PREDICTING THE PERIOD OF A FLUID OSCILLATOR

by

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PREFACE

Fluidics is a new technology and little has been published on design procedures and techniques. It is the purpose of this report to present a design procedure for determining the period of a fluid oscillator and to familiarize the reader with some of the basics of fluidics so that he may easily understand the technique.

Indebtedness is acknowledged to Dr. Ralph O. Turnquist for his suggestion of this area of study and his guidance in the preparation of this report; and to my wife, Loretta, for her typing of the manuscript.

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CHAPTER I

INTRODUCTION

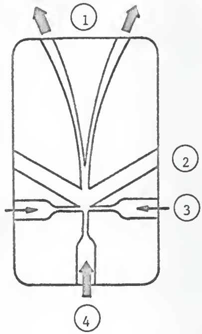
The disclosure in March, 1960 by the Diamond Ordnance Fuze Laboratories (now the Harry Diamond Laboratories) of the principles of the first fluid amplifiers launched many studies into a new technology which is now known as fluidics or fluerics (2). Since then fluidics has caught the attention of designers looking for better ways to implement logic and control schemes.

By utilizing the many properties of the two basic types of fluidic elements, one can assemble various logic and control devices such as a counter, inverter, summer, "and" gate, "or" gate, and the one of particular interest in this report: an oscillator.

The two basic types of fluidic elements from which the other devices arise are the proportional and the bistable. In a proportional element the input or supply flow is divided between the two output ports in proportion to the flow at the control ports (Figure 1a), i.e., small flows at the control ports controls the larger flow of the supply jet, hence amplification of the control signals.

A bistable element (Figure 1b) is quite different because the large flow enters the supply nozzle and is attached to one wall of the element causing the entire flow to exit at the corresponding output port. A control signal of sufficient magnitude and duration applied at the control port on the side to which the flow is attached will cause switching of the supply flow to the opposite side where the jet will attach to that wall. Control signals need not be maintained once the flow has switched.

1a. Proportional



1b. Bistable, Load Insensitive

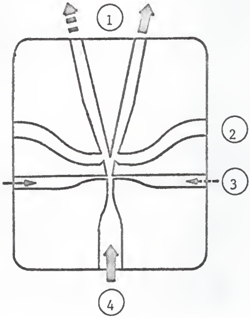


Figure 1, Silhouettes of Typical Fluidic Elements (6)

Legend
1. Output Ports
2. Bleed (both sides)
3. Control Port (both sides)
4. Supply Port

The bistable element will be of concern in this report because it becomes an oscillator when the left and right outputs are connected to their respective control ports by a path of low enough resistance to supply a switching flow.

The Bistable Element

The gains of a bistable element are taken to mean instantaneous gains. The control pressure on one side is slowly raised until switching occurs and, at this instant the pressure and flow are recorded at both the control ports and output ports. With these pressure and flow recordings the instantaneous gains can be described as follows (2):

$$\text{Pressure gain} \quad G_p = \frac{p_{lo} - p_{ro}}{p_{lc} - p_{rc}} ,$$

$$\text{Flow gain} \quad G_Q = \frac{Q_{lo} - Q_{ro}}{Q_{lc} - Q_{rc}} ,$$

$$\text{Power gain} \quad G_{pQ} = \frac{p_{lo}Q_{lo} - p_{ro}Q_{ro}}{p_{lc}Q_{lc} - p_{rc}Q_{rc}} .$$

Important geometric variables influencing the gains are length of attachment wall, area of controls, attachment wall offset, and attachment wall divergence angle (Figure 2). In general, an increase in gain means a decrease in stability, thus the gain can be increased to some maximum value and still have the element behave as a bistable one. Increase in attachment wall length, decrease in wall divergence angle, decrease in area of controls, and decrease in attachment wall offset, all result in increased stability and decreased gain (2). There are many subtle factors influencing gain, such as, roughness of input nozzle, shape and distance downstream of flow splitter, noise in the supply

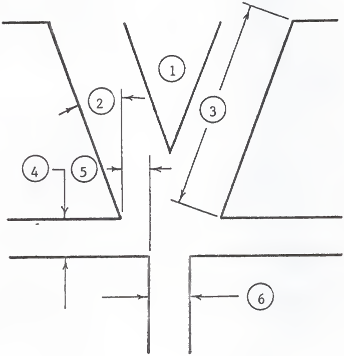


Figure 2, Important Geometric Variables of a Bistable Element

Legend

1. Flow Splitter
2. Attachment Wall Divergence Angle
3. Attachment Wall Length
4. Control Area
5. Attachment Wall Offset
6. Supply Nozzle Area

and control flows, and shape and position of the bleeds.

The main purpose of having bleeds on the side of a fluidic element is to isolate the input and output characteristics. Bleeds are very effective in impedance matching to a load, even to the point where the unit is decoupled from the load. A bistable fluidic element having such characteristics is considered in the analysis in this report.

CHAPTER II

CALCULATION OF THE PERIOD OF A FLUID OSCILLATOR

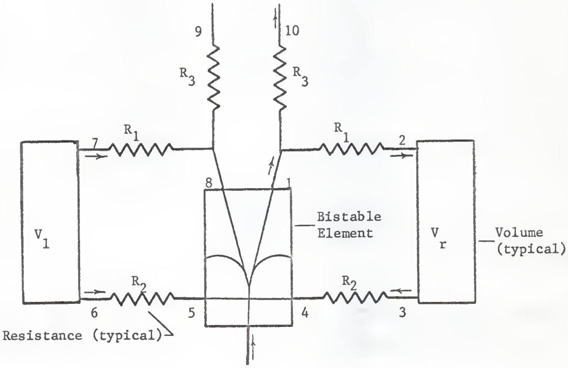
Assumptions

To construct an oscillator from a bistable fluidic element a portion of the output flow on each side is directed to the control ports on each respective side. The oscillator configuration shown in Figure 3 was assumed for this study. Each feedback path consists of two resistances and a capacitance in the form of a volume. A portion of the bistable element's output is directed out of the oscillator for use as a signal.

Oscillators are commonly used as timers or system clocks in control applications. The signals from the oscillator control the transfer of information within the control system. The period of oscillation of the assumed oscillator configuration may be varied by varying the size of the volume or value of the resistances. Effects of changing these variables can be determined using the procedure presented in the analysis.

Two conditions are necessary to make the bistable element oscillate: the signal flow must be small enough to maintain sufficient output pressure and the feedback resistance low enough to allow a switching flow. To accomplish this a sufficiently high resistance for R_3 can be selected and sufficiently low resistances for R_1 and R_2. The external resistances; R_1, R_2, and R_3 are assumed to have linear pressure drop versus volume flow characteristics. The flow is assumed incompressible except in the volumes in the feedback which are very large compared to line volumes. This last assumption is justified because of

Signal Output Flow



Supply Flow, Q_s

Note: At station 1, flow is Q_1, pressure is P_1; etc.

Figure 3, A Fluid Oscillator Consisting of a Bistable Element with Feedback the low operation pressures (3 p.s.i.g.) of fluidic elements. All connecting lines are assumed to have small resistances and capacity. Inertance in the system is neglected.

A bistable fluidic element can be designed such that it is load insensitive, so this will be the type considered in this report. The control port input impedance curves will be considered independent of the output load and for a given supply pressure the supply flow is considered constant.

Once the switching action is initiated in the bistable fluidic element a certain amount of time passes before the supply jet reaches and attaches to the opposite attachment wall. This time is considered very small compared to the time t_d that the supply flow remains attached to one side, and for this report is taken to be zero.

Other assumptions will be mentioned when they arise.

Characteristic Curves of the Bistable Element

For purposes of establishing control port input impedance curves the nomenclature shown in Figure 4 will be used (5).

The impedance of the device refers to the pressure-flow relationships of the control ports and of the output ports. Since the element under consideration is symmetrical the impedance for one control port (on the right side) will be considered and the other control port (on the left side) will be called a "bias port" but remembering that the same impedance curves apply to it. The following convention will be used: When the power jet is attached to the "control port" side, the amplifier is considered to be in a RESET condition; when the power jet is attached to the "bias-port" side, it is considered to be in a SET condition (5). Figure 5 shows the general appearance of the control port input impedance characteristic. Control port input impedance is deter-

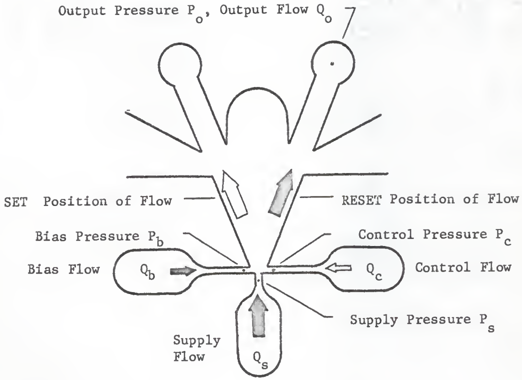


Figure 4, Nomenclature for Establishing Static Control-Port Input Impedance, Output Pressure-Flow, and Supply Pressure-Flow Characteristic Curves (5)

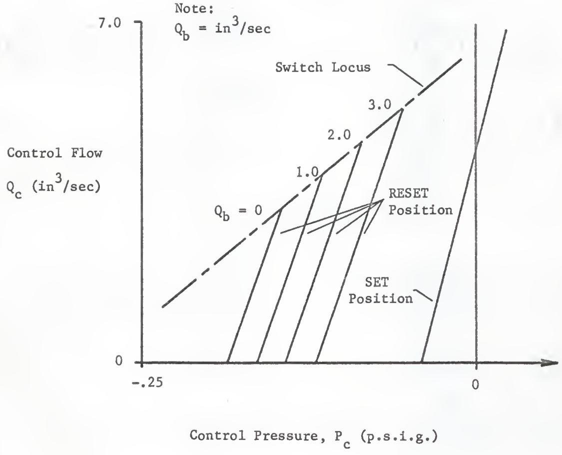


Figure 5, General Appearance of Static Control Port Input Impedance Curves (5) mined by measuring the control flow Q_c as a function of the control pressure P_c for a fixed value of bias port flow Q_b (See Figure 4). With the amplifier RESET, a family of curves results corresponding to various values of Q_b. Each curve terminates at a switch point - a point where the supply jet switches to the SET position. A line called the switch locus is drawn through all the switch points, defining values of Q_c, Q_b, and P_c for which the supply jet will switch. Note that when the amplifier is SET, Q_b has no appreciable effect on the control port input impedance; thus the curves are all coincident, except for the switch points. Although Figure 5 shows the general appearance of the control impedance data, one could expect the curves to take on a slightly parabolic shape in the actual case. For purposes of this study the control and bias impedance curves are assumed to be represented by the equations:

$$Q_c = C_1 P_c + C_2 Q_b + C_3 \quad ,$$

$$Q_b = C_4 P_b + C_5 \quad .$$

The constants involved may be determined from experimental data.

Output flow characteristics for a load insensitive bistable element may be represented by a single curve when plotted in a dimensionless form (Figure 6). This form is achieved by dividing the output pressure P_o by the supply pressure P_s, and the output flow Q_o by the supply flow Q_s. The bistable element is considered load insensitive for this report, but it might be mentioned that the main difference in the curve for a load sensitive element would be that the curve would be truncated where the element switches due to the heavy load on it. For this paper the output characteristics will be represented by:

$$\frac{Q_o}{Q_s} = C_6 \left[\frac{P_o}{P_s}\right] + C_7 \quad .$$

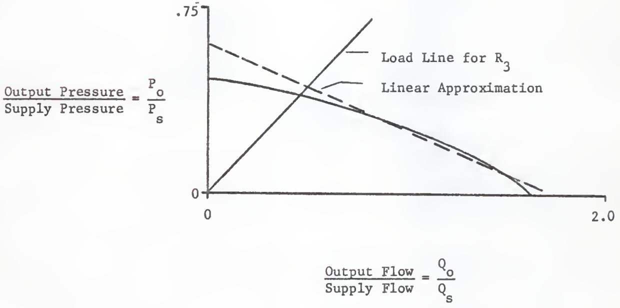


Figure 6, Typical Output Pressure-Flow Characteristic Curve (6)

This is a straight line approximation to the real curve which takes on a near parabolic shape as shown in Figure 6. Since the output resistance is always R_3 or less (Figure 3) and pressure changes small it is felt this simplification is justified. One can estimate where to draw the straight line approximation if R_3 is known and its load line is drawn on the output pressure-flow characteristic curve. The linear approximation is taken to fit, as closely as possible, the portion of the curve right of the load line (Figure 6).

The supply or power jet flow as it is sometimes called, takes on a curve that is very nearly parabolic (Figure 7), so it can be assumed to be represented by the equation:

$$P_s = C_7 \, Q_s^{\,2} \quad .$$

Supply pressures in fluidic systems are usually held constant and the loading of the element has a negligible effect on the supply flow, therefore, the above equation is very close to reality.

Analysis

Figure 3 shows the oscillator configuration considered in this analysis. The subscripted pressures and flows refer to stations on that figure and the flows are assumed positive in directions arbitrarily assigned. Assuming that the oscillator is oscillating at steady state conditions and that at time equal zero (t = 0) the element has just switched the supply or power flow to RESET position, a number of equations can be written for the oscillator. In writing these equations all pressure will be in p.s.i.g. except where noted.

It was established earlier that:

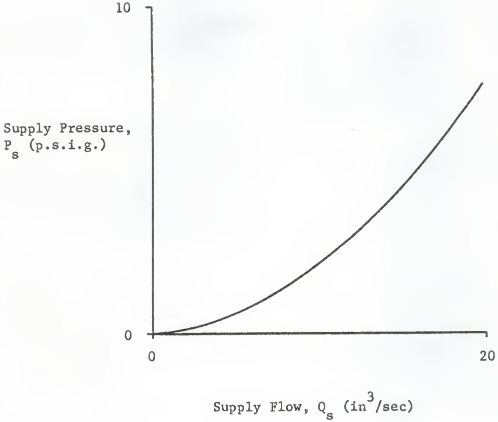


Figure 7, Typical Supply Pressure-Flow Characteristic Curve (6)

$$Q_c = C_1P_c + C_2Q_b + C_3 \quad ,$$

$$Q_b = C_4P_b + C_5 \quad .$$

Equating $Q_c = Q_4$, $Q_b = Q_5$, $P_c = P_4$, $P_b = P_5$, and then substituting into the above equations gives:

$$(1) \qquad Q_4 = C_1P_4 + C_2Q_5 + C_3 \quad ,$$

$$(2) \qquad Q_5 = C_4P_5 + C_5 \quad .$$

For the output of the element on the side of the flow the pressure-flow relationship is:

$$\frac{Q_o}{Q_s} = C_6\left[\frac{P_o}{P_s}\right] + C_7 \quad .$$

Equating $Q_o = Q_1$ and $P_o = P_1$ yields:

$$\frac{Q_1}{Q_s} = C_6\left[\frac{P_1}{P_s}\right] + C_7 \quad .$$

The pressure-flow relationships for the supply flow is:

$$Q_s = \sqrt{\frac{P_s}{C_8}} \quad .$$

Eliminating Q_s from the first equation by using the second:

$$\frac{Q_1}{\sqrt{\frac{P_s}{C_8}}} = C_6\left[\frac{P_1}{P_s}\right] + C_7 \quad .$$

Defining:

$$C_9 = \frac{C_6}{\sqrt{P_s C_8}} \quad ,$$

$$C_{10} = C_7 \sqrt{\frac{P_s}{C_8}} \quad .$$

Using these definitions:

$$(3) \qquad Q_1 = C_9 P_1 + C_{10} \quad .$$

It is assumed the output pressure on the left side of the element is zero p.s.i.g. and the atmospheric pressure P_{atm} = 14.7 p.s.i.a. = 0 p.s.i.g. From these assumptions:

$$P_8 = P_9 = P_{10} = 0 \text{ p.s.i.g.} = P_{atm} \quad .$$

The resistancesused in the oscillator are linear, therefore, equations relating the flows and pressures can be written:

$$(4) \qquad Q_2 = \frac{P_1 - P_2}{R_1} \quad ,$$

$$(5) \qquad Q_3 = \frac{P_3 - P_4}{R_2} \quad ,$$

$$(6) \qquad Q_6 = \frac{P_6 - P_5}{R_2} \quad ,$$

$$(7) \qquad Q_7 = \frac{P_7 - P_8}{R_1} = \frac{P_7}{R_1} \quad \text{since } P_8 = 0 \ ,$$

$$(8) \qquad Q_{10} = \frac{P_1 - P_{10}}{R_3} = \frac{P_1}{R_3} \quad \text{since } P_{10} = 0.$$

The volumes are considered capacitances only, therefore, it may be written:

$$P_2 + P_{atm} = P_3 + P_{atm} = P_{V_r} \quad \text{(p.s.i.a.)},$$

$$P_6 + P_a = P_7 + P_a = P_{V_1} \quad \text{(p.s.i.a.)},$$

$$\rho_2 = \rho_3 = \rho_{V_r} \quad ,$$

$$\rho_6 = \rho_7 = \rho_{V_1} \quad .$$

Some relationships used later may be observed from Figure 3:

(9) $Q_1 = Q_2 + Q_{10}$,

(10) $Q_3 = Q_4$,

(11) $Q_5 = Q_6$,

(12) $P_2 = P_3$,

(13) $P_6 = P_7$.

Applying the continuity equation for unsteady flow to the volumes:

$$\rho_2 Q_2 - \rho_3 Q_3 = \frac{\partial}{\partial t} (\rho_{V_r} V_r) = V_r \frac{d\rho_{V_r}}{dt} \quad ,$$

$$\rho_6 Q_6 - \rho_7 Q_7 = \frac{\partial}{\partial t} (\rho_{V_1} V_1) = V_1 \frac{d\rho_{V_1}}{dt} \quad .$$

Since the pressure in the volumes is oscillating and the magnitude of the pressure change is small, one may assume the process isentropic.

It is known for an isentropic process of a perfect gas:

$$\rho = \left[\frac{p\ (\text{p.s.i.a.})}{\text{constant}}\right]^{1/k} .$$

Taking the derivative with respect to time:

$$\frac{d\rho}{dt} = \frac{\rho}{kp}\frac{dP}{dt} .$$

Applying this to the unsteady flow continuity equation for the volumes:

$$\rho_2 Q_2 - \rho_3 Q_3 = \frac{V_r \rho_{V_r}}{kP_{V_r}} \frac{dP_{V_r}}{dt} ,$$

$$-\rho_6 Q_6 - \rho_7 Q_7 = \frac{V_1 \rho_{V_1}}{kP_{V_1}} \frac{dP_{V_1}}{dt} .$$

Canceling the density from all terms and substituting for P_{V_r}, P_{V_1}, $\frac{dP_{V_r}}{dt}$, and $\frac{dP_{V_1}}{dt}$:

$$Q_2 - Q_3 = \frac{V_r}{k\ (P_2 + P_{atm})} \frac{dP_2}{dt} ,$$

$$-Q_6 - Q_7 = \frac{V_1}{k\ (P_7 + P_{atm})} \frac{dP_7}{dt} .$$

An average pressure in both the left and right volume may be defined:

$$P_{ave}\ (\text{p.s.i.a.}) = \frac{P_{high} + P_{low}}{2} + P_{atm} .$$

Linearizing the continuity equations about the points $Q_2 - Q_3 = - Q_5 - Q_7 = 0$ and the average pressure P_{ave} give:

$$(14)\quad Q_2 - Q_3 = \frac{V_r}{kP_{ave}} \frac{dP_2}{dt} ,$$

$$(15)\quad -Q_6 - Q_7 = \frac{V_1}{kP_{ave}} \frac{dP_7}{dt} .$$

Equations (1) through (15) give a complete description of the pressure-flow characteristics of the oscillator when the flow is in a RESET condition. Solving these equations for P_7 gives the differential equation:

$$\frac{V_1}{kP_{ave}} \frac{dP_7}{dt} + \left[\frac{R_1C_4 + R_2C_4 + 1}{R_1(1 + R_2C_4)}\right] P_7 = \frac{-C_5}{1 + C_4R_2} .$$

Solving this differential equation yields:

$$(16)\quad P_7 = \frac{-R_1C_5}{R_1C_4 + R_2C_4 + 1}$$

$$+ \left[\frac{R_1\ (1 + R_2C_4)}{R_1C_4 + R_2C_4 + 1}\right] K_1 \ \exp - \left[\frac{R_1C_4 + R_2C_4 + 1}{R_1(1 + R_2C_4)}\right] \frac{kP_{ave}t}{V_1} .$$

At t = 0 the pressure in the left volume is at a maximum because the flow has just reached RESET position. If this maximum pressure is called P_{high}, then:

$$K_1 = \frac{(R_1C_4 + R_2C_4 + 1)\ P_{high} + R_1C_5}{R_1\ (1 + R_2C_4)} .$$

After finding P_7 and putting the constant of integration K_1 in terms of P_{high} and the system constants, Q_5 is solved:

$$(17)\quad Q_5 = \frac{C_5}{R_1C_4 + R_2C_4 + 1} + \ldots$$

$$\cdots \quad + \left[\frac{R_1C_4}{R_1C_4 + R_2C_4 + 1}\right] K_1 \quad \exp - \left[\frac{R_1C_4 + R_2C_4 + 1}{R_1\ (1 + R_2C_4)}\right] \frac{kP_{ave}t}{V_1} \quad .$$

The next step is to get a differential equation in terms of the variable P_2. Selecting equations from (1) through (15) that apply to the right side and using the result (17), the differential equation is found to be:

$$A \frac{dP_2}{dt} + B\ P_2 = C + D \exp - Ft \quad .$$

A, B, C, D, and F are constants defined as:

$$A = \frac{V_r}{kP_{ave}} \quad ,$$

$$B = \frac{C_9R_3 - 1}{R_1R_3C_9 - R_1 - R_3} + \frac{C_1}{1 + C_1R_2} \quad ,$$

$$C = \frac{C_{10}R_3}{R_3 - R_1R_3C_9 + R_1} - \frac{C_3}{1 + C_1R_2} + \frac{-C_2C_5}{(R_1C_4 + R_2C_4 + 1)\ (1 + C_1R_2)} \quad ,$$

$$D = -\frac{R_1C_2C_4K_1}{(1 + C_1R_2)\ (R_1C_4 + R_2C_4 + 1)} \quad ,$$

$$F = \left[\frac{R_1C_4 + R_2C_4 + 1}{R_1\ (1 + R_2C_4)}\right] \frac{kP_{ave}}{V_1} \quad .$$

Solving the differential equation for P_2 yields:

$$(18) \quad P_2 = K_2 \exp\frac{Bt}{A} + \frac{D}{B - AF} \exp - Ft + \frac{C}{B} \quad .$$

At $t = 0$ the pressure in the right volume is a minimum because the flow has just switched to that side and the pressure is starting to rise. If this minimum pressure is called P_{low}, then the constant of integration K_2 is:

$$K_2 = P_{low} - \frac{C}{B} + \frac{D}{AF - B} \quad .$$

Using the result of finding P_2 and Q_5, Q_4 is solved:

$$(19) \qquad Q_4 = \frac{C_1P_2 + C_2Q_5 + C_3}{1 + C_1R_2} \quad .$$

Equations (17) and (19) give Q_5 and Q_4, respectively, as functions of time, P_{high}, and P_{low}. Now the time from t = 0 for the element to switch to the right side may be found. Since this is an iterative procedure an algebraic result won't be indicated, but rather a method for finding the switching time will be indicated.

Figure 8a, shows a plot of the switch locus taken from the static control port input impedance curves (Figure 5) but plotted with the arguments Q_c and Q_b. It is noted the area above this curve contains no operating point for the bistable element. This curve can be represented mathematically and in the case under consideration is a straight line.

Numerical values may be selected for P_{high} and P_{low} and substituted in equations (17) and (19). Figure 8b shows generally how a plot of Q_4 and Q_5 would look. If the time parameter is eliminated between the two equations, (17) and (19), the resulting curve would have the appearance of Figure 8c. It may be recalled that Q_4 corresponds to Q_c and Q_5 corresponds to Q_b, therefore, when the curve Q_4 versus Q_5 (Figure 8c) is superimposed on the Q_c versus Q_b curve (Figure 8a) the intersection is the switch point for the element (Figure 8d). The time t_d may then be calculated from equation (17) or (19). To check whether the right values for P_{high} and P_{low} were assumed the necessary conditions is that $P_7 = P_{low}$ and $P_2 = P_{high}$ at $t = t_d$, that is, one volume must go from the

8a. Switch Locus Curve From Figure 5

8b. Calculated Flows Assuming a P_{high} and P_{low}

8c. Curve Obtained by Eliminating Time From Two Curves in Figure 8b

8d. Superimposition of Figure 8c on 8a

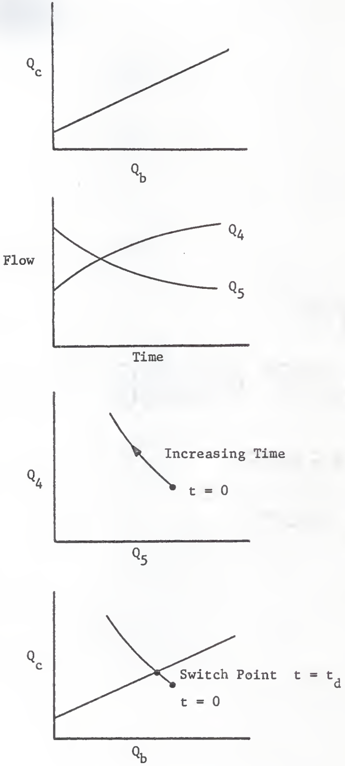


Figure 8, Illustration of Some Steps Used in Calculating the Oscillation Period low pressure to the high pressure in the same amount of time the other volume discharges from high to low.

The period of oscillation is assumed to be twice the time the supply flow is attached to one side, i.e.:

$$T = 2\,t_d\,.$$

The frequency is hence known to be 1/T.

CHAPTER III

SUMMARY AND CONCLUSIONS

It has been shown how a bistable fluidic element can be converted into an oscillator. The curves characterizing a particular type of bistable element have been considered. These curves represent the static control port impedance, the output pressure-flow characteristics, and the supply pressure-flow characteristic. With the use of these curves a procedure for finding the oscillation period for the assumed oscillator configuration may be summarized as follows:

1. Represent the static control port impedance, the output pressure-flow, and the supply pressure-flow curves by linear mathematical equations.
2. Assume flow has just switched to one side and write the unsteady pressure-flow equations for each component used to convert the bistable element into an oscillator.
3. Solve the derived equations for the pressure in the volume on the "bias" or left side. Assume this pressure is a maximum at $t = 0$ and call this maximum P_{high}.
4. Solve the equations for the bias flow as a function of time and P_{high}.
5. Using the results of the preceding step find the pressure in the volume on the "control" or right side as a function of time and P_{high}. Assume at $t = 0$ this pressure is at a minimum and call this pressure P_{low}.
6. Find the control flow as a function of time, P_{high}, and P_{low}.
7. Using the static control port impedance curve define the switch locus

for RESET to SET switching by an equation which has the variables of bias flow and control flow.

8. Eliminate the parameter time from the oscillator control flow and bias flow equations.

9. Select a numerical value for P_{high} and P_{low} and substitute into the control flow versus bias flow equation.

10. Find the intersection of the switch locus and the control flow versus bias flow equations.

11. Taking either the value of bias flow or control flow at the switch point calculate the time t_d from the proper equation derived in step 4 or step 6.

12. Check to see if the pressure in the volume on the control side equal P_{high} at $t = t_d$ and if the pressure in the volume on the bias side equal P_{low} at $t = t_d$. If this is true go to next step, if not return to step 9, assume new value for P_{high} and P_{low}, and repeat the procedure.

13. The period of oscillation for one complete cycle is known to be $2t_d$ if the time necessary for the flow to travel from one attachment wall to the other is very small (3).

It would be desirable to do the iterative portion of this procedure by a numerical method. A solution of the required accuracy could then be found with less manual computation. Although linear forms of the bistable element characteristics were used in this report, one might wish to fit nonlinear equations to the characteristic curves. The pressure-flow equation for each component would be written in a similar manner, but the resulting differential equations would necessitate numerical solutions.

Extension of this work could include experimental work to enable one to refine the analysis so the solution would conform closely with reality. Such effects as inertance, sonic delay, and distributed parameters in the feedback paths could be taken into account. Bistable elements with impedance characteristics interdependent (i.e. the output varies the static control port input impedance and vice versa) could be considered. To consider some or all of these effects would be difficult, but it is hoped that this report will serve as a starting point for more exact analyses.

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APPENDIX

NOMENCLATURE

Symbol	Description	Units
A,B,...F	Constants composed of more than one system constant	---
$C_1, C_2, C_3 \ldots$	Constants of bistable element derived or found experimentally from characteristic curves	---
G_p	Instantaneous pressure gain	dimensionless
G_{PQ}	Instantaneous power gain	dimensionless
G_Q	Instantaneous flow gain	dimensionless
K_1, K_2	Constants of integration	---
k	Ratio of specific heats, C_p/C_v	dimensionless
P_{atm}	Atmospheric pressure	p.s.i.a.
P_{ave}	Average pressure in right and left volumes	p.s.i.a.
P_b	Bias pressure	p.s.i.g.
P_c	Control pressure	p.s.i.g.
P_{high}	Highest pressure occurring in volumes	p.s.i.g.
P_{low}	Lowest pressure occurring in right and left volumes	p.s.i.g.
P_o	Output pressure	p.s.i.g.
P_s	Supply pressure	p.s.i.g.
P_{V_l}	Pressure in left volume	p.s.i.a.
P_{V_r}	Pressure in right volume	p.s.i.a.

Symbol	Description	Units
$P_1, P_2, P_3 \ldots$	Pressure at stations 1,2,3,... respectively on Figure 3	p.s.i.g.
p	Absolute pressure	p.s.i.a.
P_{lc}	Pressure at left control port	p.s.i.g.
P_{lo}	Pressure at left output port	p.s.i.g.
P_{rc}	Pressure at right control port	p.s.i.g.
P_{ro}	Pressure at right output port	p.s.i.g.
Q_b	Flow at bias control port opposite attached supply flow	in^3/sec
Q_c	Flow at control port on the side of the attached supply flow	in^3/sec
Q_{lc}	Flow at left control port	in^3/sec
Q_{lo}	Flow at left output port	in^3/sec
Q_o	Output flow	in^3/sec
Q_{rc}	Flow at right control port	in^3/sec
Q_{ro}	Flow at right output port	in^3/sec
Q_s	Supply	in^3/sec
$Q_1, Q_2, Q_3, \ldots$	Flows at stations 1,2,3,... respectively on Figure 3	in^3/sec
R_1, R_2, R_3	Linear fluid resistances	$lb_f\text{-}sec/in^5$
ρ	Density	$lb_f\text{-}sec^2/in^4$
ρV_l	Density in left volume	$lb_f\text{-}sec^2/in^4$
ρ_{V_r}	Density in right volume	$lb_f\text{-}sec^2/in^4$

Symbol	Description	Units
$\rho_2, \rho_3, \ldots$	Density at stations 2,3... respectively on Figure 3	$lb_f\text{-}sec^2/in^4$
T	Period of the Oscillator	sec
t	Time	sec
t_d	Time that supply flow is attached to one side of bistable element	sec
V_l	Left volume	in^3
V_r	Right volume	in^3

PREDICTING THE PERIOD OF A FLUID OSCILLATOR

by

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AN ABSTRACT OF A MASTER'S REPORT

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Department of Mechanical Engineering

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Title of Study: PREDICTING THE PERIOD OF A FLUID OSCILLATOR

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Scope and Method of Study: The two basic types of fluidic elements, proportional and bistable, are described and their operation briefly discussed. The bistable element is then discussed in more detail mentioning how some of the more important geometric variables affect stability. After this introduction to fluidic elements it is shown how an oscillator may be constructed by providing a feedback path for the bistable fluidic element. The feedback configuration assumed for this report is of a lumped resistance-capacitance type. An analysis is carried out on this particular type of oscillator to determine the oscillation period.

Findings and Conclusions: In order to determine the period of the oscillator certain characteristic curves for the bistable element are called to attention. These curves are: the static control port impedance curve, the output pressure-flow curve, and the supply pressure-flow curve. These are represented by linear mathematical models. The unsteady pressure-flow equation for each component of the feedback path is written, developing a system of equations. The equations are then solved for the bias and control flow and with this information the oscillation period is found. To do this one must assume certain initial conditions and adjust the assumptions until conditions a half cycle later conform to the proper values.

A summary is included which outlines the method proposed for determining the oscillation period. Suggestions are given for refining the method in order to get a more exact solution.

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