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Electronic Instrumentation of a 10,000-psig Underwater Sound Transducer Calibration Facility for the 10- to 4000-Hz Frequency Range

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ABSTRACT

The electronic instrumentation of a new measuring facility for calibrating underwater sound transducers at controlled temperature from 3 to 45°C in the frequency range 10 to 4000 Hz at hydrostatic pressure to 10,000 psig is described. The pressure vessel consists of a vertically mounted 20.3-cm-i.d. stainless-steel tube 274.3 cm long. An active-impedance termination can be established at one or both ends of the tube to provide a plane, progressive wave within it. Three phase- and amplitude-adjustable outputs from the signal source activate the source transducer and those that control the terminal impedance. Multiple probe transducers and receiving channels serve to establish and monitor the required wave condition. Delay lines enable rapid and convenient adjustment to obtain minimum standing-wave ratio.

PROBLEM STATUS

This is an interim report on the problem.

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ELECTRONIC INSTRUMENTATION OF A 10,000-psig
UNDERWATER SOUND TRANSDUCER CALIBRATION FACILITY
FOR THE 10- TO 4000-Hz FREQUENCY RANGE

INTRODUCTION

The increasing use of underwater sound transducers at great ocean depths and under wide variations of temperature has required the continued expansion of the Underwater Sound Reference Division's (USRD) capability for making acoustic calibration measurements in temperature-controlled pressure vessels. This report describes the electronic instrumentation developed for a new facility that has been placed in operation to meet some of these needs. Other reports discuss the theory and the mechanical construction of the facility [1] and the electroacoustic transducers used in the pressure vessel [2].

BACKGROUND

The validity of acoustic measurements made in a pressure vessel depends to a large extent on the characteristics of the vessel and the techniques used. If the tank is sufficiently large, conventional free-field pulse measurements can be made in it [3]. If all the dimensions of the tank are very small in comparison with the wavelength at the frequency of measurement, other techniques apply [4,5]. The upper frequency limit of a low-frequency tank can be extended somewhat by the methods described by Trott and Lide [6], although this was not the primary intent of their work.

The use of an active transducer as a terminating impedance to control the standing-wave ratio in an acoustic transmission line has been demonstrated [7,8]. Further discussion of this principle and its application can be found in the literature [9,10,11,12]. The technique has been applied for a number of years at USRD in a pressure vessel consisting of a tube approximately 41 cm in diameter and 15.3 m long; this facility is operational in the frequency range 100 to 1500 Hz at pressure to 8500 psig.

NEW FACILITY

The principle of an active terminal impedance is applied in two of the three possible modes of operation of the new facility. The full frequency range is 10 to 4000 Hz and the upper pressure limit is 10,000 psig. The controlled temperature range is from 3 to 45°C. The pressure vessel, a 20.3-cm-i.d. stainless steel tube 274.3 cm long, is mounted vertically in a manner that allows quick access to its interior for the installation and removal of transducers. Electronic equipment is contained in four enclosed racks located about 15 ft from the pressure vessel, behind a protective wall that provides for the safety of the operator in the unlikely event of rupture or leakage in the high-pressure system.

Comparison measurements can be made in the facility in the presence of standing waves in the frequency range 10 to 500 Hz; both comparison and reciprocity measurements can be made from 500 to 4000 Hz, with active transducers used as terminal impedances for the tube. Either the single- or the double-termination arrangement can be applied. For clarity, two illustrations from reference [12] are included here as Figs. 1 and 2.

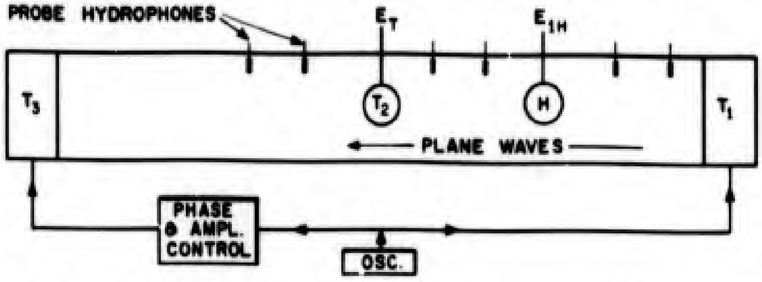

Fig. 1. Single-termination arrangement; T_1 is the source; T_3 is the terminal transducer; T_2 and H are unknown or standard transducers.

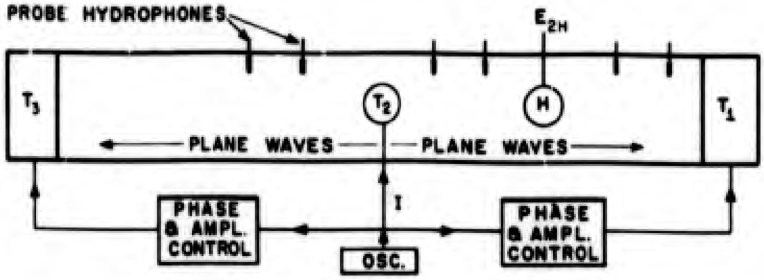

Fig. 2. Double-termination arrangement; T_2 is the reciprocal transducer and H is the hydrophone in a reciprocity calibration.

Probe hydrophones are mounted on a carrier and inserted within the tube to sample the acoustic pressure distribution along its length. This arrangement allows ready modification (if required) of the position,

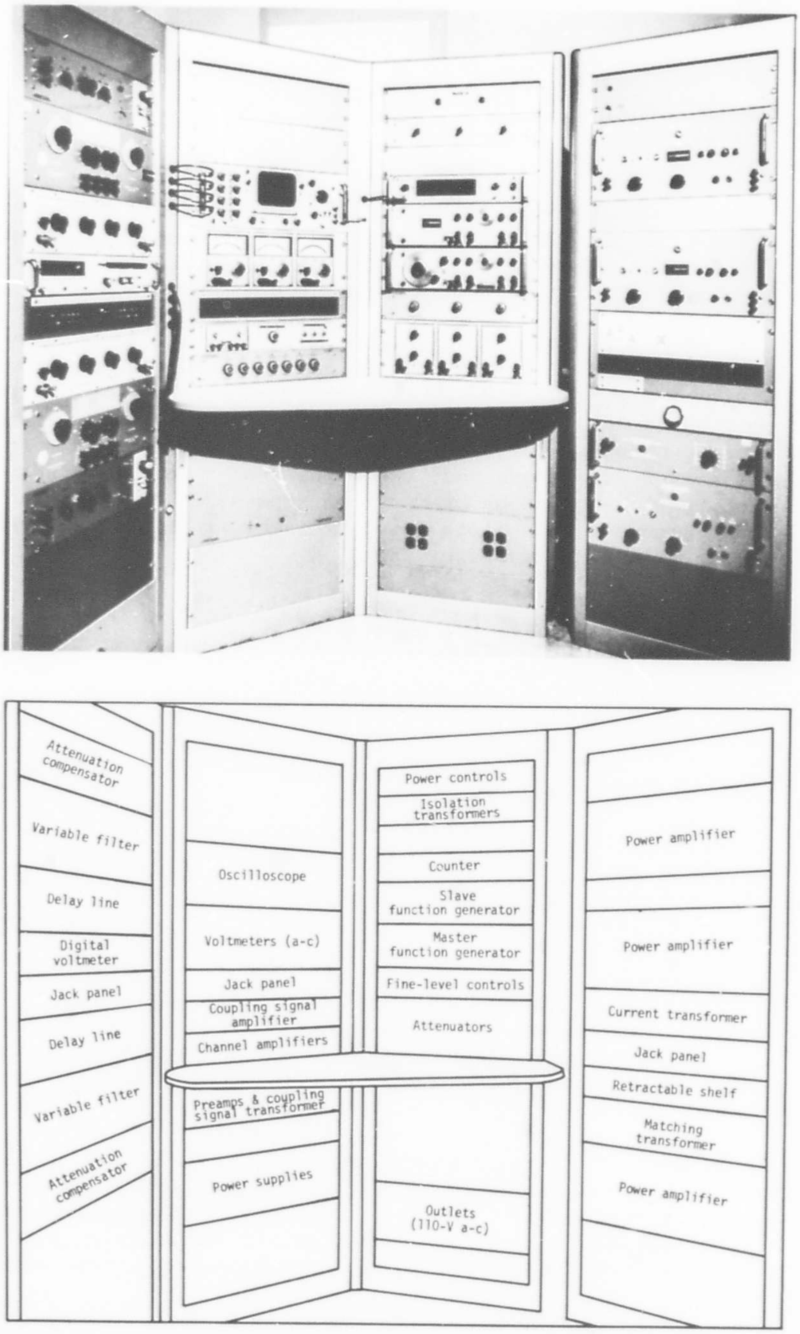

Fig. 3. Electronic equipment for System J.

number, and type of probes for a particular problem. The electronic system is designed for the use of as many as six probe hydrophones.

ELECTRONIC EQUIPMENT

Arrangement

For convenience of operation, the racks of electronic equipment are arranged in a modified "L" as shown in Fig. 3. Although the equipment is versatile and adaptable to special requirements, basically it is designed for use in any of the following three types of measurements.

(1) *Comparison calibration in the presence of standing waves.* This is the simplest method of the three, and generally is used at frequencies up to 500 Hz. The system is driven by one sound source. The output from an "unknown" hydrophone is compared with that of a calibrated standard hydrophone when both are subjected to the same acoustic field. Because of the presence of standing waves, the success of this method requires that the two hydrophones be at or very near the same location within the sound field. Figure 4 is a block diagram of the electronic equipment normally used for this kind of measurement.

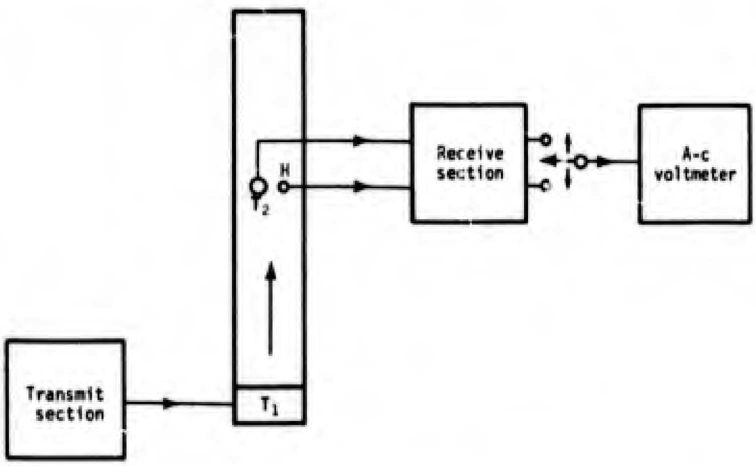

Fig. 4. Comparison calibration in the presence of standing waves; T_1 is the source; H is the standard hydrophone, and T_2 is the transducer being calibrated.

(2) *Comparison calibration in a plane progressive wave.* A transducer at one end of the tube is driven while a transducer at the other end serves as an active-impedance termination. When plane progressive waves have been established, the output of the unknown is compared with that of a calibrated standard. A block diagram of the arrangement is shown in Fig. 5.

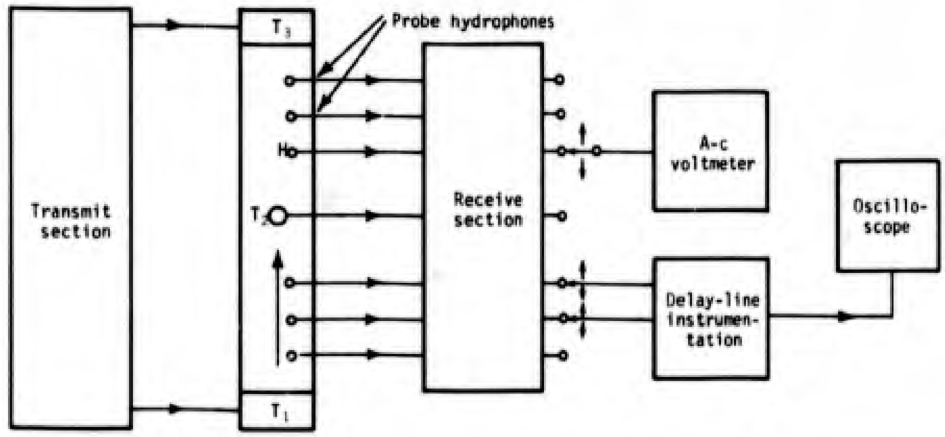

Fig. 5. Comparison calibration in a plane progressive wave; T_1 is the source; T_3 is the terminal transducer; H is the standard hydrophone, and T_2 is the transducer being calibrated.

(3) *Reciprocity calibration with dual active-impedance termination.* Three transducers are used in two series of measurements in which a reciprocal transducer at the center of the tube serves first as the source and later as a hydrophone, while transducers at each end of the tube become active terminators for the first series of measurements, and then the source and the active-termination devices for the second series. The active terminations serve to absorb the acoustic signal; when they are properly adjusted, the result is a plane progressive wave within the tube, without reflection from the termination. Figures 6 and 7 are block diagrams of electronic equipment used for reciprocity calibration measurements.

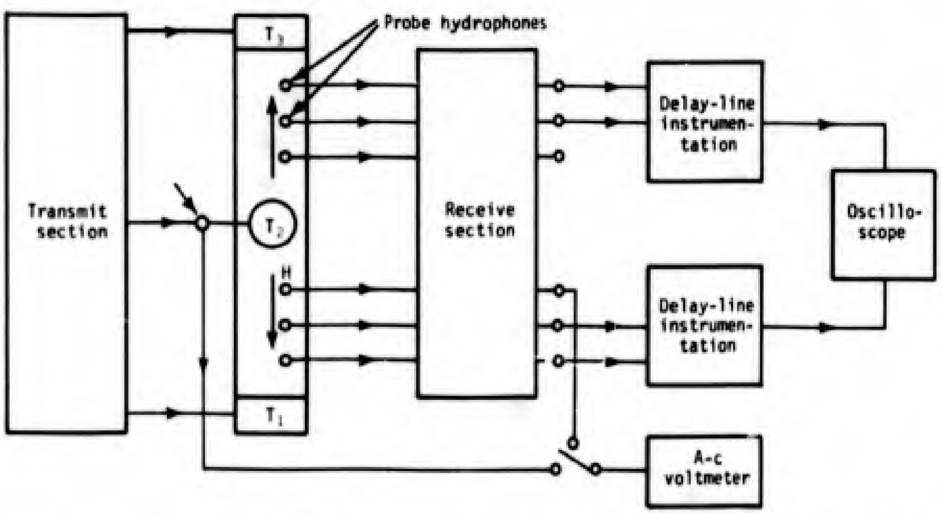

Fig. 6. Step 1 of a reciprocity calibration; T_1 and T_3 are terminal transducers; T_2 is the reciprocal transducer, and H is the unknown hydrophone.

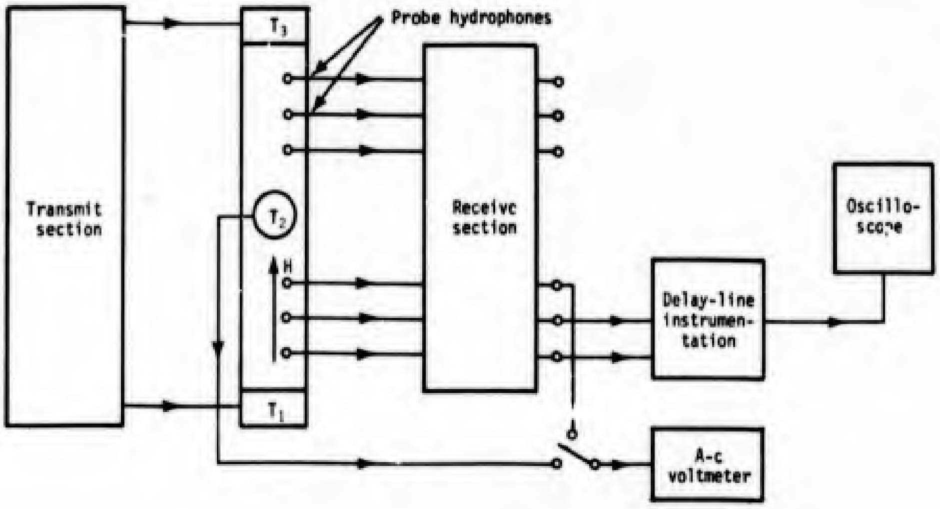

Fig. 7. Step 2 of a reciprocity calibration; T_1 is the source; T_2 is the reciprocal transducer; T_3 is the terminal transducer, and H is the unknown hydrophone.

TRANSMITTING SECTION

A block diagram of this section is shown in Fig. 8.

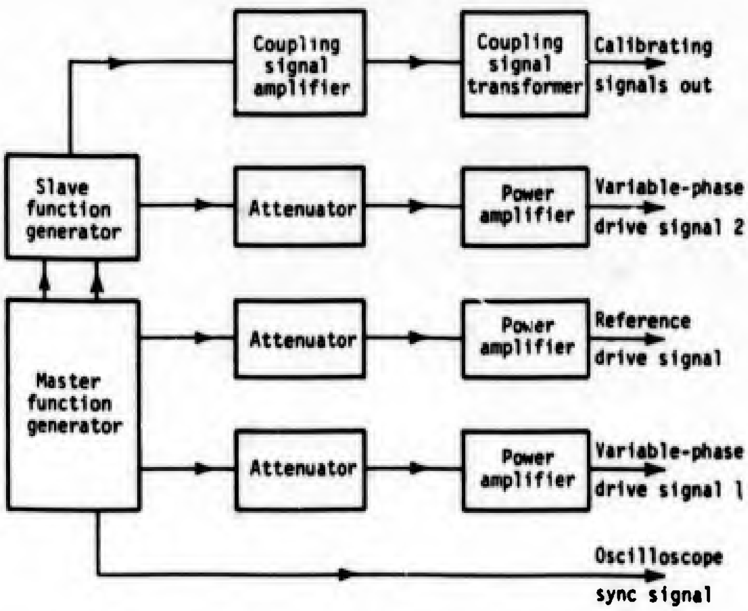

Fig. 8. Transmitting section.

The amplitudes of the four outputs of the signal source are adjustable independently; the phase of two of these also must be capable of separate adjustment. The low distortion and high stability required are met by Hewlett-Packard model E02-203A variable-phase function generator, which is a special-order item consisting of two model 203A function generators suitably modified to operate as a master/slave unit. The short-term frequency stability of this unit is better than 0.01%. The frequency is monitored continuously by an electronic counter. Distortion and hum are less than 0.06% at full output. Phase-dial accuracy is ±5%, which is adequate in this application because the normal requirement is for phase adjustment--not measurement--over 360°.

The master unit produces a phase-reference signal and another signal whose phase can be varied independently. The slave unit produces a second reference signal and a signal whose phase can be varied. Associated with each sinusoidal output is a square-wave output. The square-wave output from one reference channel is used to generate a synchronizing pulse to an oscilloscope. Each of three sinusoidal output signals (one reference and two phase-variable) is applied through an adjustable attenuator to individual power amplifiers, as required.

Another output from the reference channel is coupled through an isolating amplifier to a specially wound transformer having eight identical low-impedance windings, six of which are used individually to insert a calibration signal into the inputs of six preamplifiers. Of the remaining two outputs, one serves as the reference level and the other is available for inserting a signal into the amplifier used with the unknown hydrophone.

Power Amplifiers

Three 50-W power amplifiers are provided. Hum and noise content of these amplifiers is less than 5 mV; the harmonic distortion is less than 0.1%. The transducer normally driven by these amplifiers presents a load that is virtually capacitive (about 0.23 μF). Each amplifier will deliver 180 V maximum across this load in the frequency range 0 to 2500 Hz, dropping by approximately 4 dB at 4000 Hz. All three transducers are driven simultaneously only when the double active-impedance termination is required. In the frequency range 10 to 500 Hz, two amplifiers can be connected to develop the maximum drive, 360 V. For unusual load conditions, a transformer provides eight values of output impedance from 1000 to 0.2 Ω, which can be selected by a rotary switch on the front panel. By using the matching transformer, as much as 850 V can be obtained. Current to any transducer can be monitored through a wide-band current transformer having the sensitivity 1 V/A.

RECEIVING SECTION

Probe Hydrophones and Preamplifiers

Six probe hydrophones are placed at selected positions in the calibration tube to sample the acoustic field. As shown in the block diagram, Fig. 9, the preamplifier for each of these hydrophones is constructed in two parts. The first part is assembled with the hydrophone crystal and is packaged to withstand the high ambient pressure within the tube. The rest of the preamplifier is external to the tank. Another identical preamplifier entirely outside the pressure vessel is available for use

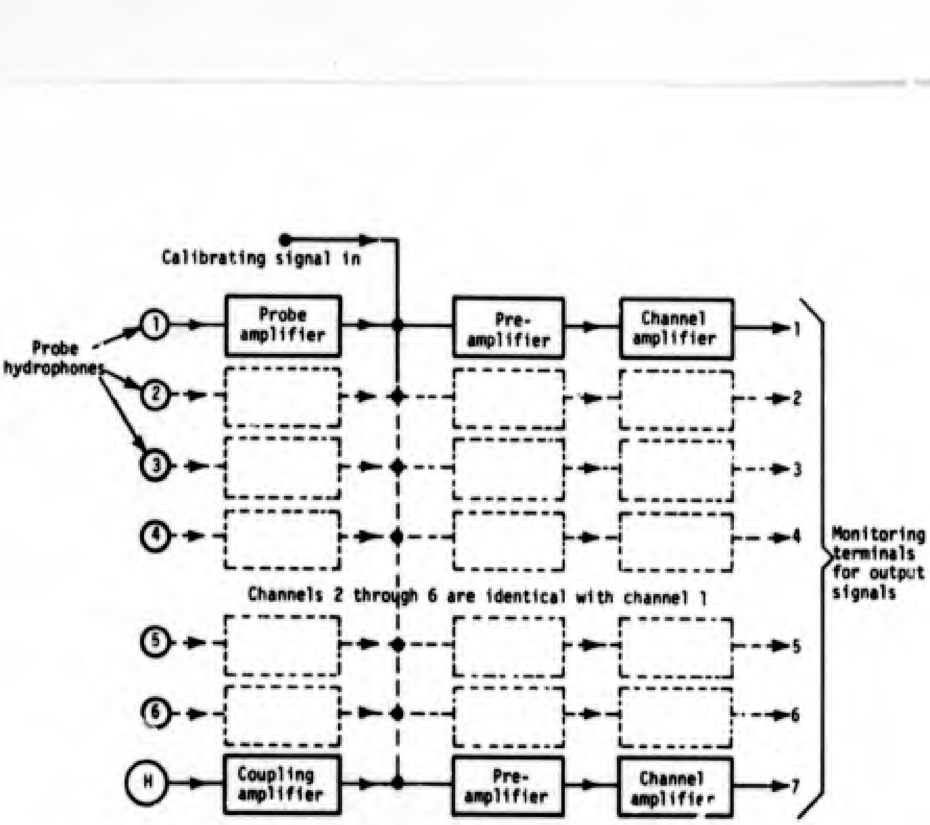

Fig. 9. Receiving section; H is the hydrophone being calibrated.

with the unknown transducer. These preamplifiers efficiently couple the very high impedance of the crystal element of the hydrophones to the low impedance of the transmission lines.

Channel Amplifier

Seven channel amplifiers having identical phase characteristics are provided. Normally, each has 10 dB gain, but the gain can be adjusted to compensate for small differences in the receiving sensitivity of its associated hydrophone.

Delay Line

Establishing the minimum standing-wave ratio in the tube by adjusting the active-impedance termination is tedious. To make this adjustment easier, two sets of delay lines and control equipment are provided. Each set of delay equipment consists of a delay line, an attenuation compensator, a differential amplifier, and a variable filter. Both sets are required only when the transducer at the center of the tube is used as the sound source and both ends of the tube require active impedance termination. The attenuation within a delay line varies with frequency and total delay. An attenuation compensator provides a dynamic correction for this loss.

In use, the signal from one of two appropriately spaced probe hydrophones is delayed by an amount equal to the calculated acoustic delay between the two. Two signals, one delayed and one direct, are compared by the differential amplifier so that when the amplitude and the phase of the two are equal, the output of the differential amplifier is a minimum. This output is filtered and displayed on an oscilloscope. The amplitude and phase of the signal driving the active-impedance transducer are adjusted manually in successive approximations until a null indication is achieved. The existence of minimum standing-wave ratio is confirmed by voltage measurements on each of the six probe hydrophones. Figure 10 shows the block diagram for the delay-line equipment.

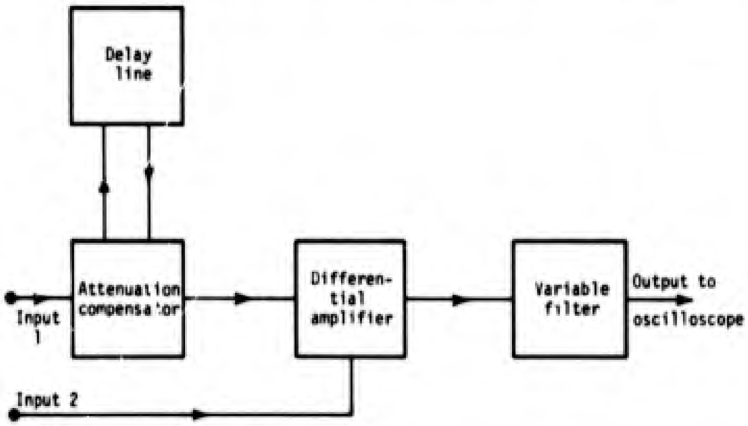

Fig. 10. Delay-line instrumentation.

The delay lines provide delay variable from 0 to 2000 μsec. The overall delay is within 2% of the dial reading. Because greater accuracy was needed, the delay lines were calibrated individually. Calibration curves allow the actual delay to be established to within 2 μsec at all frequencies of interest.

Probe Calibration

The sensitivity of each probe is established carefully before it is installed in the pressure vessel, and is verified periodically. One output from the variable function generator described earlier is amplified and applied to the primary of the specially designed transformer having multiple identical secondaries. Equal signals then are available for each of the receiving channels, thus allowing critical adjustment of gains to correct for the slight variation in sensitivity among the probe elements.

Readout

(1) *Current.* A current transformer having the sensitivity 1 V/A is used with an a-c voltmeter to measure current in any of the driving transducers.

(2) *Voltage.* One digital and three analog voltmeters are available for the basic measurements and comparisons.

(3) *Monitoring.* The 4-channel oscilloscope provides simultaneous monitoring of four separate signals.

(4) *Frequency Measurement.* An electronic counter provides precise frequency measurement.

CONCLUSION

The electronic instrumentation fully meets the design requirements of the new facility, which is operational and available for use in research problems or for calibration measurements.

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Transducers - Calibration						
Impedance tubes						
Low frequency						
High pressure						
Electronic instrumentation						
Pressure vessels						