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A FLUIDIC LIQUID LEVEL CONTROL SYSTEM

BY

VINOD KUMAR VERMA, 1944

A

THESIS

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Approved by

Richard T. Johnson
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ABSTRACT

The prime objective of this investigation was to design and construct a working "fluidic liquid level control system", and to make a functional study of the characteristics of the devices employed therein.

A working model of a "fluidic liquid level control system" is developed and experimental data is collected to describe the functional characteristics of the fluidic circuits employed. The system contains a pressure sensitive, variable frequency oscillator; appropriate demodulation stages to convert the variable frequency alternating signal into a varying non-alternating signal; and on-off control elements in the final stages.

ACKNOWLEDGEMENTS

The author is grateful to Dr. Richard T. Johnson for the suggestion of the topic of this thesis and for his encouragement, direction, and assistance throughout the course of this thesis.

The author is also thankful to Mrs. Johnnye Allen for her wonderful cooperation in typing this thesis.

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1. INTRODUCTION

1.1 Background

For most of recorded history, the bulk of the energy, which man has controlled has been that which he processes with his body. Man has always been able to think of more things to do than he has had the energy to do, so it isn't surprising that he looked for means of controlling energy beyond that in the food ingested.

One of the early ways of controlling additional energy came about through the domestication of animals. These animals expend large amounts of energy, but they do not contribute to man's energy standard of living because the element of control is missing. The direction of energy is what man wants and what he needs in order to achieve many of his goals, and he has been a prolific inventor of means to do this: water wheels, gun powder, steam engines, gasoline and diesel engines, jet engines, nuclear fission,and nuclear fusion are means of bringing various sources of energy under his control.

Now it is obviously desirable that the controlled energy ought to be greater than the energy expended in the controlling process, or, to be a little more exact, the result accomplished by the controlled energy should be greater than the results which could be accomplished by the controlling energy acting directly. If this condition is met, then the process has amplification. There are, of course, many necessary and useful controls which do not have amplification, but those with amplification have received much more attention.

Hydraulic, pneumatic, and electrical elements are used as amplifying devices, some giving a continuous range and some giving only discrete levels of output power. We can classify them either "analog" or digital systems. Up until about a half century ago, the operation of these systems required the motion of mechanical parts for measurement and control. Then the vacuum tube was developed and for half a century has dominated the higher speed electrical measurements and control of energy with minimum use of moving parts.

The transistor has augmented the capabilities of, and in many cases replaced the vacuum tube, and has retained two important characteristics: no moving parts, and single medium control.

In March, 1960 the Diamond Ordnance Fuse Laboratories (now Harry Diamond Laboratories), disclosed the principles of the first fluid amplifier, which launched a new technology known variously as fluerics, fluidics, fluid amplification, etc. It has also created an interest in internal aerodynamics, separated flows, and fluid circuit theory. Pure fluidic elements operate using stream interactions of the working fluid and have no moving parts. Figure 1.1 is a schematic representation of typical fluidic stream interaction.

A fluid amplifier has a power nozzle to provide a high speed jet or power stream. The source of energy is the pump or compressor which supplies fluid to the nozzle. In the jet, the energy takes the form of kinetic energy of translation of the fluid. The control nozzles determine where the kinetic energy of this stream is

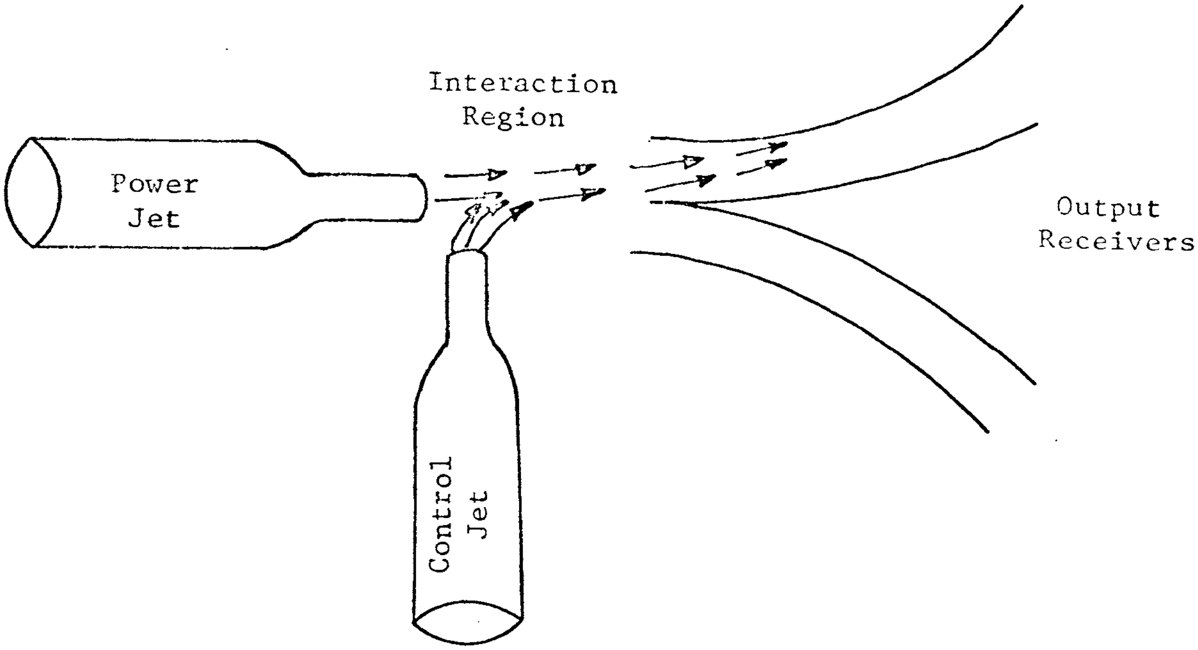

FIG. 1.1 DEFLECTION OF ONE STREAM BY ANOTHER

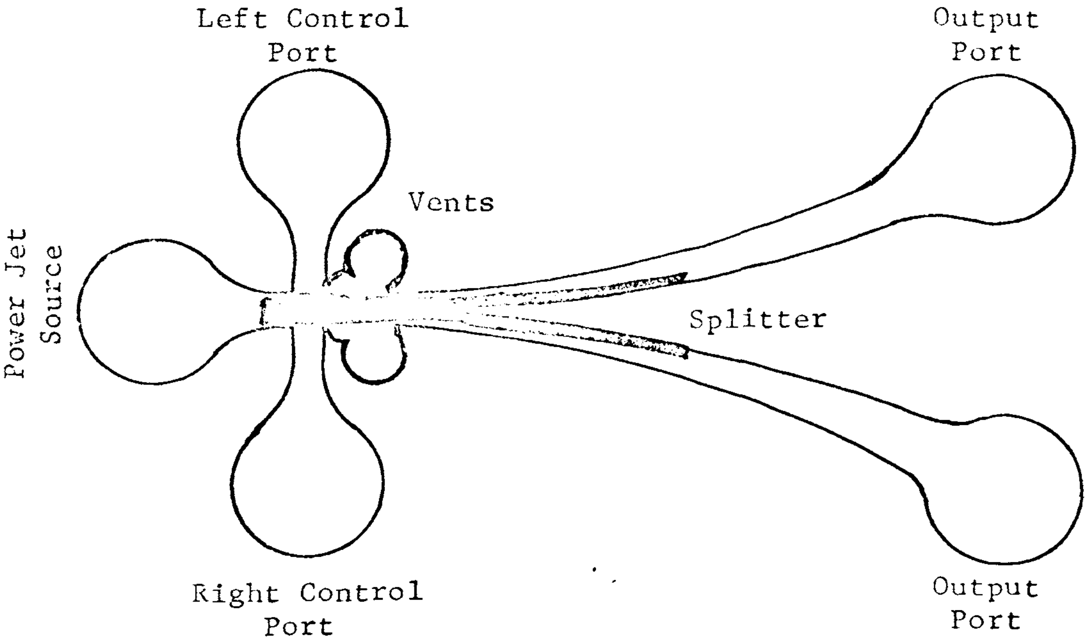

FIG. 1.2 PROPORTIONAL FLUID AMPLIFIER

delivered and hence control the flow and pressure in the output apertures. An amplifier such as this can have a power gain of 10 to 100 depending upon what other characteristics (such as pressure gain and efficiency) are desired.

Fluidic devices have various advantages when compared to other measurement and control devices. They have no moving parts. They offer a wide application range because they can provide both digital and analog control signals. Within their response capabilities, fluidic controls can duplicate or, in many instances, offer improved operation over many electromechanical, pneumatic, or other hybrid systems. They have high reliability. Their reliability is relatively unaffected by extremes in temperatures, radiation, etc. They are inherently free from failure associated with explosion hazards, electrical noise, high relative humidity, and vibrations.

Examining one of the more common types of fluid amplifier (beam deflection)(fig. 1.2) we see that it is sensible to interconnect them in "Push-Pull" since each is a "beam deflecting" device rather than a "beam stopping" device, as is a triode vacuum tube. But connecting fluid amplifiers is a big problem. First the basic forces relating fluids in motion are non linear; second, the continuity equation must hold (what goes in must come out). These two facts have special significance in fluid amplification systems. With moving parts, it is easy enough to shut off fluid flow. Without moving parts, the continuing flow must be accommodated and properly discarded after its energy has been extracted. Fluid turbulence makes the fluid amplifier a ready converter of its steady (or dc) flow energy into fluctuating forms, resulting in the familiar noises and whistles of fluid jets, a consequence of the surface forces on the stream of fluid which conveys the signal. However, the advantages of fluidic devices outweigh these characteristics and the resulting difficulties. Engineers and scientists working in this new field have developed many useful component devices, and systems. Applications of fluid amplification currently being investigated include: a heart pump, a respirator, and other medical devices; logic and timing circuits; rocket thrust vectoring, missile altitude control; automatic piloting of aircraft; hydrofoil control and jet engine control; and some industrial inspection and control. The large scale application of fluidics to measurement and control is just beginning.

1.2 Objective

In an attempt to add to the knowledge concerning the application of fluidic devices to control systems, the goal of this investigation was to design and construct a working "fluidic liquid level control system". It was decided that this liquid level control system would involve the use of variable frequency sensing elements. The variable frequency signal produced by the sensing elements would be demodulated and rectified to produce a non-alternating control signal. Equipment availability required that the final control stages be of the on-off type.

2. REVIEW OF LITERATURE

"Fluid Amplifier State of the Art", a NASA contractor report(1)* has surveyed the current state-of-the-art of fluid amplifiers including both theoretical and practical aspects of devices having no mechanically moving parts. The report is a review of the published literature, and information obtained from various organizations involved in fluid amplifier development. J. H. Kirshner(2) has thoroughly discussed the theoretical background for fluid amplifiers. He has also tried to relate the mathematics used to physical models, whereas the Corning "Fluidikit" Manual(3) has only discussed practical applications of fluidic elements for control systems.

Proportional fluidic devices have been studied and discussed by many. B. A. Ostap(4) and C. A. Belsterling and K. K. Tusi(5) have respectively presented realistic and useable information on vortex and beam deflection type amplifiers.

Variable frequency sensing elements and associated demodulation circuits have been examined by many authors. A temperature control system using frequency modulation and phase discrimination technique has been developed by L. R. Kelly(6). The temperature sensing device developed was a fluidic oscillator, having a frequency output proportional to square root of absolute temperature. Another variable frequency technique for measuring the average temperature in a gas

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*Numbers in parenthesis refer to numbered references at the end of this thesis.

turbine exhaust duct is discussed by C. G. Ringwall and L. R. Kelly(7). They have used a phase discrimination technique to demodulate the frequency information. Variable frequency sensing elements are also discussed in "Feasibility Study of a Fluid Amplifier Steam Turbine Speed Control" by W. A. Boothe(8). This study includes an extensive computer analysis to determine the relative merits of all-analog, all-digital, or hybrid analog/digital operation using frequency modulation techniques. Applications of similar pure fluid techniques to a speed control is also studied by J. R. Colston and E. M. Dexter(9).

One of the better discussions of the application of on-off control elements is given by D. J. Nelson and H. Iwata(10) in their application of pure fluid logic to on-off control systems.

3. DESCRIPTION OF SPECIFIC FLUID DEVICES

To better acquaint the reader with the phenomenological behavior of specific fluidic devices, this section has been included. Of particular interest are those devices employed in this investigation.

3.1 Proportional Fluid Amplifier

The basic configuration of the beam deflection proportional fluid amplifier is shown in figure 3.1. A high energy fluid is supplied to the power jet chamber. When the fluid passes out of this chamber through the rectangular power nozzle into the intersection region, it becomes the power jet, its center line will strike the divider and equal amounts of flow will enter the two output channels and exit through the appropriate output ports. With equal restrictors between output ports and the next stage, the pressure developed at the output ports will also be equal. Usually there are only two outputs, symmetrically placed. They may be next to each other, or separated by a vent. There is an optimum size and position for the output apertures. They are far enough downstream to take advantage of the deflection of the non uniform-velocity jet and yet far enough upstream to recover an appreciable portion of the power jet stagnation pressure.

If a pressure difference does exist between the control jets in the intersection chamber, a force is present which deflects the power jet so more fluid exists through one output port than the

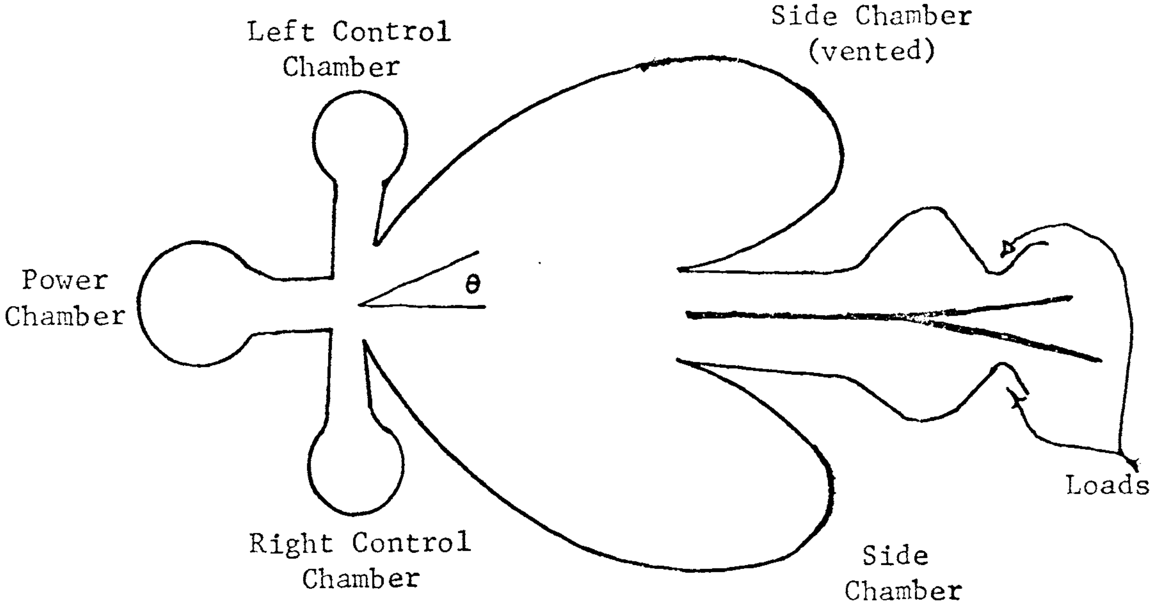


FIGURE 3.1

BASIC CONFIGURATION OF BEAM-DEFLECTION TYPE OF PROPORTIONAL FLUID AMPLIFIER

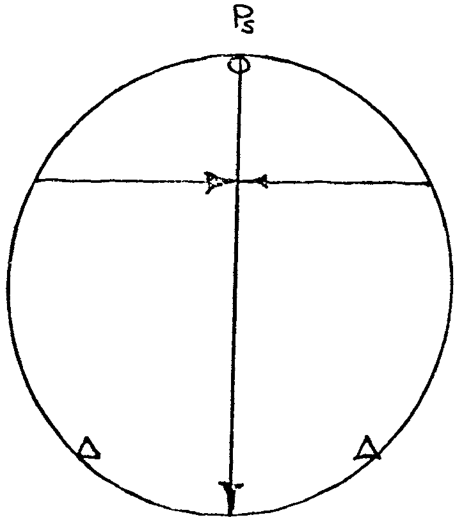
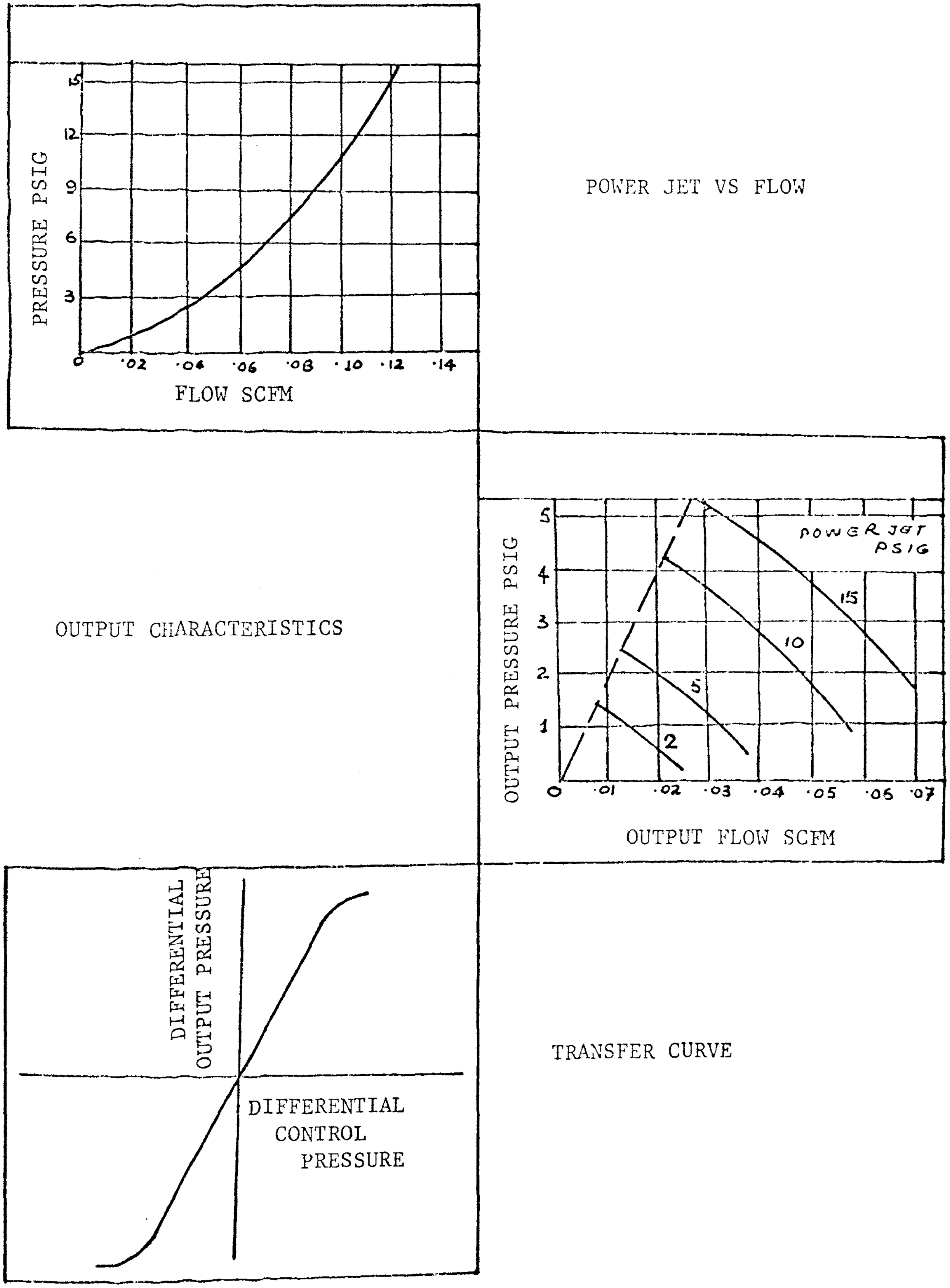


FIGURE 3.2

CIRCUIT SCHEMATIC OF PROPORTIONAL FLUID AMPLIFIER other. With equal output restrictors, a pressure difference is generated between output ports. Thus, a control fluid ejected at low energy into intersection regions can control the relatively high energy fluid in the power jet.

As shown in figure 3.1 the side walls are removed between the intersection region and the output aperture. This is done to prevent the power stream from attaching to the walls and making the amplifier bistable. The shape and dimension of these cutout areas have a considerable influence on the performance of the amplifier. Any fluid not collected by the output or any disturbances present in the power jet may be reflected from the wall back toward the power jet to produce an unwanted feed back effect. To minimize these effects in open type amplifier units, holes are drilled through the base plate and cover plate of the amplifier assembly above and below the cutout regions. Thus, open type units are vented through these holes to the atmosphere. These vents are sometimes called bleeds. They serve two main purposes: They tend to equalize the static pressure across the power jet and they also provide overflow ports for fluid not captured by the output apertures.

To accomplish a similar effect in closed units, the cutouts are connected together to equalize the pressure across the power jet. In this case there are no bleeds. All the fluid supplied to the power jet and control jets must pass through the output apertures. Closed units may operate with either liquid or gas as the working



POWER JET VS FLOW

OUTPUT CHARACTERISTICS

TRANSFER CURVE

FIGURE 3.3

PROPORTIONAL AMPLIFIER CHARACTERISTICS

(Source: Corning Fluidikit Manual)

fluid. Open type units usually, but not necessarily, use gas as the working fluid.

In a fluid amplifier there are four variables of interest: (1) input (control) pressure, (2) input (control) flow, (3) amplifier pressure drop, and (4) amplifier load flow. Thus we can generate the characteristics defining the relationship between (a) control flow and control pressure, (b) load flow and amplifier pressure and (c) control flow or control pressure and load flow or amplifier pressure. These are relationships which are sufficient to describe amplifier performance. They are also very useful in matching this fluidic device to others for operation as a system. Typical characteristic curves are shown in fig. 3.3.

3.2 Flip-Flop

Analog fluidic devices utilize a design concept referred to as moment exchange. In comparison, digital devices are on-off types, and they perform as they do because of wall attachment effects.

The flip-flop is a bistable digital fluidic device employing the coanda or wall attachment effect for its operation. The basic configuration of the flip-flop is shown in figure 3.4.

Referring to figure 3.4, the operation of the flip-flop may be briefly described as follows:

In the absence of any control signal from the control ports, fluid leaving the power jet will be directed to either one or the

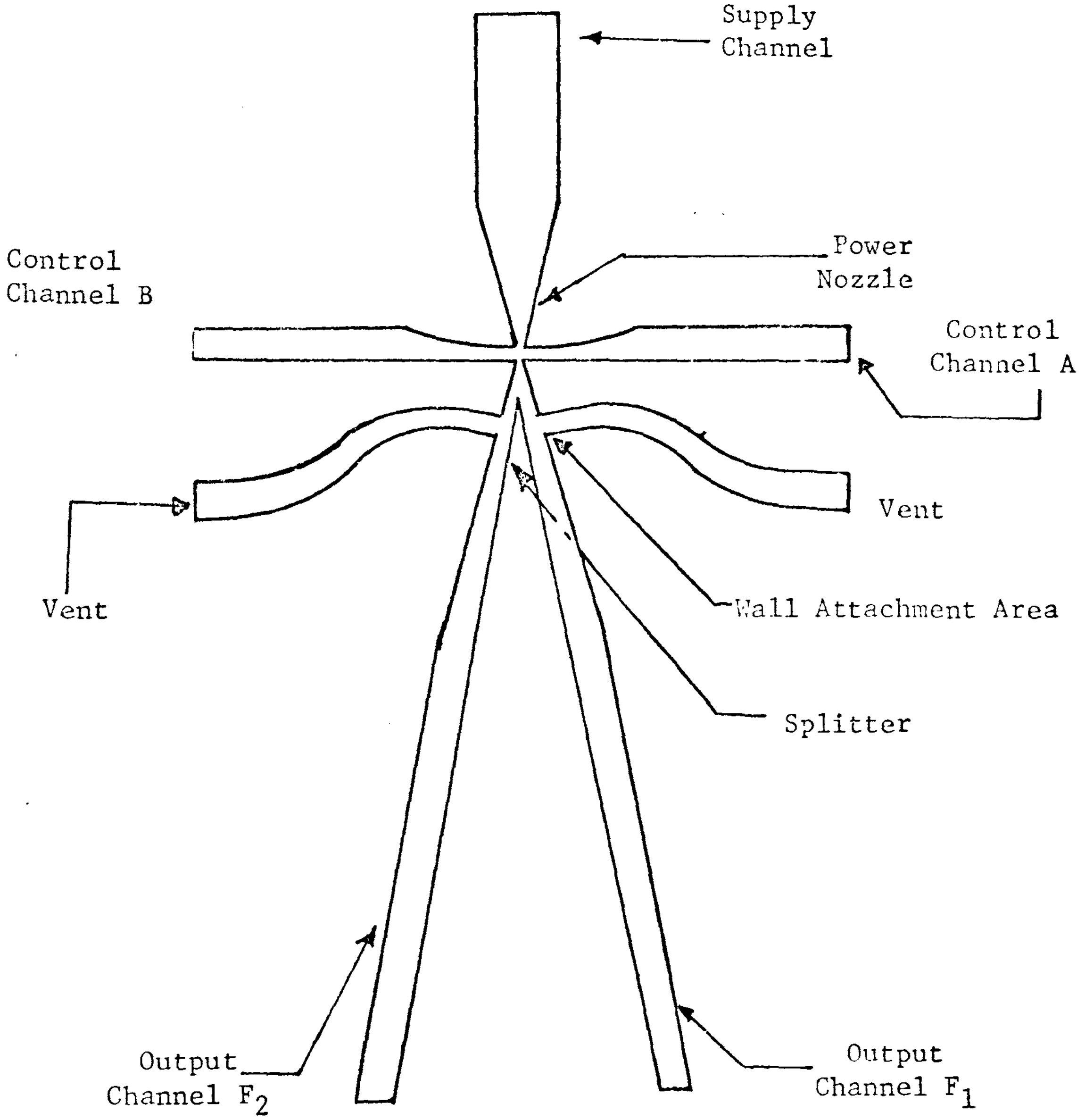
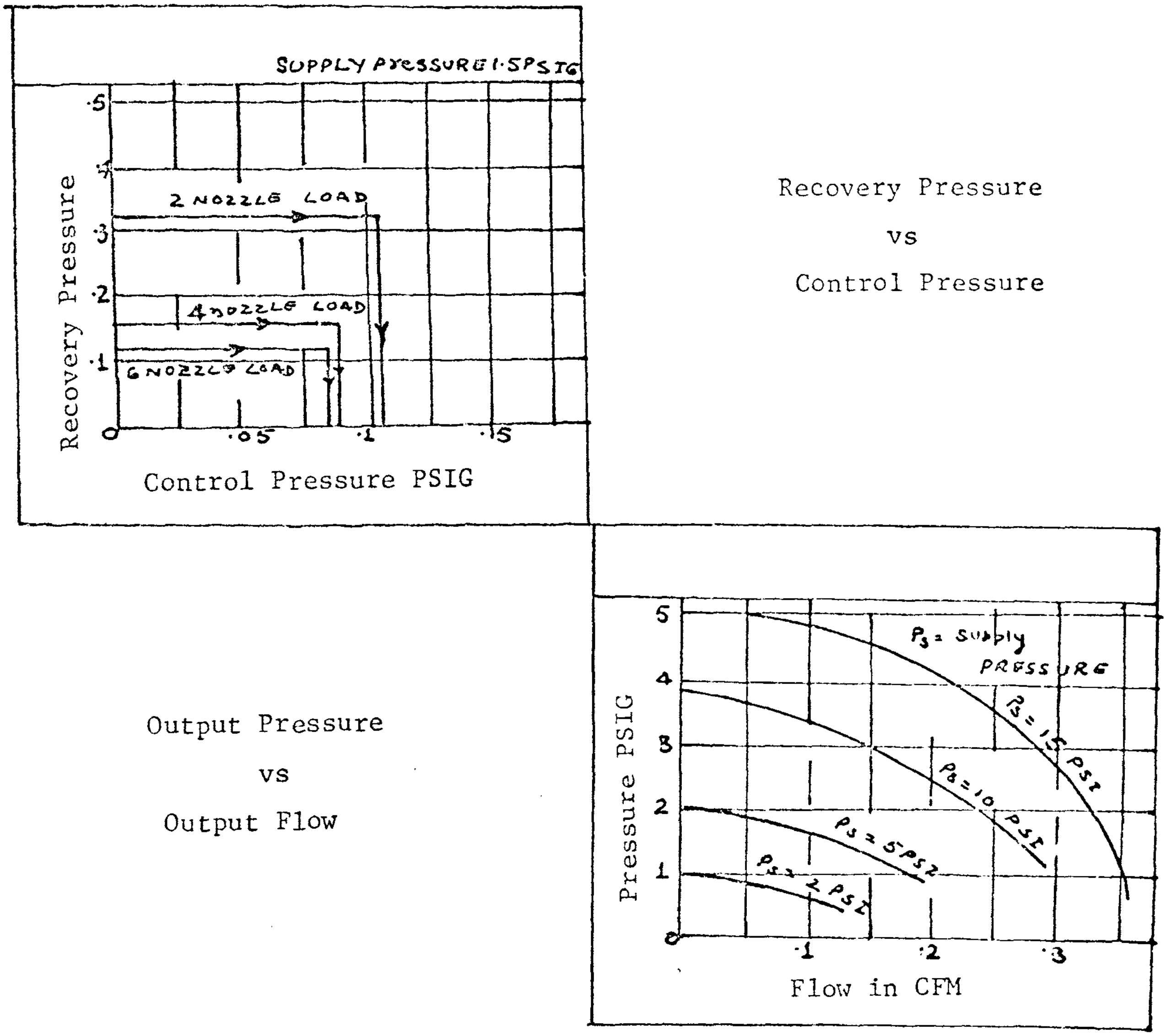


FIGURE 3.4

FLIP FLOP DESIGN



Recovery Pressure

vs

Control Pressure

Output Pressure

vs

Output Flow

FIGURE 3.5

FLIP-FLOP CHARACTERISTICS

(Source: Corning Fluidikit Manual)

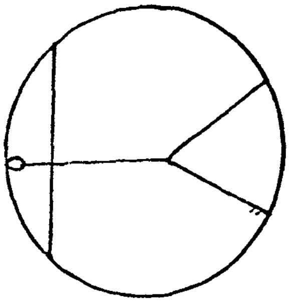


FIGURE 3.6

CIRCUIT SCHEMATIC OF FLIP-FLOP

other of the output channels. Let us say it is at F_2. As long as there are no control signals, and power jet flow continues, the output will remain at F_2 indefinitely. Whenever a sufficient signal is applied at control port B, the power jet flow is switched to the opposite wall causing output at port F_1. To return the output to the original leg, a control signal must now be applied to control port A. These signals must be large enough to overcome the wall attachment effects established by the power jet.

Typical characteristics of flip-flop operation are shown in figure 3.5.

3.3 NOR Gate

Gate fluidic devices are perhaps the most frequently used building blocks in fluidic circuits. The NOR Gate is a monostable device, favoring or biased to one output leg. Biased design can be accomplished in several ways. One approach is by the design shown in figure 3.7.

This device uses the Coanda or wall attachment effect while the proportional amplifier specifically avoids this phenomenon. This device has control ports on the same side of the device. A special auxiliary control port with no fitting is provided on the other side. This auxiliary port has a larger nozzle area than that of the combined control input port. This size makes it more difficult to entrain fluid through the control nozzle than through the auxiliary nozzle causing the power jet to be pulled to the control jet side

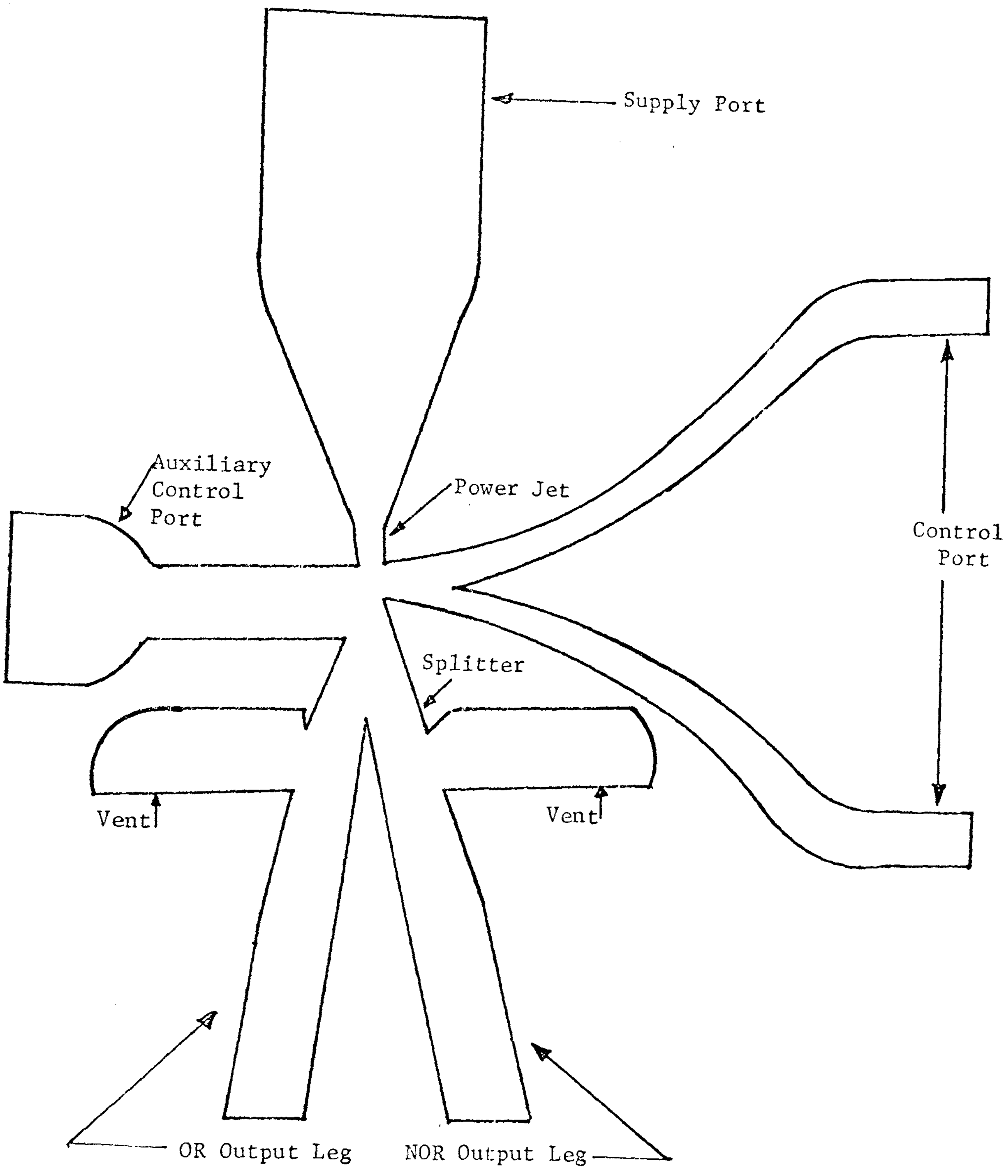
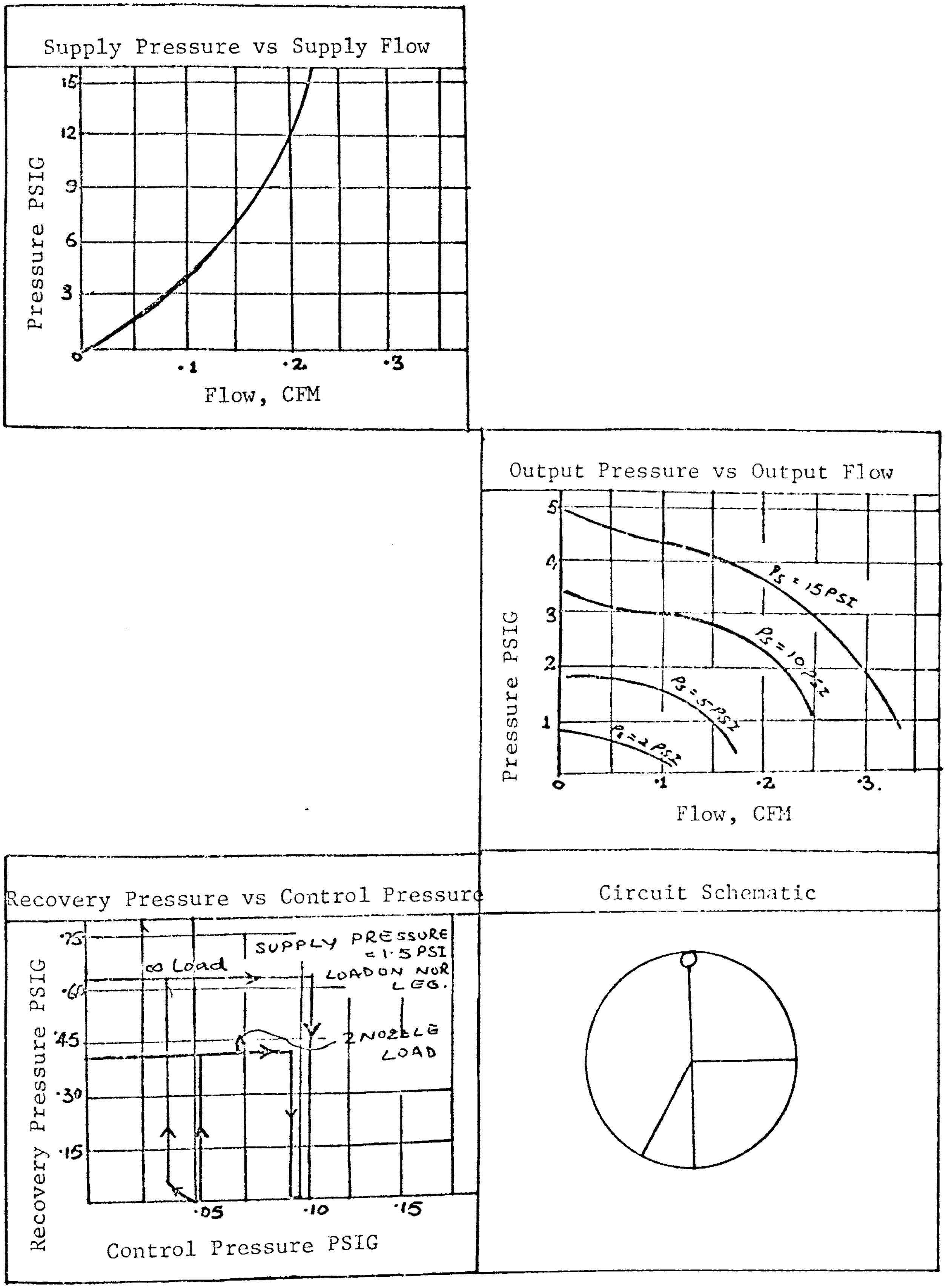


FIGURE 3.7

NOR GATE DESIGN



Supply Pressure vs Supply Flow

Output Pressure vs Output Flow

Recovery Pressure vs Control Pressure

Circuit Schematic

FIGURE 3.8

NOR GATE CHARACTERISTICS

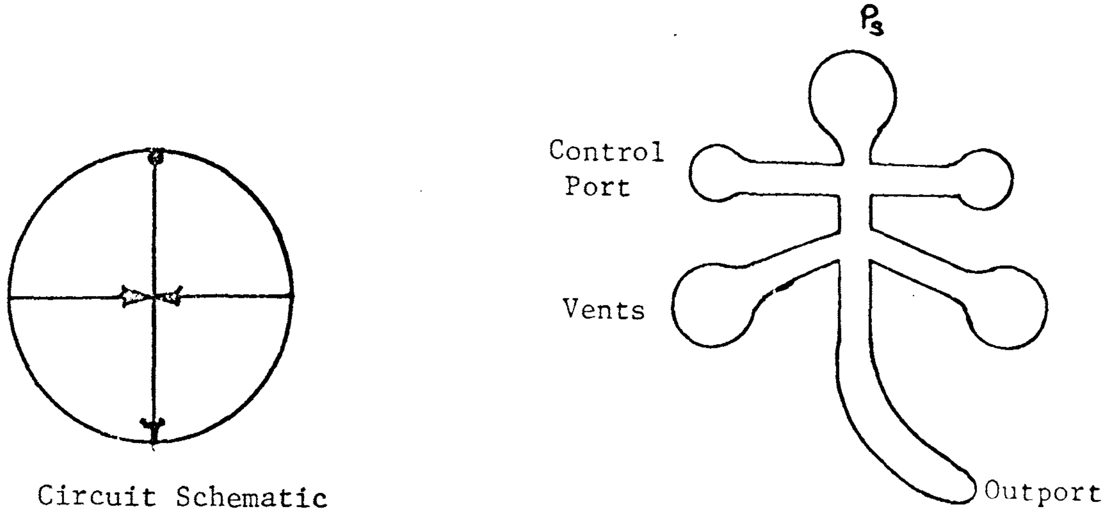
(Source: Corning Fluidikit Manual)

of the device. Pressure differences established are responsible for this behavior. Also, the wall on the auxiliary port side of the intersection area is further from the power nozzle than the wall on the control port side. This type of design further reinforces the tendency of the power jet to attach to the control port, or biased side of the intersection area. Another way to strengthen the initial bias would be to move the splitter toward the auxiliary side.

When pressurized fluid leaves the power jet in the absence of any control signal from the control ports, it becomes attached to the biased leg and NOR output is obtained. Whenever sufficient signal from either or both control ports is present, the power jet flow is switched to the OR leg. Typical characteristics of the NOR Gate are shown in figure 3.8.

3.4 Rectifier

The fluidic rectifier is an element which provides an output signal inversely proportional to the magnitude of the differential input signal and independent of input signal polarity. It utilizes jet interaction operating principles. Figure 3.9 (a) is a schematic diagram of the device. Referring to figure 3.9 (b), rectifier operation can be described as follows: When the input differential signal is zero (equal pressure at C_1 and C_2) the power jet impinges on the signal output receiver and maximum recovery occurs at the output port 0. If the power jet is deflected to either side by an input signal the recovery pressure at the output receiver will be reduced



a. Circuit Schematic

b. Silhouette of rectifier

FIGURE 3.9

FLUIDIC RECTIFIER REPRESENTATION

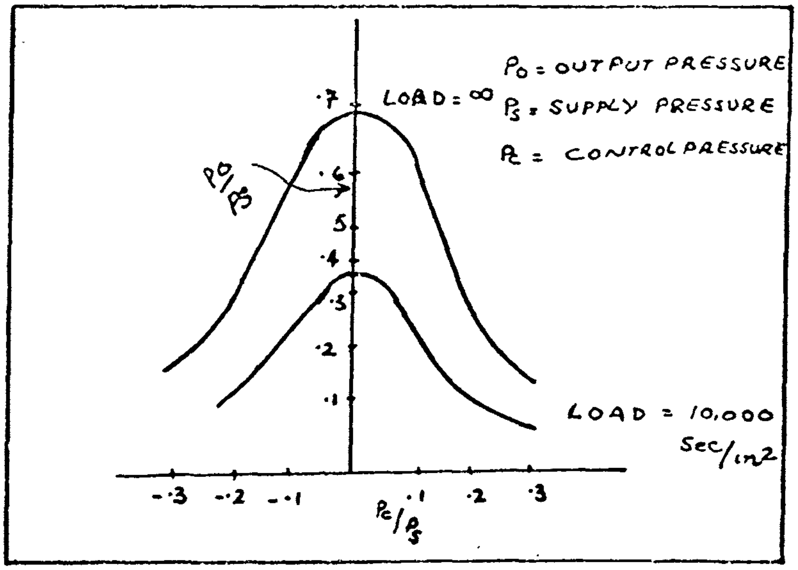


FIGURE 3.10

RECTIFIER INPUT OUTPUT CHARACTERISTICS

(Source: General Electric Co.)

by an amount proportional to the input signal amplitude. Hence the output is independent of input signal polarity, but is proportional to the magnitude of the input signal.

The fluidic rectifier is generally used in circuits where signal rectification is needed. Typical applications are frequency to analog conversion, phase discrimination, and beat frequency detection. The rectifier can also be used for frequency doubling.

Figure 3.10 shows the typical input-output pressure relations of the fluidic rectifier.

3.5 FLICR Valve

The Fluidic Industrial Control valve (FLICR valve) answers the need for higher pressure operation up to 100 psig. It is an interface device which uses the output from a NOR Gate to switch a separate supply flow of up to 100 psig. Its operation can be explained as follows:

When the NOR leg of the NOR Gate delivers a signal to the control port of the FLICR valve, the signal goes to one side of a small piston in the valve. The piston moves causing the grooved swiggle in the valve to pivot around a center post. This pivoting directs the high pressure air coming into the pilot valve to move out the leg on the NOR side of the valve. The high pressure air is routed through the swiggle and, due to a planned tolerance between center post and swiggle, the flow creates an air bearing between swiggle and post. When a control signal is applied to the FLICR valve

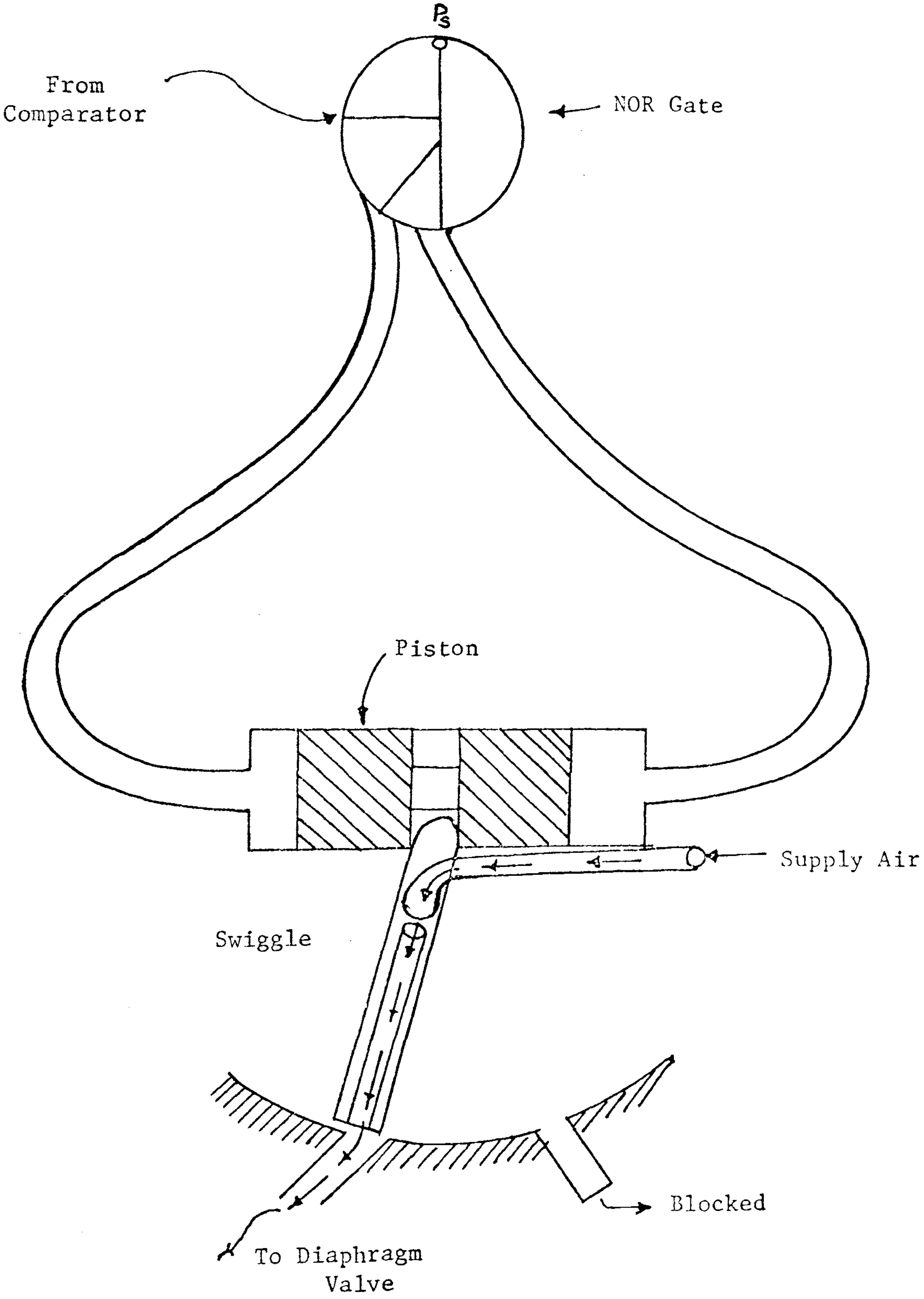


FIGURE 3.11

FLICR Valve

NOR Gate, the pilot gate output switches to its OR leg actuating the piston and swiggle and causing the valve to switch. Figure 3.11 is a schematic diagram of the FLICR valve.

4. THE FLUIDIC LIQUID LEVEL CONTROL SYSTEM

4.1 Description of Control System Elements

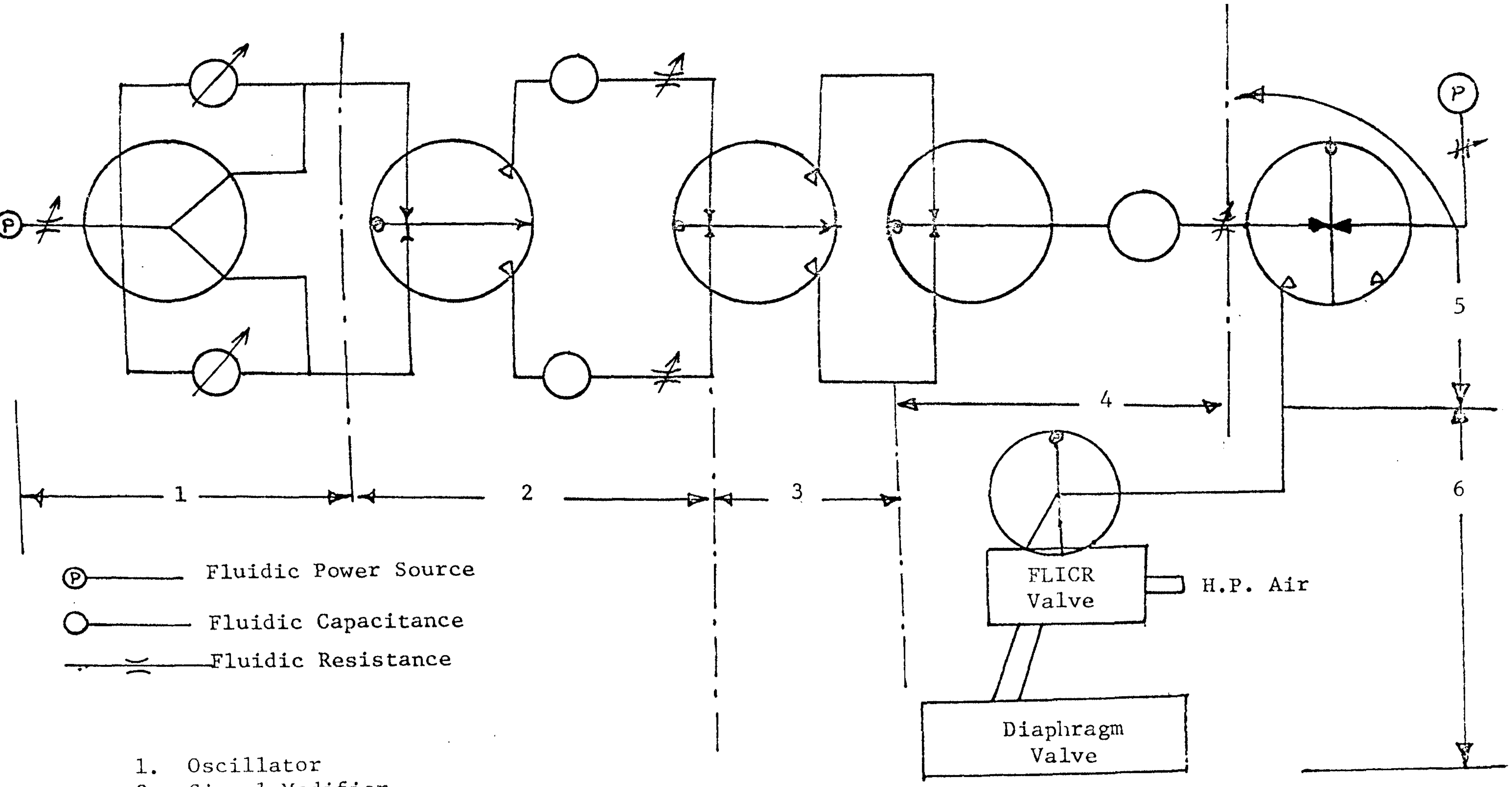
4.1.1 Operational System

The fluidic liquid level control system developed consists of six stages and is shown schematically in figure 4.1 and pictorially in figures 4.2 and 4.3. A description of each stage follows.

4.1.2 Oscillator-Sensor

The oscillator is essentially a flip-flop element. As we know, the change of the output from one leg to another is known as switching. Whenever the output legs feed back into the control ports and generate control signals on the same side of the device they cause the device to switch continuously. This repetitive process is known as oscillation and the device is known as an oscillator.

The frequency of oscillation is dependent on the time constant of the feed back path. This feed back path is usually made up of resistive and capacitive elements. By changing the value of this R-C combination the oscillator frequency can be altered. The larger the R--C product, the longer the time constant and hence the slower the frequency of oscillation. For a bistable device such as the flip-flop, the R-C networks in each feed back path must be essentially identical to produce a balanced output oscillation. The basic liquid level sensing element for the control system developed is a variable capacitance in each feed back loop of the fluidic oscillator. These



1. Oscillator
2. Signal Modifier
3. Signal Amplifier Isolation
4. Rectifier
5. Comparator
6. Actuator

FIGURE 4.1

CIRCUIT SCHEMATIC FLUIDIC LIQUID LEVEL CONTROLLER

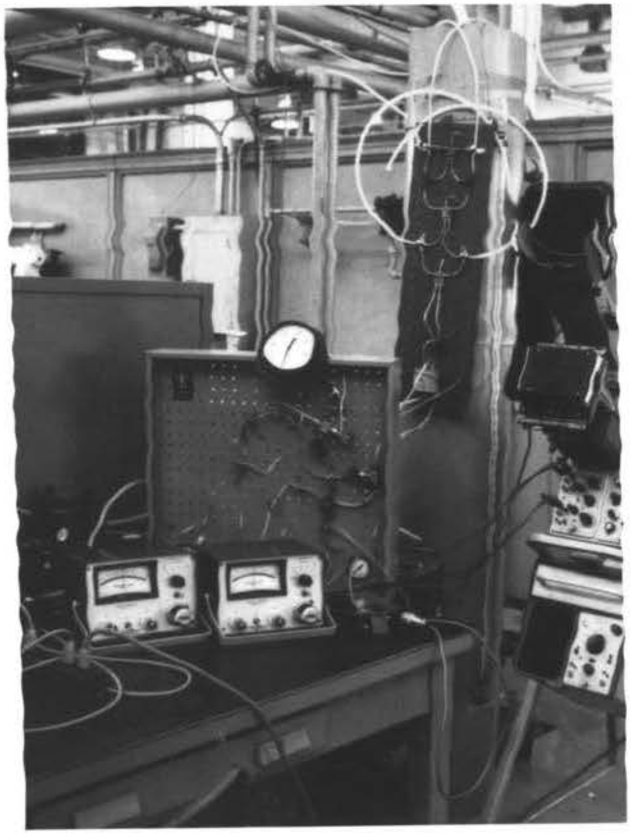


FIGURE 4.2

COMPLETE CONTROL SYSTEM
AND INSTRUMENTATION

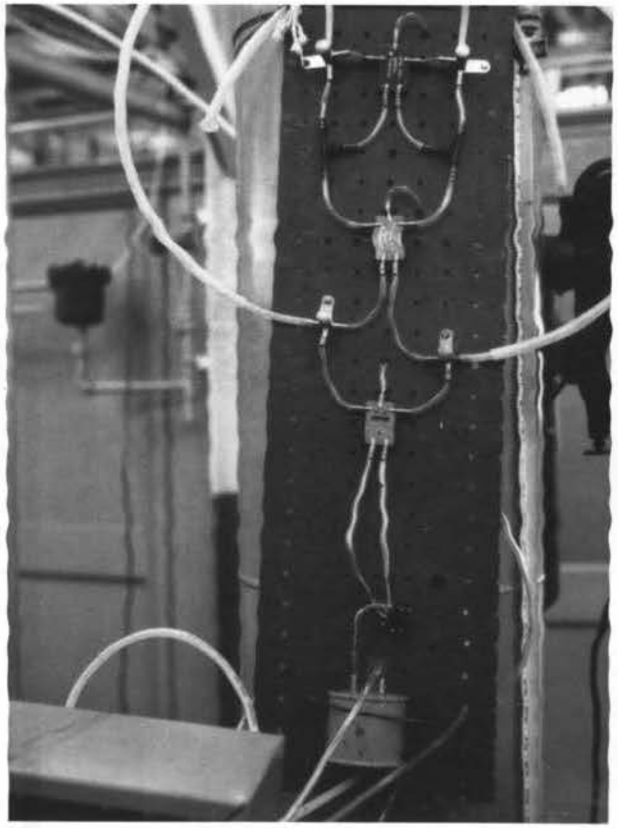


FIGURE 4.3

MAJOR FLUIDIC ELEMENTS
OF CONTROL SYSTEM

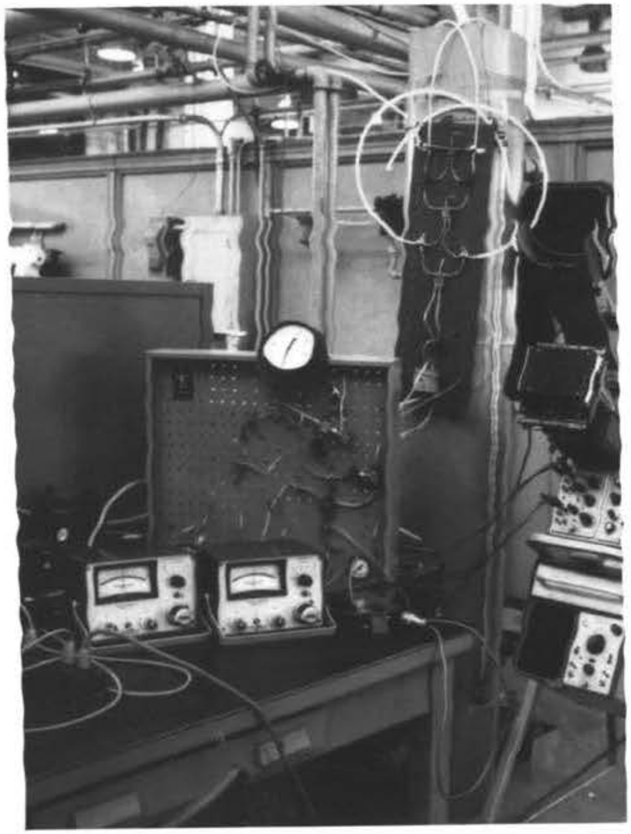


FIGURE 4.2

COMPLETE CONTROL SYSTEM
AND INSTRUMENTATION

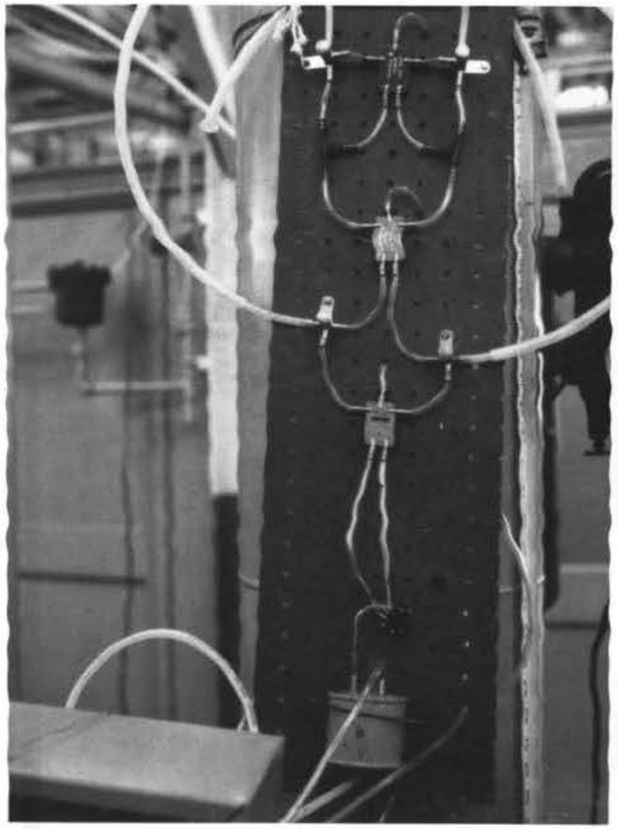


FIGURE 4.3

MAJOR FLUIDIC ELEMENTS
OF CONTROL SYSTEM

variable capacitances consist of small flexible chambers fabricated from toy balloons and rigid tubing. When submerged in the bottom of the liquid tank the volume of the balloon-tube chamber is dependent on the liquid level above the chamber and the supply jet pressure of the oscillator.

As the liquid level in the tank drops the increased differential pressure across the flexible capacitors causes the volume to increase. Since an increase in R-C product in the oscillator feed back path increases the time constant, the frequency of oscillation decreases. Thus, changes in liquid level are sensed as changed in the frequency of the oscillator sensor stage. Due to the digital nature of the flip-flop oscillator the amplitude of the output wave is essentially unchanged with these frequency changes.

4.1.3 Signal Modifier

The signal modifier consists of a proportional amplifier preceeding a low frequency R-C filter. The oscillator provides the control signal for this stage. The proportional amplifier acts as a signal amplifier and it also helps to isolate the oscillator from downstream disturbances. The R-C filter is set so that its output signal amplitude diminishes with increasing signal frequency. On the whole, this stage tends to smooth the output from the oscillator and convert frequency information to amplitude information.

4.1.4 Signal Amplifier and Isolation

This stage consists of a proportional amplifier element. At this stage the signal which is received from the signal modifier is amplified, particularly its flow. This stage helps to isolate the preceding stages from the rectifier and minimize loading effects of the rectifier on these stages.

4.1.5 Rectifier and Filter

The rectifier and filter stage consists of a rectifier and capacitor filter. The output of the signal amplifier and isolation stage is directly fed into the control ports of the rectifier. As pointed out previously, the output of the rectifier is independent of the input signal polarity but is proportional to the magnitude of the input signal. Actually it provides an output signal inversely proportional to the magnitude of the differential input signal. At this stage the alternating signal is simply rectified and filtered to produce a non-alternating signal that is proportional to the frequency of the alternating signal, produced by the oscillator.

4.1.6 Comparator

The comparator stage is a proportional amplifier. It essentially compares the rectified and filtered signal to a reference signal. The output of the filter is fed to one control port and the reference signal is fed into the other control port. If the two control signals received are of equal magnitude, the output will be evenly divided between the two output ports. When the two control signals are different the differential output pressure of the proportional amplifier varies. One output leg of this device is vented to the atmosphere and the second leg provides a signal above atmospheric pressure. The actual signal magnitude depends on the state of the system.

4.1.7 Actuator

This unit consists of FLICR valve connected to a normally open diaphragm valve. The diaphragm valve controls water flow into the tank. Only one output of FLICR valve is connected to the diaphragm valve, and the other output is blocked.

As explained in sec. 3.5, when high pressure air comes out of the output connected to diaphragm valve the flow valve is closed. When the output of the FLICR valve is switched to the blocked side, pressure on the diaphragm is released and a spring opens the valve allowing fluid to flow into the tank.

4.2 Description of Control System Operation

The performance of the control system as a whole can be described as follows:

The oscillator oscillates at a fixed frequency at a particular liquid level. Whenever the liquid level changes, the frequency of oscillation changes due to the capacitance change in the feedback circuit of the oscillator. Thus, an alternating signal is generated and fed to the signal modifier. This stage modifies the signal and provides an approximate sinusoidal wave whose amplitude varies with frequency. This signal is fed to the signal amplifier and isolation stage. At this stage the input signal is amplified, particularly its flow. Variable resistances between the two stages are used to remove any bias from the alternating signal which is fed from the signal amplifier to the rectifier and filter stage. The latter stage simply rectifies and filters the signal fed into it. This non-alternating signal obtained, which is proportional to the frequency of the previous alternating signal is then compared with a reference signal in the comparator. This reference signal is adjusted so that at a particular liquid level, the output stages will operate, causing the flow valve to open. If the signal from the comparator, which is fed to the NOR Gate of the FLICR valve, is insufficient to cause switching, the high pressure air is obtained from the NOR leg of FLICR valve which is connected directly to the diaphragm valve. Thus, there is pressure on the actuator and the flow valve remains closed. As the water level falls the level of the rectified signal falls. When sufficient difference between this signal and the reference signal is developed, the comparator output from the leg connected to the control port of the NOR Gate gives a signal sufficient to switch the high pressure air to OR leg of the FLICR valve. Switching this high pressure air releases the spring actuated diaphragm valve allowing water to flow into the tank. When the signal from the comparator decreases, the high pressure air switches back to the NOR leg, thus applying pressure to the diaphragm valve causing it to close.

This type of control processes using either a fully open or fully closed valve is called an "on-off" control process.

4.3 Functional Block Diagram

The fluidic liquid level control system can be represented by the functional block diagram as shown in figure 4.4. Due to the

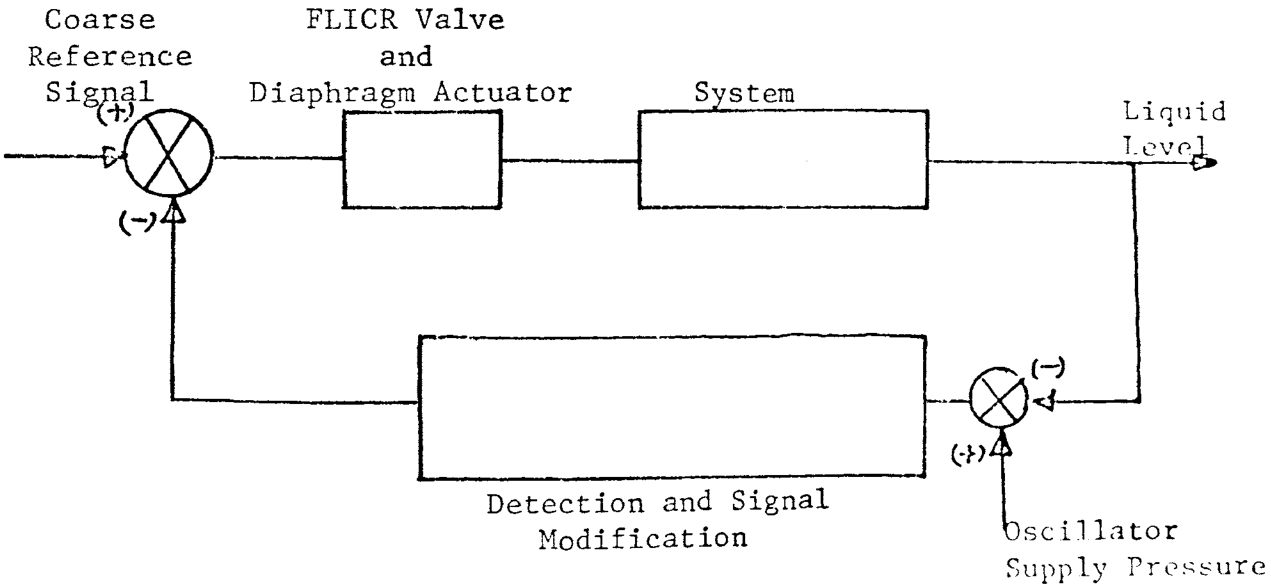


FIGURE 4.4

FUNCTIONAL BLOCK DIAGRAM

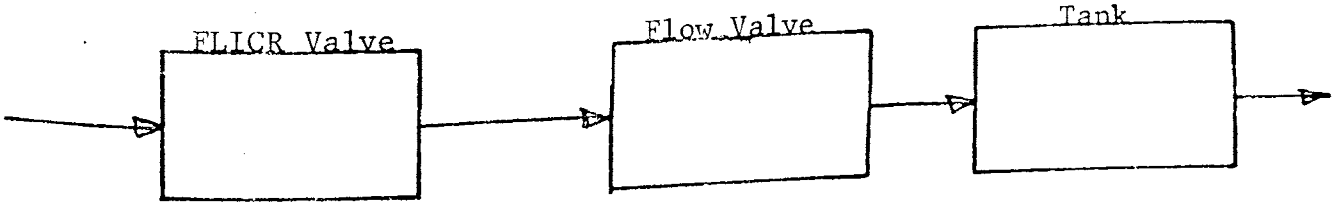


FIGURE 4.5

FORWARD LOOP BLOCK DIAGRAM

lack of sufficiently accurate valves and components required to produce repeatable operation, satisfactory transfer functions for the system elements could not be measured. For this reason, only a functional block diagram has been developed.

The forward loop consists of the FLICR valve, flow valve and tank and is represented as shown in figure 4.5.

The FLICR valve is a non-linear element of the on-off type and thus causes the final control stages to behave in an on-off fashion. The flow valve is a diaphragm actuated spring return valve and is normally open. Whenever actuating pressure is applied to the diaphragm, the valve closes, stopping flow into the tank. The tank is 72" inches high and 12" inches in diameter. A variable outlet valve allows the outflow to be changed or adjusted.

The feed back loop consists of the detection and signal modification elements. These elements consist of the oscillator, signal modifier, signal amplifier and isolation; and rectifier and filter stages. Figure 4.6 is a block diagram of the feed back loop.

The oscillator-sensor senses the change of fluid level in the tank and generates a signal whose frequency is a function of the level. This frequency information is converted into amplitude information by the signal modifier stage. The signal amplifier and isolation stage is essentially an impedance matching device required to prevent the following stages from overloading the previous stages. The rectifier and filter convert the alternating signal of variable

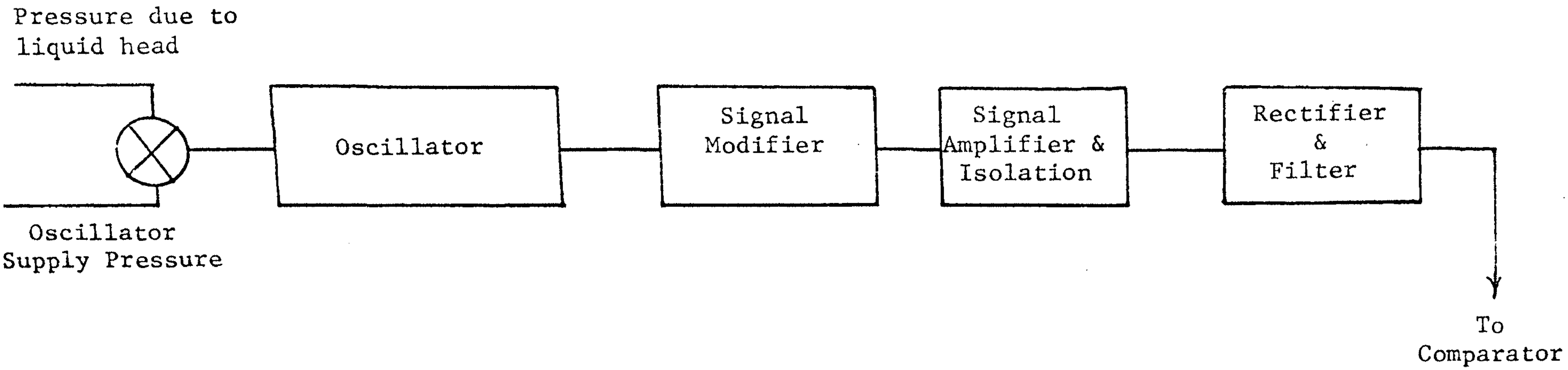


FIGURE 4.6

DETECTION & SIGNAL MODIFICATION BLOCK DIAGRAM amplitude and variable frequency into a non-alternating signal of variable level.

The comparator compares the reference signal with the feed back signal. A coarse level adjustment is made with the reference signal and fine level adjustments are made with the oscillator supply pressure. The fine adjustment is necessary because of the non-linear characteristics of the oscillator-sensor. Adjustment of the oscillator pressure produces the greatest frequency to liquid level sensitivity for each range of liquid level control.

4.4 Typical Operational Characteristics

The operational characteristics of each stage were obtained experimentally. The results of these experimental measurements are described in the following paragraphs.

4.4.1 Oscillator

The measurement of the output of the oscillator stage was made at point a-a shown in schematic diagram figure 4.7. Using a pressure transducer and an oscilloscope the differential output pressure and frequency of oscillation were measured at different liquid levels, and different oscillator power jet supply pressures. A typical wave shape for the oscillator output is shown in figure 4.8. Figure 4.9 shows how the differential output pressure changes with changes of liquid level at different oscillator supply pressure. The peak to peak (P-P) output pressure is essentially independent of liquid level. Figure 4.10 shows that the frequency of oscillation increases as

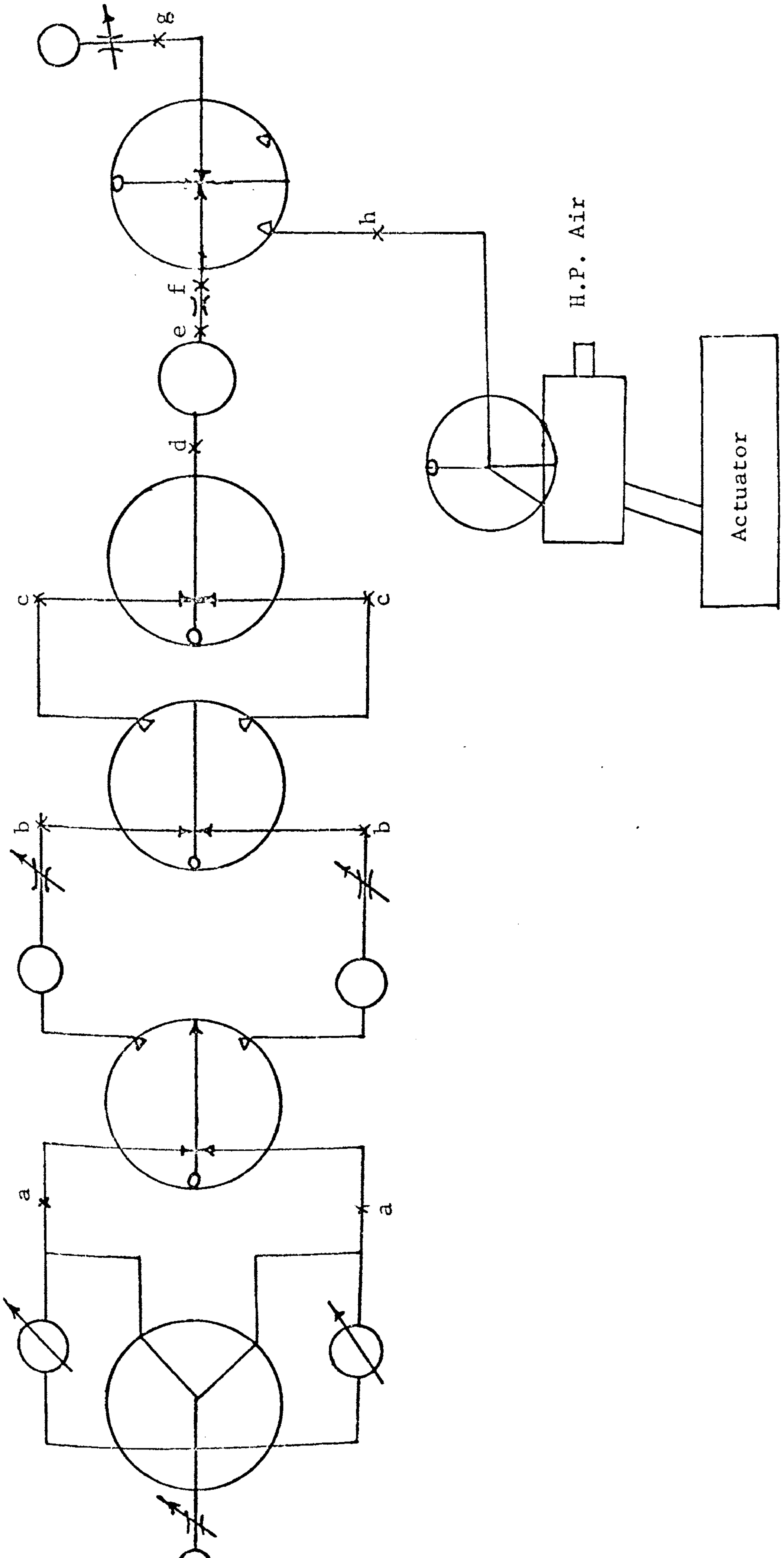


FIGURE 4.7

CIRCUIT SCHEMATIC FLUIDIC LIQUID LEVEL CONTROL SYSTEM

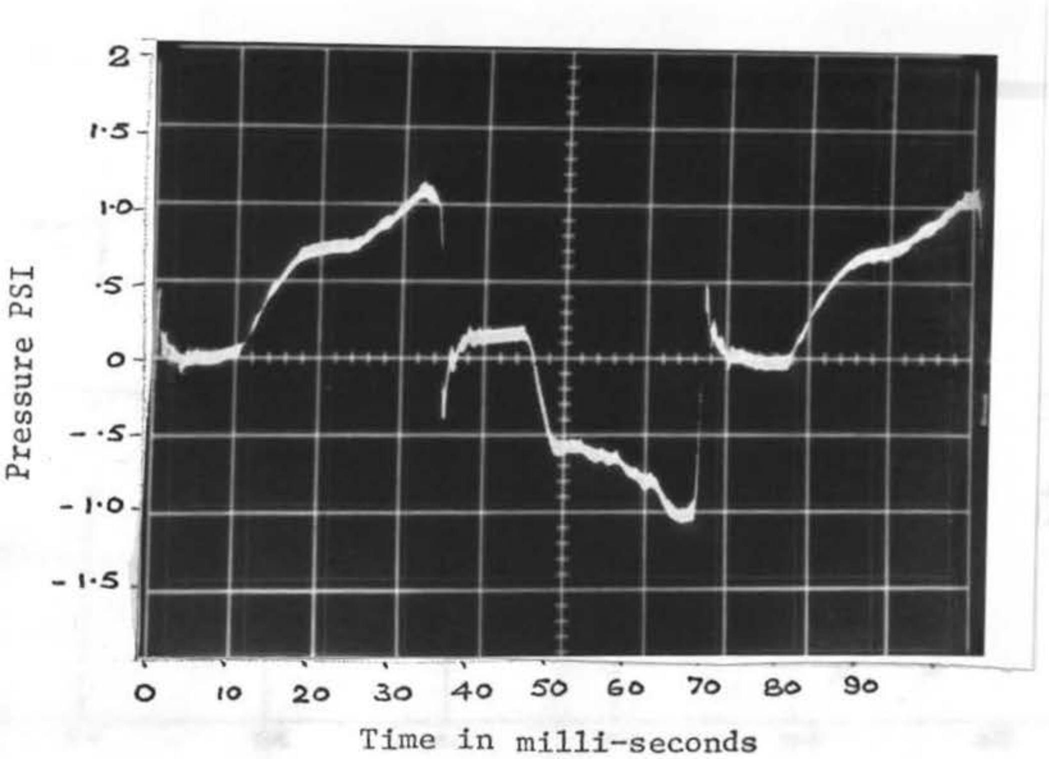


FIGURE 4.8

OUTPUT WAVE SHAPE OF OSCILLATOR

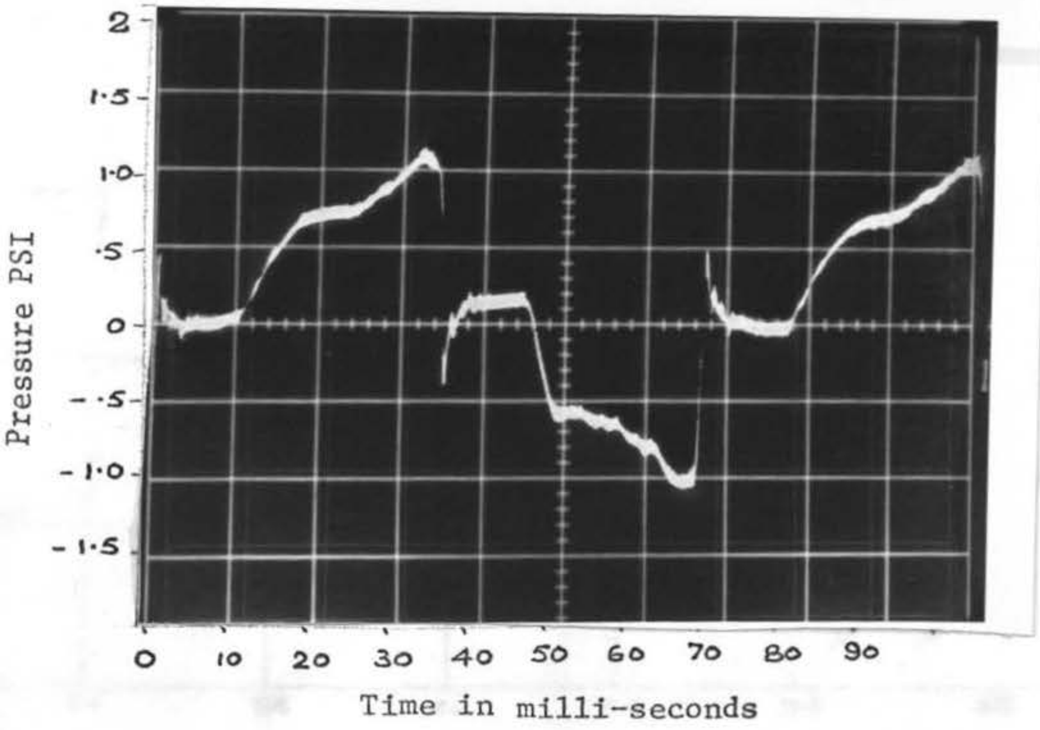


FIGURE 4.8

OUTPUT WAVE SHAPE OF OSCILLATOR

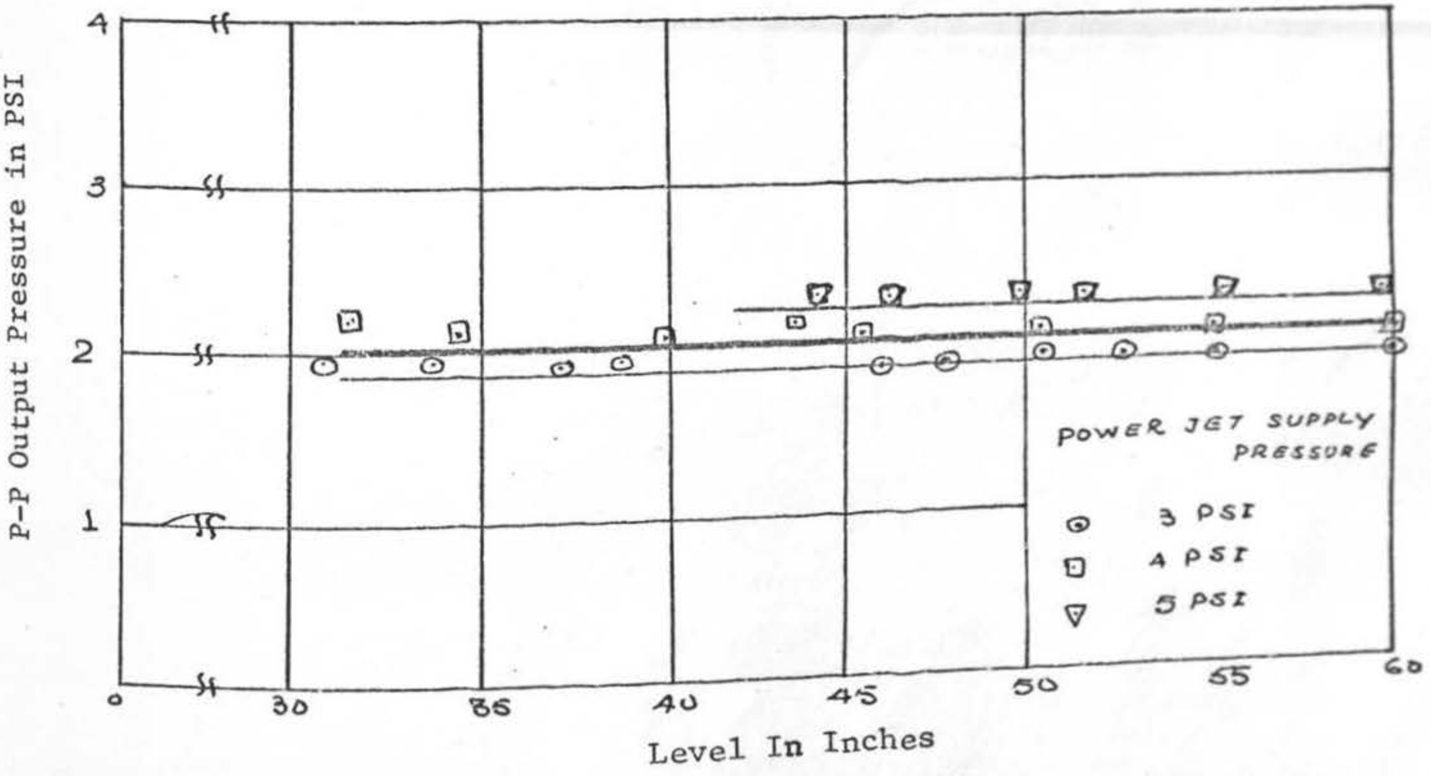


FIGURE 4.9

P-P OUTPUT PRESSURE OF OSCILLATOR AS A FUNCTION OF LIQUID LEVEL

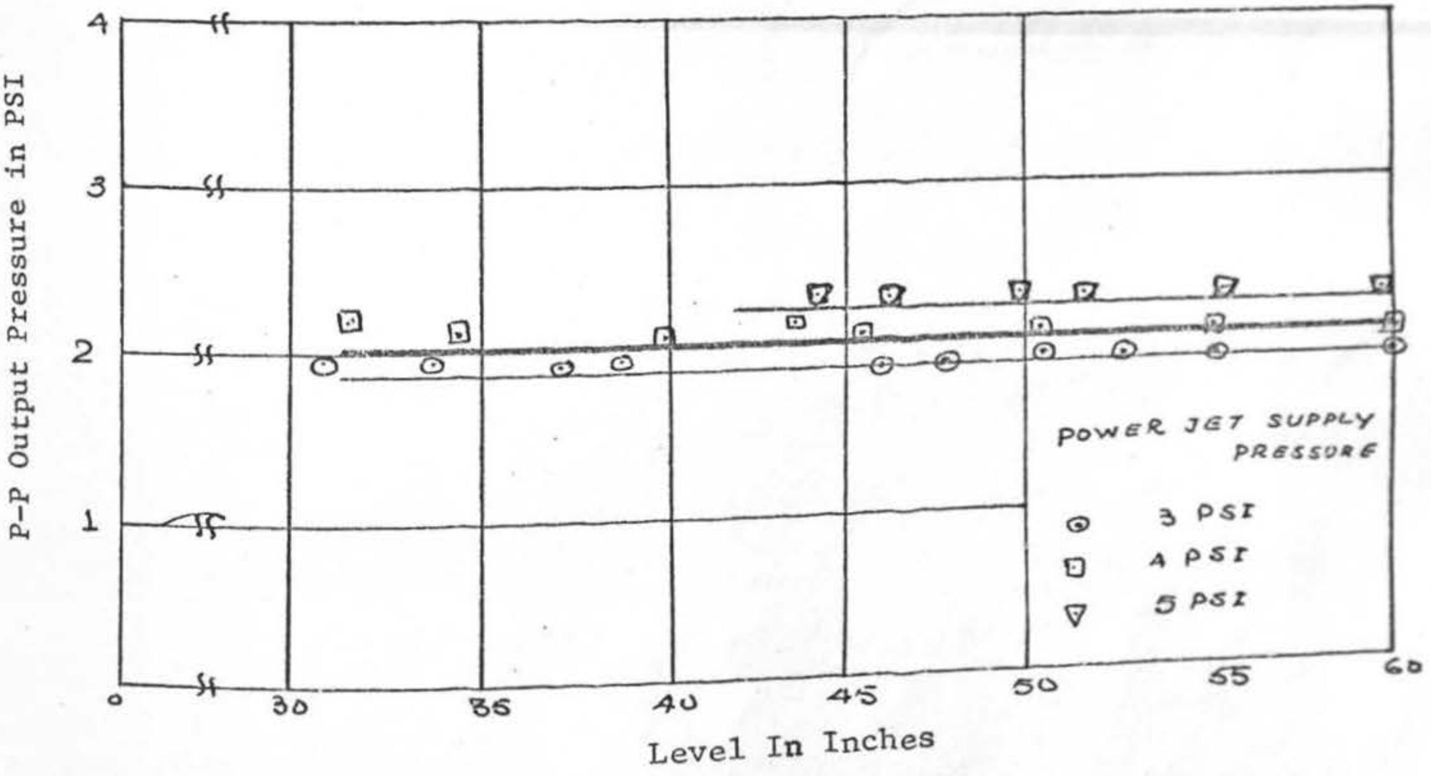


FIGURE 4.9

P-P OUTPUT PRESSURE OF OSCILLATOR AS A FUNCTION OF LIQUID LEVEL

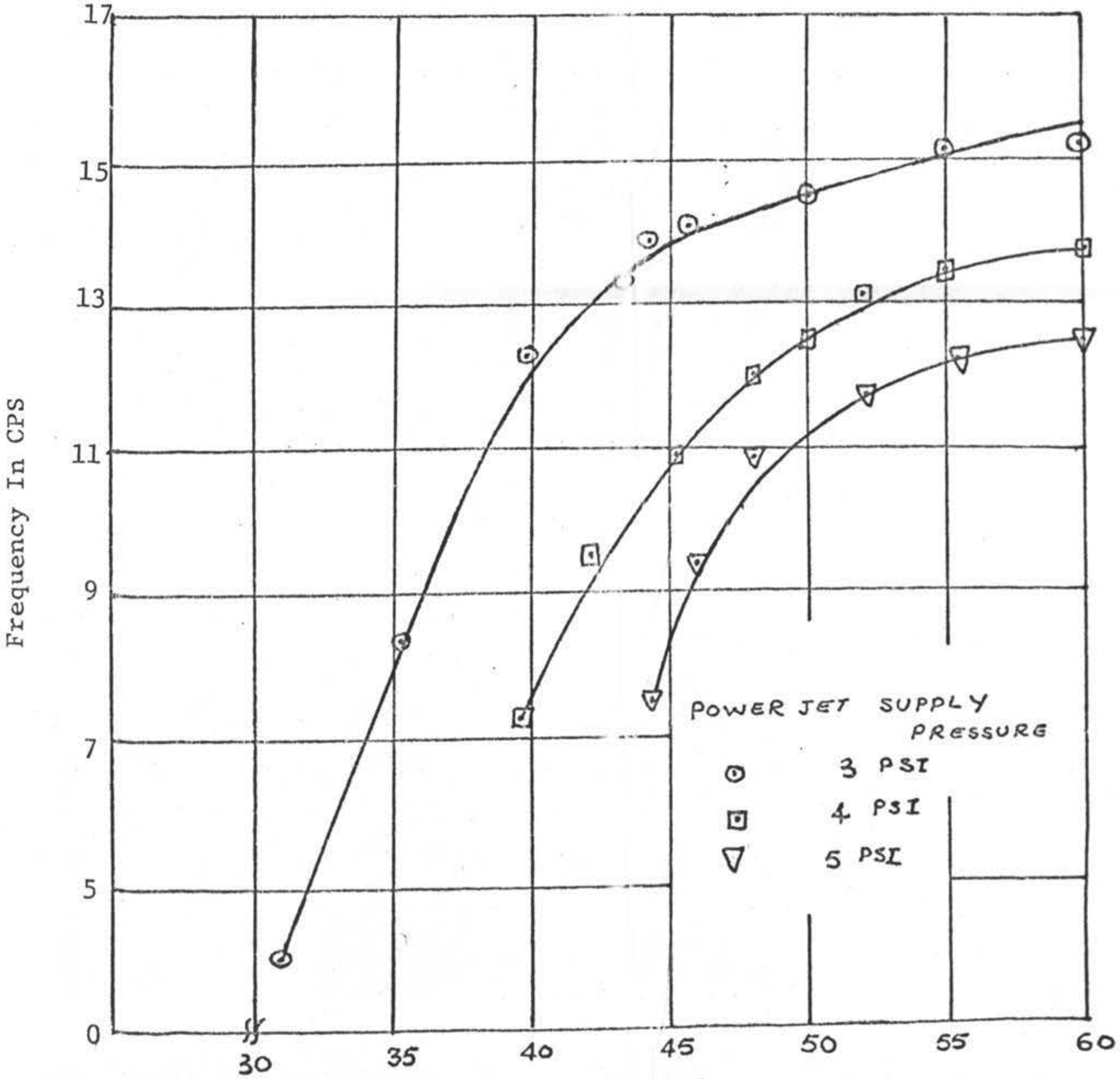


FIGURE 4.10

FREQUENCY OF OSCILLATOR AS A
FUNCTION OF LIQUID LEVEL

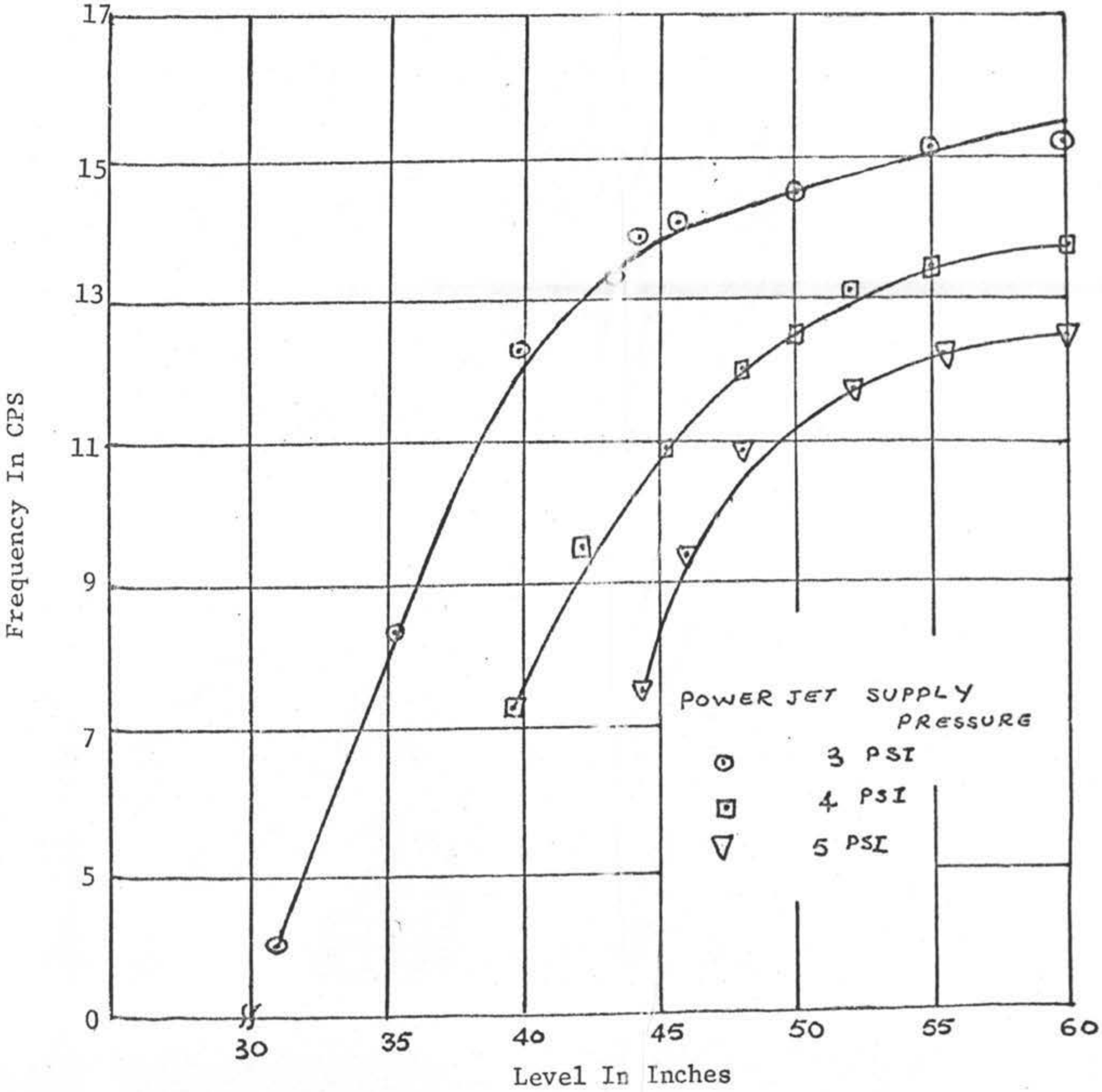


FIGURE 4.10

FREQUENCY OF OSCILLATOR AS A
FUNCTION OF LIQUID LEVEL

liquid level increases. The nominal liquid level control range is from 37" to 52" of water.

4.4.2 Signal Modifier

The measurement of the output of this stage was made at point b-b shown in figure 4.7. A typical output wave from this stage is shown in figure 4.11. Figure 4.12 shows peak to peak differential output pressure variation with changes of liquid level at different oscillator supply pressures. The power jet pressure for this stage was fired at 11.75 psi.

4.4.3 Signal Amplifier and Isolation

The measurement of the peak to peak differential output pressure of this stage was made at point c-c shown in schematic diagram, figure 4.7. A typical output wave from this stage is shown in figure 4.13. Figure 4.14 shows how the differential peak-to-peak output pressure changes with variations of liquid level at different oscillator supply pressures. The power jet supply pressure for this stage was fixed at 4.25 psi.

4.4.4 Rectifier and Filter

The measurement of output of the rectifier-filter stage was made at point e, of the schematic diagram shown in figure 4.7. Figure 4.16 displays the non-alternating pressure as a function of liquid level and various oscillator power jet supply pressure. The power jet supply pressure for rectifier was fixed at 7.75 psi. Figure 4.15 is a typical output pressure level curve.

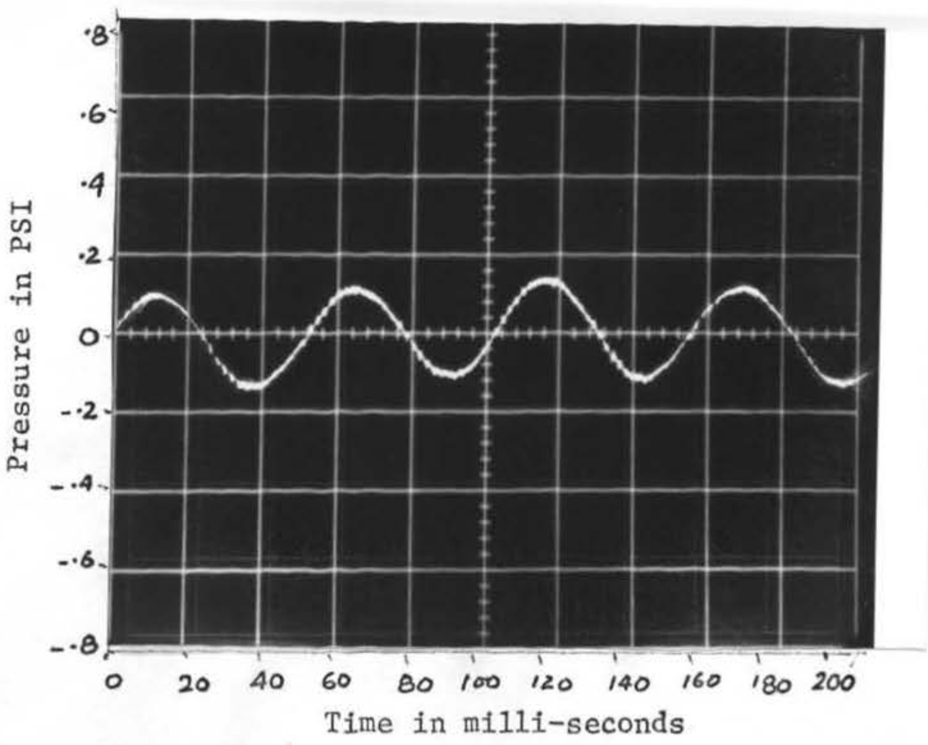


FIGURE 4.11

OUTPUT WAVE SHAPE OF SIGNAL MODIFIER

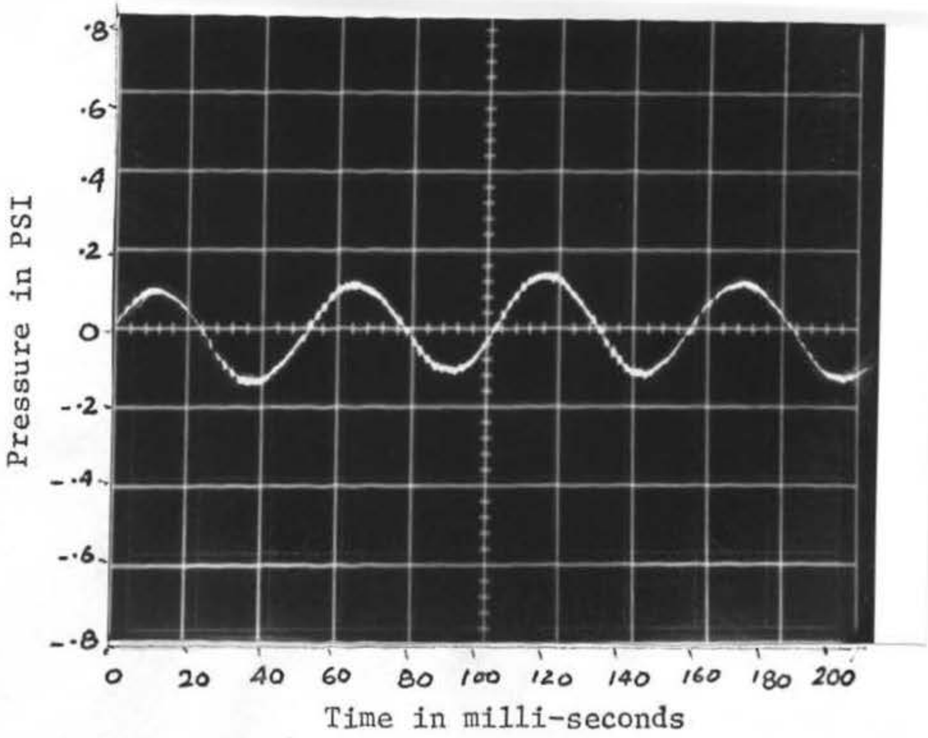


FIGURE 4.11

OUTPUT WAVE SHAPE OF SIGNAL MODIFIER

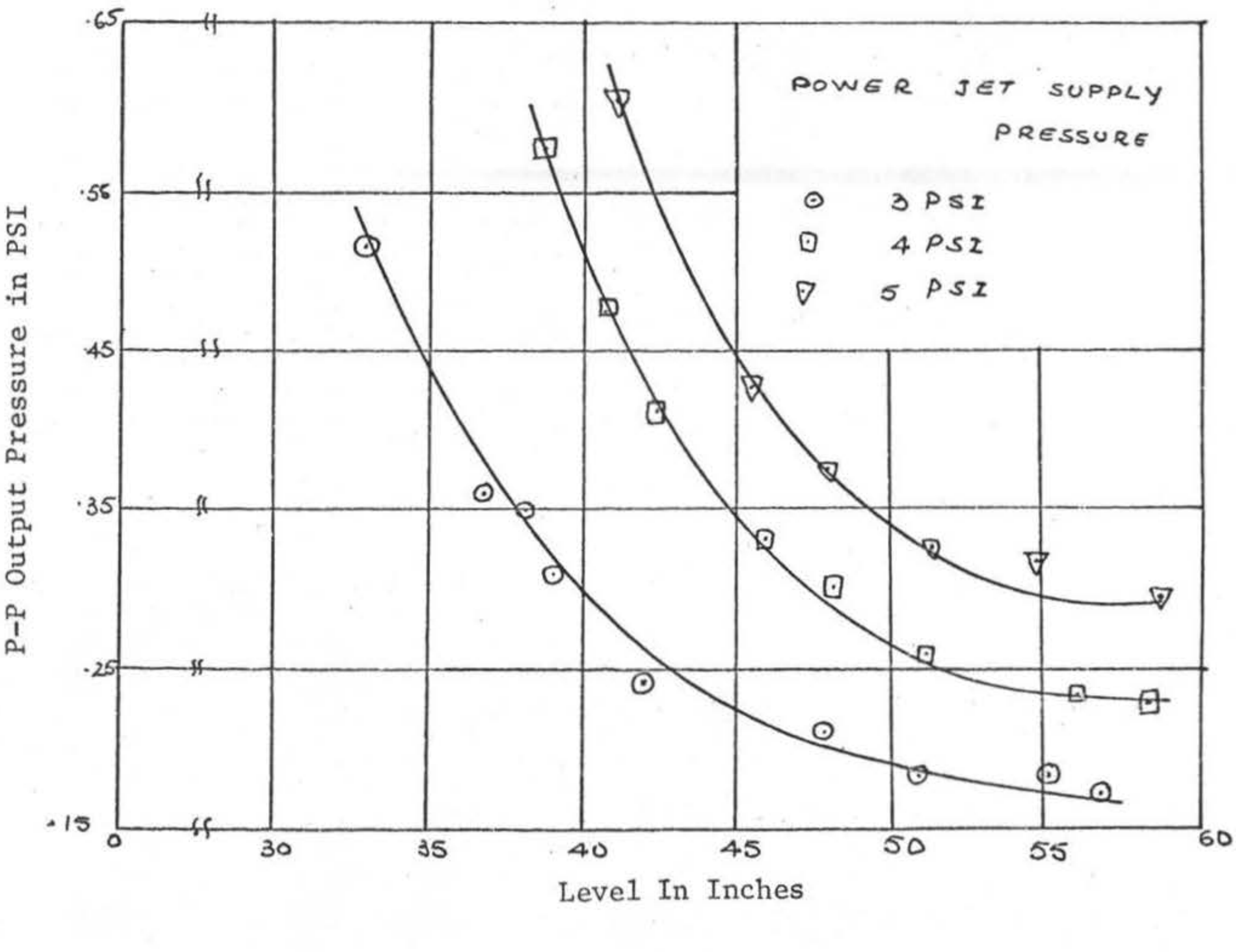


FIGURE 4.12

P-P OUTPUT PRESSURE OF SIGNAL MODIFIER
AS A FUNCTION OF LIQUID LEVEL

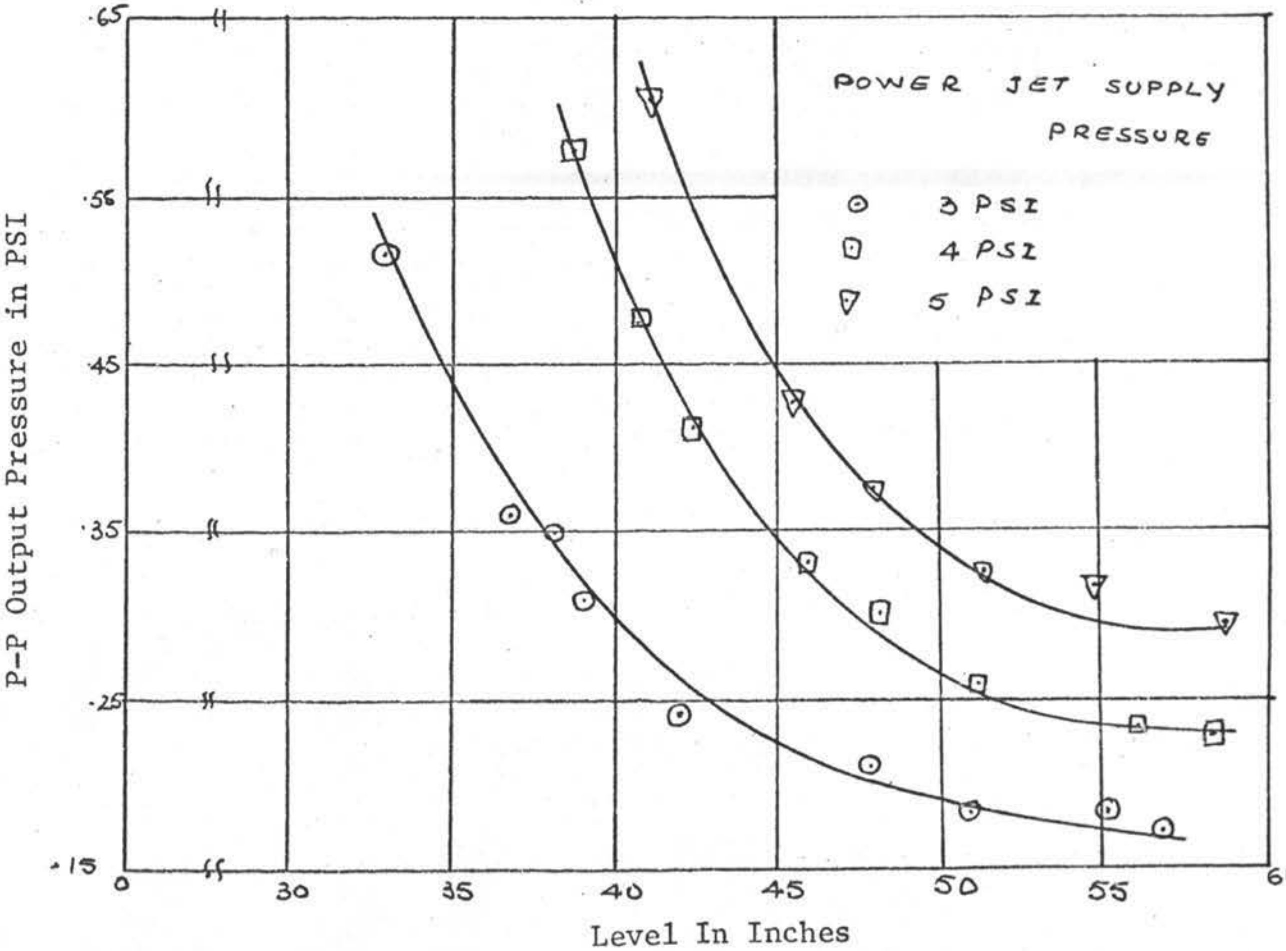


FIGURE 4.12

P-P OUTPUT PRESSURE OF SIGNAL MODIFIER
AS A FUNCTION OF LIQUID LEVEL

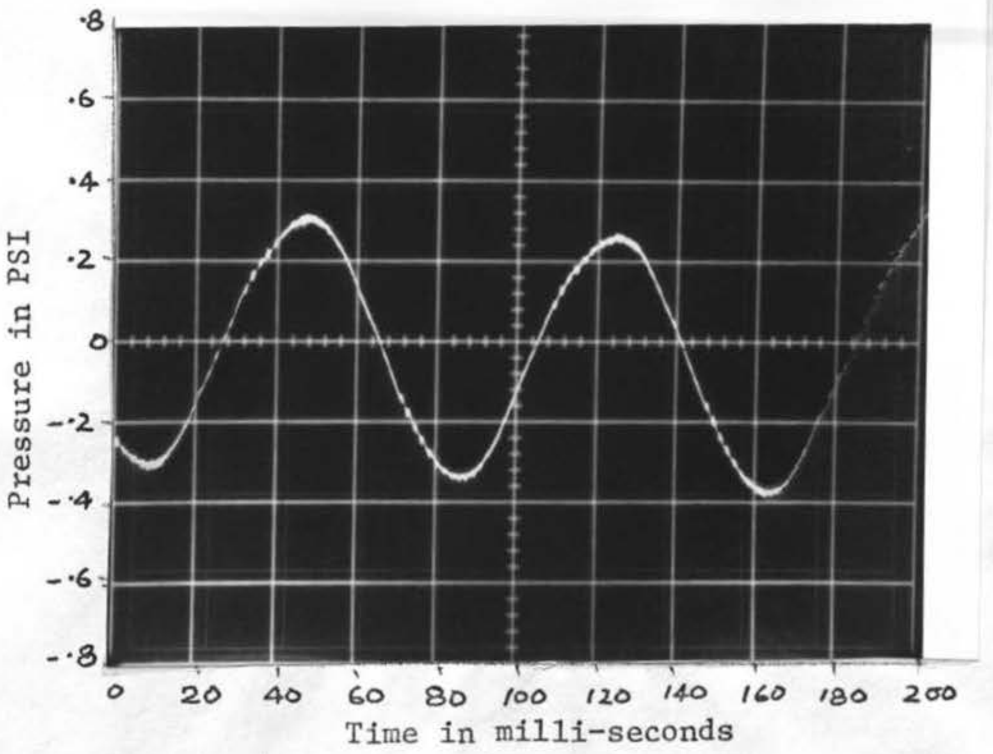


FIGURE 4.13

OUTPUT WAVE SHAPE OF SIGNAL AMPLIFIER AND ISOLATION STAGE

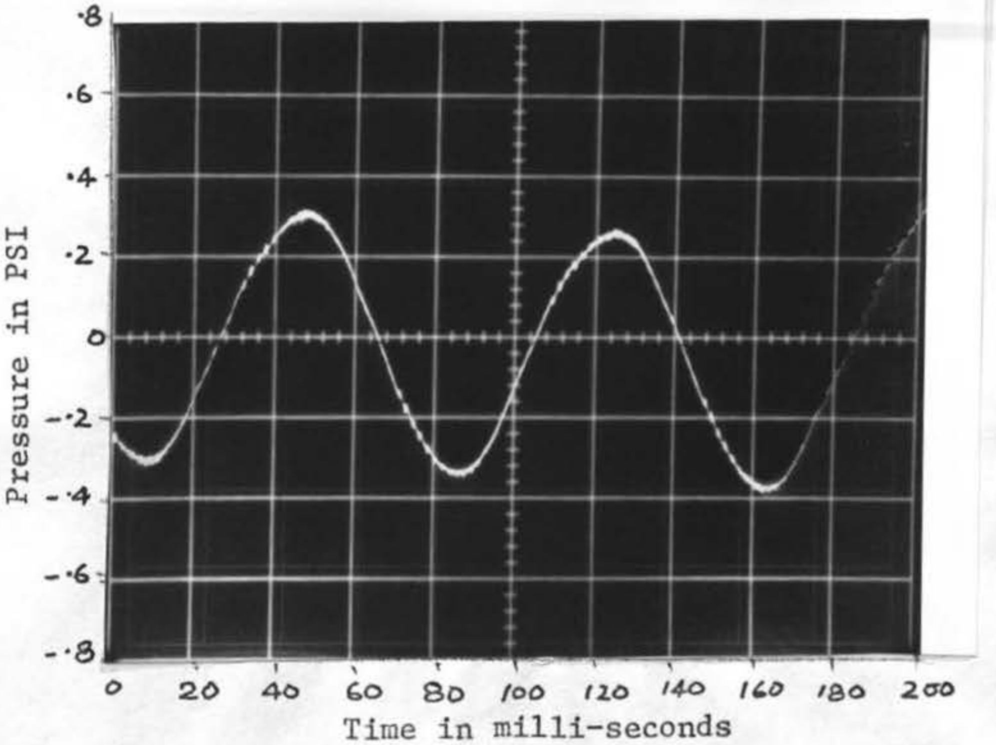


FIGURE 4.13

OUTPUT WAVE SHAPE OF SIGNAL AMPLIFIER AND ISOLATION STAGE

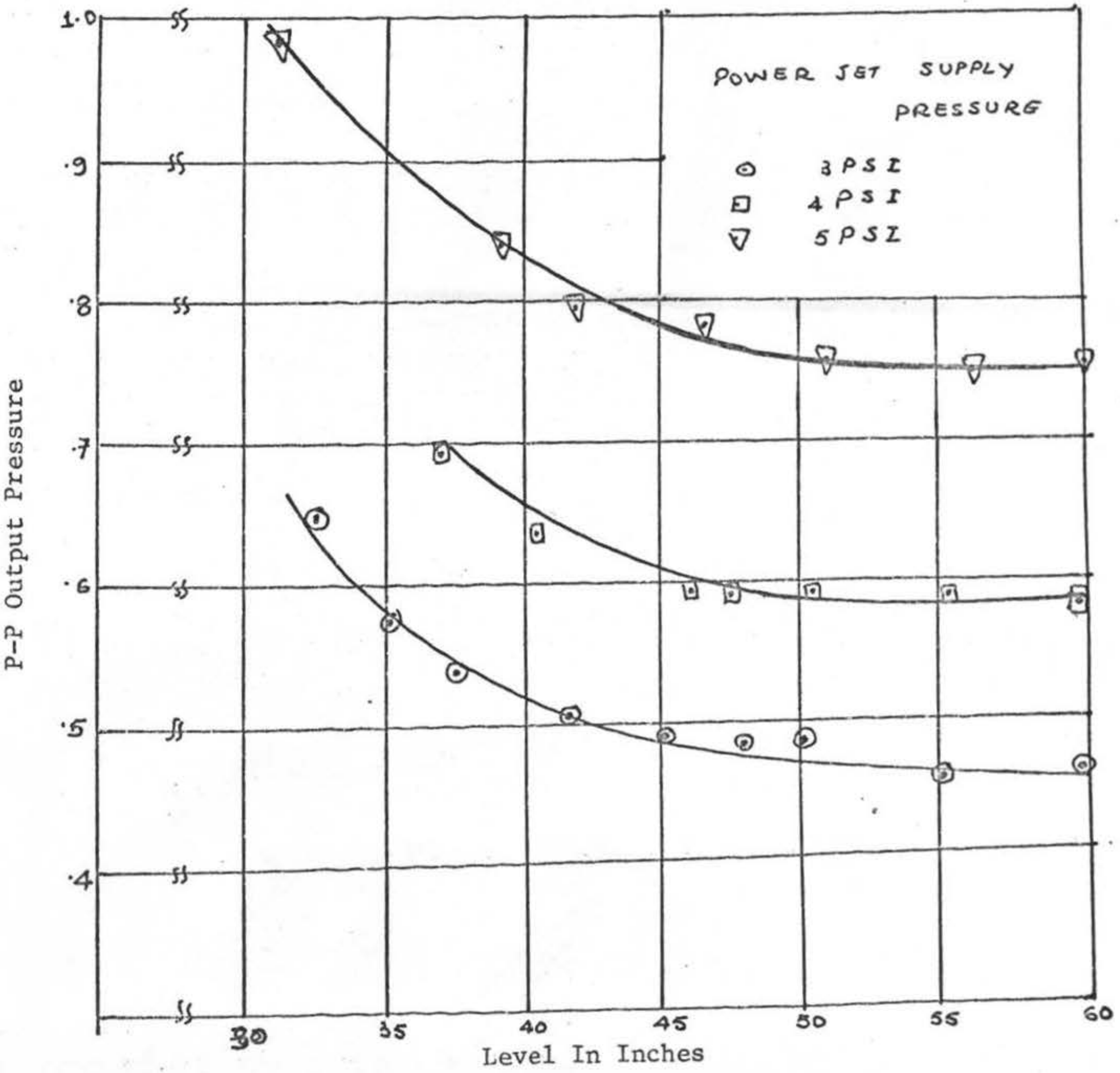


FIGURE 4.14

P-P OUTPUT PRESSURE OF SIGNAL AMPLIFIER AND ISOLATION STAGE AS A FUNCTION OF LIQUID LEVEL

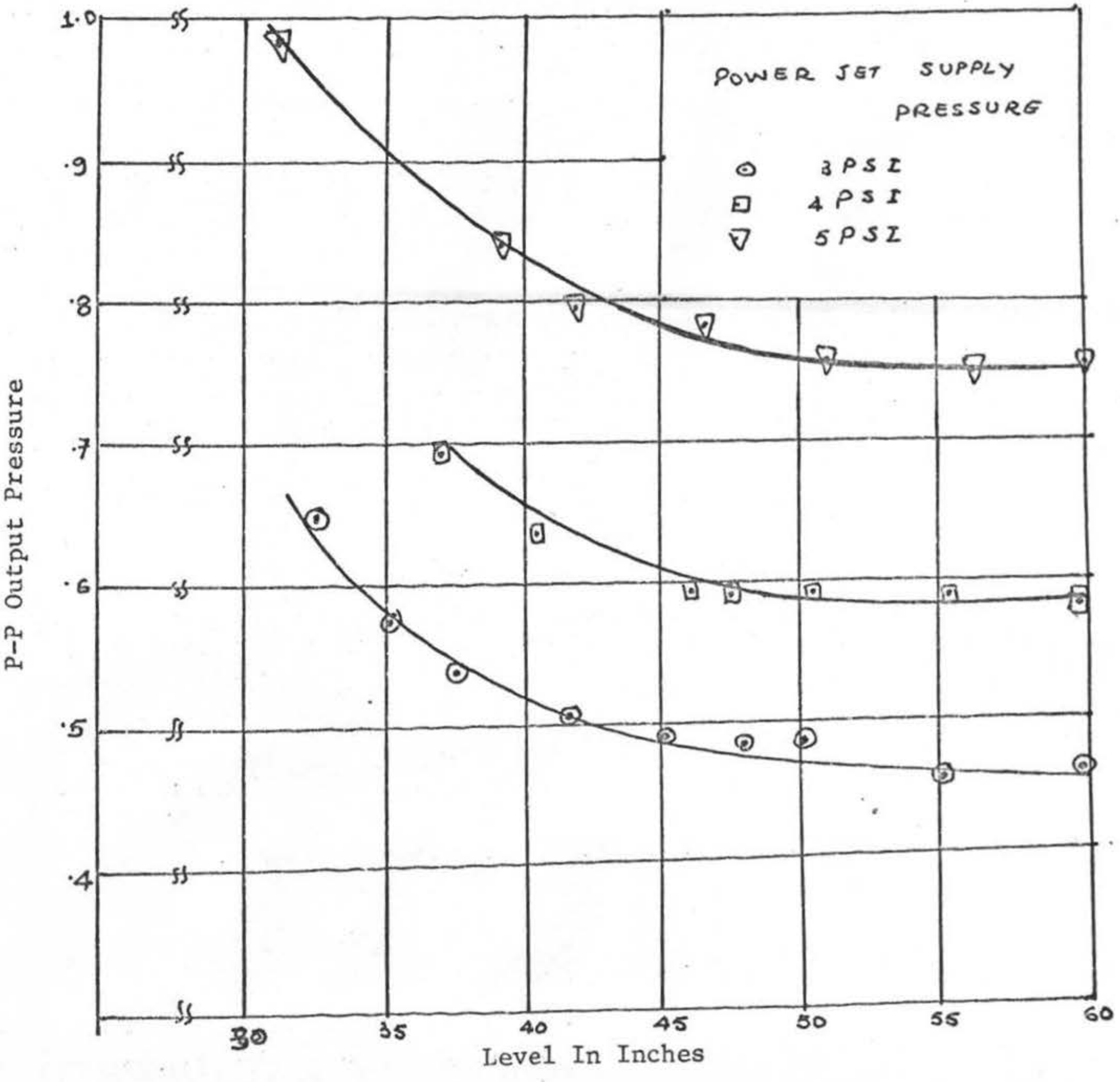


FIGURE 4.14

P-P OUTPUT PRESSURE OF SIGNAL AMPLIFIER AND ISOLATION STAGE AS A FUNCTION OF LIQUID LEVEL

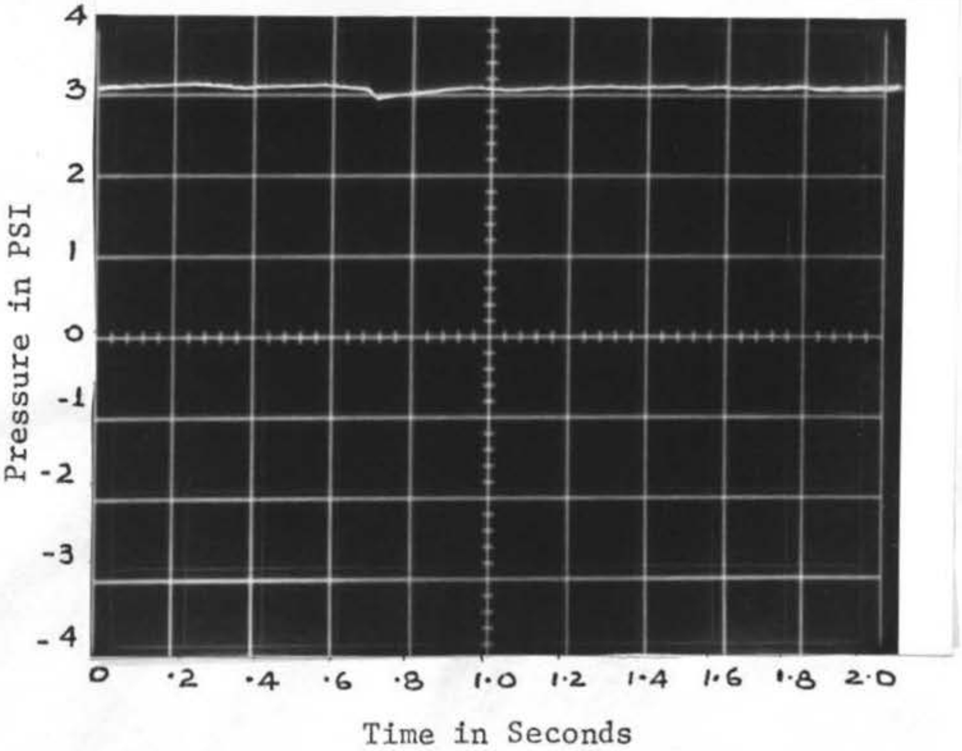


FIGURE 4.15

OUTPUT WAVE SHAPE AT FILTER

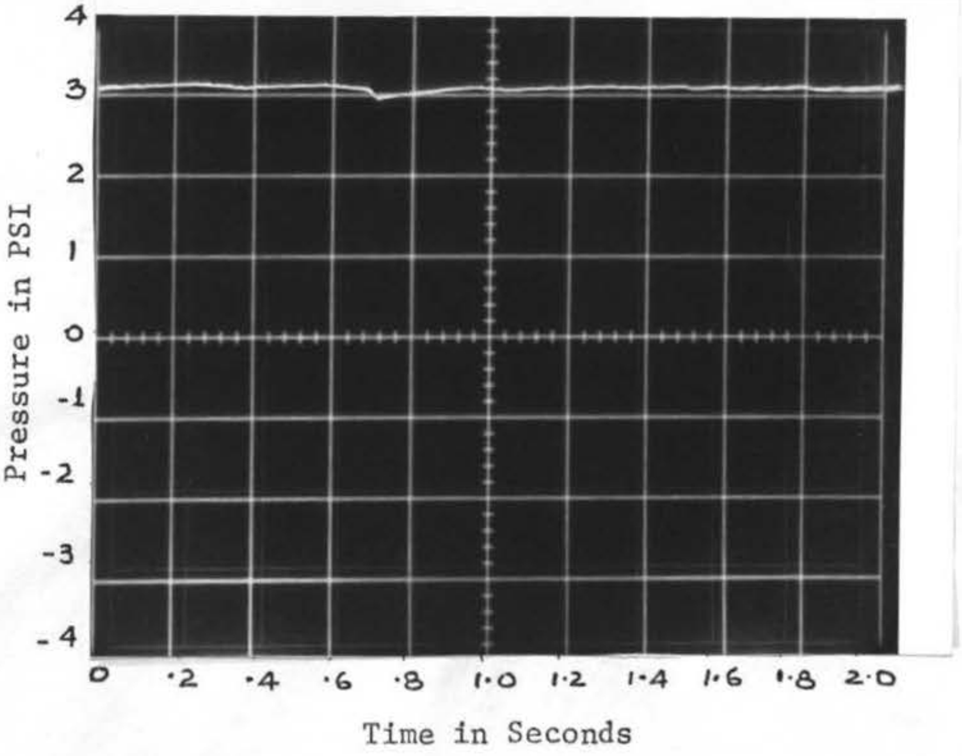


FIGURE 4.15

OUTPUT WAVE SHAPE AT FILTER

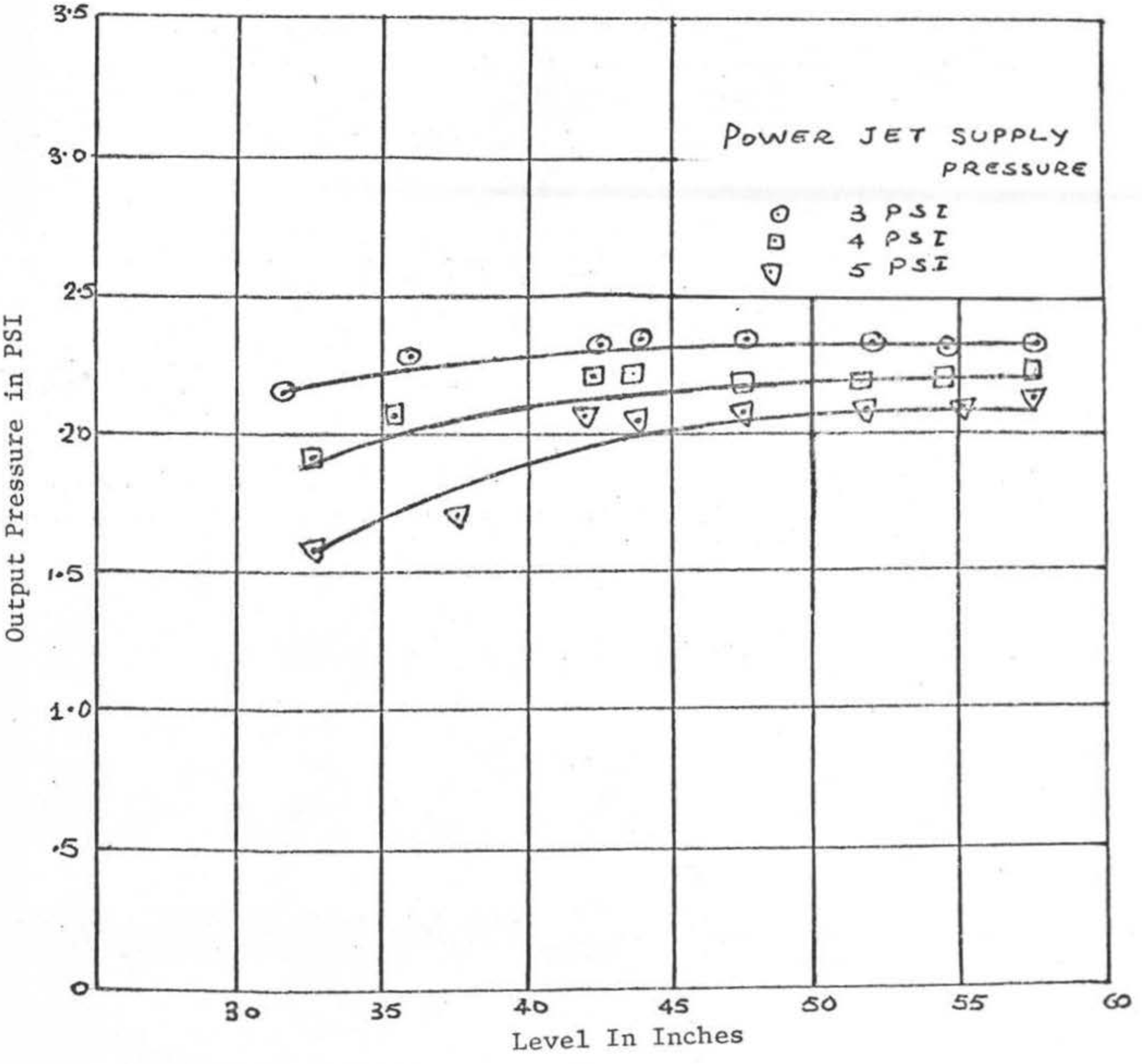


FIGURE 4.16

OUTPUT PRESSURE OF FILTER & RECTIFIER
AS A FUNCTION OF LIQUID LEVEL

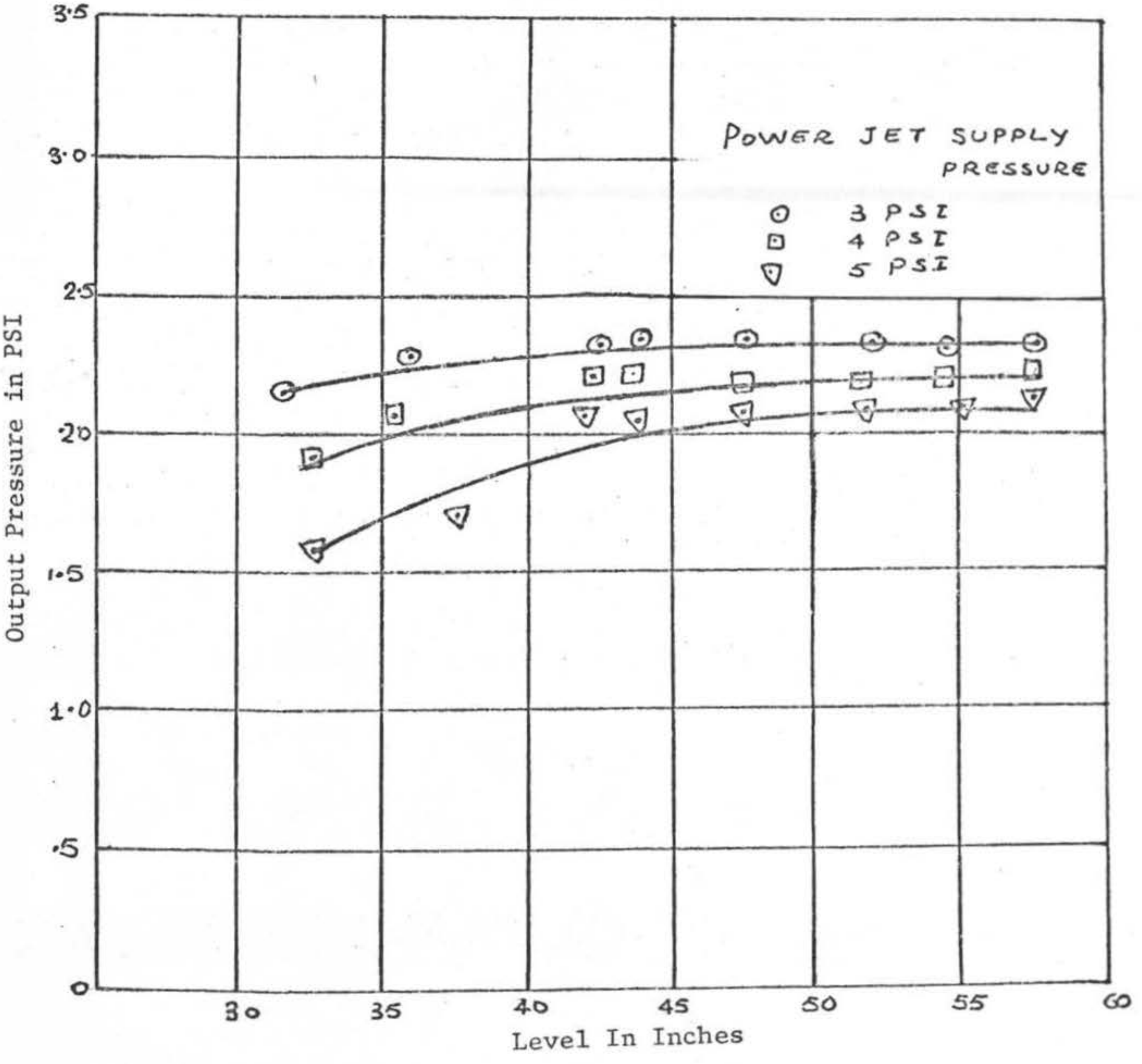


FIGURE 4.16

OUTPUT PRESSURE OF FILTER & RECTIFIER
AS A FUNCTION OF LIQUID LEVEL

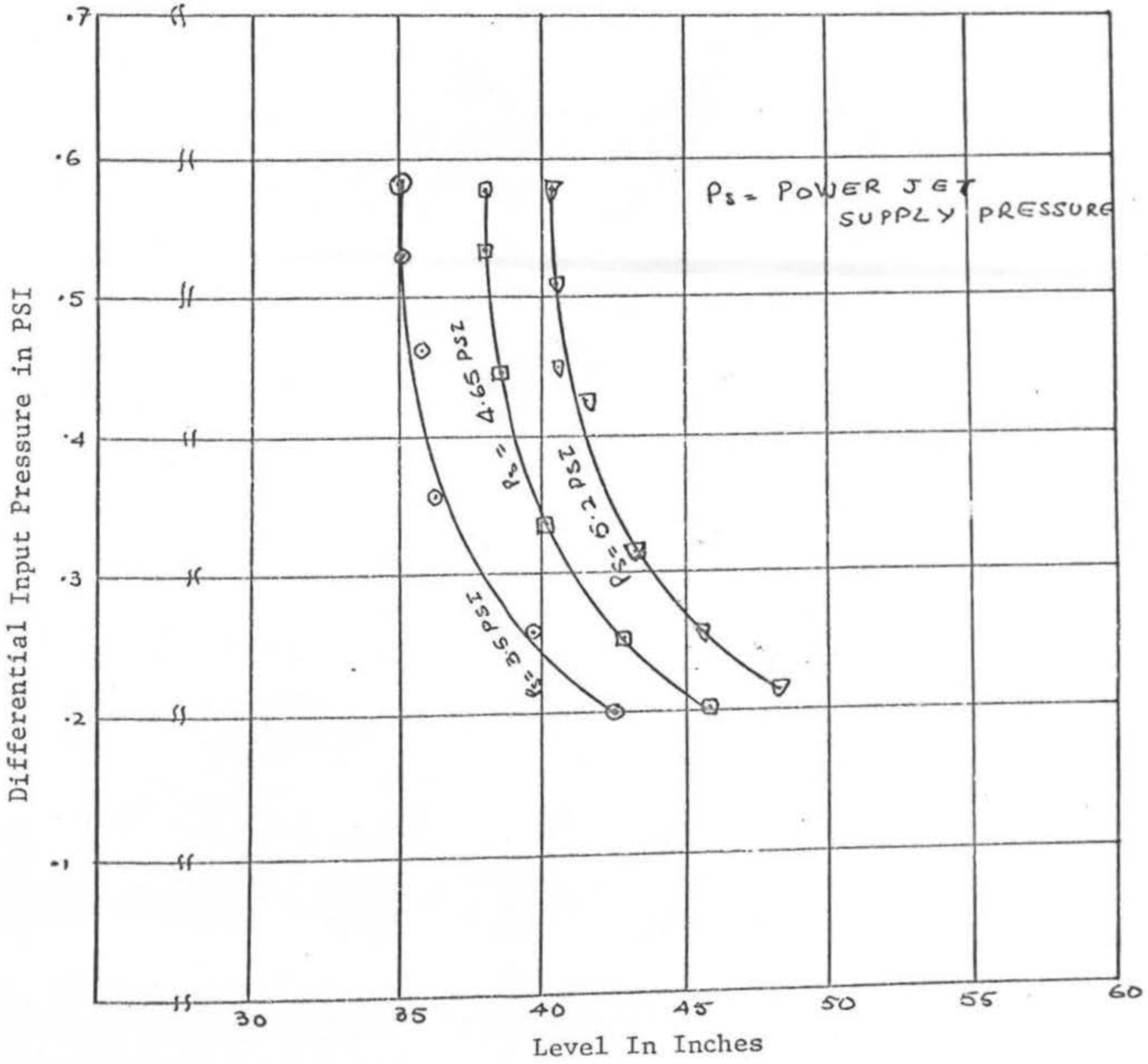


FIGURE 4.17

DIFFERENTIAL INPUT PRESSURE OF COMPARATOR AS A FUNCTION OF LIQUID LEVEL

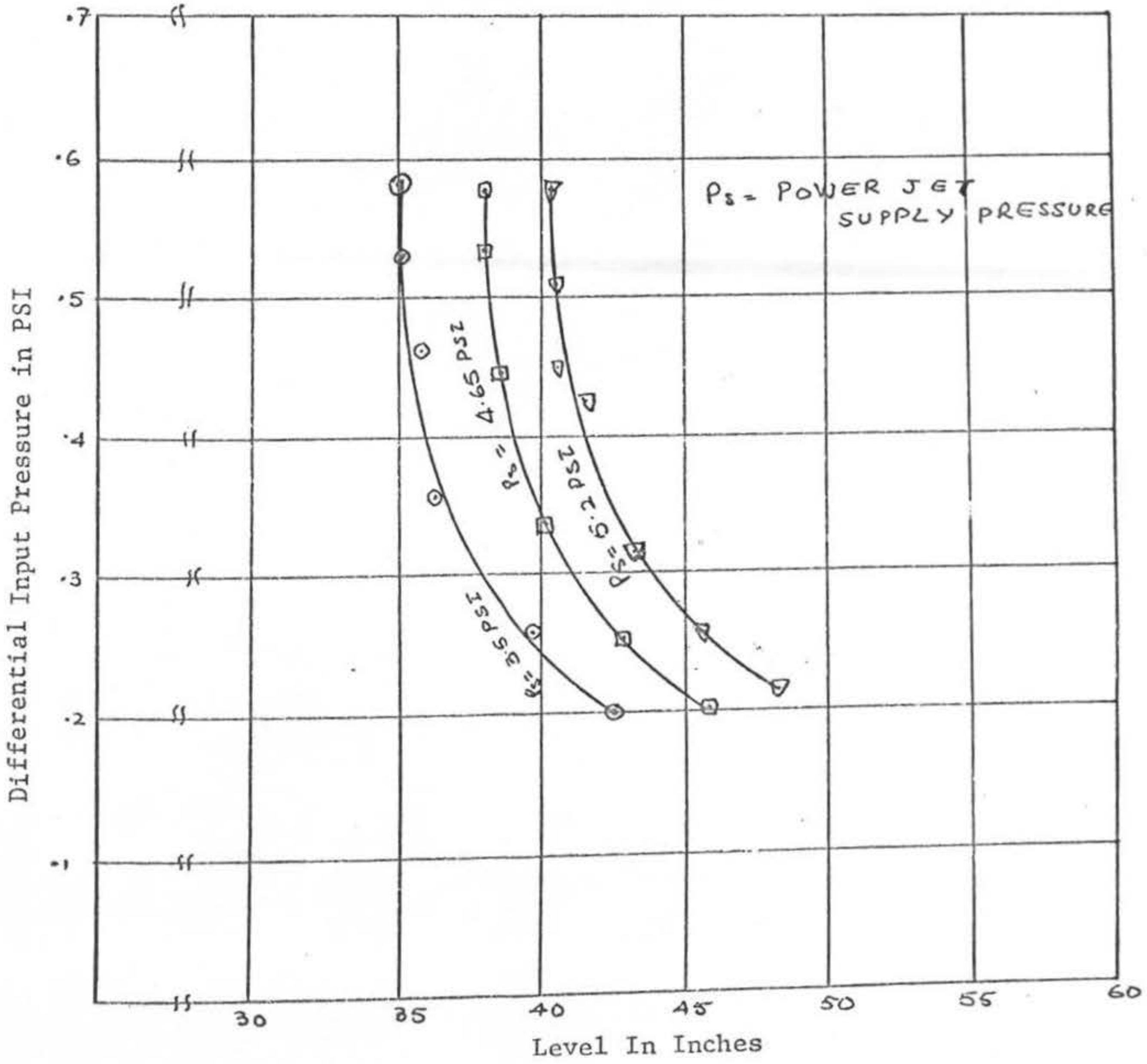


FIGURE 4.17

DIFFERENTIAL INPUT PRESSURE OF COMPARATOR AS
A FUNCTION OF LIQUID LEVEL

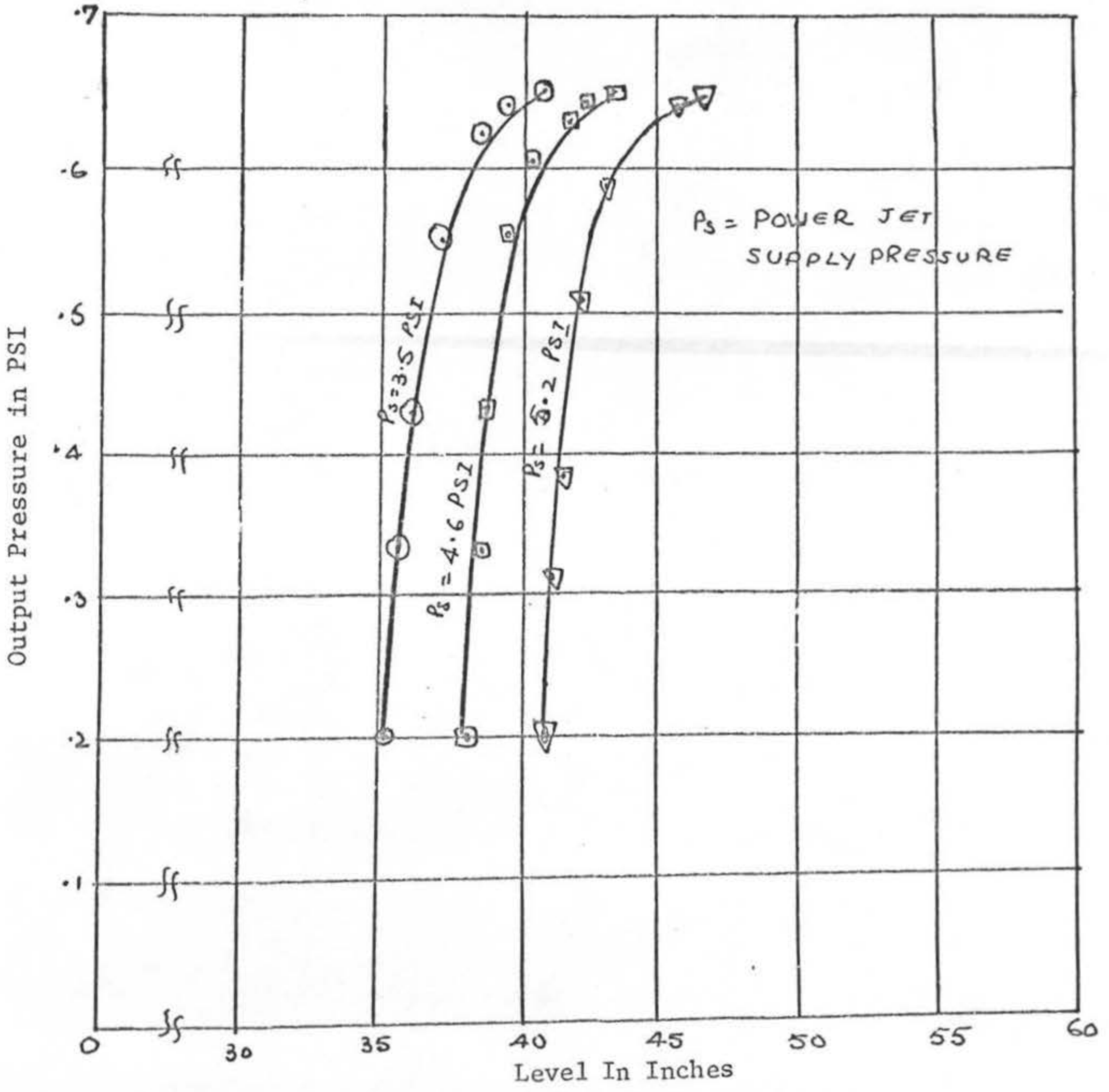


FIGURE 4.18

OUTPUT OF COMPARATOR AS A
FUNCTION OF LIQUID LEVEL

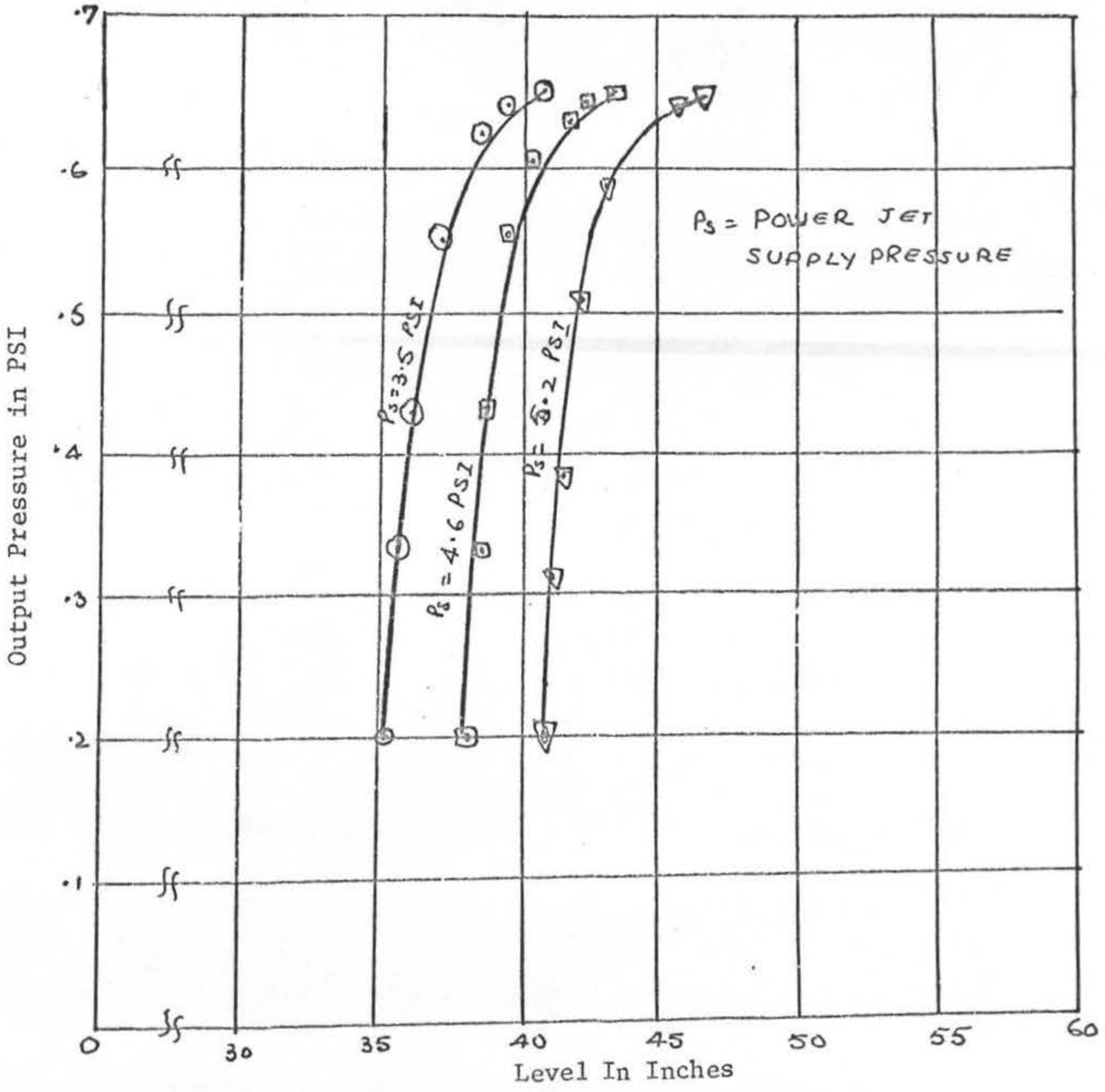


FIGURE 4.18

OUTPUT OF COMPARATOR AS A
FUNCTION OF LIQUID LEVEL

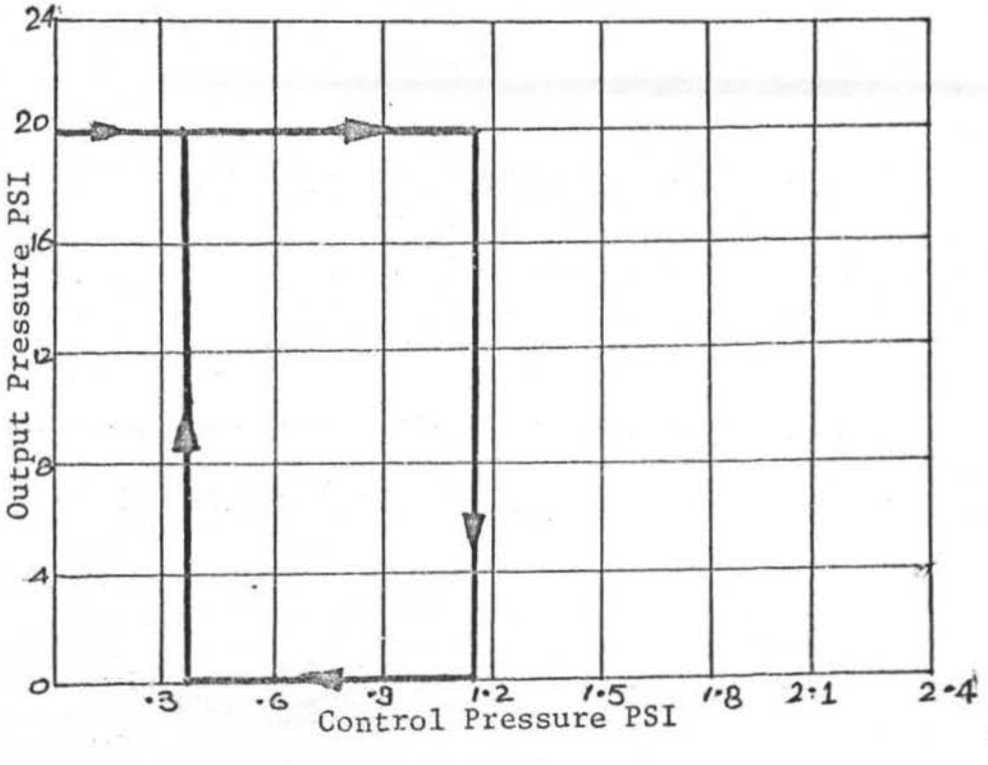


FIGURE 4.19

TYPICAL INPUT OUTPUT SWITCHING CURVE OF NOR GATE FLICR VALVE

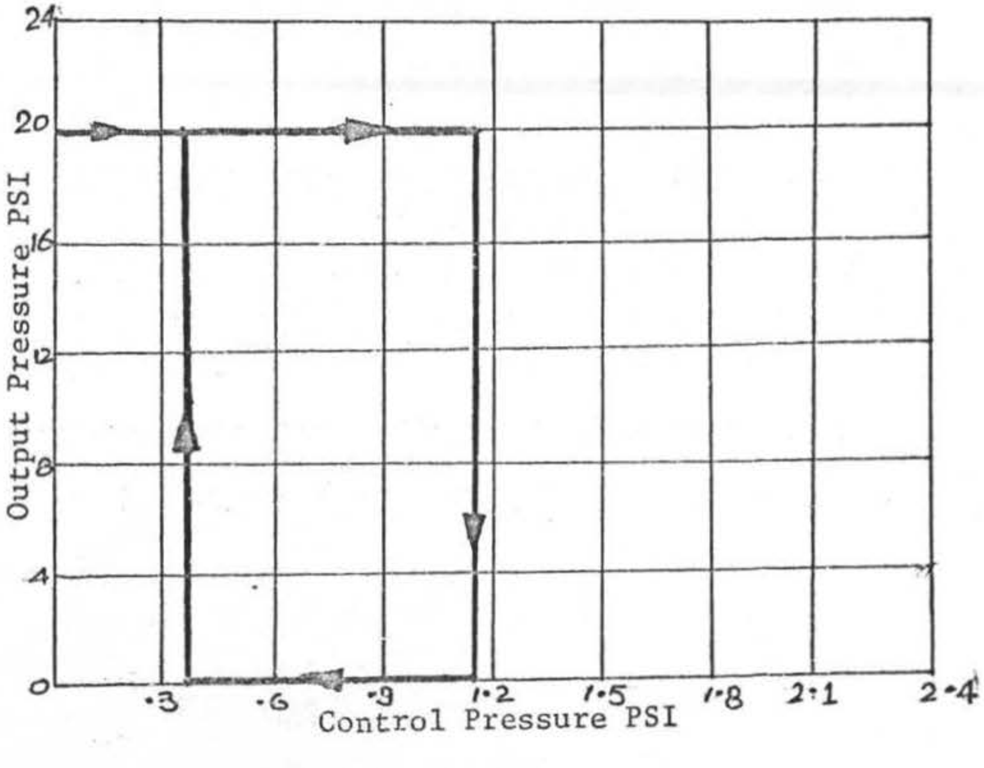


FIGURE 4.19

TYPICAL INPUT OUTPUT SWITCHING CURVE OF
NOR GATE FLICR VALVE

4.4.5 Comparator

The measurement of input and output of this stage was made at point f and g as shown in the schematic diagram of figure 4.7. Figure 4.17 and figure 4.18 show typical input and output signal values as a function of liquid level.

4.4.6 FLICR Valve

A typical input-output switching curve of FLICR valve is shown in figure 4.19.

5. GENERAL CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

The prime objective of this investigation was to develop an operational fluidic liquid level control system and to make a functional study of the fluidic elements used therein.

The result of the experimental test program indicated that original objectives of this investigation were accomplished. A "fluidic liquid level control system" was developed, which controlled the liquid level. Experimental data were gathered to describe the operational characteristics of the devices used in the system.

A few suggestions for further work are:

(a) To develop a proportional power amplification stage to replace the FLICR valve, thus allowing some form of proportional control.

(b) With the help of better instrumentation determine the transfer characteristics of each stage.

(c) Employ more precise passive elements in the fluidic circuits. Two desirable elements of this type would be resettable micrometer stem valves and better fluid capacitors.

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