The Use of Analog Computers in Teaching Process Control

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The use of indirect electronic analog computers is steadily increasing in both industry and engineering education. Such computers are used primarily for the solution of linear and non-linear ordinary and partial differential equations, and for the simulation of systems. An analog computer facility for educational purposes which is reasonably accurate and large enough to handle linear problems of moderate complexity can be obtained for $2,000. Increasingly accurate equipment with greater capacity and specialized auxiliary components requires a correspondingly larger investment.

The minimum equipment requirements include an analog computer with the necessary computing resistors and capacitors and some sort of readout device. Some of the manufacturers of small analog computers and computer components are Applied Dynamics, Inc., 2275 Platt Road, Ann Arbor, Michigan; Donner Scientific Division, Systron-Donner Corp., 888 Galindo St., Concord, California; Electronic Associates, Inc., Long Branch, N. J.; The Heath Company, Benton Harbor, Michigan; George A. Philbrick Researches, Inc., 127 Clarendon St., Boston 16, Massachusetts.

The necessary computing resistors and capacitors (if not built into the computer) may be made up by the user or they may be purchased ready to use. The resistors may be made up by attaching precision resistors having the desired resistance (one percent tolerance or better) to General Radio double plugs. Computing capacitors may be similarly made up, but it is difficult to obtain capacitors which have exactly the capacitance desired, so that trimming is almost always necessary. Further, condensors of radio quality do not have high enough leekage resistances for accurate computation purposes. Computing resistors and capacitors may be purchased from several sources, such as Donner Scientific Division of Systron-Donner Corp. and Southern Electronics Corp., 239 West Orange Grove Ave., Burbank, California. The precision capacitors are expensive.

The readout device may be an oscilloscope or some sort of recorder. A recorder is recommended for educational use, so that the student may obtain a permanent record of the solution. Recorders tested here which are quite acceptable for analog computer readout include the Brush Mark II, the Offner Type 542 and Type RP Dynographs, the Sanborn Model 1525460, the Varian G-11A, and the EAI Model 1100E Variplotter (an X-Y recorder). The July 1962 issue of Instruments and Control Systems contains a survey of 1,000 recorders.

A group of laboratory experiments follows which were developed at Illinois Tech for the process control laboratory course given in the Chemical Engineering curriculum. These experiments introduce the student to the use of the computer gradually. There are eight experiments, and a two- or three-man team of students should be able to work all of them in nine three-hour laboratory periods without too much supervision. The experiments are written for the 15-amplifier Heath Group C Computer ($945), although any computer with nine amplifiers would suffice, with the exception of the Heath Model EC-1 Computer, which can be used for only seven of the experiments.

The recorder used here was the Offner Type 542 Dynograph ($1,145). This is a two-channel, galvanometer-type recorder which is also used for a great variety of other applications around the department. If money is tight, excellent results should be obrained with a single-pen, potentiometer-type recorder such as the Varian G-11A recorder (base price with Type B-1 Input Chassis is $540). The range of applications of such recorders is not as broad as that of the galvanometer-type recorders, since the potentiometric recorders cannot be used for signals having frequencies above one cycle per second. However, the equations can be time-scaled so that good results can be obtained with these recorders.

The computing capacitor requirements for these experiments are: one 0.01 ufd, one 0.1 ufd, and four 1.0 ufd capacitors. Resistors required are: two 0.1 megohm, one 0.2 megohm, one 0.4 megohm, four 0.5 megohm, eight 1.0 megohm, two 2.0 megohm, one 5.0 megohm, and one 10.0 megohm resistors (one percent tolerance or better).

In addition to the equipment already specified, the second part of Experiment Two requires a diode function generator (DFG) for the generation of the valve characteristic curve. There are a number of diode function generators on the market, but by far the least expensive is the Model ES-600 (kit) manufactured by the Heath Company ($72.95). This DFG provides only ten straight line segments, and it is understandably less accurate than a DFG costing $450, but it is adequate for instructional purposes and the price is attractive.

These experiments have worked out very well; the students have learned how to solve relatively simple process control problems on the computer. There have, in addition, been some bonus results which were not anticipated when the program was begun. Students tend to get rather disconcertingly enthusiastic about the computer after they begin to understand how to operate it, and they leave the laboratory only after repeated threats of bodily harm. They concoct their own problems and return to the laboratory on their own time. Further, they experience a renewed interest and a more mature understanding for differential equations, and the electrical engineering department reports that our students are badgering their staff to give them more electronics. This awakening of intellectual curiosity in nearly all the students who have worked with the computer has been a delightful, if somewhat wearing, experience for the staff members who teach this laboratory.

Building an analog computer laboratory poses the problem of how many students can be handled at one time. A team should consist of no more than three students, and two is better. A class of twelve students may thus imply four to six computers, and this becomes an expensive operation. The Donner Model 3500 and Model 3400 computers have removable problem boards, as do many of the larger computers (Applied Dynamics, Electronic Associates, Berkeley Division of Beckman Instruments). Also, Prof. James O. Osburn of the Chemical Engineering Department, State University of Iowa, Iowa City, has devised a plugboard for use with the Heath Group C computer. This plugboard has connections to four of the computer amplifiers, three of the initial condition power supplies, and a 100-volt and a -100-volt supply. Each plugboard also contains four integral coefficient potentiometers. A plugboard costs about $15.50 to make. A team of students can patch up a problem on their own plugboard and when wiring is completed the board is attached to the computer and the solution can be run off in a short time. In this way one computer can serve a class of perhaps ten to twelve students. Osburn's plugboard is described in the Journal of Chemical Education, 38, 492 (1961), and further details may be obtained direct from Dr. Osburn.

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EXPERIMENT ONE

INTRODUCTION TO THE HEATH GROUP C ELECTRONIC ANALOG COMPUTER

This experiment is intended to familiarize the student with the basic techniques of analog computation on the Heath Group C electronic analog computer. After the various mathematical operations which the computer can perform have been studied, they can be utilized to solve a classical rpoblem in physics, such as the body falling freely in a vacuum from a position of rest.

EXPERIMENT TWO

FUNCTION GENERATION

PART I: Use of the Computer to Generate Functions

An analog computer can be used to generate a variety of functions for use as problem inputs.

PART II: Use of the Diode Function Generator

EXPERIMENT THREE

COMPUTER SOLUTION OF LINEAR SECOND-ORDER DIFFERENTIAL EQUATIONS

Ordinary linear differential equations occur commonly in science and engineering. The examples used here will be limited to differential equations with constant coefficients, so that function multipliers will not be required. A classical problem in mechanics is the mass-spring-damper system, in which a mass is supported by a spring and a dashpot.

EXPERIMENT FOUR

FREQUENCY RESPONSE DIAGRAM FOR A MECHANICAL SYSTEM

In the previous experiment, the analogy between the mass-spring-damper system and the time-scaled R L C circuit was developed, and the transient response of these systems was studied for the case with no forcing function applied. In this experiment, the mechanical system will be forced to oscillate by impressing a sinusoidal forcing function on the mass. The system will be subjected to forcing functions of different frequencies, and a frequency response diagram will be constructed for the system.

EXPERIMENT FIVE

COMPUTER SIMULATION OF SYSTEM COMPONENTS

One of the most important applications of analog computers is the simulation of physical systems. The computer is programmed to solve the differential equation or set of equations which represent the system. When this has been done, it turns out that certain portions of the computer circuit represent identifiable parts of the physical system under study, so that it becomes natural to think of these circuit components as though they were the corresponding components of the physical system. This will be illustrated in the several parts of this experiment.

PART I: Single-Tank Liquid Flow Process

This is illustrated by a liquid flow process in which liquid flows into a tank at a rate of $F_o(t)$ cubic feet per minute, and flows out at a rate of $F_1(t)$ cubic feet per minute. The capacity of the tank is C_1 cubic feet of liquid per foot of depth, which is numerically equal to the cross-sectional area of the tank in square feet. To keep the problem simple, assume that the cross-sectional area of the tank is uniform from top to bottom, as would be the case with a vertical cylinder or a rectangular tank. The head of liquid in the tank is h_1 feet. The

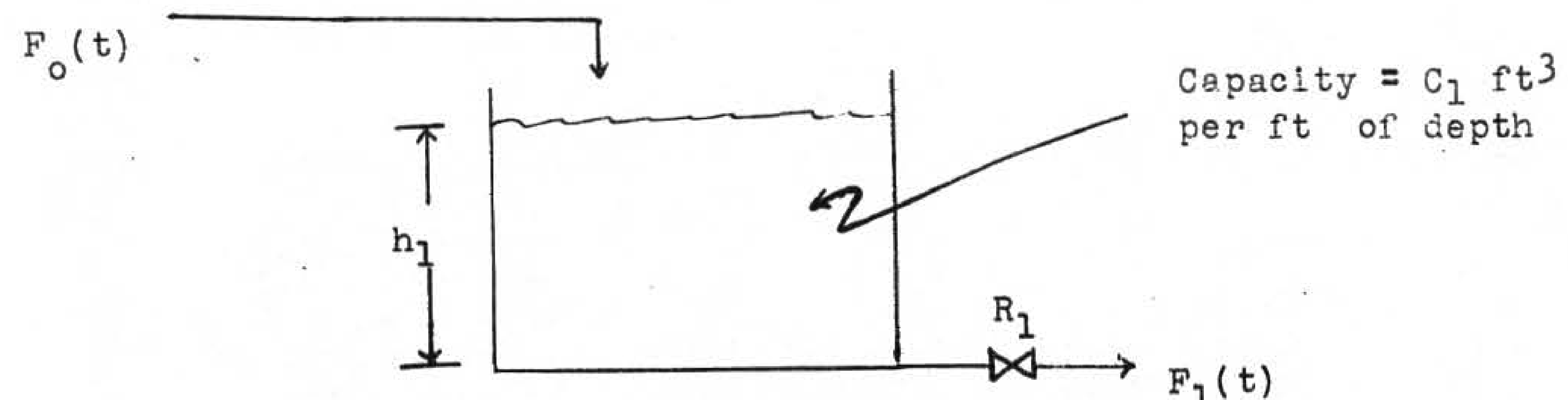

Figure 5-1: Single-Tank Liquid Flow Process

liquid flowing out of the tank suffers head losses due to contraction and expansion, and friction in the piping and fittings. All of these factors are lumped into one equivalent resistance term which is designated R_1 (foot) (minutes) per cubic foot of flowing liquid. This equivalent resistance is equal to the slope of the head versus flow curve in the region of interest. This curve is not normally linear, but it may be approximately linear in the region of interest. Again in the interests of keeping the problem simple, the curve which relates head to flow F_1 will be assumed to be a straight line.

PART II: A Second Single-Tank Liquid Process

A second tank will be simulated, the new tank being similar to the first. The process time constant will be different, since the second tank will have a larger cross-sectional area (capacity) and a somewhat different equivalent resistance. As before, capacity and resistance will be assumed constant. The flow into Tank 2 will be $F_1(t)$ cubic feet per minute, and the flow out will be $F_2(t)$ cubic feet per minute.

PART III: Two-Tank Liquid Flow Process

Tank 1 is the tank of Part I and Tank 2 is the tank of Part II. It is desired to know what the transient response of this system will be if a step input is applied suddenly increasing flow $F_o(t)$. When the transient response curve has been obtained, it will be used to calculate the time constants of the process.

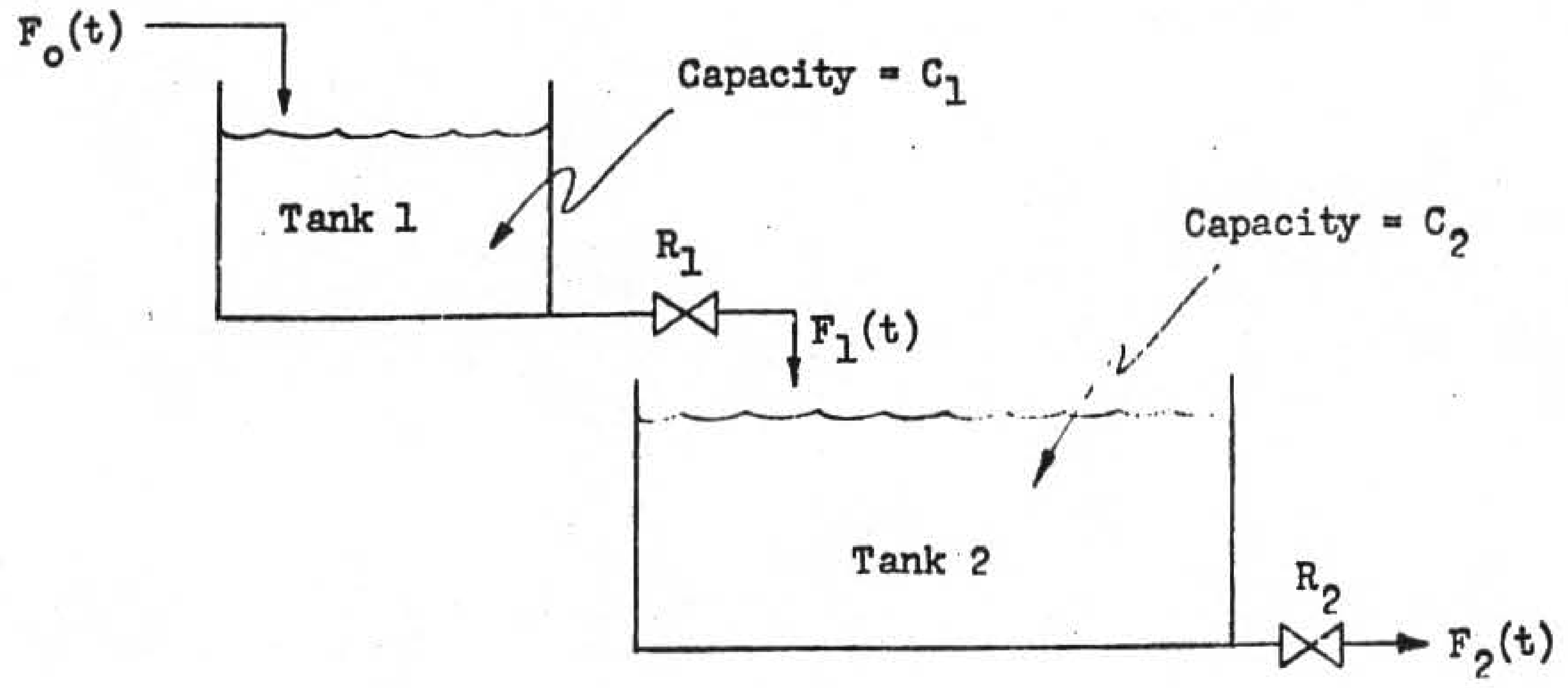

Figure 5-3: Two-Tank Liquid Flow Process

EXPERIMENT SIX

OPEN-LOOP RESPONSE OF PROCESS

The two-tank process of Experiment Five is to be instrumented to maintain a flow rate of twenty gallons per minute for flow $F_2(t)$. The control valve and the flow sensing device will be simulated in this experiment and the open-loop response of the system will be studied. In Experiment Seven the pneumatic controller will be studied. The controller will be added to the rest of the equipment in Experiment Eight, and the closed-loop behavior of the entire system will be observed for various controller settings.

Flow $F_2(t)$ out of Tank 2 will be maintained constant by controlling flow $F_o(t)$ into Tank 1. Flow $F_L(t)$ is an intermittent stream which also flows into Tank 1 at arbitrary intervals and for varying lengths of time. To simplify the analysis, it will be assumed that the nature of the process is such that Tank 1 will never run dry or overflow.

EXPERIMENT SEVEN

COMPUTER SIMULATION OF A PNEUMATIC CONTROLLER

In order to control the system in the previous experiment, some sort of controller is necessary. This controller receives the air pressure signal from the flow sensing device, subtracts this signal from the set point signal to produce an error signal, and acts upon the error signal to reposition the control valve.

Pneumatic controllers can be obtained with up to three modes of control, these being proportional, derivative (also called rate or preact), and integral (also called reset rate) modes. The particular process under study can be controlled very nicely by a controller having proportional and integral action, and this is the type of controller which will be simulated.

EXPERIMENT EIGHT

BEHAVIOR OF THE CLOSED-LOOP PROCESS

The complete process of Experiment 6 will be simulated and the effect of various controller settings will be observed. The pertinent facts about the process are summarized below.

(1) It is desired to maintain a constant flow of twenty gallons of liquid per minute out of the bottom of the second of two non-interacting, series-connected tanks. This flow is designated $F_2(t)$. To accomplish this a pneumatic control valve regulates the flow of liquid into the top of the first tank, the regulated stream being $F_o(t)$.

(2) In addition to $F_o(t)$ there is an intermittent stream, $F_L(t)$, which also flows into the top of the first tank. This flow is unregulated, and occurs in varying amount and on no regular schedule. The amount of this flow is small compared to $F_o(t)$.

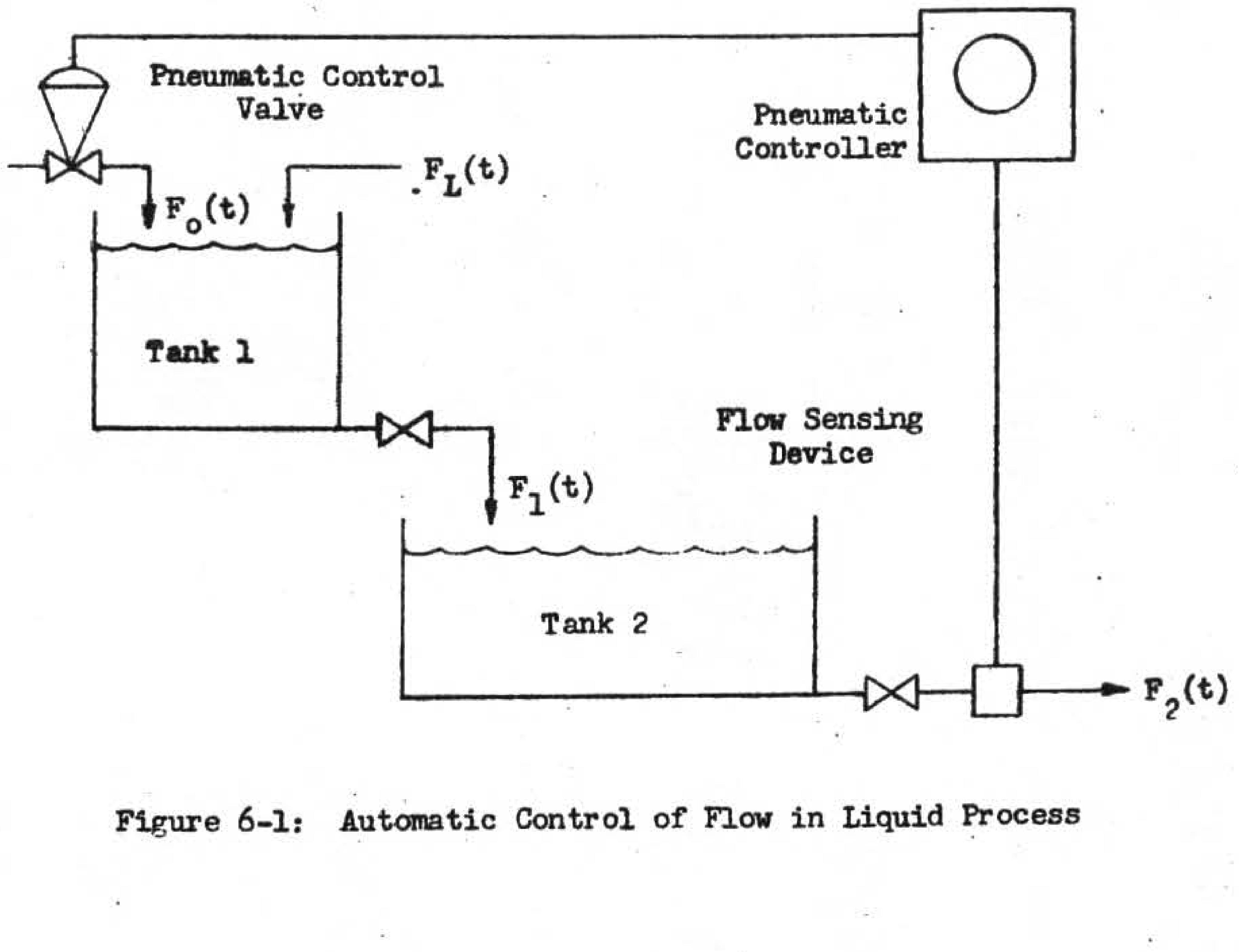

Figure 6-1: Automatic Control of Flow in Liquid Process