area (compare Tests 3, 8, 9, and 10, Table 4) produced little improvement in the damping. Further pursuit of this approach, at least with the less viscous liquids, will be limited. One tube, Tube 2 in Figure 3, remains to be tested. Attempts were made earlier to obtain useful data with this tube, but the maximum pressure signal frequency was very low and unstable. It is suspected that, because the complex structure of this tube, air may have remained trapped in the many corners and pockets causing the instability. Vacuum filling the test fixture would minimize the possibilities of trapping air in the tube. The vacuum chamber will be modified to allow vacuum filling and Tube 2 will be retested.

Of the liquids of density greater than water (compare Tests 2, 5, 6, and 7, Table 4), tetrabromoethane, based on the analysis in Section 2.2 was expected to, and showed, the most promising results. The maximum signal frequency could be increased to 1650 Hz by using a 13.0 cm (5.1 in.) column, while maintaining the same pressure amplitude as a 34.9 cm (13.7 in.) column of water. Also, confirming the analysis in Section 2.2, the fluorocarbon proved unsatisfactory in that the maximum pressure signal obtainable was less than half that for a column of water of the same height.

Tests with the filters are not yet complete. Only one filter, "C," has been tested and with only two liquids, water and light oil (Tests 11 and 12, Table 4; Also see Figure 9). Attempts were made to test the other filters, "E" and "HZ", and to test filter "C" with tetrabromoethane, but the maximum-pressure signal frequency was not stable, probably because of trapped air, as in the test with Tube 2. Plans call for retesting when the test fixture can be vacuum filled. Some improvement in the damping was accomplished when filter "C" was used with the light oil (Tests 4 and 12, Table 4) and tests will be continued with the filters.

Tests 1 and 2 were made with the one-piece test fixture and show close agreement with Tests 3 and 5 made with the universal test fixture.

3. Plans for the Next Reporting Period

Experiments will be conducted to check the effect of the transducers being recessed from the main chamber on the maximum pressure signal frequency.

The vacuum chamber will be modified to facilitate vacuum filling of the test fixture. The tube and filters which did not have stable maximum pressure signals will be tested after being vacuum filled.

Further tests will be conducted using tetrabromoethane. This will probably necessitate a brass test fixture as the liquid is reported to be corrosive to aluminum.

Additional methods of improving the damping will be tried, including magnetic damping.

Tests with the pressure transducers supplied by NASA will be initiated.

TABLE 1
CALIBRATION OF TEST FIXTURE ACCELEROMETER

Frequency Hz	Applied Acceleration g (0-to-peak)	Fixture Accelerometer Output V (rms)	Fixture Accelerometer Equivalent Acceleration g (0-to-peak)	Response Ratio
10	1.00	0.69	0.97	0.97
15	2.00	1.39	1.97	0.99
20	4.00	2.83	4.00	1.00
25	5.00	3.55	5.03	1.01
30	5.00	3.57	5.04	1.01
40	10.0	7.16	10.1	1.01
50	10.0	7.15	10.1	1.01
75	10.0	7.17	10.1	1.01
100	10.0	7.20	10.2	1.02
200	10.0	7.27	10.3	1.03
300	10.0	7.30	10.3	1.03
400	10.0	7.33	10.4	1.04
500	10.0	7.34	10.4	1.04
600	10.0	7.36	10.4	1.04
750	10.0	7.38	10.4	1.04
1000	10.0	7.41	10.5	1.05
1500	10.0	7.44	10.5	1.05
2000	10.0	7.46	10.6	1.06
3000	10.0	7.47	10.6	1.06

TABLE 2
ESTIMATED MEASUREMENT UNCERTAINTIES

Source of Error	% of Reading	
	Systematic	Random
A - Calibration of Accelerometer		
Overall uncertainty of knowledge of acceleration applied	±0.64	±0.52
Charge amplifier noise: 1 pC rms/10,000 pf (Manuf. Lit.) source capacitance = 3250 pf		±0.10
Voltmeter calibration accuracy: ±(.05% Reading + .02% Range) (Manuf. Lit.) signal = 7 V	±0.08	
Repeatability and resolution of voltmeter reading (Estimate) ±5 mV		±0.07
Totals (root sum square)	±0.645	±0.534
TOTAL ESTIMATED UNCERTAINTY (Systematic + 3 x Random) ±2.25%		
B - Static Pressure Calibration		
Voltmeter calibration accuracy: ±(.01% Reading + .01% Range) (Manuf. Lit.) signal = 50 mV	±0.03	
Repeatability and resolution of voltmeter reading (Estimate) ±0.05 mV		±0.10
Static pressure dial gage accuracy (Manuf. Lit.)	±0.33	
Static pressure dial gage sensitivity (Manuf. Lit.)	±0.20	
Repeatability and resolution of gage reading (Estimate)		±0.02
Totals (root sum square)	±0.387	±0.102
TOTAL ESTIMATED UNCERTAINTY (Systematic + 3 x Random) ±0.69%		
C - Dynamic Pressure Response: Transducer (B)		
Overall uncertainty of knowledge of acceleration applied	±0.64	±0.52
Voltmeter calibration accuracy: ±(.05% Reading + .02% Range) (Manuf. Lit.) Signal = 800 mV	±0.08	
Repeatability and resolution of voltmeter reading (Estimate) ±5 mV		±0.63
Height of liquid column (Estimate) ±0.30 in.		±0.30
Liquid density variation due to temperature variation (Estimate) ±2°C		±0.10
Totals (root sum square)	±0.645	±0.875
TOTAL ESTIMATED UNCERTAINTY (Systematic + 3 x Random) ±3.27%		
D - Dynamic Pressure Response: Transducer (A)		
Overall uncertainty of knowledge of acceleration applied	±0.64	±0.52
Voltmeter calibration accuracy: ±(.05% Reading + .02% Range) (Manuf. Lit.) signal = 100 mV	±0.07	
Repeatability and resolution of voltmeter reading (Estimate) ±0.5 mV		±0.50
Height of liquid column (Estimate) ±0.03 in.		±0.30
Liquid density variation due to temperature variation (Estimate) ±2°C		±0.10
Totals (root sum square)	±0.643	±0.788
TOTAL ESTIMATED UNCERTAINTY (Systematic + 3X Random) ±3.01%		

TABLE 3

COMPARISON OF REPEATABILITY OF DEMOUNTABLE TEST FIXTURE VS. ONE-PIECE FIXTURE

Frequency Hz	Run Number	Acceleration Applied g (0-to-Peak)	Demountable Transducer (B) Output mV (rms)	Demountable Transducer (B) Output mV (0-to-Peak)	Demountable Transducer (B) Response mV/g	One-piece Transducer (B) Output mV (rms)	One-piece Transducer (B) Output mV (0-to-Peak)	One-piece Transducer (B) Response mV/g
100	1	5	3.93	5.56	1.11	4.02	5.68	1.14
	2	5	4.02	5.68	1.14	4.02	5.68	1.14
	3	5	4.04	5.71	1.14	4.00	5.66	1.13
	4	5	4.02	5.68	1.14	4.04	5.71	1.14
	Average				1.13			1.14
	Repeatability				0.03 (2.6%)			0.01 (0.9%)
	Ratio: Demountable/One-piece				0.99			
50	1	5	--	--	--	3.95	5.59	1.12
	2	5	3.96	5.60	1.12	3.98	5.63	1.13
	3	5	4.00	5.66	1.13	3.94	5.57	1.11
	4	5	3.95	5.59	1.12	4.00	5.66	1.13
	Average				1.12			1.12
	Repeatability				0.01 (0.9%)			0.02 (1.8%)
	Ratio: Demountable/One-piece				1.00			
25	1	4	3.06	4.32	1.08	3.92	5.54	1.11
	2	5	3.90	5.51	1.10	3.98	5.63	1.13
	3	5	3.94	5.57	1.12	3.90	5.51	1.10
	4	5	3.92	5.54	1.11	3.95	5.59	1.12
	Average				1.10			1.11
	Repeatability				0.04 (3.6%)			0.03 (2.7%)
	Ratio: Demountable/One-piece				0.99			

MAXIMUM PRESSURE SIGNAL FREQUENCY

Run Number		Demountable	One-piece
1	N.A.	935 Hz	982 Hz
2	N.A.	940 Hz	982 Hz
3	N.A.	947 Hz	982 Hz
4	N.A.	952 Hz	980 Hz
Average		943.5	981.5
Repeatability		17.0 (1.8%)	2.0 (0.2%)
Ratio: Demountable/One-piece		0.96	

TABLE 4

Test	Assembly	Liquid	Resonant Frequency	
			(Hz)	(Q)
1	2.54 cm i.d. soldered fixture (No. 4 in Fig. 3)	water	968	13.0
2	Same as above	tetrabromoethane	673	4.5
3	2.24 cm i.d. smooth tube, univ. fixture (No. 5 in Fig. 3)	water	944	14.0
4	Same as above	oil	918	16.0
5	Same as above	tetrabromoethane	642	5.0
6	Same as above	tetrabromoethane 13.0 cm column height	1650	8.5
7	Same as above	fluorocarbon	425	9.0
8	1.27 cm i.d. smooth tube, univ. fixture (No. 6 in Fig. 3)	water	732	12.0
9	51 channel tube, universal fixture (No. 3 in Fig. 3)	water	713	9.0
10	Spiral fluted tube, univ. fixture (No. 1 in Fig. 3)	water	639	9.5
11	1.27 cm i.d. smooth tube, univ. fixture, filter "C" (No. 7 in Fig. 3)	water	702	8.0
12	Same as above	oil	691	3.8

Note: Column height is 34.9 cm (33.3 cm from center of transducer diaphragm) unless otherwise stated.

TABLE 5

STATIC VS. DYNAMIC RESPONSE

Test (see Table 4)	Static Response mV/Pa x 10^{-4}	Static Response mV/psi	Dynamic Response* mV/Pa x 10^{-4}	Dynamic Response* mV/psi	Response Ratio Dynamic/Static
2	3.25	2.24	3.29	2.27	1.01
3	3.31	2.28	3.34	2.30	1.01
5	3.26	2.25	3.34	2.30	1.02
7	3.28	2.26	3.35	2.31	1.02
8	3.26	2.25	3.32	2.29	1.02
11	3.22	2.22	3.32	2.29	1.03
12	3.26	2.25	3.29	2.27	1.01

Note: No static calibrations were made during tests 9 and 10 as the flutes and chambers in the tubes made it impractical to insert a stopper in the top of the tube. No static calibrations could be made during tests 4 and 6 as the leads to transducer (B) had broken. (The test numbers are for identification only and do not reflect the order in which the tests were performed.)

*The average response for the frequency range 20 Hz to 50 Hz was used.

The pressure amplitude for the dynamic response is calculated from:

$$p = h \rho a ,$$

where h is the height of the liquid column above the transducer,

ρ is the density of the liquid, and

a is the acceleration amplitude

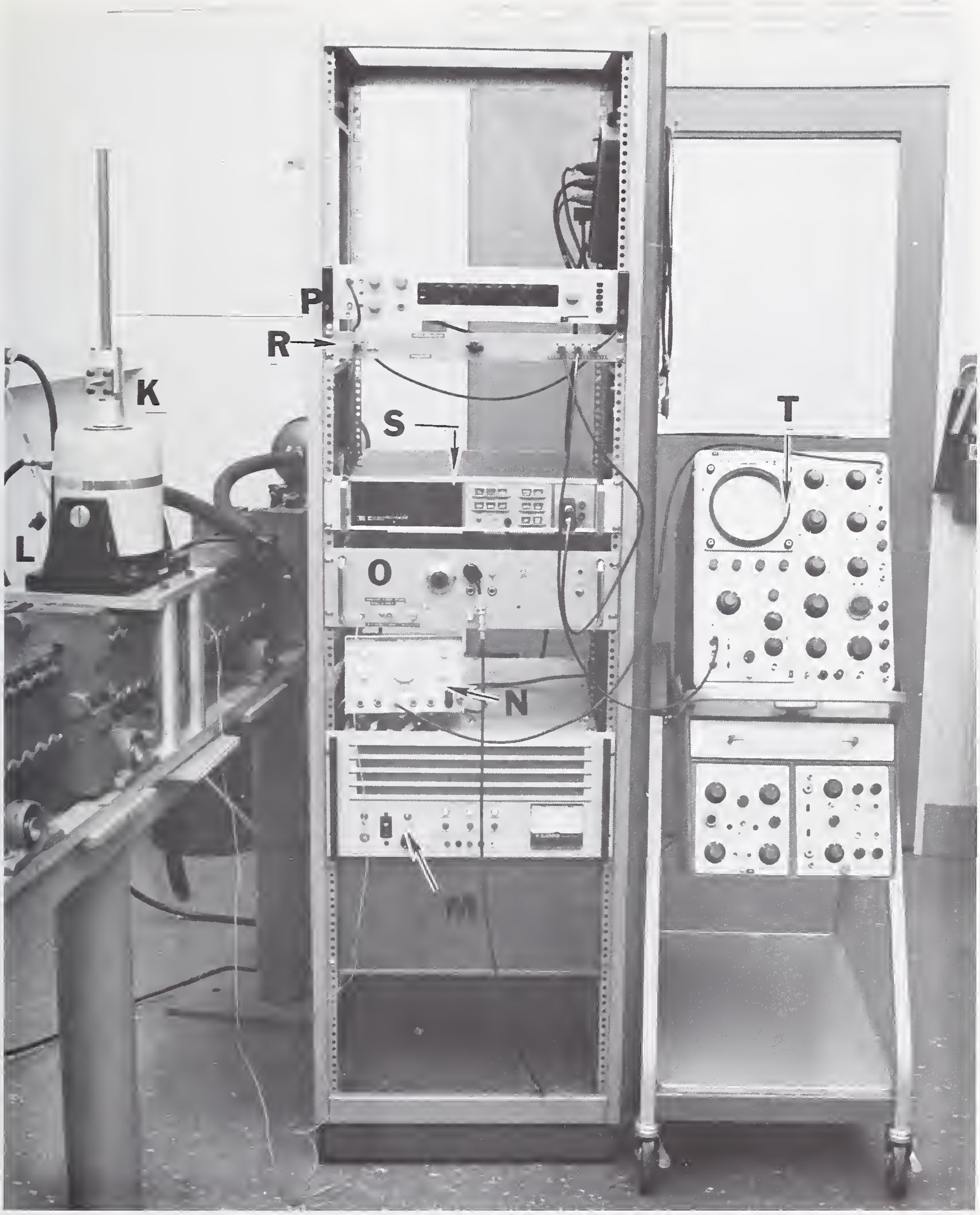


FIGURE 1: OVERALL VIEW OF SMALL VIBRATION EXCITER TEST SET UP. K-VIBRATION EXCITER WITH UNIVERSAL TEST FIXTURE; L-VIBRATION EXCITER TRUNNION; M-VIBRATION EXCITER POWER SUPPLY; N-VARIABLE OSCILLATOR; O-ACCELEROMETER CHARGE AMPLIFIER; P-FREQUENCY METER; R-SELECTOR SWITCH; S-DIGITAL VOLTMETER; T-OSCILLOSCOPE.

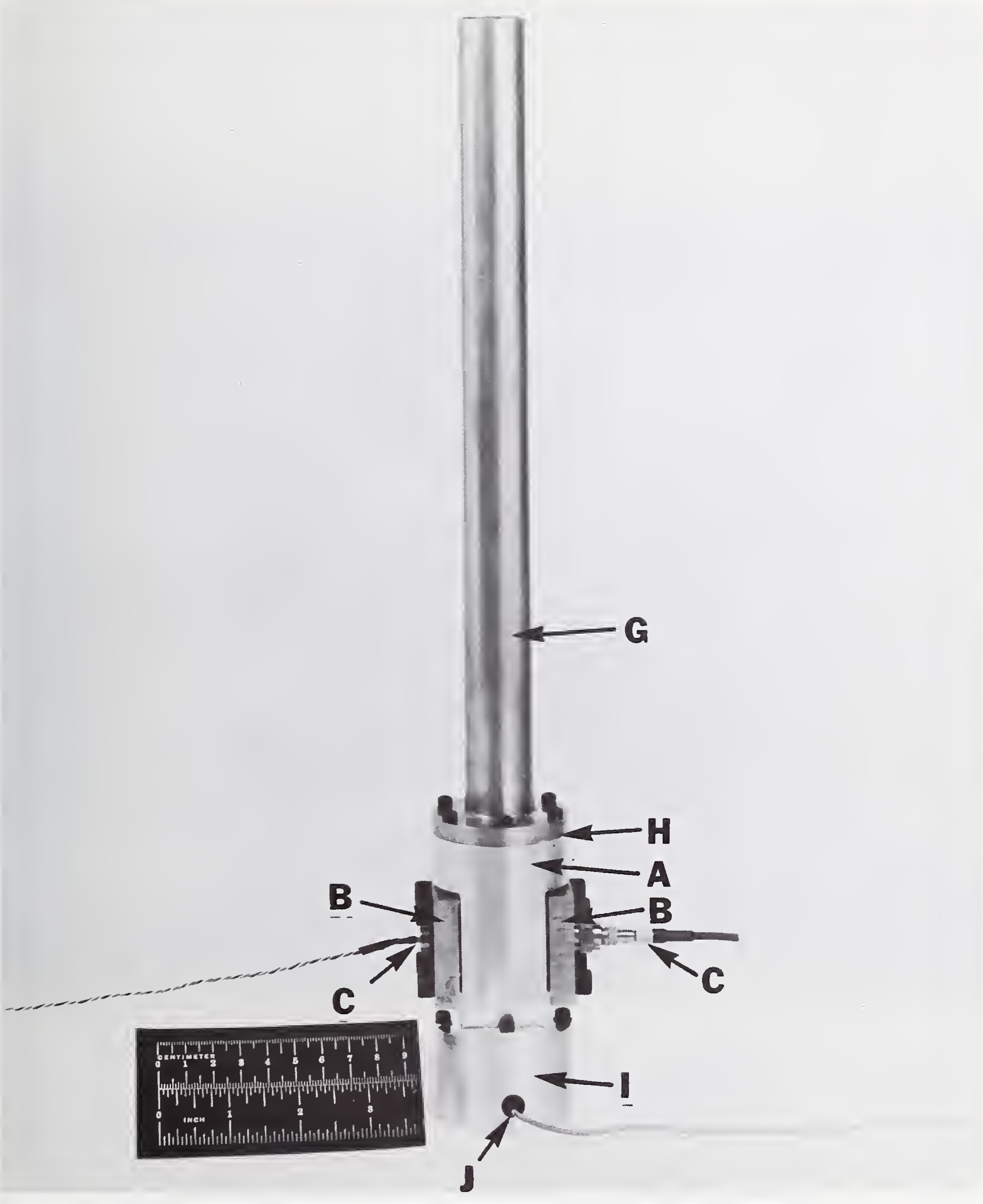


FIGURE 2: ASSEMBLED UNIVERSAL TEST FIXTURE WITH 2.2 CM (0.9 IN.) INSIDE DIAMETER TUBE ATTACHED. A-CHAMBER SECTION; B-TRANSDUCER PLATES; C-PRESSURE TRANSDUCERS; G-INTERCHANGEABLE TUBE; H-PAPER GASKET; I-ACCELEROMETER SECTION; J-LEAD FROM ACCELEROMETER.

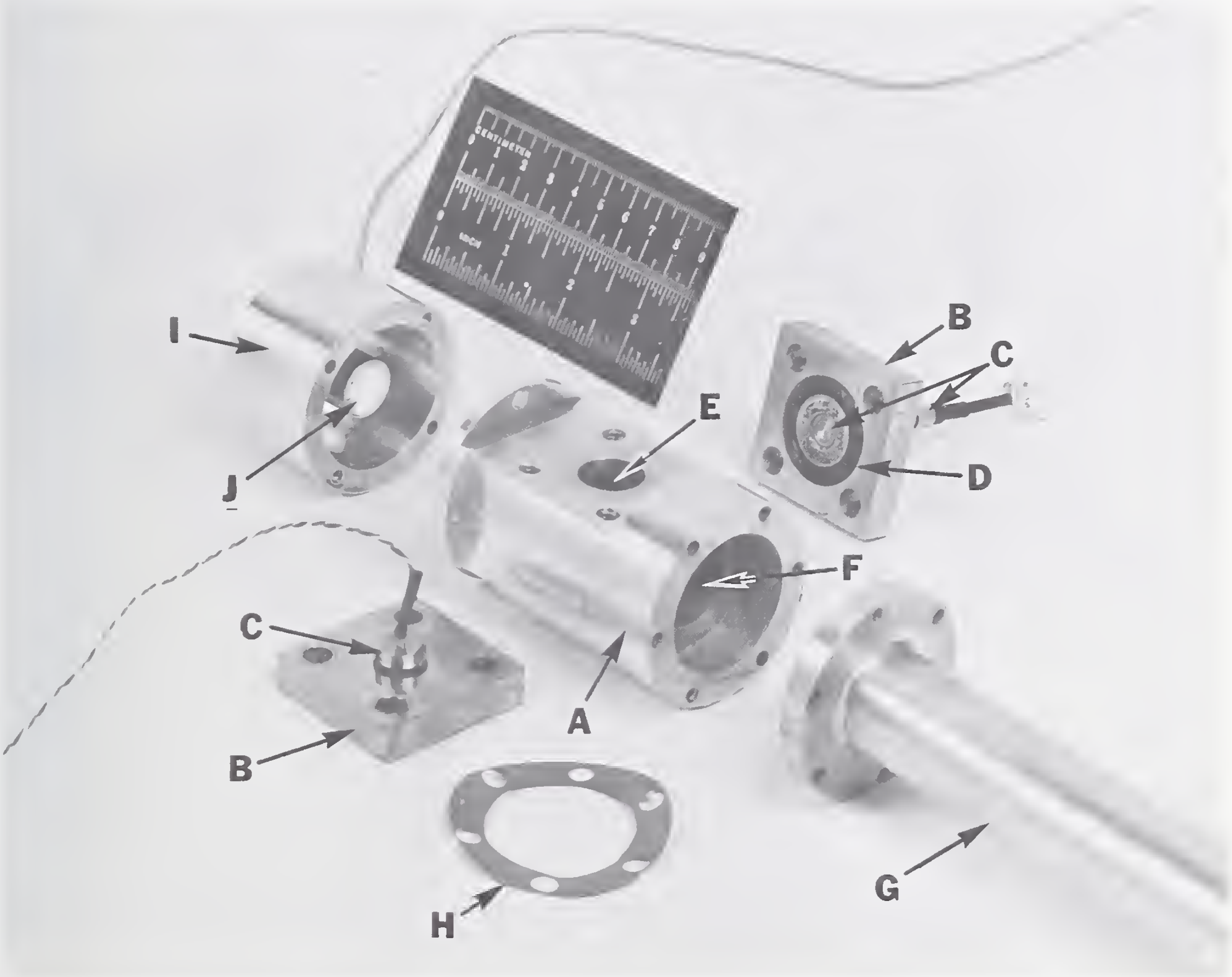


FIGURE 3: Components of the universal test fixture. A-Chamber Section; B-Transducer Plates; C-Transducers; D-O-Ring; E-Transducer Port; F-Chamber Cavity; G-Interchangeable Tube; H-Paper Gasket; I-Accelerometer Section; J-Accelerometer.

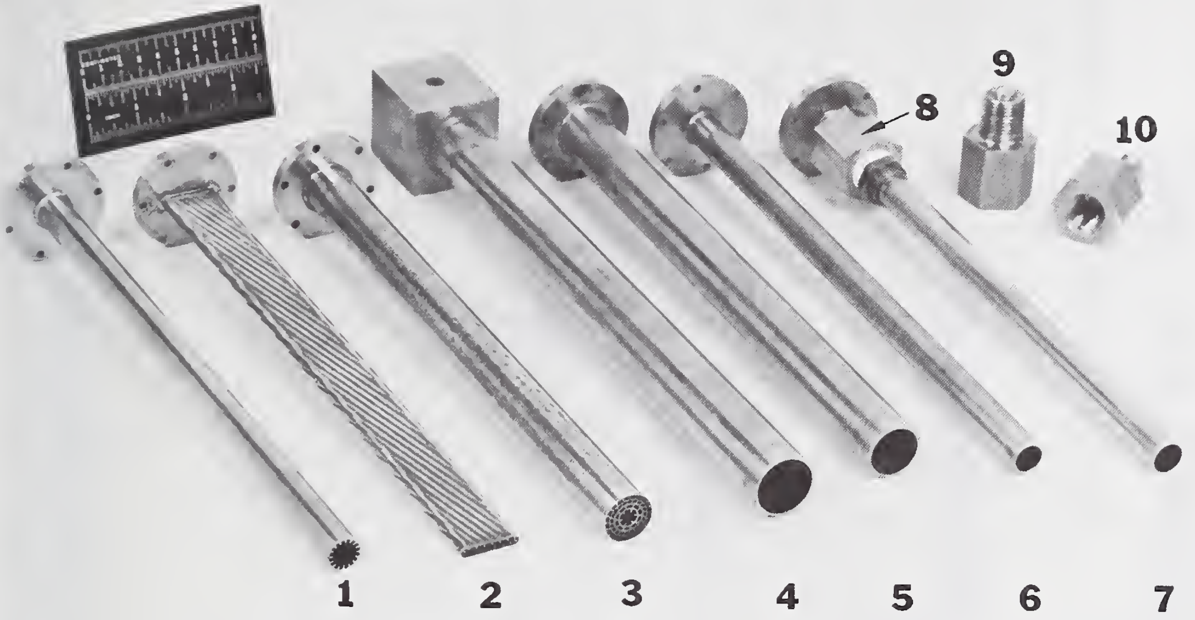
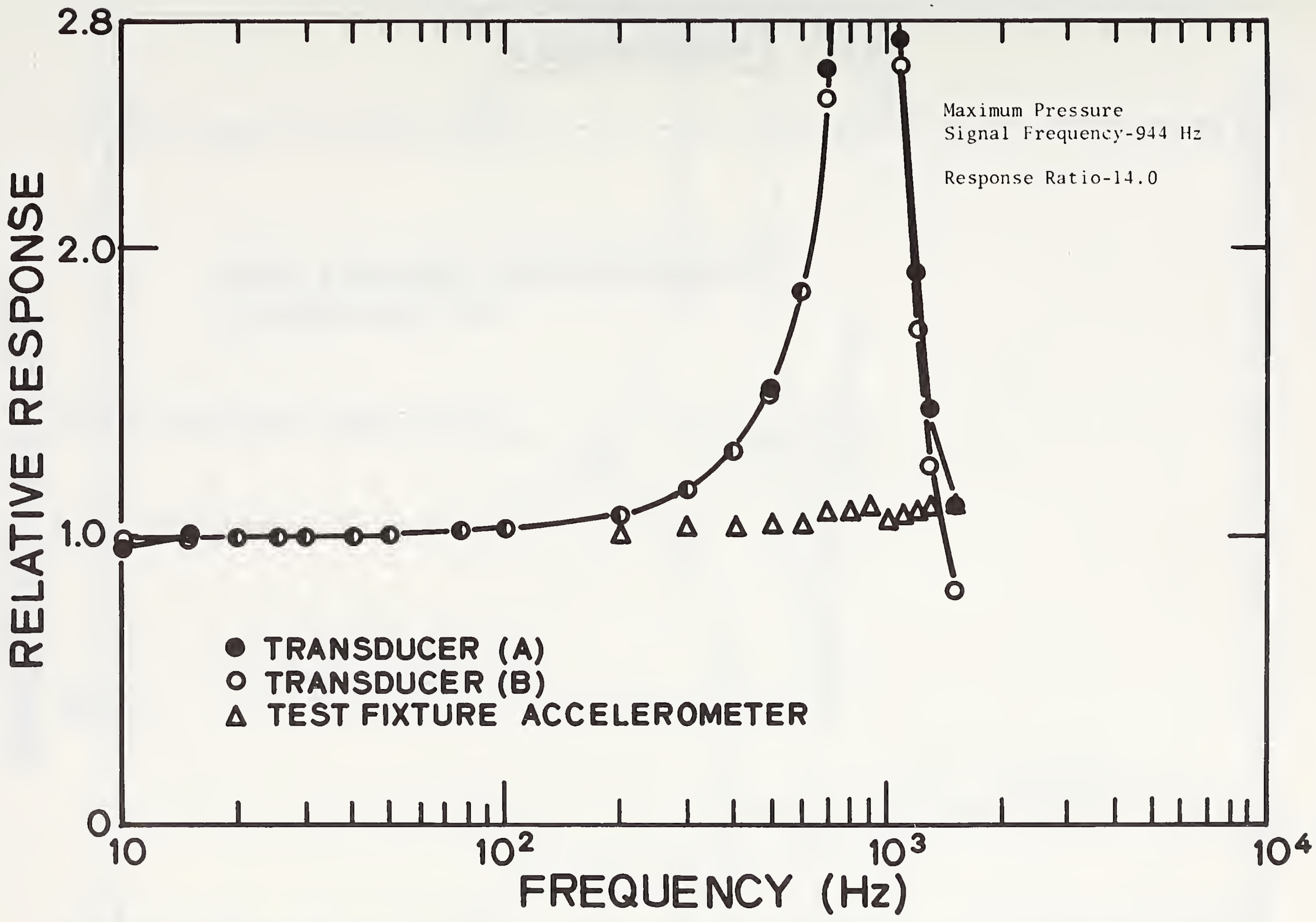


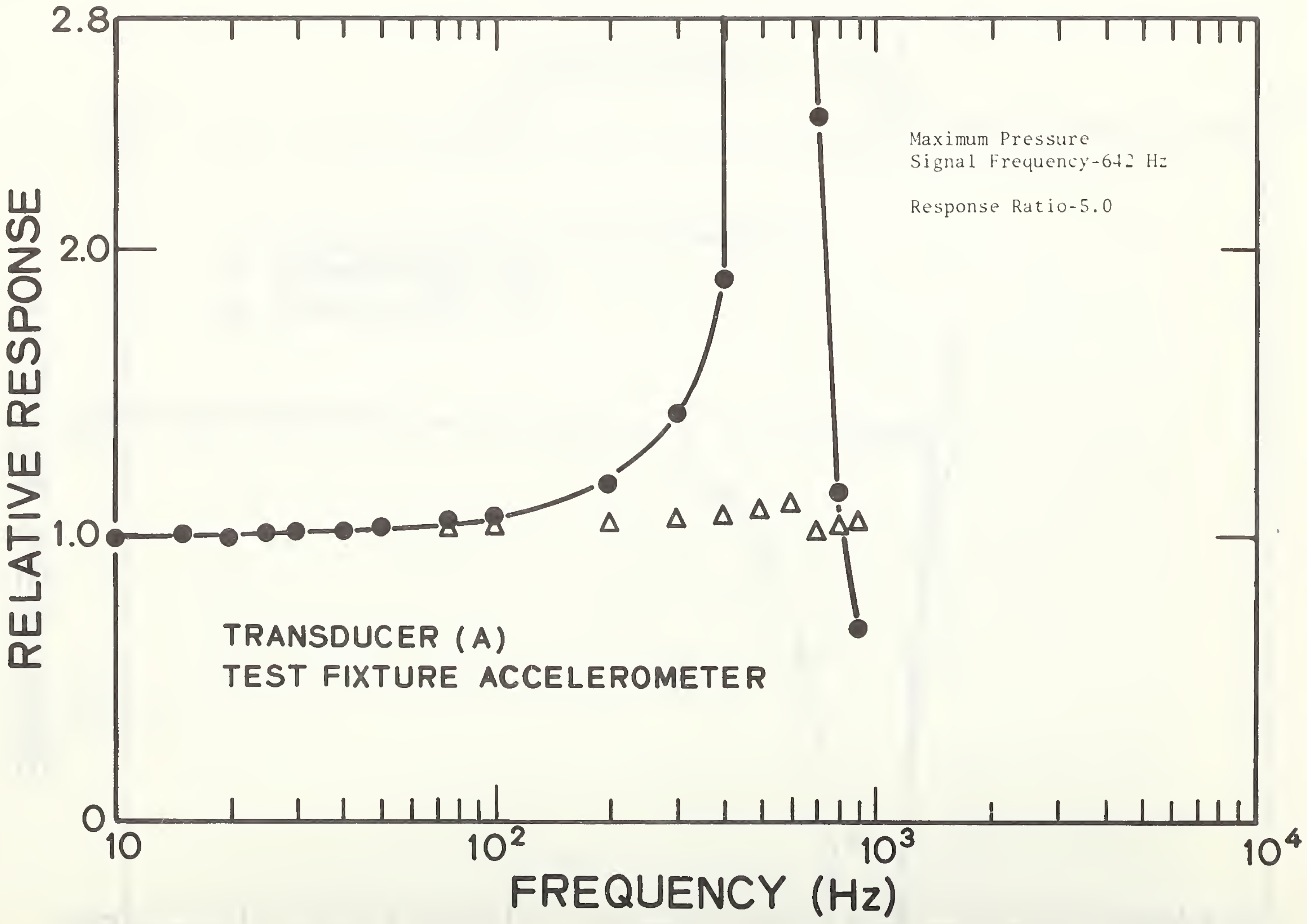
FIGURE 4: TUBES AND FILTERS USED IN EXPERIMENTS WITH THE UNIVERSAL TEST FIXTURE. 1-SPIRAL FLUTED TUBE; 2-FLAT TUBE; 3-51 CHANNEL TUBE; 4-ONE-PIECE TEST FIXTURE; 5-SMOOTH TUBE, 2.2 CM (0.9 IN.) INSIDE DIAMETER; 6-SMOOTH TUBE, 1.3 CM (0.5 IN.) INSIDE DIAMETER; 7-SMOOTH TUBE, 1.3 CM (0.5 IN.) INSIDE DIAMETER, WITH FILTER "C"; 9-FILTER "E"; 10-FILTER "HX".

FIGURE 5



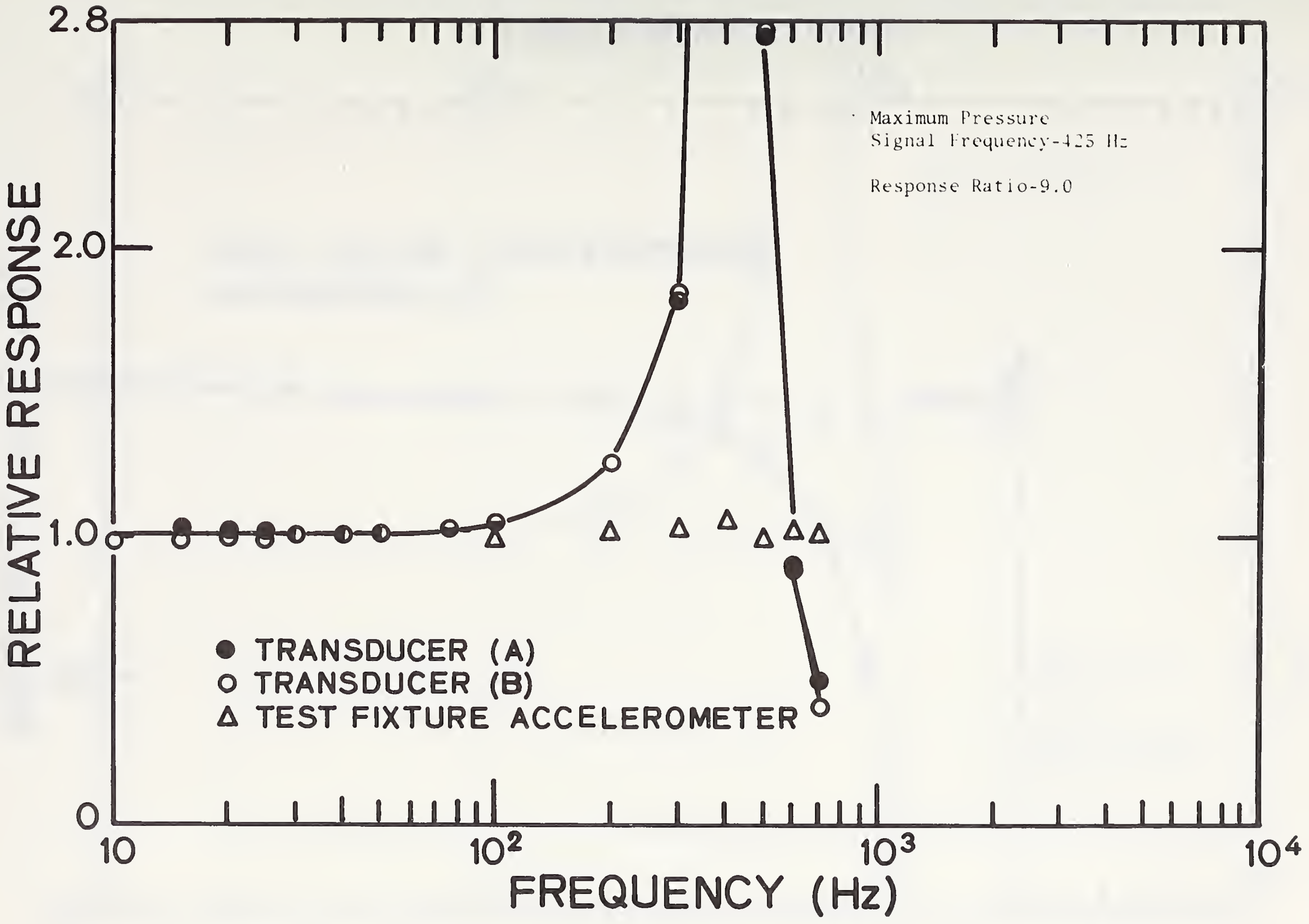
FREQUENCY RESPONSE TEST 3

FIGURE 6



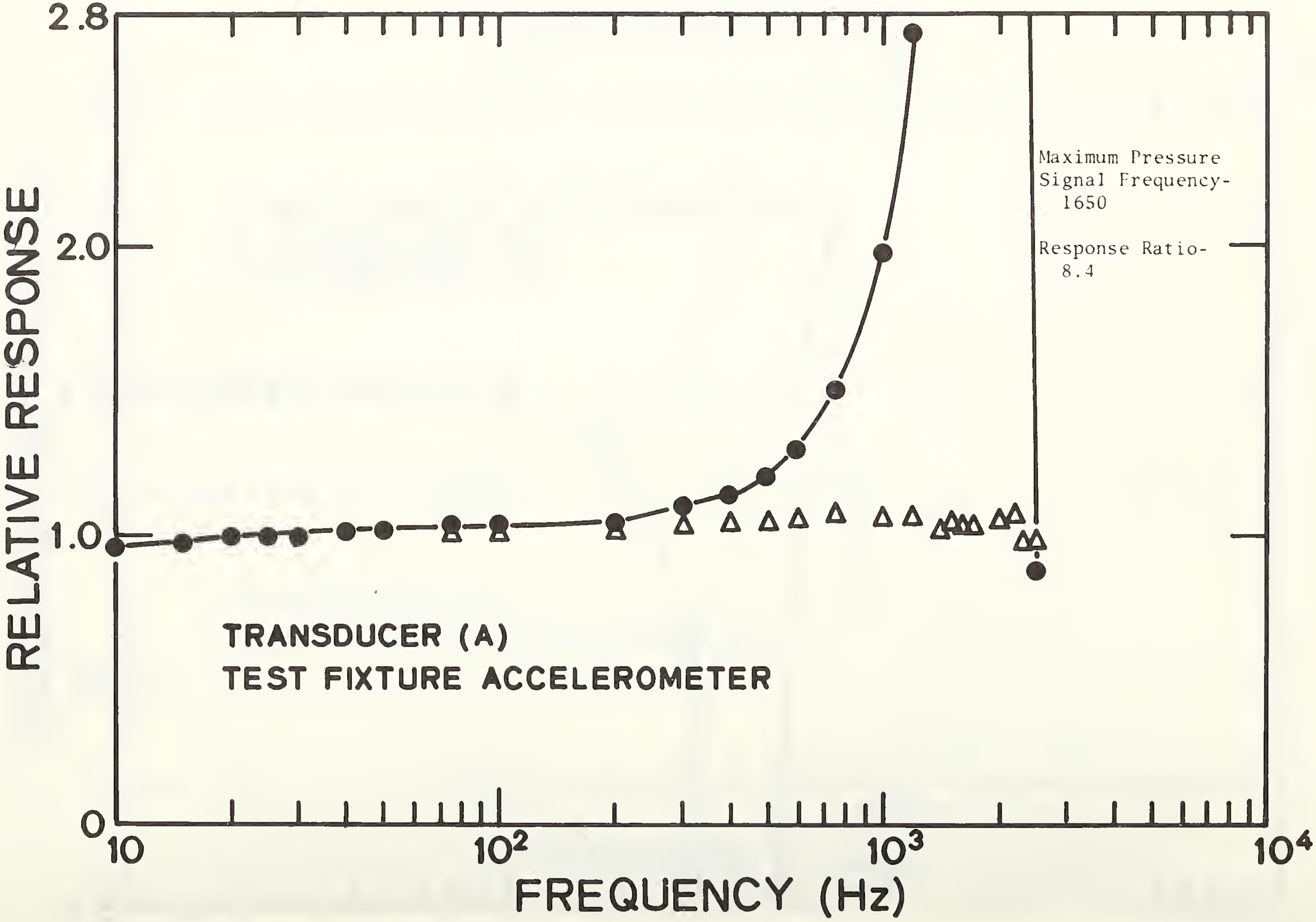
FREQUENCY RESPONSE TEST 5

FIGURE 7

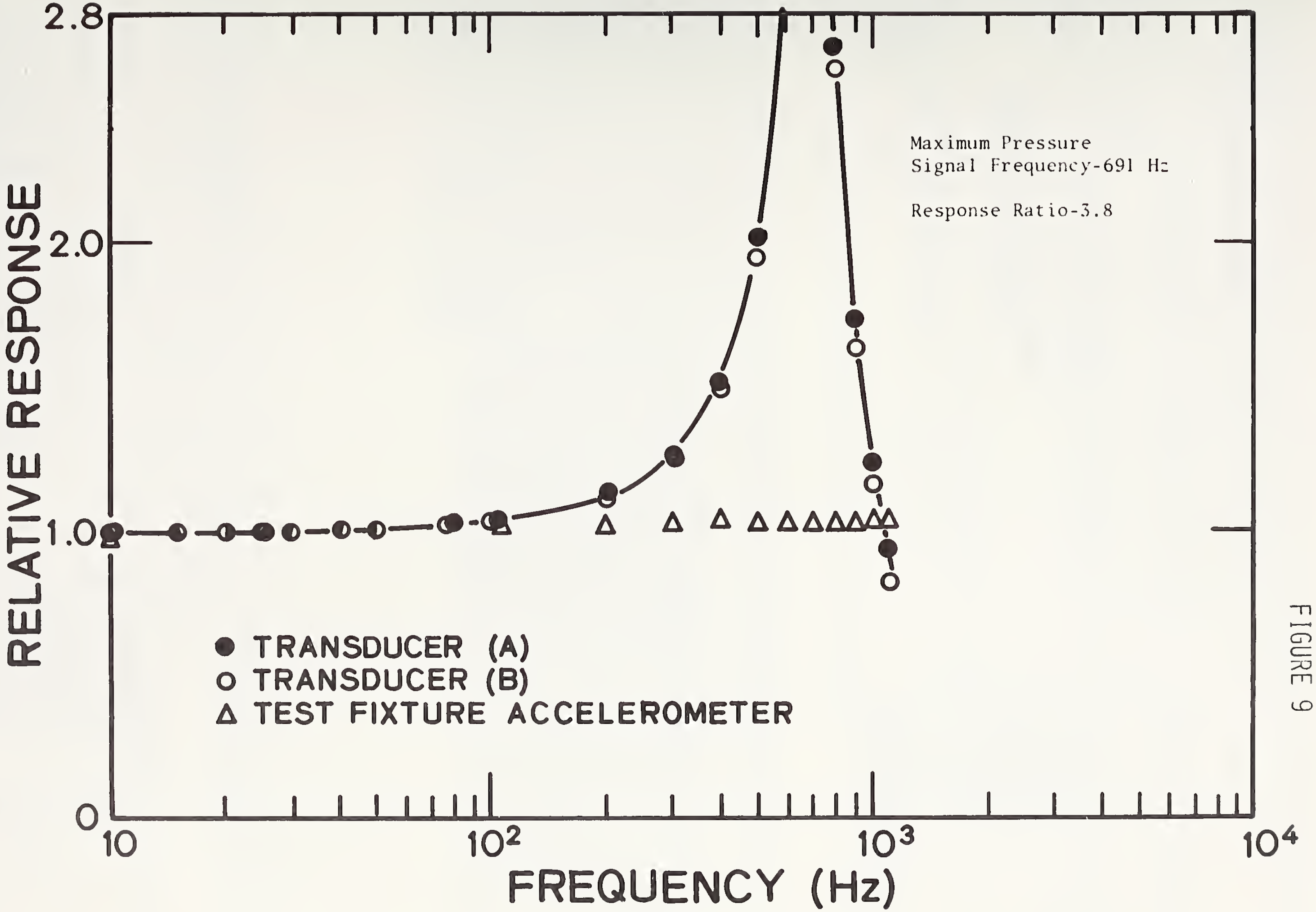


FREQUENCY RESPONSE TEST 7

FIGURE 3



FREQUENCY RESPONSE TEST 6



FREQUENCY RESPONSE TEST 12

FIGURE 9

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The objective of this task is to develop a dynamic pressure calibration technique yielding a flat frequency response to 2000 Hz or greater and amplitude capability of at least 3.4 x 10^4 Pa (5.0 psi) zero-to-peak. Equipment was set up, a universal test fixture fabricated, and testing was initiated of various liquids and damping schemes for a hydraulic sinusoidal pressure generator consisting of a vibrating liquid column. Two liquids of density greater than water, tetrabromoethane and a fluorocarbon, were tested. As was expected from the densities and bulk moduli, improved frequency response could be accomplished only with the tetrabromoethane. Very little improvement of damping has been obtained by using tubes with large wetting surface area. Although tests using filters are only in early stages, indications are that the proper combination of liquid viscosity and filter porosity may result in improved damping.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Calibration; dynamic; liquid column; pressure; sinusoidal.

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