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Final Report

Design, Fabrication and Testing of a  
5-Hz Acoustic Exciter System

Contract NAS8-29184 30 April 1973

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## FOREWORD

This final technical report is prepared by Applied Dynamics Research Corporation in partial fulfillment of MSFC Contract NAS8-29184, "Design, Fabrication, and Testing of a 5-Hz Acoustic Excitation System." The period of performance of this contract was from July 31, 1972 to April 30, 1973.

The program was conducted under the technical direction of S&E-AERO-YA, Mr. Kenneth A. Kadrmas.

ADRC personnel involved were D. H. Lundy and G. D. Robinson.

## SUMMARY

A 5-Hz Acoustic Excitation System was designed, fabricated and checked out for use in the modulation of a stagnant gas volume contained in an absorption cell. Included in this report are a detailed system description of the test equipment, both mechanical and electronic, and an operating procedure. Conclusions are also presented.

Three complete sets of final design drawings, one of which is reproducible, and two sets of operation manuals for procured commercial components have been forwarded through S&E-AERO-R separately.

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## Section 1

### INTRODUCTION

The 5-Hz Acoustic Excitation System is to be used for the modulation of a stagnant gas volume in an absorption cell. The effects of pressure and heat modulation on the absorption characteristics of various gases will be investigated by NASA/MSFC.

In arriving at the final design, the basic design objectives were analyzed and electrical and mechanical approaches that appeared feasible were studied.

The delivered hardware meets these design requirements:

- (1) Volume displacement capability is from 0 to 5 cubic inches.
- (2) The displacement to time function is sinusoidal at 5 Hz with an accuracy of approximately 1%.
- (3) The initial volume displacement is less than 100 cubic inches.
- (4) The entire system is housed in an enclosure that is dust-free, noise-isolated, and can be operated at increased or reduced pressure. It contains feed-throughs, and pressure, temperature, and displacement transducers.
- (5) The enclosure will interface with the absorption chamber with NASA MSFC Part No. 80M42313.
- (6) Instrumentation requirements are:
  - (a) A resolution of 0.01 psi is desired in measurement of the absolute pressure of the absorption cell.
  - (b) A resolution of .01°C is desired in measurement of absorption cell gas temperature.

## Section 2

### SYSTEM DESCRIPTION

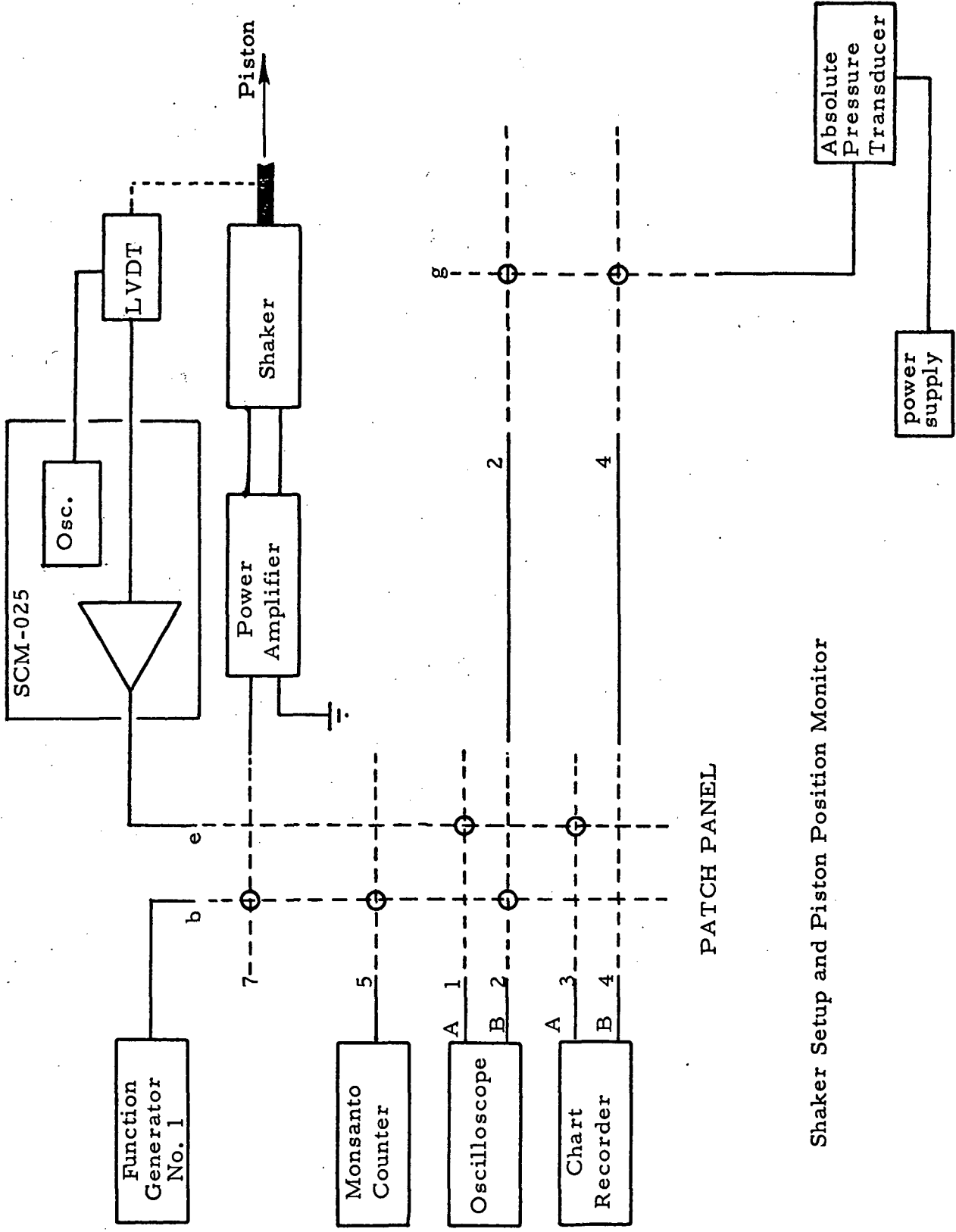
#### 2.1 Pressure Wave Generator (Refer to Figure 1)

A 5-Hz sinusoidal variation in pressure is introduced into the Absorption Cell by movement of a piston-and-bellows assembly. The piston is driven by an electromagnetic shaker, the Ling Model 411. The shaker can produce 25 pounds of force without forced air cooling. The total force required to move the piston at full stroke ( $\pm .35$  inches) is calculated to be 15 pounds. The 3 inch diameter piston, if moved a total of .70 inches, produces the required 5 cubic inches of displacement.

Power is supplied to the shaker by a Ling Model TP-450 Power Amplifier. The power amplifier can provide 500 volt-amperes of power for the shaker. This is sufficient drive for the shaker to produce 55 pounds of force at full stroke. The control signal for the power amplifier is supplied by an Exact Model 123 Function Generator. The Exact can provide a 5-Hz sine wave at less than 0.5% total distortion. This added to the 0.5% distortion figure of the Ling Power Amplifier yields a sinusoidal drive available to the shaker with less than 1% total distortion.

#### 2.2 Piston Position Monitoring System (Refer to Figure 1)

A linear variable differential transformer (LVDT) is used to sense the position of the piston. The core of the LVDT is attached to the armature of the shaker. The LVDT is connected to a Schaevitz Model SCM-025 oscillator/demodulator which provides a D. C. voltage proportional to the position of the core. The LVDT's active range is  $\pm 0.50$  inches. Connection diagram for the LVDT is shown in Figure 2.



Shaker Setup and Piston Position Monitor

Absolute Pressure Measurement System

Figure 1

Cavity Pressure and Piston Displacement Systems



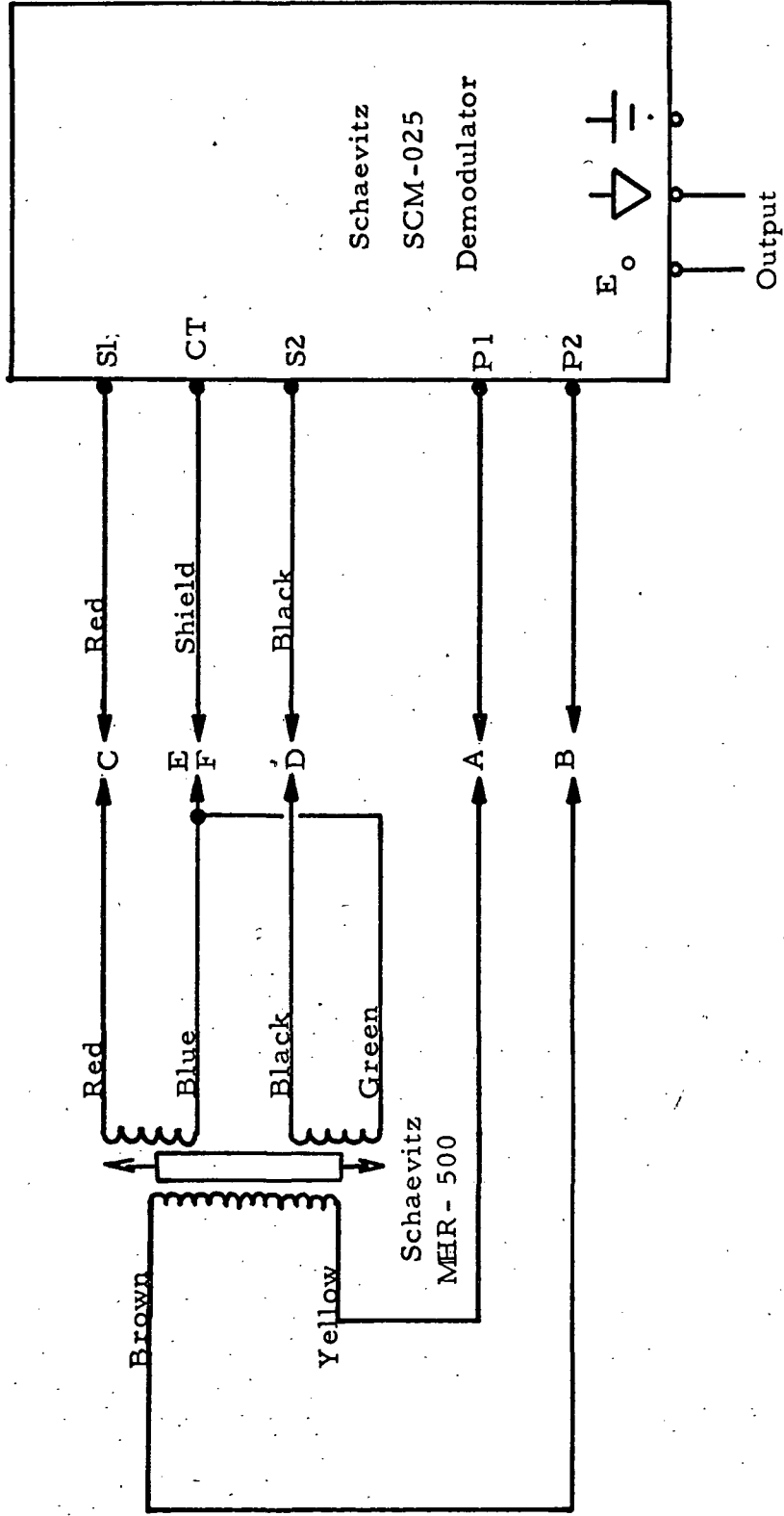


Figure 2. Connection Diagram for LVDT Displacement Transducer

### 2.3 Absorption Cell Pressure Monitoring System

Two separate pressures are monitored within the system. The first is the differential pressure around the piston. This pressure is sensed by a Schaevitz Model PTA-2100-50W differential pressure transducer. Excitation and signal conditioning for the transducer is provided by a Schaevitz Model SCM-025.

The second monitored pressure is the absolute pressure of the absorption cell. This pressure is measured by a Kistler Model 314A servo pressure sensor. The range of the transducer is 0 to 29 psia with an overall accuracy of 0.06% of full scale. Excitation is provided by a Schaevitz Model PSM-115R power supply. The Kistler model 314A has a high level output ( $\pm 5$  volts D. C.) and can drive monitoring and recording equipment directly. However, in order to provide the .01-psia resolution in pressure fluctuation even at elevated or reduced chamber pressures a zero suppression circuit is introduced between the transducer and the monitoring equipment. The offset voltage introduced by the zero suppression circuit is calibrated so that the bulk of the pressure signal is nulled out by a known voltage. The smaller fluctuations caused by the piston displacement can then be monitored at high resolution ( $1 \text{ mv} \approx .003 \text{ psia}$ ) on the oscilloscope. The zero suppression circuit contains a precision voltage reference set at 10.000 volts, a 10-turn pot and calibrated dial for tapping off the desired offset, and a summing amplifier for combining the offset with the transducer signal. The connection diagram for the absolute pressure transducer is shown in Figure 3 and the schematic diagram for the zero suppression circuit appears in Figure 4.

### 2.4 Temperature Wave Generator (Refer to Figure 5)

A 0.1-Hz (10-second period) temperature wave is produced by heating the piston with a Lepel induction heater. At maximum output the 1-kilowatt

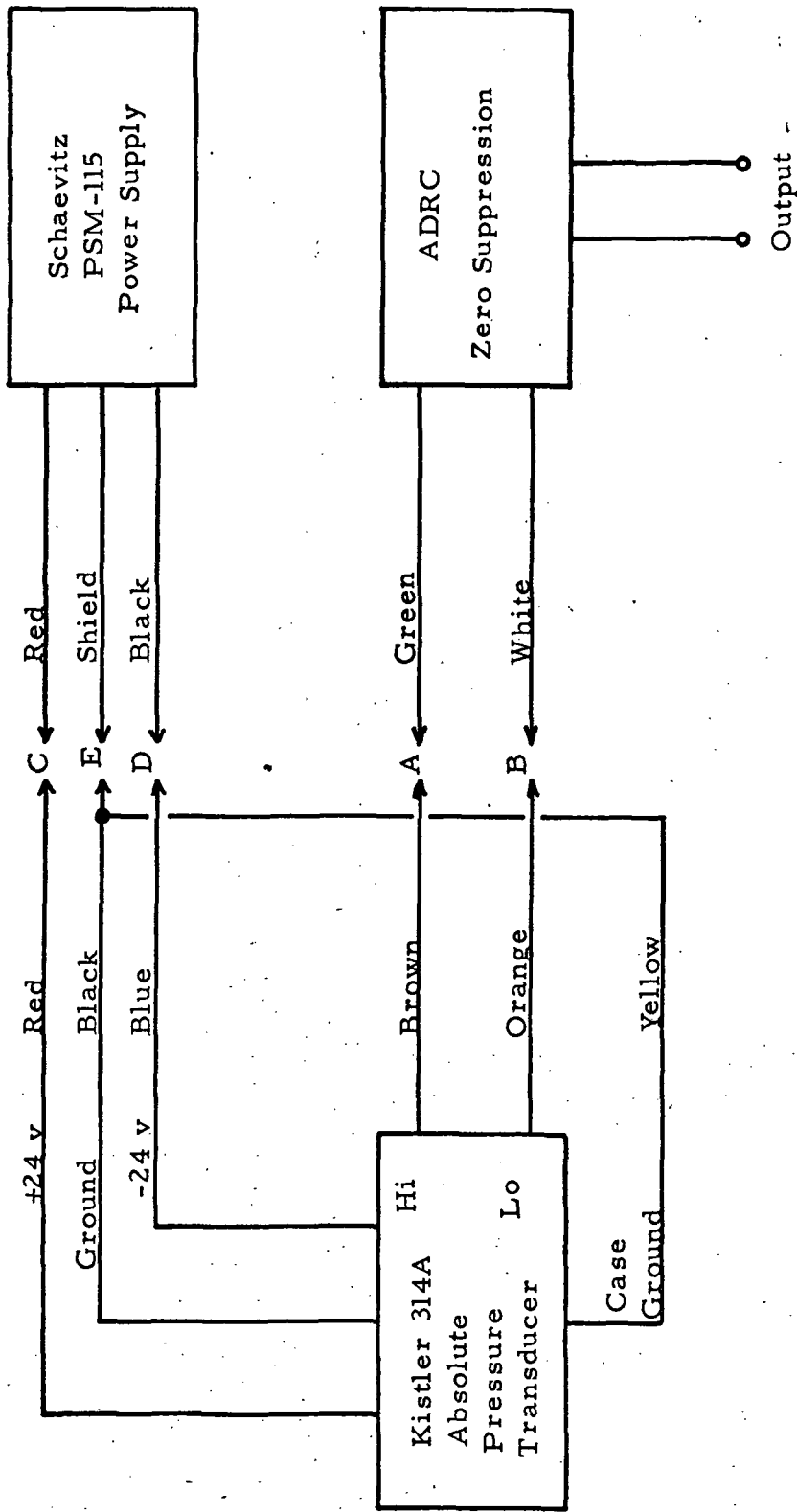


Figure 3 Connection Diagram For Absolute Pressure Transducer



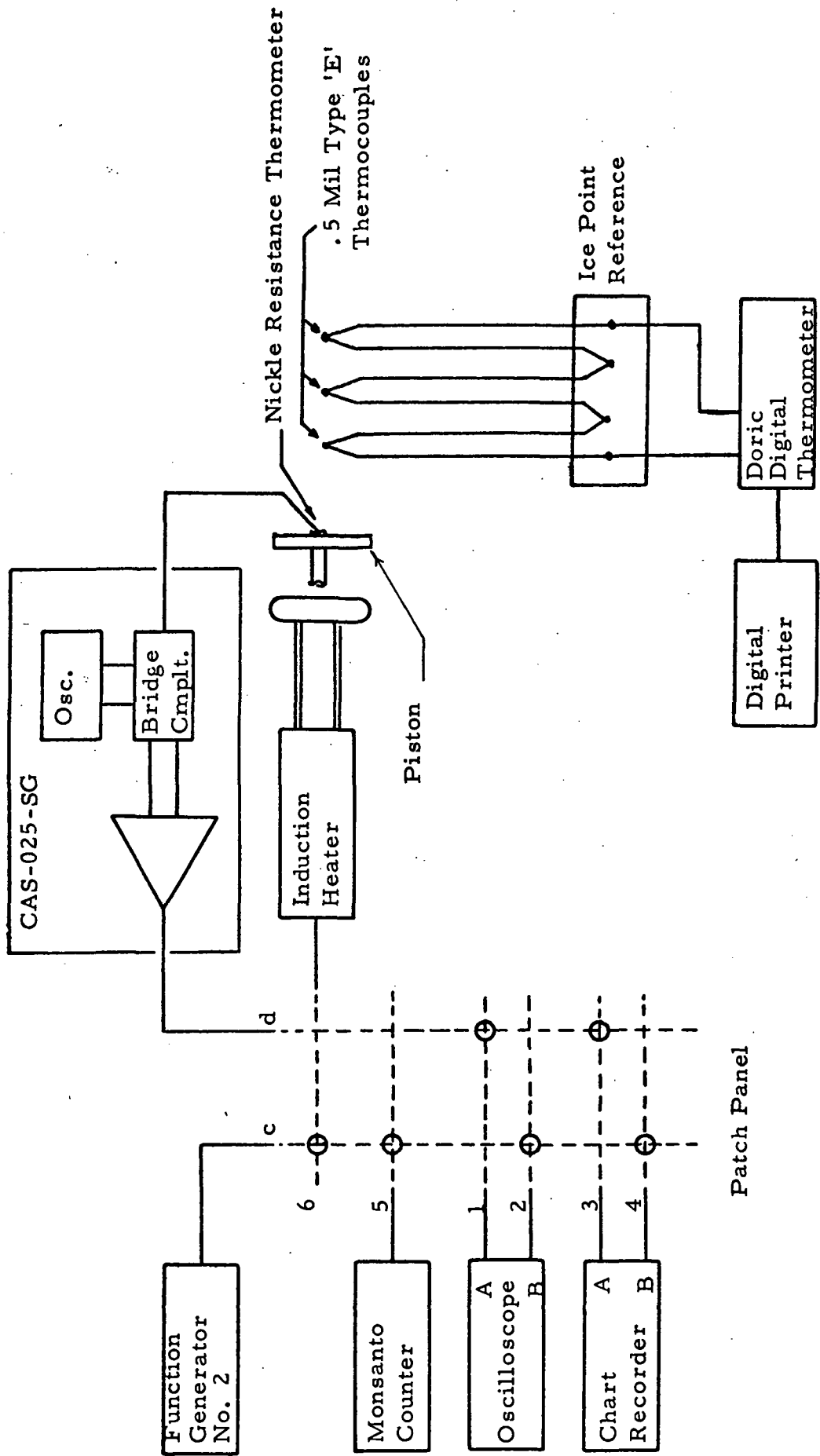


Figure 5 Piston Heater and Temperature Monitoring

induction heater can transfer into steel 57 BTU per minute. With perfect coupling between the induction coil and the piston that level of heat transfer could raise the piston temperature  $9.2^{\circ}\text{C}$  per second. A rise of only  $2^{\circ}\text{C}$  per second would provide the desired peak-to-peak variation of  $10^{\circ}\text{C}$  every 10 seconds. According to the manufacturer coupling efficiency is typically greater than 75%. The output energy of the induction heater can be varied with a voltage applied to the control input. This voltage is supplied by a second Exact Model 123 function generator.

#### 2.5 Cavity Temperature Measurement System (Refer to Figures 5 and 6)

Temperatures are monitored at two points in the system. The first is the temperature of the piston face. A stick-on type nickel resistance gage made by BLH is used as the sensor. The gage is used in a bridge configuration with excitation and signal conditioning provided by a Schaevitz Model CAS-025-SG. The connection diagram for the piston face temperature sensor is shown in Figure 6.

The second point monitored is the gas temperature 2 inches from the face of the piston. Three type "E" thermocouples are used as the sensor. The thermocouples are made of .5-mil wire in order to have a short time constant. A Kaye Model K-110 is used for an ice point reference. A Doric Model DS-100-73 is used to provide a digital readout with  $0.01^{\circ}\text{C}$ -resolution. A permanent record of the temperature reading is made every  $1/2$  second on a Digitec Model 691 Printer.

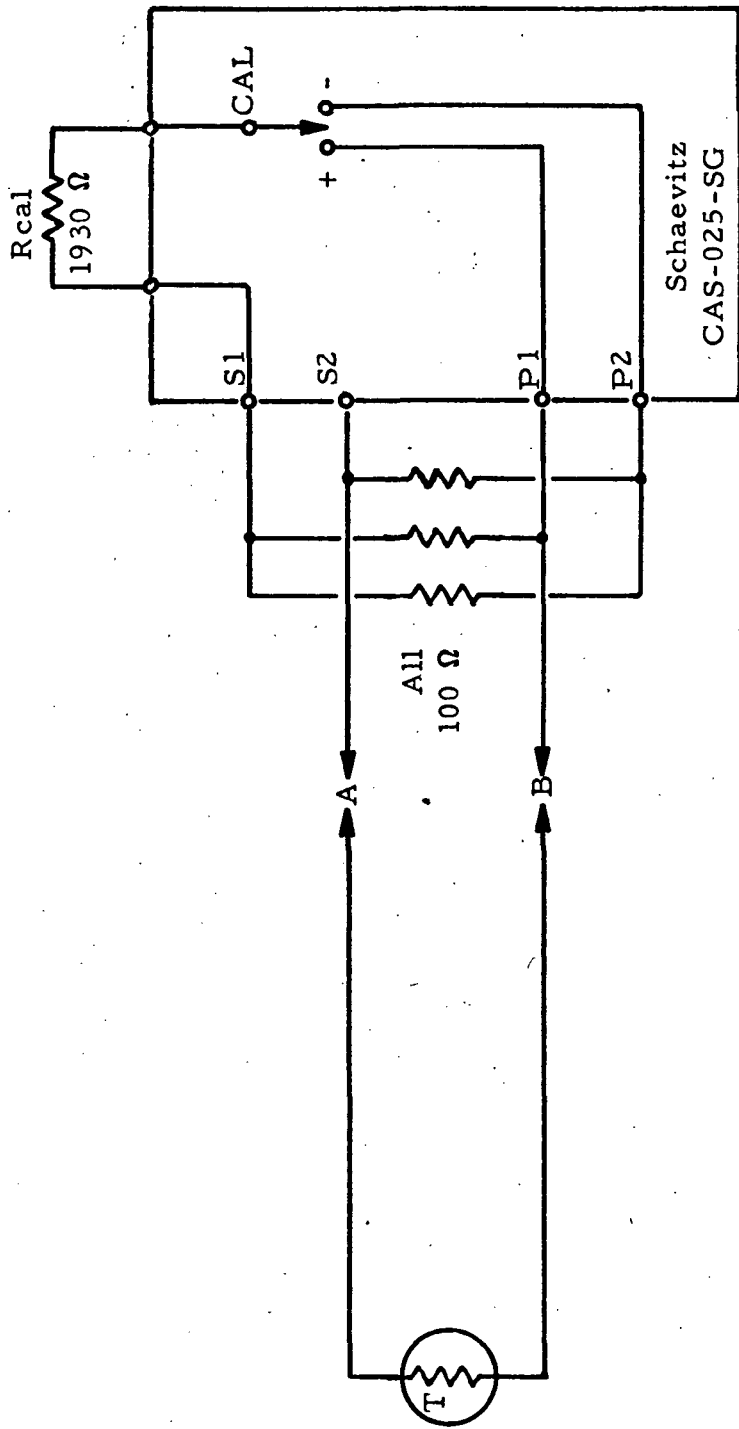


Figure 6 Connection Diagram for Piston Face Temperature Sensor

## 2.6 Monitoring and Recording Equipment (Refer to Figure 7)

An oscilloscope, chart recorder and electronic counter are provided for setup, testing, and recording various signals within the system.

The oscilloscope is a Tektronix Model RS103N/D10. The scope uses a plug-in dual-trace vertical amplifier Model 5A18N with a sensitivity down to 1 millivolt per division. The plug-in horizontal amplifier and time base Model 51310N has a bandwidth from DC to 1 M Hz. and sweeps from 100 ns/div to 5 sec/div.

The chart recorder is a Houston Omniscrite Model 5210-2. The recorder has 2 pens each with a recording span of 25 cm. The unit will record up to 10 Hz and has variable chart speeds. Overall accuracy is + 0.3%.

The counter is a Monsanto Model 100B.

## 2.7 Patching System (Refer to Figure 8)

The various inputs and outputs of the exciter system are connected together using a Seaelectro patch panel. Patching is done by single pin placement on a grid matrix. In this report coordinates are called out for test setup as (number-letter) corresponding to x, y locations for pins.

## 2.8 Mechanical Components

The System Components are housed in a sealed chamber which interfaces to the NASA Adapter MSFC 80M 42312. A removable top cover has the electrical feed-thru fittings and a pressure relief valve set at 60 psi.

The electro-magnetic shaker mounted on the support pedestal drives the piston of the piston-bellows assembly. The piston-bellows assembly is the flexible wall between the test chamber and the equipment chamber.



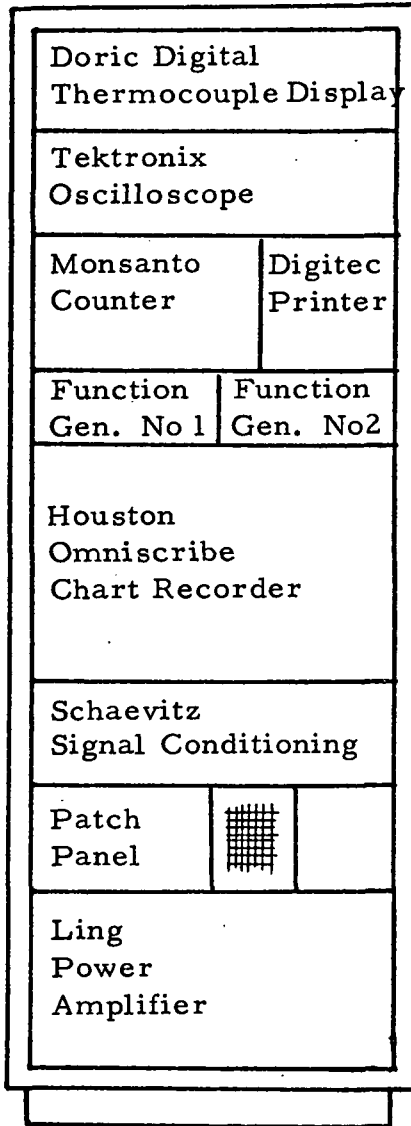


Figure 7. Rackmounting Layout of Instrumentation

		1	2	3	4	5	6	7
		OSCILLOSCOPE CHANNEL A	OSCILLOSCOPE CHANNEL B	CHART RECORDER CHANNEL A	CHART RECORDER CHANNEL B	PERIOD COUNTER	INDUCTION HEATER CONTROL INPUT	POWER AMPLIFIER INPUT
GROUND	a	○	○	○	○	○	○	○
FUNCTION GENERATOR No. 1	b	○	.	.	.	.	.	.
FUNCTION GENERATOR No. 2	c	○	.	.	.	.	.	.
PISTON FACE TEMPERATURE	d	○	.	.	.	.	.	.
PISTON POSITION	e	○	.	.	.	.	.	.
DIFFERENTIAL PRESSURE	f	○	.	.	.	.	.	.
ABSOLUTE PRESSURE	g	○	.	.	.	.	.	.

NOTE: Two pins in the same vertical column are not allowable

Figure 8 PATCH PANEL

The piston is made of magnetic stainless steel so that the induction heater is able to drive with the grid and plate currents in good balance. The bellows is made of brass (80 Cu-20 Zn) work hardened for long fatigue life. The bellows assembly is joined together with heat-cured epoxy.

The piston rod attached to the shaker, in addition to carrying the piston, has the induction heater coil and its electrical and cooling water lines clamped to it. The flexible coupling between the moving coil assembly and the fixed water and power source consists of reinforced rubber tubing with clamps and flat copper bands soldered into place. Insulated fittings serve as feed-throughs for the water and electrical power.

The core piece of the LVDT is attached through an adapter to the shaker table. The LVDT transformer casing is mounted to the support pedestal which also carries the absolute and differential pressure transducers with tubes leading to sensor ports. A pressure-vacuum relief valve on the support pedestal is used to limit differential pressure between the two chambers to 3.5 psi maximum.

The thermo-pile assembly is installed through the outer chamber, and the support pedestal into the adapter chamber two inches below the piston. A "Swagelok" fitting on the outside repositions the thermopile assembly each time it is replaced. A Conax pressure gland seals the thermopile assembly between the two chambers.

The following precautions should be taken when working on this assembly:

1. When the sealed chamber is removed from the adapter, the sensor wires at the end of the thermopile must not touch against anything. They are .5 mil thick and are very delicate.
2. The flexible heater connections must be kept clear of the shaker support bracket, and the copper bands should be spread fan-like to give maximum surface for the heater current.

3. Ensure that the heater coil is electrically insulated from the piston rod, piston, and bellows.

4. The LVDT core is locked to the adapter with "Loctite". If the LVDT is removed, upon replacement position the holder so that the core is centered.

Section 3  
SYSTEM OPERATION

3.1 Setup of Shaker Drive and Piston Position Sensor (Refer to Figure 1)

- a. Monitor the output of the LVDT demodulator on the oscilloscope, Channel B (Patch 2-e).
- b. Connect function generator No. 1 to the period counter (Patch 5-b) and to the oscilloscope Channel A (Patch 1-b). Adjust the function generator frequency control for 5.000 Hz.
- c. Connect function generator No. 1 to the input of the power amplifier (Patch 7-b). Adjust the function generator amplitude control for the desired piston displacement. The LVDT signal calibration is 1 volt equals .1 inch of displacement. The maximum total displacement of the piston is 0.7 inches.

3.2 Setup for Monitoring Fluctuation in the Absolute Pressure of the Cavity

- a. Monitor the output of the absolute pressure transducer on Channel A of the oscilloscope (Patch 1-g).
- b. Using the zero suppression unit, null the output to zero as seen on the scope.
- c. With the shaker on, fluctuation in the absolute pressure can be measured on the oscilloscope. Each millivolt represents .003 psia.
- d. The quiescent pressure in the chamber can be read off of the calibrated 10-turn dial. Each turn represents 1 volt or 3.0042 psia.

3.3 Setup of Piston Induction Heater & Air Temperature Sensor (Refer to Fig. 5)

- a. Connect the output of the resistance thermometer amplifier to the chart recorder channel A (patch 3-d).
- b. The resistance thermometer is calibrated over the range 0°C to 100°C. Each 10°C temperature change equals 1 volt output. Offset caused

by the CAL switch also equals a  $10^{\circ}\text{C}$  temperature change.

c. Turn on the power to the Doric digital thermometer and allow it to warm up for one hour.

d. Connect function generator No. 2 to the period counter (Patch 5-c). Adjust the frequency control for 10.00 - sec. period.

e. Connect function generator No. 2 to the input of the induction heater control. Adjust the amplitude control of the function generator to obtain a  $10^{\circ}\text{C}$  change in temperature of the piston face. In order to obtain a temperature variation that best approximates a sine wave, the input wave shape should be a sine wave riding above ground.

f. Ground the input of the Doric digital thermometer and adjust for  $00.00^{\circ}\text{C}$  display. (Do not attempt adjustment until unit has had one hour warm up time).

g. Connect the air temperature thermopile through the ice point reference to the input of the Doric digital thermometer. This is a hard-wire connection and does not pass through the patch board.

h. The temperature of the simulated heat wave can now be read out on the Doric unit and simultaneously printed on the digital printer.

#### 3.4 Final Testing Configuration (Refer to Figures 1 and 5)

The absolute pressure of the absorption cell and the temperature of the gas in the cell are the two parameters of interest in an actual test. The temperature measurement system is hard-wired and does not require patching. The absolute pressure will be monitored on the oscilloscope (Patch 1-g).

## Section 4

### CHECKOUT TEST DOCUMENTATION

#### 4.1 Control of Pressure Fluctuation Intensity

The intensity of the fluctuation in absolute pressure of the cavity is controlled by the amplitude of the sine wave driving the shaker's power amplifier. With the gain of the power amplifier set at 50% and function generator at a frequency of 5 Hz, the displacement of the piston was varied by the output amplitude control of the function generator. The variation of cavity pressure with the output voltage of the function generator appears in Fig. 9. Patch points were (1-g), (2-e), (5-b) and (7-b).

#### 4.2 Verification of Sinusoidal Response

The test set up used to check the characteristics of the Absolute Pressure Signal is shown in Fig. 10. In order to fully define the sinusoidal response, the harmonic content and the phase lag in reference to the sine wave drive signal were determined. With the function generator set to 5.00 Hz the output of the absolute pressure transducer was recorded for the fundamental, 2nd and higher harmonics. The harmonic content is plotted on Fig. 11.

The phase delay was measured at various frequencies around 5 Hz by using the dual trace scope. Using the function generator sine wave as a reference, the time lag of the pressure signal could be determined by the calibrated time base of the oscilloscope. The phase delay is plotted on Fig. 12. By placing sine waves of equal amplitude at the same vertical position time delays can be resolved to 1 millisecond.

#### 4.3 Cavity Temperature Measurement

The cavity temperature was measured for both a step input and sine wave input to the induction heater. Cavity temperature vs. time appears in Fig. 13 for the step input and in Fig. 14 for the sine wave input. As seen from the graphs the resolution of the air temperature is  $.01^{\circ}\text{C}$ . The piston face temperature is shown on Fig. 13 for reference. Patch points were (6-c) and (3-d).

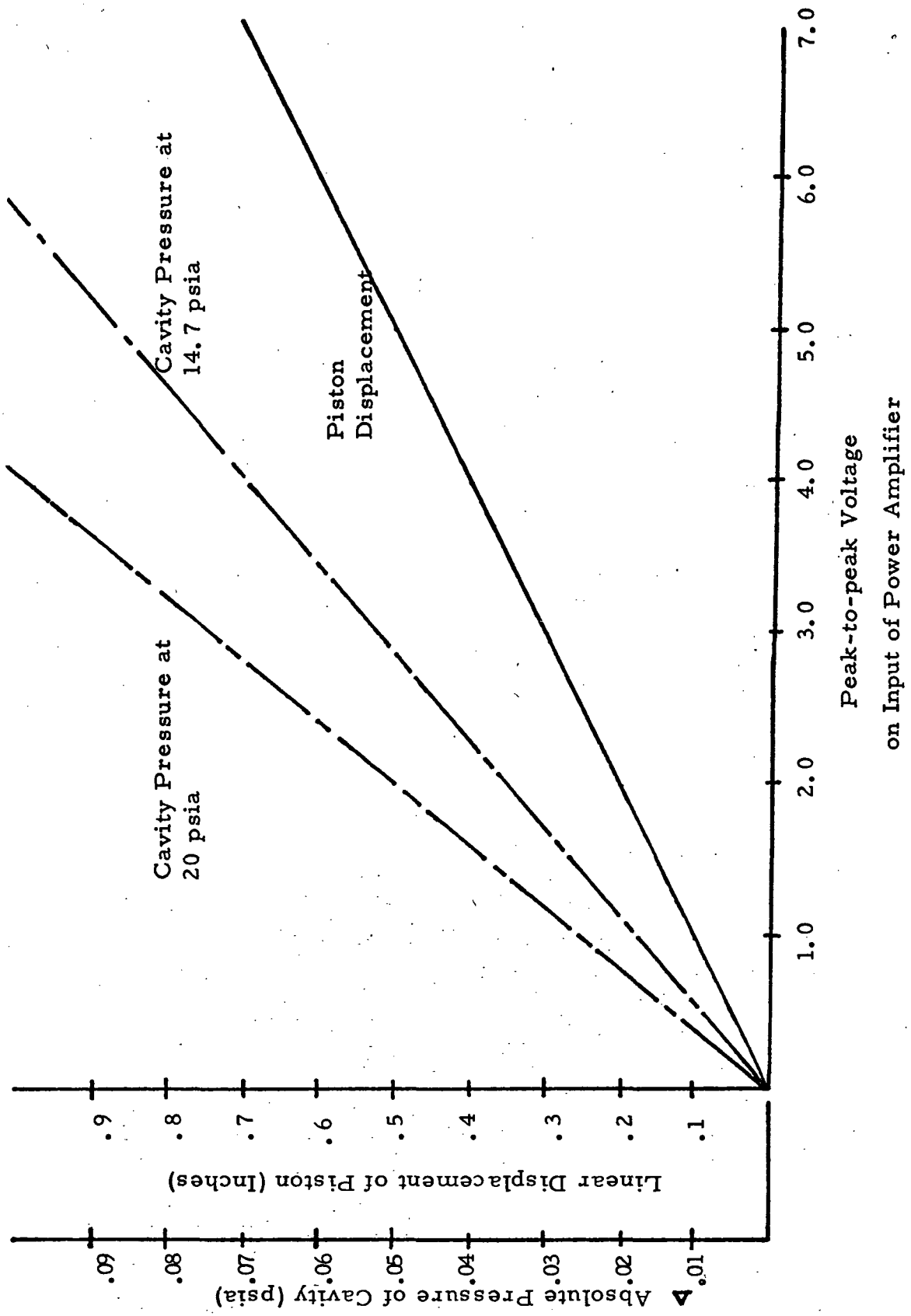


Figure 9. Control Voltage vs. Absolute Pressure on Input of Power Amplifier



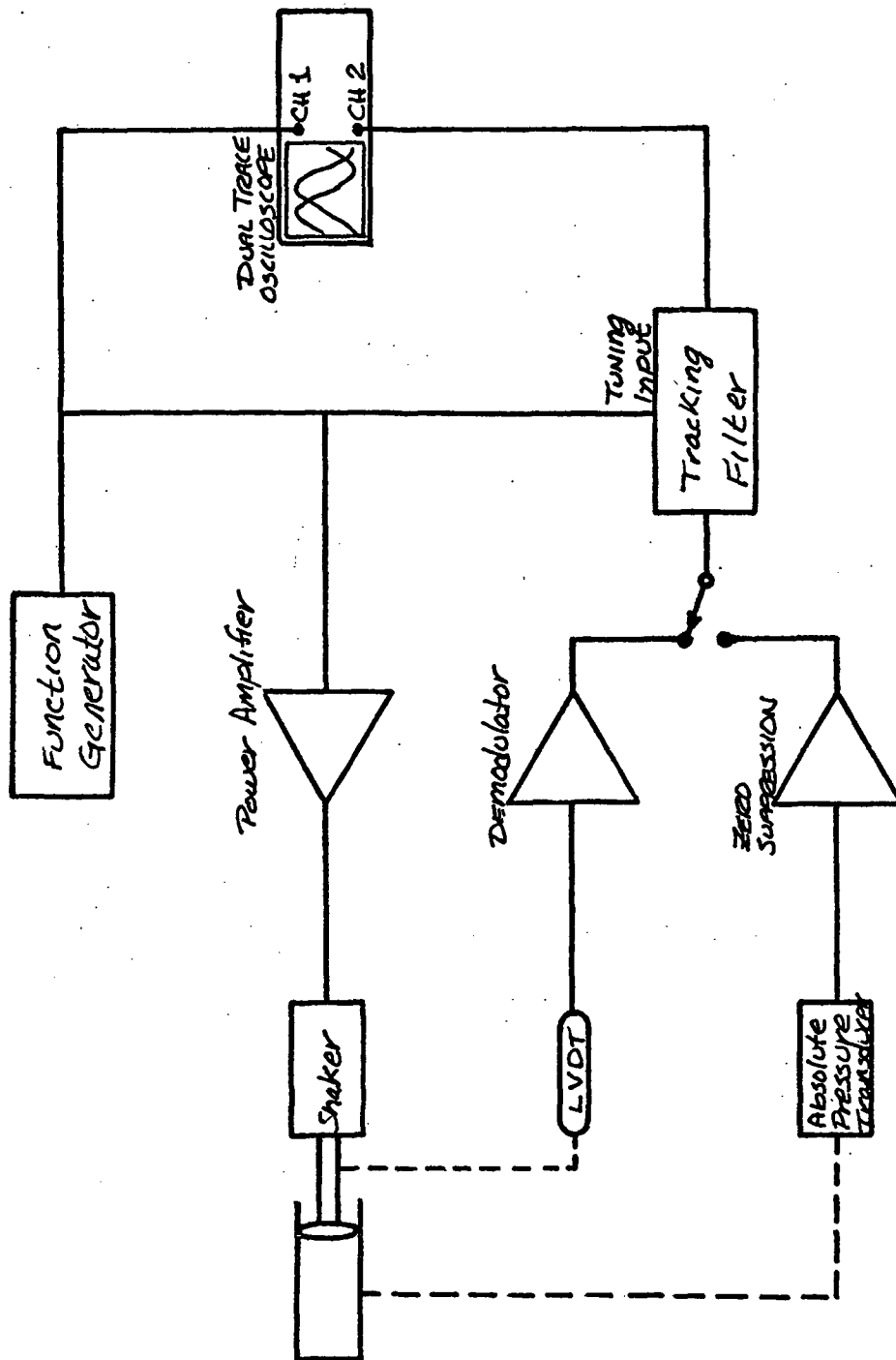


Figure 10. Test Setup for Measurement of Harmonic Distortion and Phase Delay

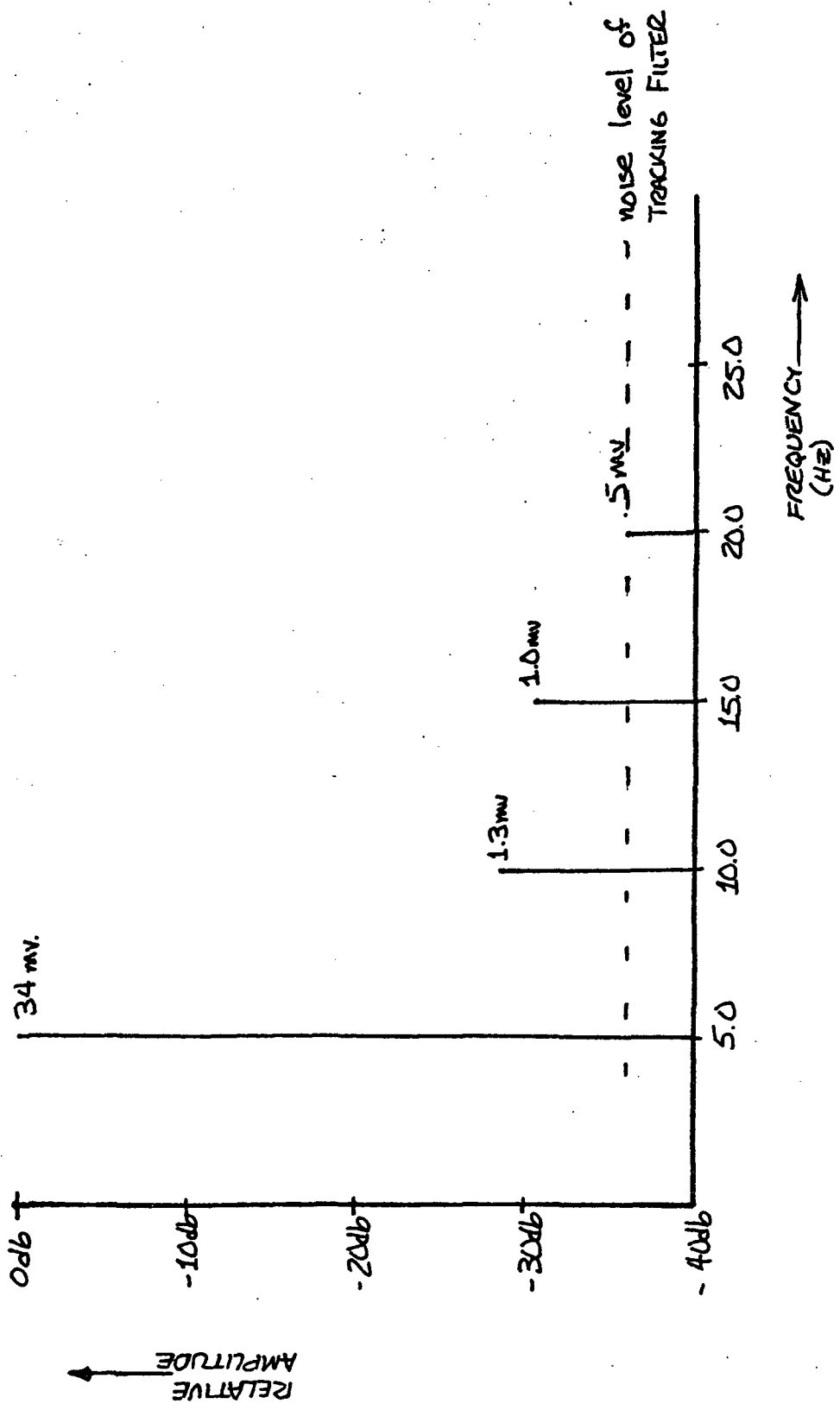


Figure 11. Harmonic Distortion of Absolute Pressure Transducer Signal

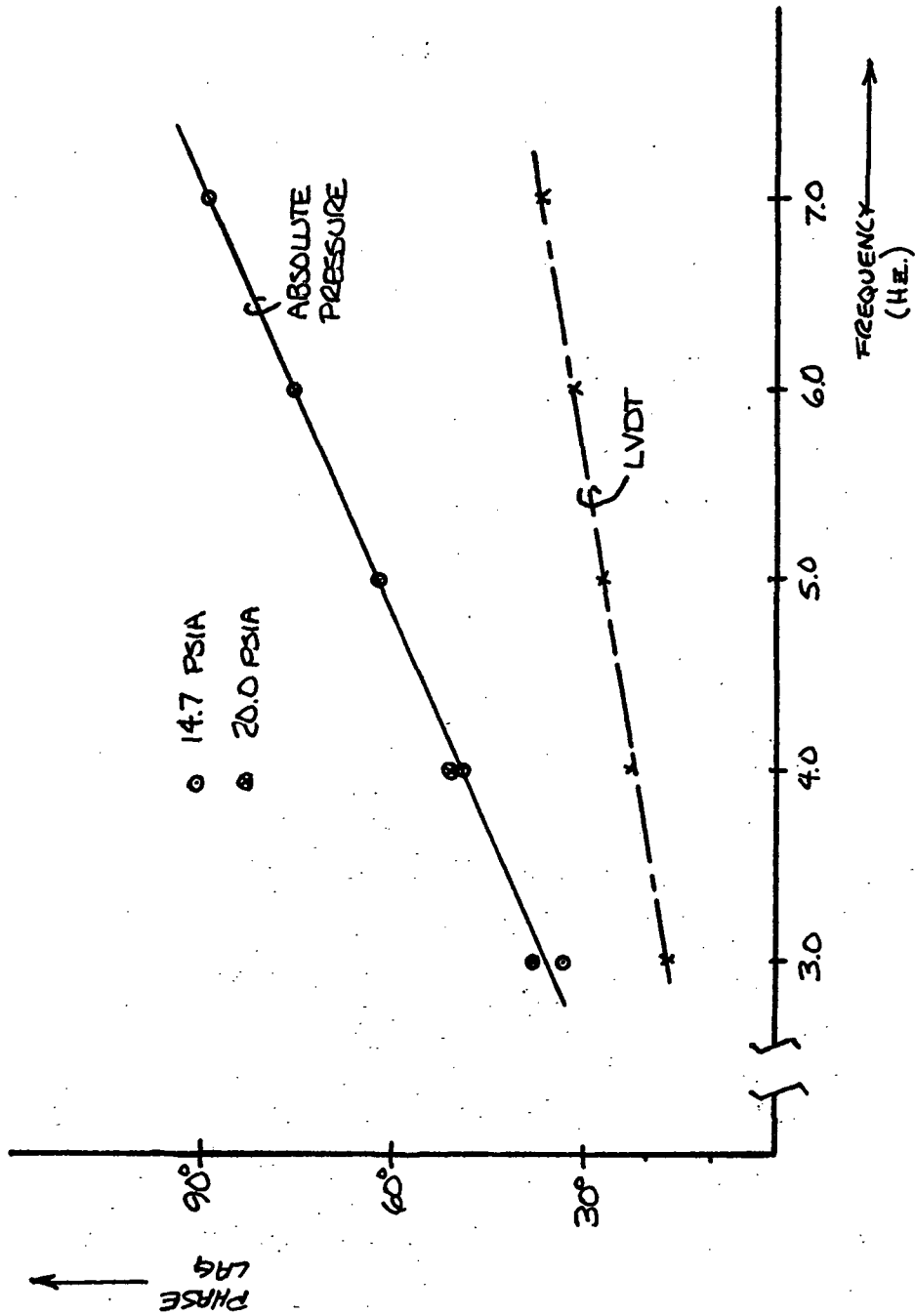


Figure 12. Phase Delay of LVDT and Absolute Pressure Transducer

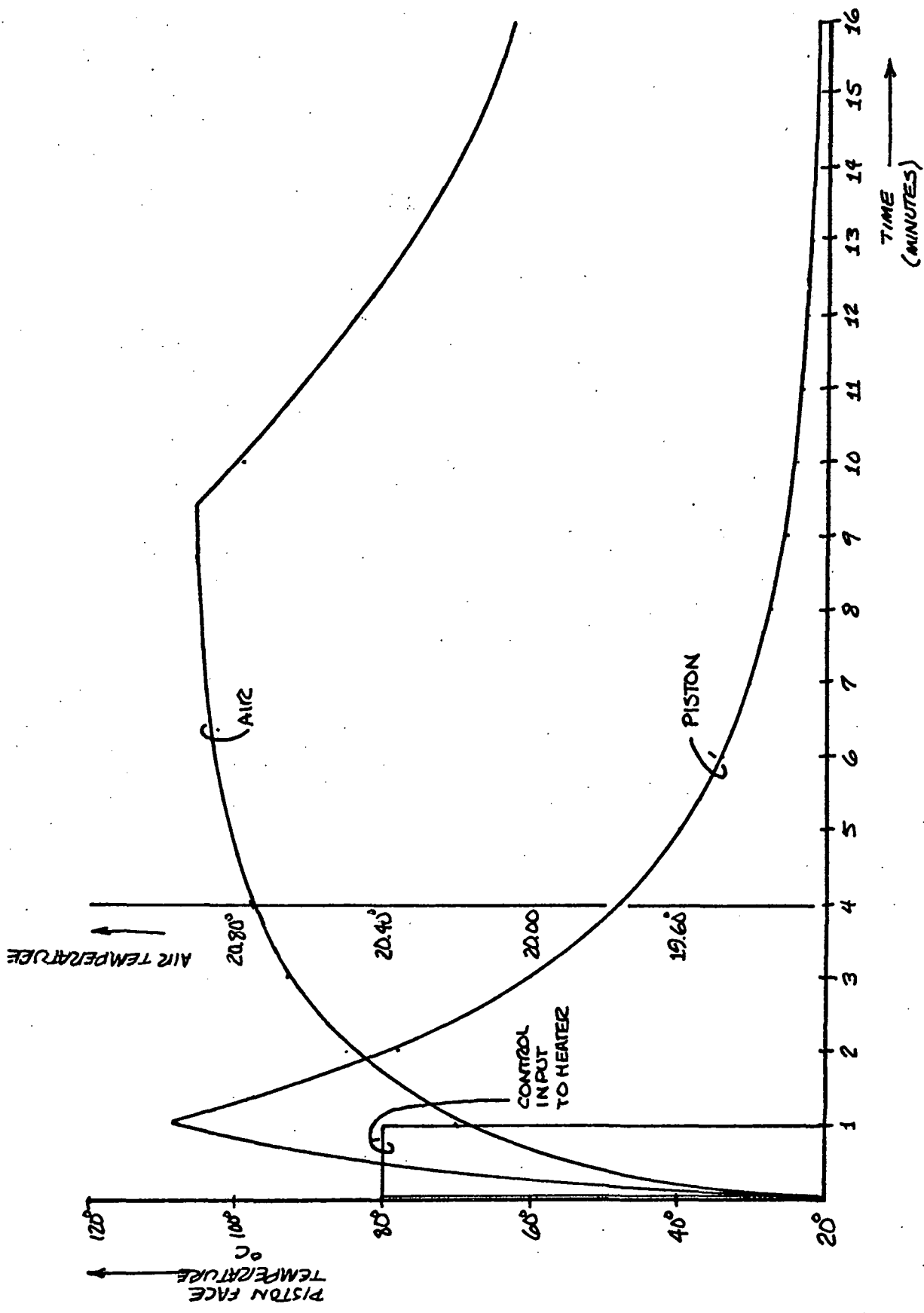


Figure 13. Air Temperature vs. Time for Step Input to Heater with Shaker Off

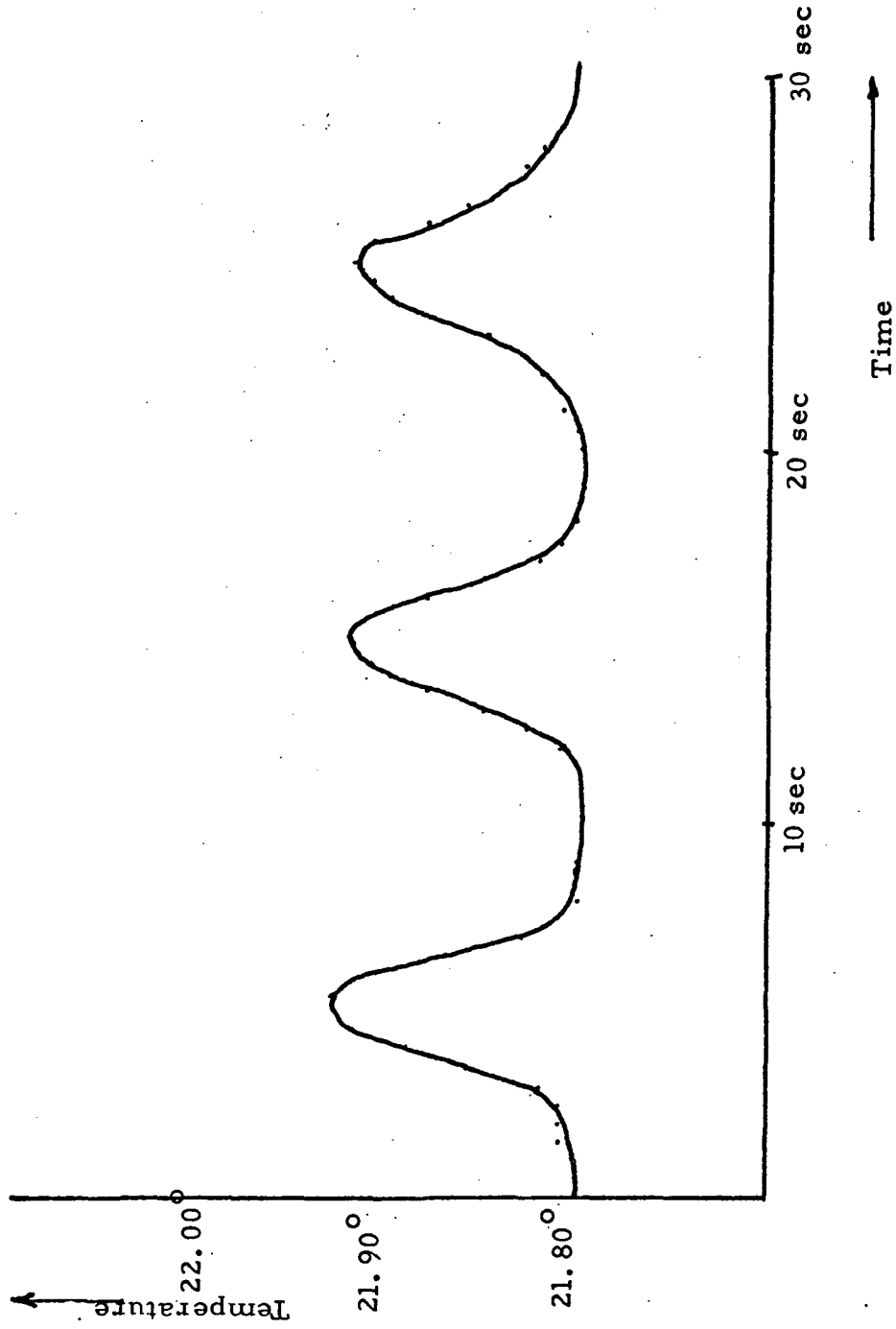


Figure 14. Air Temperature Variation for a 5° C Variation In Piston Face Temperature

#### 4.4 Cavity Pressure Measurement

The change in absolute pressure of the cavity was measured at two chamber pressures - ambient (14.7 psia) and 20.0 psia. The signal resolution of 1 millivolt equals a pressure of .003 psia. Plots of cavity pressure variation for the two chamber pressures appear in Fig. 15. Patch points were: (1-g) (2-e) (5-b) and (7-b). The chamber was checked under less than atmospheric pressures by pumping down with a vacuum pump. Vacuum holding capability is demonstrated by the results shown in the following table. Test No. 1 was with the thermopile hole plugged because the thermopile was out for repair. The test procedure was:

- (1) Pump-down chamber
- (2) Inject freon and test for leaks with T1F 200 Detector. A small leak was found and plugged.
- (3) The chamber was pumped down, and monitored to the stable zero-leak value shown in the table.

Procedure for Test No. 2 was:

- (1) Remove the top cover, the plug in the thermopile hole, and separate lower joint for installation of the thermopile.
- (2) Install the thermopile and complete lower and upper joints. (For vacuum test, they were simply set in place and not bolted.)
- (3) The chamber was pumped down and pressure increase was monitored over a 92 hour period and showed a loss of 0.036 mm Hg per hour. It is felt that this small leakage can be controlled at time of assembly, since the joints remade for Test No. 2 must be remade at installation.

Date	& Time	Test No. 1	Absolute Pressure mm-Hg
4-17-73	12:51		15.5
	16:07		15.8
	20:41		15.8
4-18-73	8:45		15.9
	9:30		16.0
	11:25		16.1
	13:16		16.1
	15:40		16.1
4-19-73	8:00		16.1

---

Test No. 2

4-19-73	12:25		14.0
	12:40		14.1
	12:54		14.3
	13:55		14.6
	15:00		14.9
	17:00		15.1
4-20-73	8:30		15.7
	10:30		15.8
	17:15		16.0
	18:00		16.1
4-21-73	10:45		16.4
	19:40		17.0
4-23-73	8:45		17.3

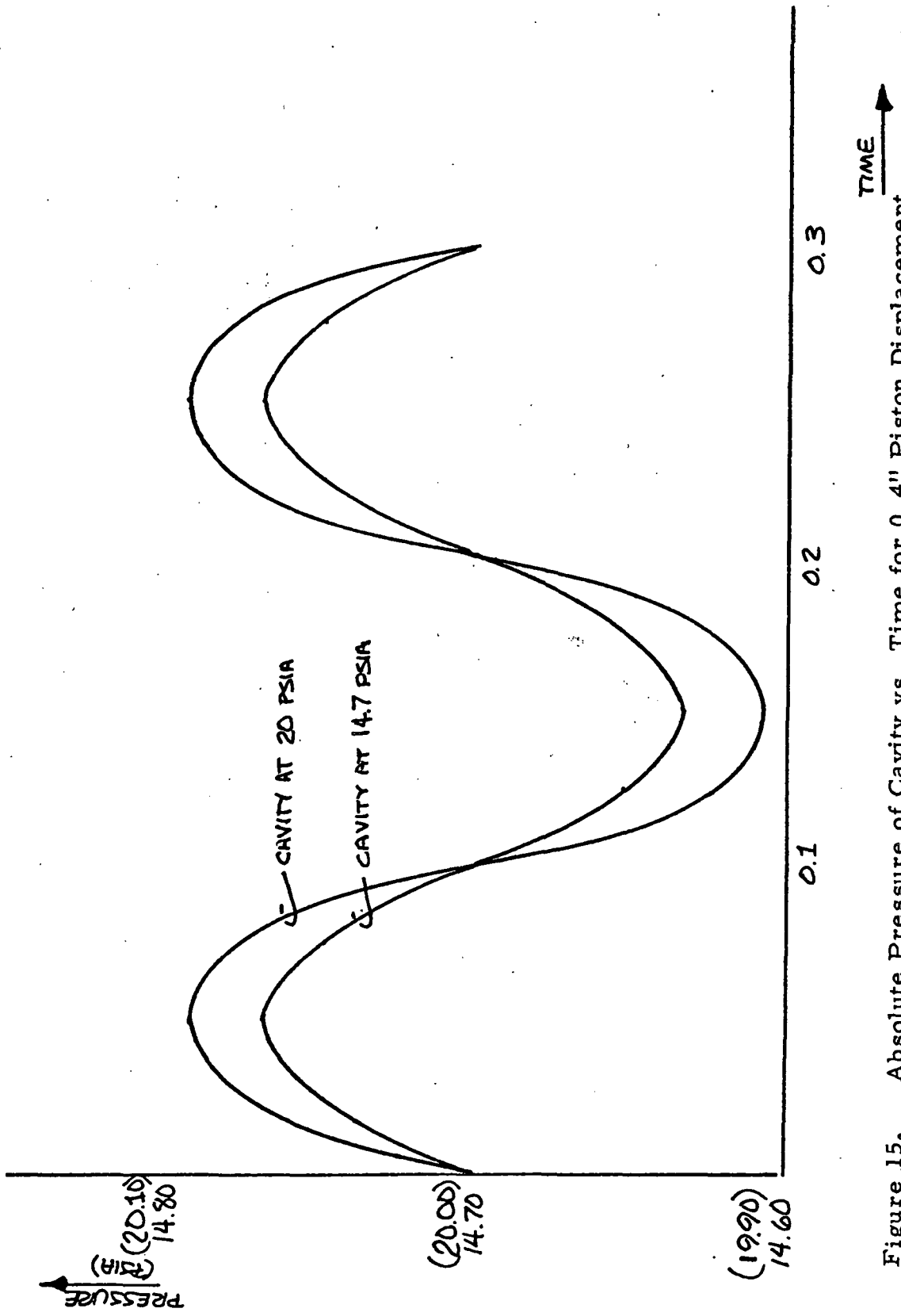


Figure 15. Absolute Pressure of Cavity vs. Time for 0.4" Piston Displacement



## CONCLUSIONS - ACOUSTIC EXCITER

The 5-Hz Acoustic Exciter has been designed and constructed as contract specifications required. All checkout tests for pressure and temperature measurements have achieved or surpassed the accuracy and resolution requirements. One recommendation for improved heat change characteristics would be the inclusion of a cooling device on the piston face. This would enable a greater fluctuation in piston face temperature at a lower mean value.