

To the Graduate Council:

I am submitting herewith a thesis written by John C. Rowe entitled "A Microcomputer-Based Flowmeter for Determining Average Liquid Phase Flow in a Two-Phase Fluid." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Electrical Engineering.

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A MICROCOMPUTER-BASED FLOWMETER FOR DETERMINING
AVERAGE LIQUID PHASE FLOW IN A
TWO-PHASE FLUID

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ABSTRACT

A microcomputer-based flowmeter was developed to meter the average liquid phase flow in a two-phase fluid, where the two phases are liquid and gas. An experimental system was set up to test the flowmeter and to develop a mathematical model for the device. The resulting experimental model fits the data with a prediction error of less than 0.2 percent of flow rate over the tested span of zero to five gallons per minute. A microcomputer performs all flow calculations using the model, and also controls flowmeter functions and displays diagnostic information.

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CHAPTER I

INTRODUCTION

This paper describes the development of a new flow metering device to precisely meter the average liquid phase flow in a two-phase fluid, where the two phases are liquid and gas. The project originated with work at the Oak Ridge Gaseous Diffusion Plant which is operated by the Nuclear Division of Union Carbide Corporation for the United States Department of Energy, and is the subject of an unclassified patent assignment by the author and co-workers to the United States Government.

The basic design was initiated to fill a requirement that could not be reliably satisfied by known commercial systems, which is to meter one phase of a two-phase fluid in partially full pipes. As constructed, the two-phase nature of the fluid has little deleterious effect on the reliability or repeatability of the flowmeter, the reasons for which will be described in later chapters. A flow rate is determined by measuring the time required for the process fluid to traverse the distance between two fixed probes as the unit fills with fluid. A microcomputer then utilizes the time measurement to calculate a flow rate from an experimentally derived mathematical model.

To identify the mathematical model, a calibration system was required as a standard against which to compare the new flowmeter. The calibration system that was used is based on a measurement of the time required to collect a quantity of fluid equal in weight to a standard weight. Knowing the density of the fluid, a very accurate flow rate can

then be calculated. Over 60 tests were run with the calibration system and flowmeter to determine the appropriate experimental model.

Once the model was known, the required software was developed. The software not only calculates a flow rate from the measured time, but also controls the operation of the flowmeter and indicates error codes for various error conditions that might occur.

The organization of the following chapters generally follows the order of development of the flowmeter. Chapter II gives a detailed description of the flowmeter system and how it functions. Chapter III describes the flow calibration system and its operation. Following in Chapter IV is a description of the experimental procedure used in obtaining test data, the results of testing, and development of the mathematical model. Chapter V describes the electronic hardware used in the flowmeter system, and Chapter VI outlines the software developed for the flowmeter. Concluding is a short summary in Chapter VII and various appendices.

CHAPTER II

DESCRIPTION OF THE FLOWMETER

The flowmeter system consists of an in-line liquid vessel and the external controls required to complete a measurement. In the following chapter a full description of the system will be given, beginning with details of the flowmeter vessel. That will be followed by a description of the control and measurement system and an outline of the sequence of operation during a flow measurement.

Flowmeter Vessel

A cross section of the flowmeter vessel is shown in Figure 1. It will be referred to several times in the following discussion with the numbers shown in parenthesis referencing those in Figure 1.

As shown in the figure, the vessel in part consists of two concentric tubes (1,2). In the model used for the current project, the outer tube was a section of six-inch diameter commercial glass pipe and the inner tube was four-inch diameter commercial plastic tubing. The fluid enters at the top (3) and passes through a nozzle (4) which directs the fluid downward at an angle against the inside of the plastic tube (2). The fluid exits through the outlet (5) in the bottom flange (6) of the vessel and out through an automatic valve (7) to system piping. The valve is a two-inch plastic ball valve. Except when a flow measurement is in progress, this valve is open and no fluid is retained in the vessel. As configured, the flowmeter only measures flow "on demand."

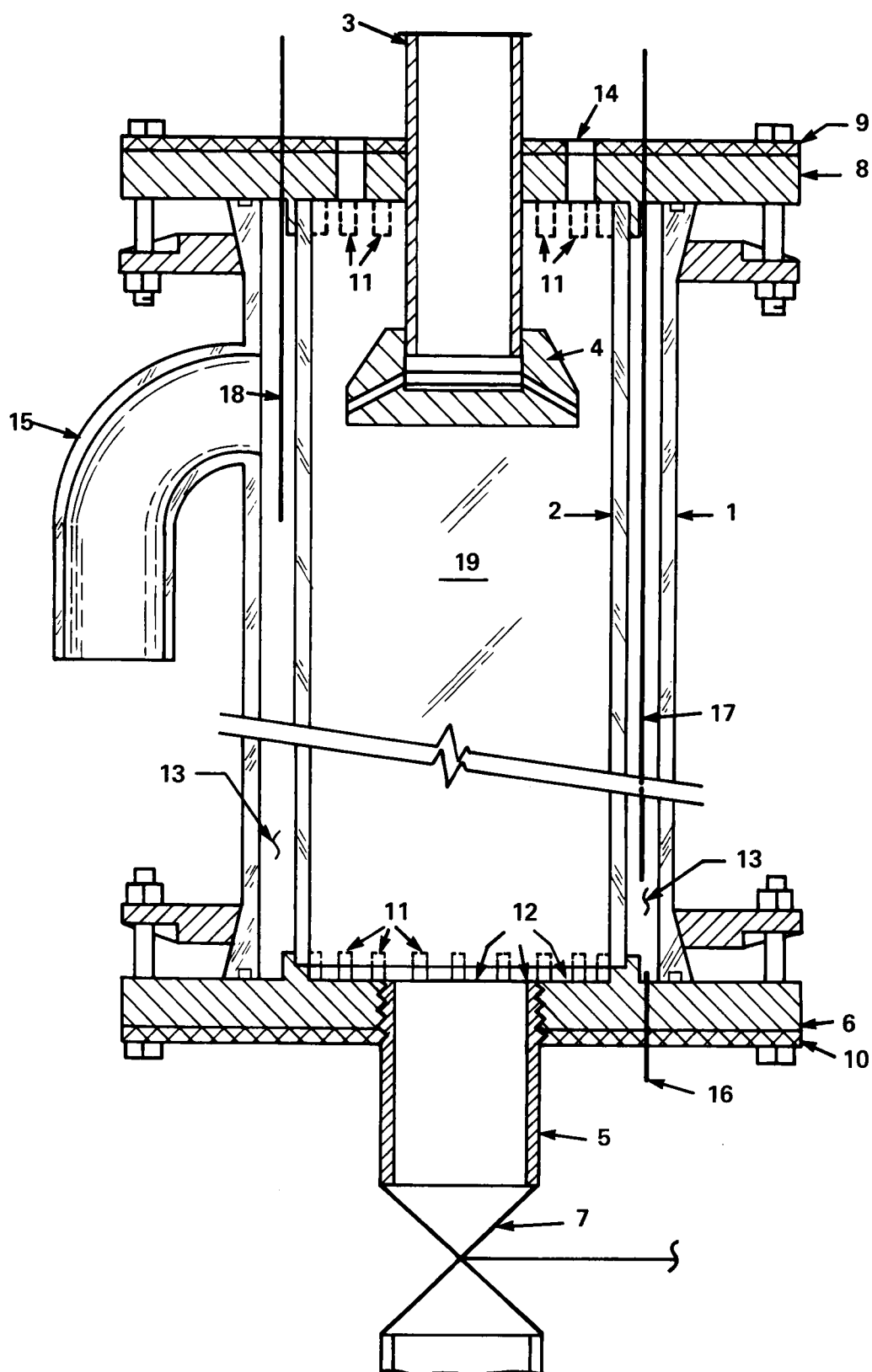


Figure 1. Flowmeter Vessel

The flanges at the top (8) and bottom (6) of the device are constructed of Teflon [Trademark, E. I. DuPont de Nemours & Co.] with metal backing plates (9,10) to give them some additional mechanical strength. The inside surfaces of the flanges have been machined to leave a ring of tabs (11) which center the inner plastic tube (2) and prevent it from shifting. The lower end of the plastic tube is also held off of the face of the flange (6) by the tabs, defining fluid passages (12) between the center chamber (19) and the annular space (13) formed by the two tubes. The upper flange has a number of holes (14) drilled in it to vent the two chambers and to prevent pressure from building up as the chambers fill with fluid.

An overflow (15) has been attached at the upper end of the vessel above the level to which fluid should rise in normal service. This is a safety measure to prevent the vessel from bursting or leaking fluid to the outside should the outlet valve fail to open following a measurement. The likelihood of such an event is reduced by using a normally-open valve with a spring to supply the opening force. An overflow, however, could occur if the valve were to stick or if there were a failure in the control circuitry.

Three probes (16,17,18) extend into the annular chamber (13) for sensing the surface of the fluid as it rises in the annular space. The three probes form two circuits in which the lower probe (16) is the common in the sensing circuits for the upper two conductivity probes (17,18). The upper probes are the fluid level sensors which signal the beginning and end of time measurements.

Control and Measurement System

Figure 2 shows a block diagram of the flowmeter system, including the vessel and the control and measurement circuitry. Some details have been left out in order to make the diagram easier to follow, but a detailed description of the circuitry will appear in Chapter V.

As shown, two liquid detector circuits interface the microcomputer to the conductivity probes described in the previous section on the flowmeter vessel. These circuits output logic levels which indicate the presence or absence of liquid, thereby signaling the microcomputer at the required times to start and stop the counting of pulses generated by the oscillator. Using this arrangement, the elapsed time required for the liquid level to rise from the lower conductivity probe to the upper conductivity probe can be measured.

After a flow rate has been calculated from the elapsed time measurement, a sequence of control signals is output to the display driver and the results to be displayed are latched in. The display driver then handles the task of multiplexing signals to the four-digit LED display. In addition to displaying flow rates, the display is also used to indicate error codes when an error condition is detected.

The microcomputer is the central control element in the flowmeter system, receiving signals from the liquid detectors, oscillator, and manual controls, then sending control signals out to the control valve and display driver. The manual controls allow a measurement to be initiated manually and allow the system to be reset.

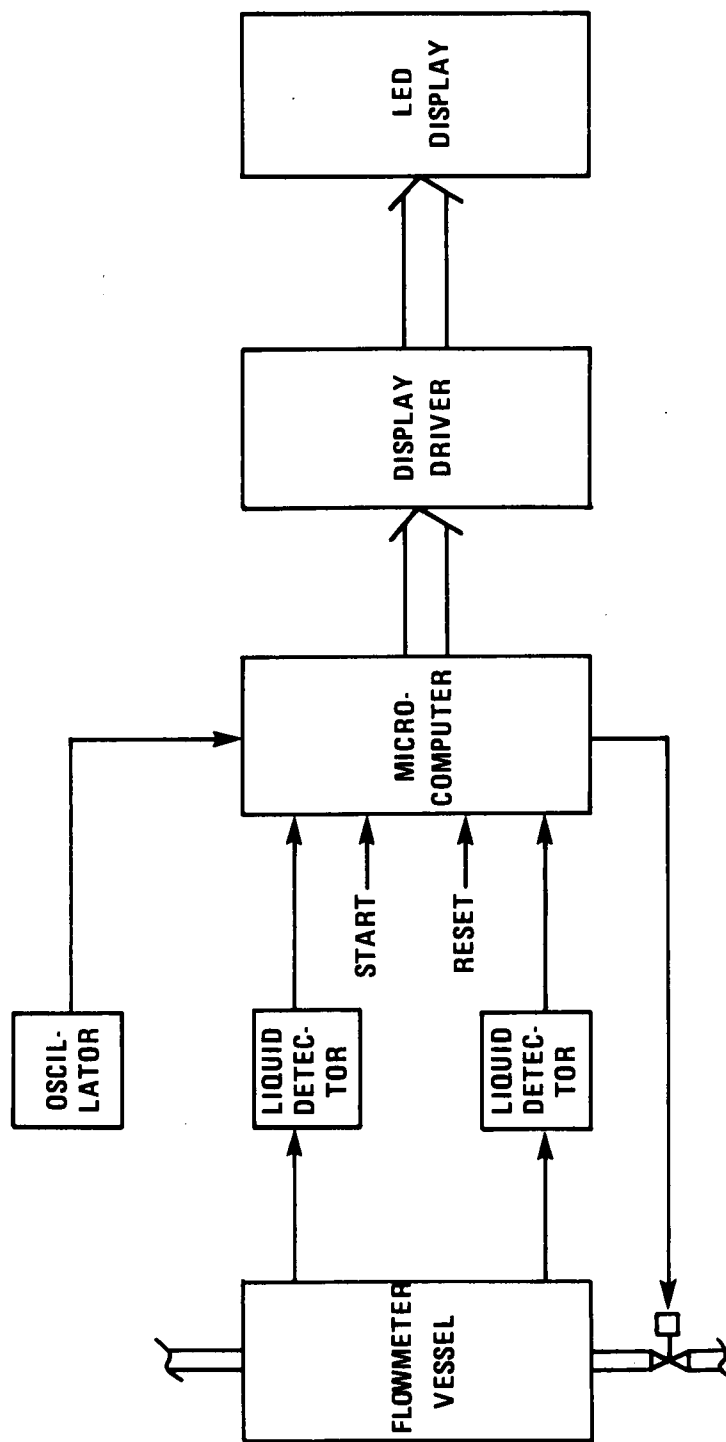


Figure 2. Flowmeter System Block Diagram

System Operation

During standby, flow passes downward through only the inner chamber (19) [Numbers in parenthesis again refer to Figure 1] of the vessel and is not retained. When a measurement is initiated, the flow is interrupted at the outlet by the valve (7) and fluid begins to rise in the vessel. This interruption in flow is not seen as a disturbance in the flow upstream of the flowmeter. That was a major requirement for the design, along with the required elimination of the gas phase from the measured liquid phase. Both requirements are met by having the fluid enter at the top of the vessel where there is an air break. Pressure disturbances cannot be communicated upstream, and the gas phase is allowed to escape.

As fluid rises in the inner chamber (19), it flows through the passages (12) at the bottom of the vessel and simultaneously begins to rise in the annular space (13). Although the fluid in the inner chamber is very turbulent and contains many bubbles, the fluid in the annular space contains very few bubbles and has an extremely calm surface. As a result of the smooth surface, the liquid level in the annular space can be sensed very precisely. Again, although the fluid in the inner chamber is very turbulent, the rate that the fluid rises in the annular space is primarily dependent on the increase in mass in the inner chamber, and the turbulence is averaged out.

When the fluid surface reaches the lower conductivity probe (17), timing begins. The height of this probe is a small distance from the bottom of the vessel so that any initial disturbances will have settled

out before timing is started. Timing is stopped when the fluid surface reaches the upper conductivity probe (18). Immediately the valve (7) is opened and the collected fluid is returned to the process piping. It should be noted that, due to the air break in the flowmeter, gravity is the only driving force acting to drain fluid from the device.

Once the time measurement is complete, the microcomputer utilizes the mathematical model to calculate a flow rate which is then transferred to the display driver for display.

Chapter III

DESCRIPTION OF THE EXPERIMENTAL SYSTEM

An experimental system was utilized to test the flowmeter and to develop a model describing the relationship between flow rate and elapsed times. In the following chapter, a complete description of the overall experimental system will be given, beginning with details of the flow loop and the calibration standard. This is followed by a description of the test instrumentation and then by an outline of the operation of the system.

The Fluid System

The overall experimental system is diagramed in Figure 3. Throughout the following description of that system, all numbers in parenthesis will refer to corresponding numbers on the figure.

Liquid is supplied to the system from a pressurized tank (1). It is a constant-head tank in that changes in liquid volume do not result in corresponding changes in head pressure. The tank was designed to eliminate the decrease in system flow rate that is observed with a declining liquid level and the corresponding decline in supply pressure. Such an arrangement overcomes the problem by maintaining two separate reservoirs in the tank. Liquid is continuously pumped from the larger reservoir into the smaller standpipe where it overflows back into the larger reservoir. The continuous overflow maintains a uniform liquid level from which to provide constant flow rates. The additional energy

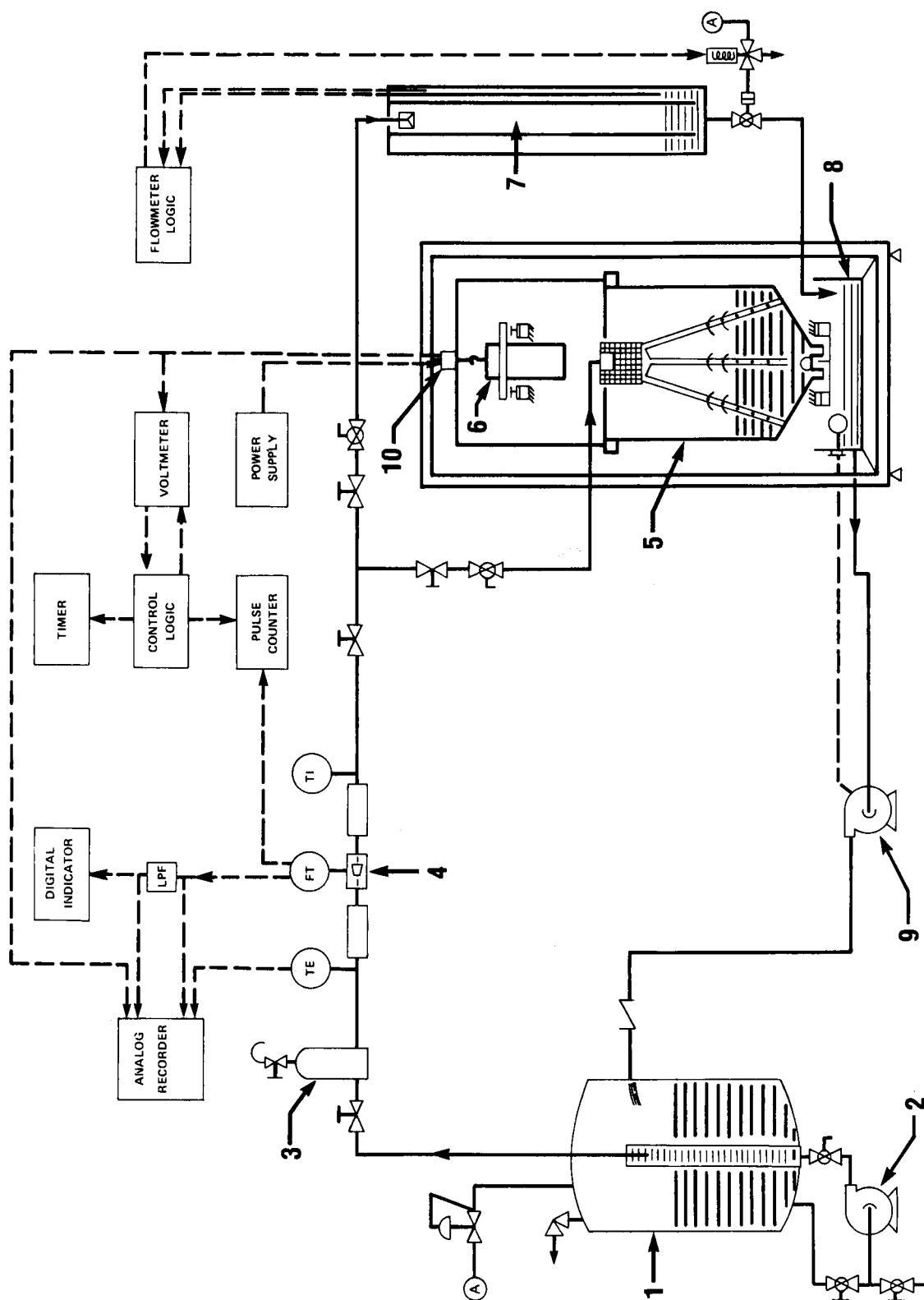


Figure 3. Experimental System

that is required for most flow rates is provided by regulating the tank at an elevated pressure (in this project, up to 47 psig). It should be noted that since liquid is continuously withdrawn from the standpipe to supply a flow of liquid to the external system, the recirculation pump (2) must be capable of somewhat higher flows in order to maintain the overflow.

Following the feed tank is a 10 μ m filter (3). Its purpose is to clean the liquid and to protect the turbine flowmeter downstream. A valve is provided at the top of the filter for venting air from the housing and eliminating air pockets. Eliminating such pockets of air in the system results in a more stable flow and reduced noise in the flow signal. A clear filter housing is provided which allows the operator to see when the air has been eliminated.

In order to continuously monitor the system flow rate, a turbine flowmeter (4) has been installed. The unit chosen is an ITT Barton model 7283-0008 with a range of 0.5 to 5.0 gallons per minute. Ball bearings fitted with Teflon ball separators provide the turbine meter with good sensitivity and extend their useful life in water service. Because water alone does not have much lubricity, ordinary ball bearings usually wear quickly.

After passing through either the calibration standard (5) or the flowmeter (7) under test, the liquid is collected in a sump(8). When the sump becomes full, a level switch activates the gear pump (9) to return the liquid to the feed tank (1). It is important that the experimental

runs with the system are conducted while the sump pump is not running because the pump upsets system flows significantly.

The Calibration Standard

The calibration standard is based on a measurement of the time required to collect a known weight of liquid. A sketch of the device (5) is shown in Figure 3.

Liquid enters the device through a nozzle which sprays the water horizontally into a cup containing several layers of wire mesh. The purpose is to transfer as little vertical momentum to the weighing reservoir as possible and to prevent fluid from splashing out. The liquid then flows from the small cup through its supporting legs and into the larger reservoir where it can be collected. Liquid is collected only during a test. At other times, the fluid flows out through a valve in the bottom of the reservoir and into the sump where it can be recirculated.

The weighing reservoir and framework (5) are suspended from a load cell (10) with a range of 50 pounds. A hook is provided on the same framework so that a 39.9165 pound weight (6), which is the standard for calibration, can be added to or removed from the assembly. Two air cylinders provide the capability of lifting the specified weight automatically. Because the collected weight of water is always referenced to the standard weight, variations in load cell output due to cell or power supply drift have little or no effect. Only variations during the collection period have an effect and these variations are observed to be less than 0.04 percent of the weight.

The procedure is to begin collecting fluid with the 39.9165 pound weight added to the framework. When the total weight reaches a specified level, such as 45 pounds, the timer is started and the standard weight is automatically lifted from the assembly. Liquid is then collected until the total weight again reaches 45 pounds. At that point, the added weight of liquid precisely matches the 39.9165 pounds previously removed and the timer is stopped. Because the density of the fluid is known, a precise volume flow rate can be calculated. The method has the additional advantage of requiring no calibration of the load cell.

Instrumentation

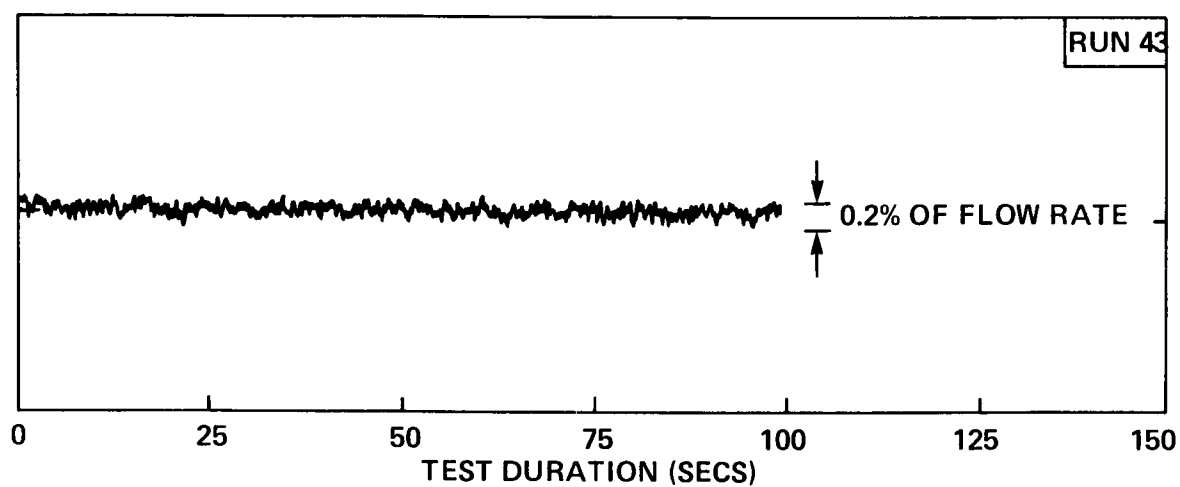
As indicated in Figure 3, several of the important variables in the experimental system are recorded on a strip chart recorder. The device is a six-channel Gould Inc. series 2000 recorder with four model 13-4615-10 DC preamplifiers and two model 13-4615-42 thermocouple amplifiers. Five signals were recorded: liquid temperature, room temperature, load cell output, turbine transmitter output, and the turbine transmitter output filtered by a low-pass filter.

Temperatures were recorded so that any important trends which might have an effect on the results could be seen. Liquid temperature was also displayed on a United Systems Corporation Digitec HT 5820 digital thermometer which could be read with much greater precision than the analog recorder. Values obtained from the digital thermometer were used for density and flow calculations. The sensing element was a Digitec thermistor probe number 710A.

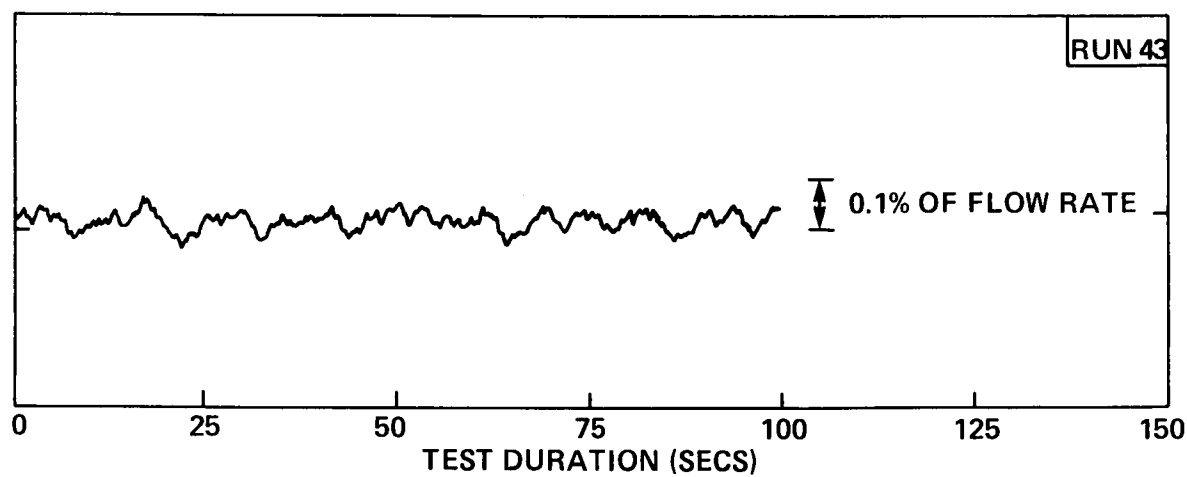
As mentioned, two versions of the flow rate signal monitored by the turbine flowmeter were recorded (see Figure 4): one (A) with only the 5 Hz cutoff frequency of the preamplifier affecting it, and the other (B) with an additional 0.16 Hz low-pass filter in the circuit. Since flow signals tend to be rather noisy, the signal with additional filtering seemed to be the more useful, especially for taking readings from the digital indicator. The flow transmitter provided a 4 to 20 mA current loop into which a 500 Ω resistor and 2000 μ F capacitor were inserted for the extra filtering. A 112 Ω precision resistor was used to sample the normal signal. Since the resistor used for the filtered signal was much larger than the other, the amplitude of that signal was larger and, therefore, smaller changes were observable.

The purposes for recording the flow signals were to verify that no significant shifts in flow rate occurred during a test and to have a record of each test. As can be seen from the sample flow recordings shown in Figure 4 and in Appendix A, shifts in average flow were minimal. The noise visible in the recordings would average out over the duration of a test.

A custom logic circuit controls the operation of the calibration standard. Its purpose is to store a specified digital trigger level and then to strobe the voltmeter during a test to sample the load cell output and compare the digital output of the voltmeter to the stored value. The voltmeter is a Hewlett Packard Co. Model 2402A. The logic also starts and stops the timer (a United Systems Corporation Digitec model 8510A), gates pulses to the counter, controls the standard weight, and



A. CUTOFF FREQUENCY 5 HZ



B. CUTOFF FREQUENCY 0.16 HZ

Figure 4. Sample Flow Record

operates the valve in the bottom of the weighing reservoir. A detailed sequence of operation will be given in the following section.

The power supply, which applies a voltage to the load cell bridge, is a Hewlett Packard Co. Model 6205B DC supply.

Another custom circuit was used to operate the flowmeter under test. It was a temporary system to control the flowmeter and to display measured elapsed times until the microcomputer system and model were developed. Included in the circuit are a crystal oscillator, counter, display, valve control, liquid detectors, and operator controls.

Operation

Since the calibration standard and the flowmeter both function by timing the flow for a measured length of time, it was not feasible to operate them simultaneously. Therefore, they were operated in parallel with the fluid diverted to only one of them at a time. In order to assure that the flow through the flowmeter was the same as that through the standard, the turbine flowmeter was used to monitor the flow. The separate sections of piping were balanced by observing the strip chart output and digital indicator and adjusting needle valves in the two sections for equal flows.

When the two sections were balanced, it was possible to switch from the calibration standard to the flowmeter and back without significantly changing the flow rate as indicated by the turbine flowmeter. Manual ball valves were used to divert the flow.

At the beginning of a typical test, the flow is adjusted to a nominal value and the two sections of the system balanced. The flow is then diverted to the calibration standard. When the sump pump is not operating and the flow has leveled out, the calibration system controls can be reset and a test started.

The control logic automatically closes the valve in the bottom of the weighing reservoir and liquid begins to collect. The logic monitors the weight on the load cell through the voltmeter and starts the timer when the trigger level is reached. Pulses are gated to the pulse counter at the same time. The standard weight is then lifted from the weighing system and the load cell output drops. When enough fluid has collected to replace the weight of the standard, the trigger level is again reached. The timer and pulse counter are stopped and the liquid is automatically released from the weighing reservoir. The total number of pulses from the turbine flowmeter is used to verify the uniformity of the average flow between different runs by calculating an average frequency. The total elapsed time is used to calculate a flow rate.

Fluid is next diverted to the flowmeter under test. Again, when the sump pump is not operating and the flow has leveled out, the flowmeter control is activated. The valve at the outlet of the flowmeter is automatically closed and the liquid level begins to rise. A timer is started when the liquid touches the lower conductivity probe and is stopped when it reaches the upper conductivity probe. The valve is then automatically opened and the fluid released.

A sequence of such tests is repeated at the same flow rate,

alternating between the flowmeter and the calibration standard. The flow rate is then adjusted to a new value, the two sections of piping balanced, and another series of tests conducted. Results of the many tests are then used to compare the calibration standard to the flowmeter and to model the flowmeter.

The flow rates determined with the calibration standard have to be calculated from the time required for 39.9165 pounds of liquid to flow. The formula used for these calculations is:

$$F = W/(\rho)(T)$$

where

F = Flow rate in gpm,

W = 39.9165 lb.,

ρ = Density of the water in lb./gal.,

and T = Time in minutes.

Test results obtained with the experimental system are detailed in the next chapter.

CHAPTER IV

RESULTS OF TESTING

Data collected with the experimental system was utilized to identify an appropriate model for the flowmeter. In the following chapter, a description of the experimental design utilized to accumulate the data will be provided along with a summary of the acquired data. Finally, the process of model development and the resulting model will be discussed.

Experimental Design

A total of 60 separate test runs was made on the experimental system using water as the test fluid. The order of these test runs was randomized and also conducted on two different days in order to minimize any bias in the results. Repeated measurements were made at five approximately evenly-spaced flow rates between zero and five gallons per minute.

On the first day, two flow rates (F) from the calibration standard and two elapsed times (T) from the flowmeter were taken at each of the five flows. An average of the two flow rates was then paired with an average of the two elapsed times. On the second day, four flow rates (F) from the calibration standard and four elapsed times (T) from the flowmeter were taken at flow rates as near as possible to the same five flow rates as on the first day. Again, the data were paired as averages of two data points so that the sample size for all of the averages is

identical. The end result is 15 different flow rate versus elapsed time pairs which consist of averages of sample size two. This data is summarized in Table 1 and Table 2.

The order of flow rate settings within a day and the measurement order of F and T at a particular flow rate were randomized. This randomization has the benefit of reducing or eliminating the effects of bias from such things as liquid clinging to the walls of the flowmeter vessel. Drops of liquid are left on the walls of the vessel after a measurement and will vary in amount depending on the time period between measurements. By randomizing the order of measurements between the flowmeter and the calibration standard, the time between repeated measurements on the flowmeter is effectively randomized, and thus the effect of the residual water is accounted for in the variability of the measurement. A summary of the variability of the time measurement at the five flows on the second day is shown in Table 3. The first day's data are not included since that would introduce additional variability related to the ability to return to a particular flow rate with the feed system.

Modeling

Least squares regression analysis was used on the pairs of 15 averages in order to determine the best model to fit the data. Several models were tried, including forms with logarithms, exponentials, and polynomials up to fourth order. Forms containing $1/T$ were also included. Since the flowmeter utilizes a measurement of the time needed

TABLE 1
DATA AND AVERAGES FOR DAY 1

Nominal Flow Rate (gpm)	Actual Flow Rate (gpm)	Flowmeter Elapsed Time (sec)
1.1	1.0788	197.31
	1.0795	197.11
AVE =	1.07915	197.210
2.0	2.0418	103.67
	2.0411	103.65
AVE =	2.04145	103.660
2.9	2.8912	72.88
	2.8909	72.88
AVE =	2.89105	72.880
3.8	3.8040	55.10
	3.81215	55.08
AVE =	3.80807	55.090
4.5	4.4903	46.55
	4.5002	46.58
AVE =	4.49525	46.565

TABLE 2
DATA AND AVERAGES FOR DAY 2

Nominal Flow Rate (gpm)	Actual Flow Rate (gpm)	Flowmeter Elapsed Time (sec)	Actual Flow Rate (gpm)	Flowmeter Elapsed Time (sec)
1.1	1.0764	197.33	1.0731	197.58
	1.0786	197.51	1.0756	197.62
AVE =	1.07750	197.420	1.07435	197.600
2.0	2.0399	103.86	2.0397	103.88
	2.0414	103.86	2.0375	103.78
AVE =	2.04065	103.860	2.03860	103.830
2.9	2.8880	72.98	2.8813	72.98
	2.8830	72.96	2.8887	72.92
AVE =	2.88550	72.970	2.88500	72.950
3.8	3.8018	55.14	3.8041	55.16
	3.8001	55.09	3.8073	55.13
AVE =	3.80095	55.115	3.80570	55.145
4.5	4.4897	46.61	4.4893	46.61
	4.4925	46.57	4.4901	46.58
AVE =	4.49110	46.590	4.48970	46.595

TABLE 3

TIME ERROR VARIABILITY ESTIMATES FOR DAY 2

Nominal Flow Rate (gpm)	Variance		Standard Deviation	
	Actual	Percent Of Time	Actual	Percent Of Time
1.1	0.016467	0.0083	0.12832	0.0650
2.0	0.001967	0.0019	0.04435	0.0427
2.9	0.000800	0.0011	0.02828	0.0388
3.8	0.000867	0.0016	0.02944	0.0534
4.5	0.000425	0.0009	0.02062	0.0443

to displace a given volume, one would expect that the model required to calculate a flow rate would contain a term of the form $1/T$.

As it turns out, the best model is of the form $F = A - BT + C(1/T)$, which contains other terms in addition to $1/T$. This is not so intuitively obvious, but is probably related to nonlinearities in the fluid system. Possible causes include changes in the momentum of the falling water which are related to flow rate, changes in volume occupied by the falling water which are related to flow, or some other hydraulic effect. It is expected that the $A-BT$ terms are only a linear approximation to some more complex expression which would exactly describe the phenomenon.

Results of the regression analysis for the model $\hat{F} = 0.077294 - 0.00022543T + 206.1398(1/T)$ are shown in Table 4. The model fits the data averages extremely well, with percentages of prediction error ranging from 0.005 to 0.15 percent and with all three of the constants

TABLE 4

$$\text{MODEL: } \hat{F} = 0.077294 - 0.00022543T + 206.1398(1/T)$$

Nominal Flow Rate	Average Actual Flow Rate	Average Flowmeter Elapsed Time	Predicted Flow Rate	Residual	Percentage Error	
	(F)	(T)	($\hat{F}$)	(F- $\hat{F}$)	$\frac{F-\hat{F}}{F}$	.100
1.1	1.07915	197.210	1.07812	0.0010323	0.09566	
2.0	2.04145	103.660	2.04254	-0.0010907	0.05343	
2.9	2.89105	72.880	2.88935	0.0017029	0.05890	
3.8	3.80807	55.090	3.80675	0.0013268	0.03484	
4.5	4.49525	46.565	4.49372	0.0015276	0.03398	
1.1	1.07750	197.420	1.07696	0.0005415	0.05026	
1.1	1.07435	197.600	1.07597	-0.0016167	0.15048	
2.0	2.04065	103.860	2.03867	0.0019838	0.09722	
2.0	2.03860	103.830	2.03925	-0.0006464	0.03171	
2.9	2.88550	72.970	2.88584	-0.0003382	0.01172	
2.9	2.88500	72.950	2.88662	-0.0016172	0.05605	
3.8	3.80095	55.115	3.80505	-0.0040953	0.10774	
3.8	3.80570	55.145	3.80300	0.0026962	0.07085	
4.5	4.49110	46.590	4.49134	-0.0002413	0.00537	
4.5	4.48970	46.595	4.49087	-0.0011654	0.02596	

in the model significantly different from zero at the 99.99 percent level. A plot of the residuals versus flow rate is shown in Figure 5. There it can be seen that the model predicts equally well for all flow rates. In addition, a graph of the model is shown in Figure 6. All fifteen of the averages are plotted, although the variability at a given point is so small that they are not individually distinguishable.

For comparison purposes, the results of the regression analysis for the simpler model $F = A + B(1/T)$ are shown in Table 5. Again, both of the constants are significantly different from zero at the 99.99 percent level, but the percentages of prediction error are greater, ranging from 0.04 to 0.76 percent. With the fitted constants, this model is $\hat{F} = 0.029431 + 208.08105(1/T)$, but is not acceptable due to the larger prediction error involved.

To summarize the test results, a statistical model, $\hat{F} = 0.077294 - 0.00022543T + 206.1398(1/T)$, has been developed from experimental data which provides an excellent fit to the data. The percent prediction error from the data ranges from 0.005 to 0.15 percent.

The next two chapters will describe the flowmeter hardware and software used to implement the model and to provide the other flowmeter functions.

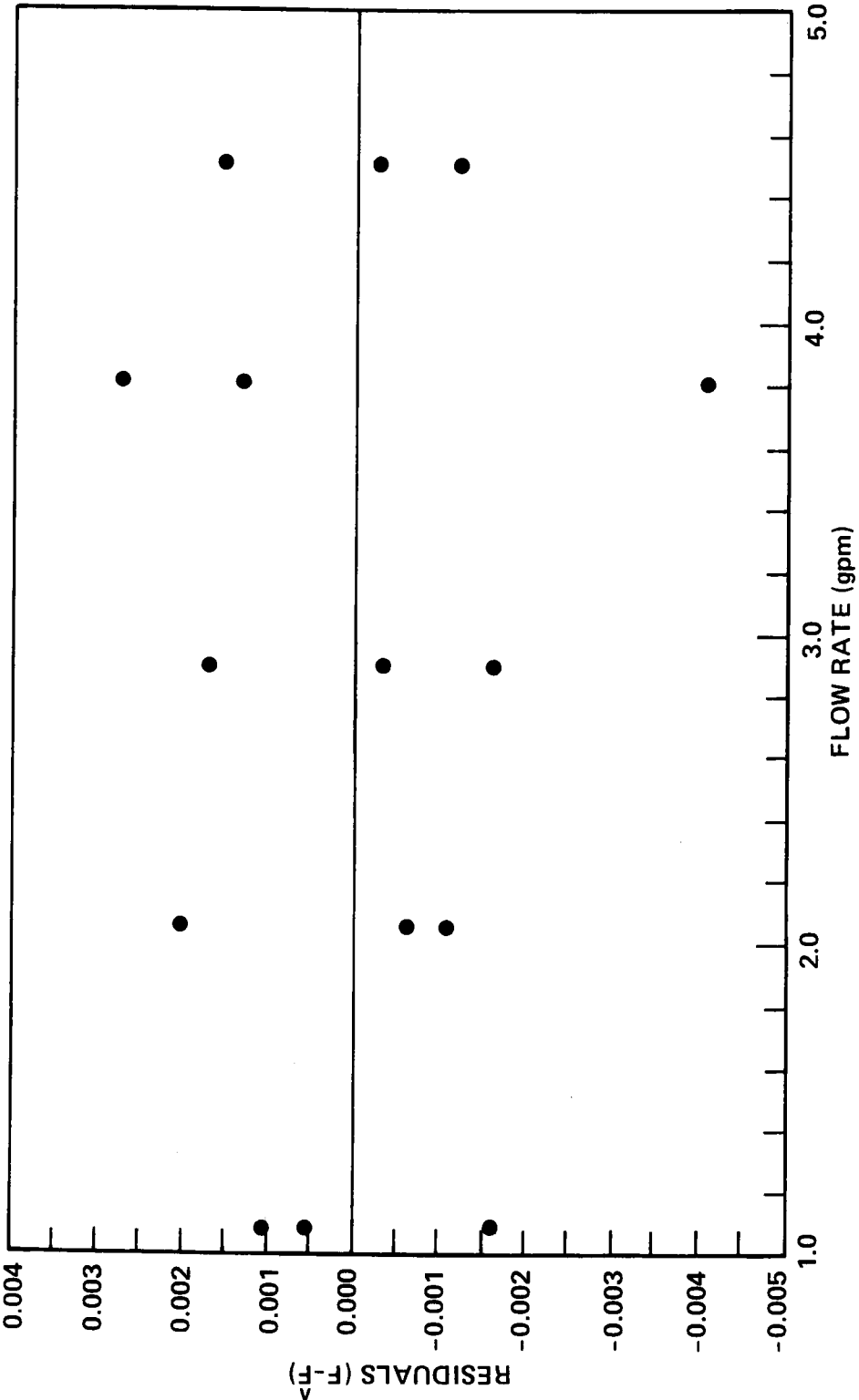


Figure 5. Residuals of Model vs Flow Rate

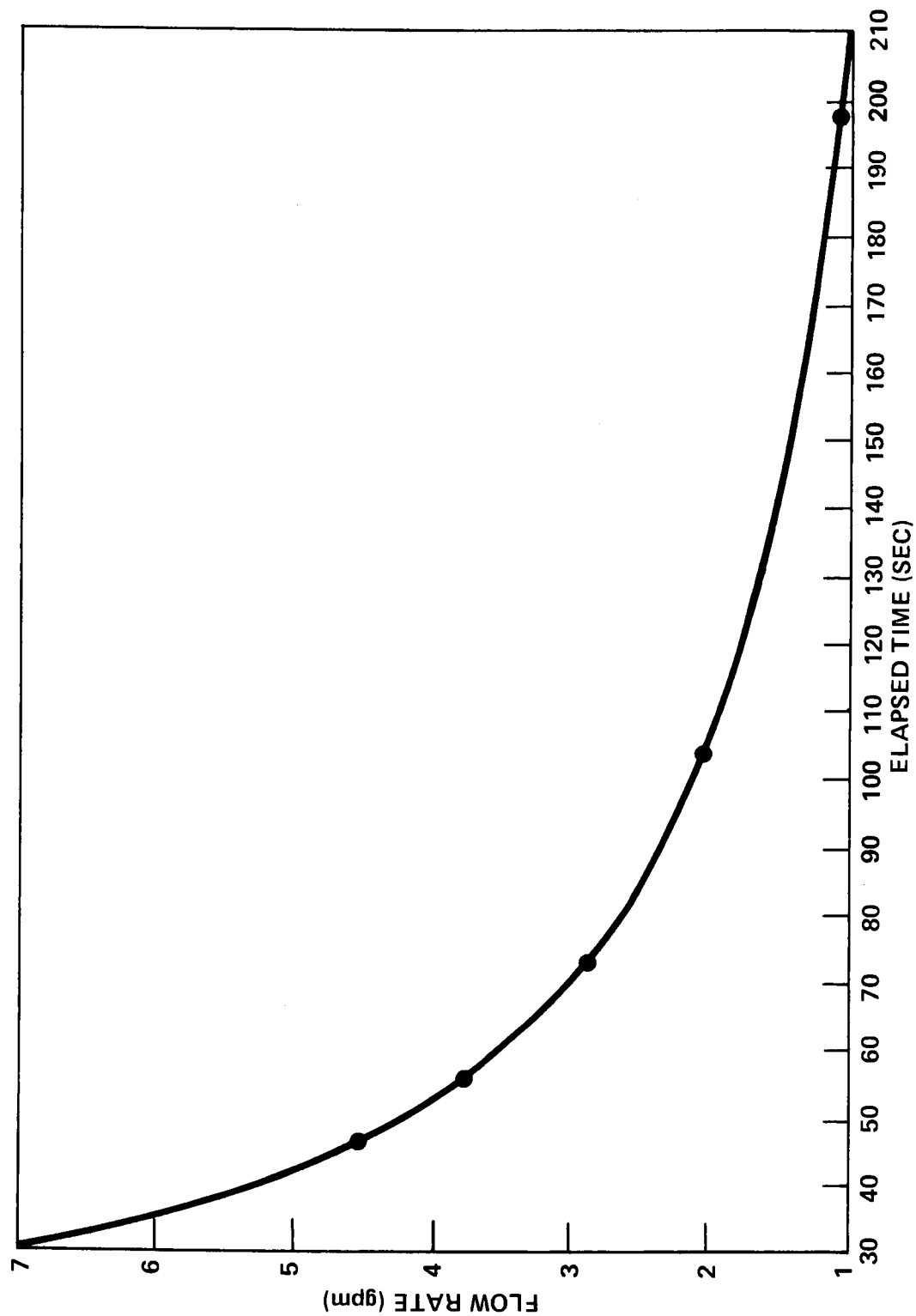


Figure 6. Graph of Fitted Model

TABLE 5

$$\text{MODEL: } \hat{F} = 0.029431 + 208.08105(1/T)$$

Nominal Flow Rate	Average Actual Flow Rate	Average Flowmeter Elapsed Time	Predicted Flow Rate	Residual	Percentage Error	
	(F)	(T)	($\hat{F}$)	($F - \hat{F}$)	$\frac{F - \hat{F}}{F}$	.100
1.1	1.07915	197.210	1.08456	-0.0054053		0.50089
2.0	2.04145	103.660	2.03677	0.0046771		0.22911
2.9	2.89105	72.880	2.88455	0.0065002		0.22484
3.8	3.80807	55.090	3.80654	0.0015328		0.04025
4.5	4.49525	46.565	4.49805	-0.0027960		0.06220
1.1	1.07750	197.420	1.08343	-0.0059329		0.55062
1.1	1.07435	197.600	1.08247	-0.0081228		0.75607
2.0	2.04065	103.860	2.03291	0.0077426		0.37942
2.0	2.03860	103.830	2.03349	0.0051137		0.25085
2.9	2.88550	72.970	2.88103	0.0044717		0.15497
2.9	2.88500	72.950	2.88181	0.0031899		0.11057
3.8	3.80095	55.115	3.80483	-0.0038789		0.10205
3.8	3.80570	55.145	3.80278	0.0029250		0.07686
4.5	4.49110	46.590	4.49565	-0.0045481		0.10127
4.5	4.48970	46.595	4.49517	-0.0054689		0.12181

CHAPTER V

FLOWMETER CIRCUITRY

The flowmeter circuitry consists of six basic elements: a single-board microcomputer, a display decoder/driver, a four-digit display, an oscillator, liquid detector circuits, and interface circuits. Each of the basic elements will be covered in the following discussion. All of the elements except the interface circuits are indicated in the flowmeter system block diagram, Figure 2, page 7. A more complete schematic of the circuitry is shown in Figure 7.

Microcomputer

The central element in the flowmeter circuitry is an Intel Corporation SBC-80/10 single-board computer. The CPU, system clock, read/write memory, non-volatile read-only-memory, I/O ports and drivers, serial communications interface, and bus control logic all reside on the board. A functional block diagram is shown in Figure 8.

The central processor for the single-board computer is an Intel 8080A. In addition, there are 1K 8-bit words of read/write memory and sockets for up to 4K 8-bit words of EPROM. Additional memory boards may be added as necessary. The 48 parallel I/O lines are software configurable in combinations of input, output, and bidirectional ports, and the serial communications interface is also programmable.

Three I/O ports are required for the flowmeter, two configured as mode 0 output ports and one configured as a mode 0 input port. One

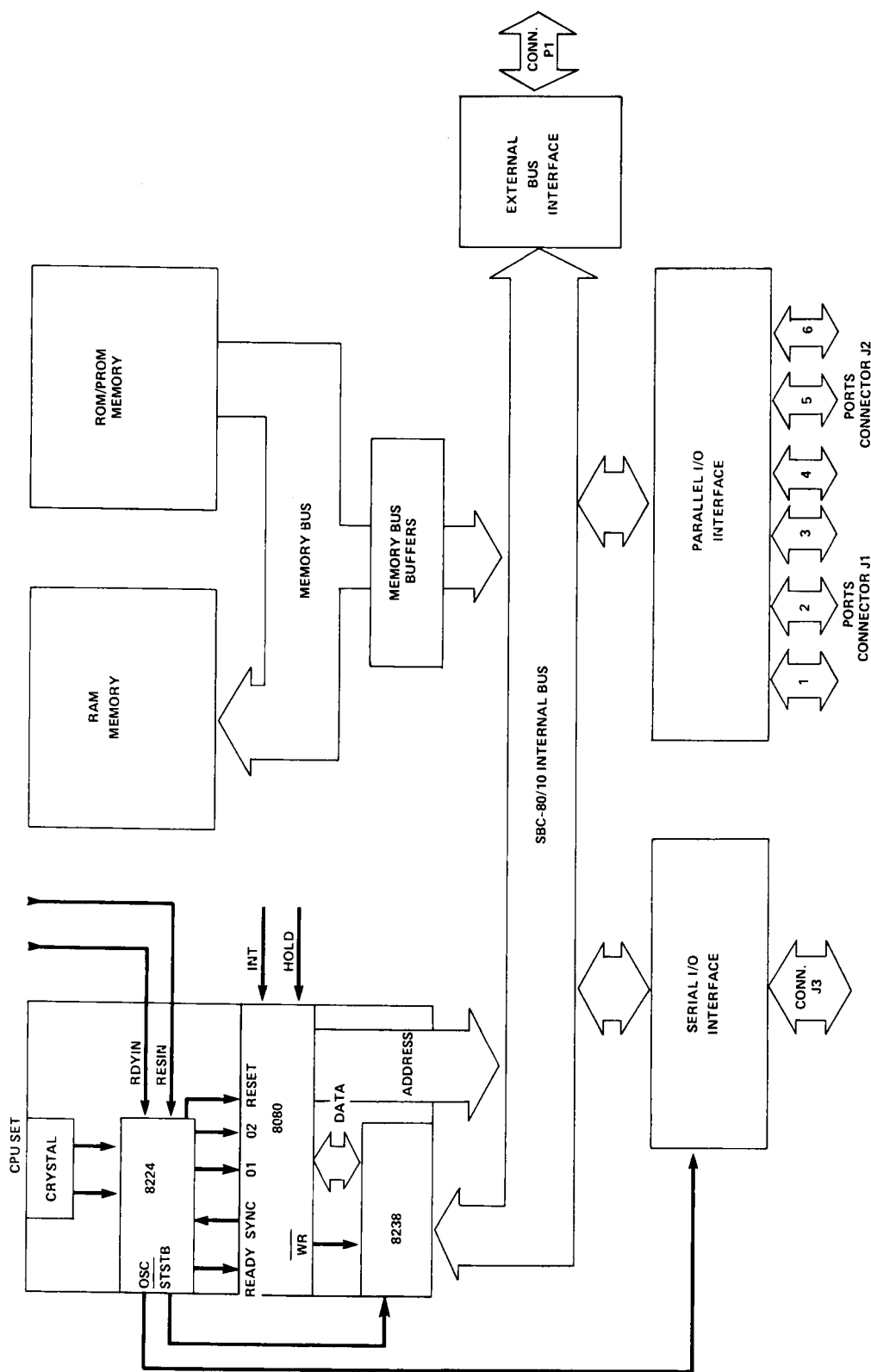


Figure 8. SBC 80/10 Functional Block Diagram

Source: SBC 80/10 Single-Board Computer Hardware Reference Manual, Number 98-230B. Santa Clara, California: Intel Corp., 1976.

output port has been assigned to port one, which includes permanently installed line drivers. The other output port is assigned to port three in order to take advantage of its single bit set/reset feature, which leaves port two as the input port. Line drivers have been installed at port three and I/O terminators consisting of 1 k Ω pull-up resistors have been installed at port two. It is also necessary to assure that certain jumpers are in place to implement the above configuration. They are 40-41, 44-45, 46-47, 48-49, and 50-51. Pin assignments for the three ports on connector J1 are listed in Table 6 along with their associated functions. Address and socket assignments for the ports and control register are indicated in Table 7.

As already mentioned, port three has been assigned to take advantage of its single bit set/reset feature. Its capability is utilized for control of the flowmeter valve, to drive an indicator light, and to strobe data into the display driver, applications where only a single bit is required. To alter a given bit, the appropriate control word from Table 8 is output to the control register address E7.

As a final note, one must keep in mind that since inverting drivers are used on the output ports, whatever bits are sent to the output registers will be inverted at the external connector.

TABLE 6
PIN ASSIGNMENTS FOR CONNECTOR J1

Pin	Signal	Function
1	Port 2 - Bit 3	Upper Liquid Detector
3	Port 2 - Bit 2	N.C.
5	Port 2 - Bit 1	Reset
7	Port 2 - Bit 0	Start
9	Port 2 - Bit 4	Lower Liquid Detector
11	Port 2 - Bit 5	Oscillator Input
13	Port 2 - Bit 6	N.C.
15	Port 2 - Bit 7	N.C.
17	Port 3 - Bit 3	Timing Indicator
19	Port 3 - Bit 2	Valve
21	Port 3 - Bit 4	N.C.
23	Port 3 - Bit 6	N.C.
25	Port 3 - Bit 0	Decoder/Driver Mode
27	Port 3 - Bit 5	N.C.
29	Port 3 - Bit 1	Decoder/Driver <u>Write</u>
31	Port 3 - Bit 7	N.C.
33	Port 1 - Bit 7	D7
35	Port 1 - Bit 6	D6
37	Port 1 - Bit 5	D5
39	Port 1 - Bit 4	D4
41	Port 1 - Bit 1	D1
43	Port 1 - Bit 0	D0
45	Port 1 - Bit 2	D2
47	Port 1 - Bit 3	D3
49	Ext Intr	Interrupts
Even	Gnd	Ground

TABLE 7
I/O ADDRESS AND SOCKET ASSIGNMENTS

Port	Address	Socket Numbers
1	E4	A1, A2 Drivers Permanently Installed
2	E5	A5, A6
3	E6	A3, A4
Control	E7	None

TABLE 8
PORT 3 BIT SET/RESET CONTROL WORDS

Bit	Status	Word	Function
0	Set	00000000	Decoder/Driver Mode High
	Reset	00000001	Decoder/Driver Mode Low
1	Set	00000010	Decoder/Driver $\overline{\text{Write}}$ High
	Reset	00000011	Decoder/Driver $\overline{\text{Write}}$ Low
2	Set	00000100	Valve Open
	Reset	00000101	Valve Closed
3	Set	00000110	Timing Indicator On
	Reset	00000111	Timing Indicator Off
4-7	-	-	Unused

Display Decoder/Driver

The display decoder/driver is an Intersil, Inc., ICM7218AIJI CMOS universal eight-digit LED driver which provides all of the circuitry necessary to interface the microcomputer to the display. Included on the chip is an 8x8 static memory array which provides storage for the displayed information, two types of seven-segment decoders, the required multiplex scan circuitry, and the digit and segment drivers.

Since the eight-digit device is used to drive a four-digit LED display, the digit drivers have been paralleled in pairs of two, effectively doubling the average current per digit. The average drive current in this configuration is 10 mA per segment, derived from two pulses supplying peak drive currents of 40 mA. A blanking time of approximately 10 μ sec occurs between digit strobes to ensure that segment information is correct before the next digit drive is applied, thereby preventing ghosting.

Data is read directly from the microcomputer I/O port one. Two bits from computer I/O port three are used for control lines (Write and Mode) to define mode select and to write to the chip either four bits of control information (Data Coming, Shutdown, Decode, Hexa or Code B decoding) or eight bits of "Display Input Data" (See Table 9). "Display Input Data" consisting of eight words, eight bits each, is sequenced into the chip memory using a negative-going Write pulse generated with bit 1 of I/O port three. The Code B format was chosen for this application because a code word for display blanking is available in addition to the numbers 0 to 9.

TABLE 9
DISPLAY DECODER/DRIVER CONTROL INPUTS

Input	Pin	Status	Function
<u>Write</u>	8	High	Input Not Latched in Memory
		Low	Input Latched in Memory
Mode	9	High	Load Control Word on <u>Write</u> Pulse
		Low	Load Input Data on <u>Write</u> Pulse
D4	10	High	Normal Operation
		Low	<u>Shutdown</u>
D5	6	High	No Decode
		Low	Decode
D6	5	High	Hexadecimal
		Low	Code B Decoding
D7	7	High	Data Coming
		Low	No Data Coming (<u>D.P.</u> in Data Mode)
Input Data (D0-D7)	12, 11, 13, 14, 10, 6, 5, and 7	High	Loads "One"
		Low	Loads "Zero"

The sequence for loading information into the display driver is as follows (Figure 9): 1) with the Mode bit high, a control word is strobed into the data port with the Write bit; 2) with the Mode bit low, each digit is then sequentially strobed into the data port with the Write bit; 3) further inputs are ignored until the Mode bit is again raised.

LED Display

The four-digit LED display is a Litronix, Inc., DL4530. The four digits are mounted on a printed circuit board where all of the connections necessary for multiplexing the display are brought to the edge of the board. These connections are listed in Table 10. Each digit has seven segments and a right hand decimal point.

Oscillator

The oscillator, which is utilized both for measuring time periods and for generating timed delays with the software, is a Vectron Laboratories, Inc., CO-236 crystal oscillator. The device output is derived from a CMOS gate, but the drive requirement for the computer input port is low enough (10 μ A) that the oscillator can drive the port directly. The frequency of oscillation is 100Hz $\pm$.001 percent with a stability from 0°C to 70°C of $\pm$.0025 percent. Connections for the device are shown in the system schematic of Figure 7.

Liquid Detector Circuits

Each liquid detector circuit utilizes a National Semiconductor Corporation LM1830 bipolar integrated circuit specifically designed for

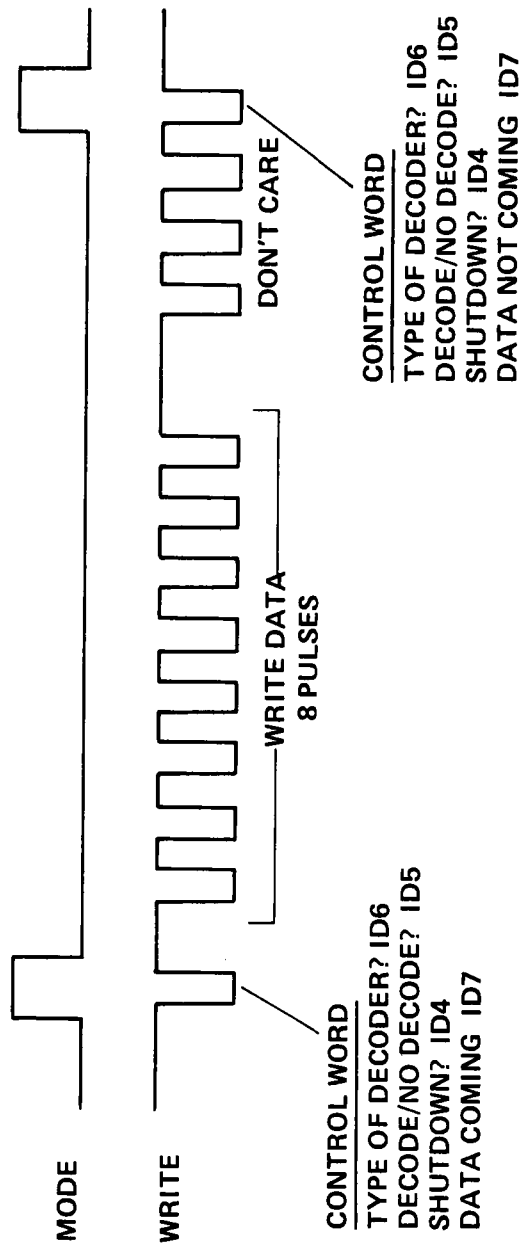


Figure 9. Decoder/Driver Address Sequence

Source: Data Book 1981. Cupertino, California: Intersil, Inc., 1981.

TABLE 10
LED DISPLAY PIN ASSIGNMENTS

Pin	Function
1	Common Anode Digit 1
2	Decimal Point Cathode Digit 1
3	Common Anode Digit 2
4	Decimal Point Cathode Digit 2
5	Segment A Cathode
6	Segment F Cathode
7	Segment E Cathode
8	Segment D Cathode
9	Common Anode Digit 3
10	Decimal Point Cathode Digit 3
11	Segment C Cathode
12	Segment G Cathode
13	Segment B Cathode
14	Common Anode Digit 4
15	Decimal Point Cathode Digit 4

use in fluid detection systems. The circuits generate an approximately 6 kHz signal which is passed through the fluid to be detected, thereby avoiding the plating effects associated with a dc signal. The presence or absence of fluid is determined by comparing the resistance of the fluid between the probes to a reference resistance. When the probe resistance exceeds that of the reference resistance, the filtered oscillator signal switches an open collector output transistor and grounds the output line. Thus, the absence of fluid is indicated by a low output voltage and the presence of fluid is indicated by a high output voltage.

The external parts required with the LM1830 are indicated in the schematic, Figure 7. One external capacitor is required to filter the oscillator signal for switching purposes, one capacitor is required for the internal oscillator circuit, and one blocking capacitor is required to eliminate any dc voltage on the level probe. Two resistors have been used: a pull-up resistor for the open collector output and a potentiometer to set the resistance value at which detection is desired. As set (50 k Ω), the circuit is sensitive enough to detect tap water with the probes separated by several feet.

Interface Circuits

The interface circuits include all of the miscellaneous circuit elements not yet considered. They consist of the manual inputs to the microcomputer, the interrupt interface, and the output circuits to the valve and timing indicator. All are shown in Figure 7.

The manual inputs allow operator control of the flowmeter. A momentary-contact, normally-open switch is utilized to ground input pin 7 and initiate a flow measurement. A momentary-contact, two-position switch is utilized to reset the system. Since the reset input also generates an interrupt request, two spare inverters have been utilized to debounce that input, the reason being that the microcomputer must scan the inputs to determine what device generated the interrupt. If the signal were not stable, it is possible that the computer would not see the signal following the interrupt.

The interrupt interface converts a level change on any of three lines to an inverted interrupt pulse on pin 49 of the microcomputer connector. A 2.2 k Ω resistor and a 1 μ F capacitor are utilized in each line to convert the signal changes to pulses, which are then combined using an AND gate. Since the liquid detector outputs are sufficiently stable when switching, it was not necessary to debounce them as was required for interrupt service with the reset switch. It was necessary to invert the liquid detector outputs.

Two inverters have been utilized as output drivers. Since they will sink 16 mA each, the inverters are used to activate the external devices by pulling them low. One lights an LED to indicate when timing is in progress during a flow measurement and the other activates a solid state relay used to operate the flowmeter valve.

CHAPTER VI

FLOWMETER SOFTWARE

The assembly language code necessary to implement the flowmeter was developed using an Intel microcomputer development system. The following chapter includes both a description of that development system and of the software itself.

The Development System

The Intel system used for software development consisted of an Intellec development system, an Intellec diskette operating system, an ICE-80 in-circuit emulator, a UPP-103 universal PROM programmer, and a system console.

The Intellec microcomputer development system contains a CPU, 64K of random access memory, manual interrupt request switches, and peripheral interfaces. Due to the resident monitor, assembler, and text editor, this unit alone can be used for writing software, but most of the capabilities of the system are realized only through the addition of the other peripherals.

The dual drive diskette operating system provides access to additional software which makes program development much more convenient and also provides mass storage. The additional software is part of the Intel Systems Implementation Supervisor (ISIS-II) and includes the ISIS-II 8080 Macro Assembler, the ISIS-II Linker, the ISIS-II Object Locator, the ISIS-II Library Manager, and the ISIS-II Text Editor.

After a program is written and edited in symbolic 8080 assembly language, the assembler is used to convert the instructions into relocatable object modules. Those modules may be linked to other object files and to Intel library files to form larger modules which are then converted by the locator from relocatable code to absolute code.

The ICE-80 in-circuit emulator connects the Intellec system to a prototype system through a 40-pin connector that plugs into the prototype 8080 socket. With ICE-80 in the prototype system, software can be debugged as it is written, whether or not all of the new hardware is available. Intellec memory and I/O can be substituted for prototype memory and I/O which is not yet available. In addition, ICE-80 software provides the ability to control program execution, and to examine and modify status during emulation.

Once a program has been completed, the universal PROM programmer can be utilized to transfer the code to some form of programmable read-only-memory. The software which controls the transfer of data to the PROM is the Universal PROM Mapper (UPM). With it, data can be manipulated, examined, verified, or transferred from one PROM to another.

Software

Software development for the flowmeter preceded as diagramed in Figure 10. Segments of the program were written in 8080 assembly language using the ISIS-II text editor. The resulting assembly language source code was then converted to a relocatable module with the ISIS-II assembler. That relocatable object module was linked to routines in the Intel Floating-Point Arithmetic Library to provide various math functions

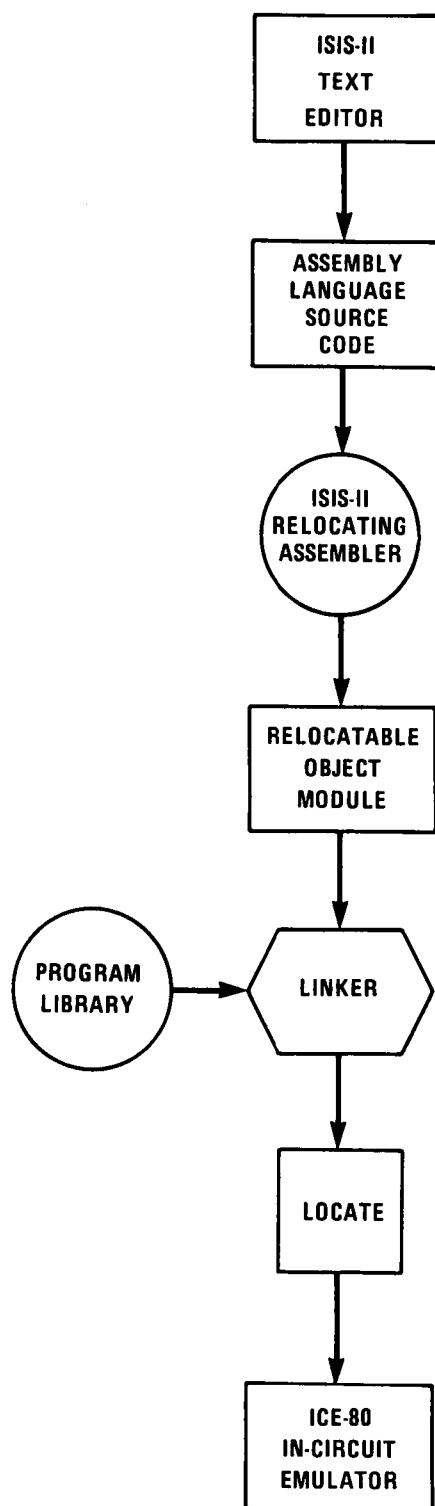


Figure 10. Program Development Sequence

Source: Data Catalog 1977. Santa Clara, California: Intel Corp., 1977.

and then located as the appropriate absolute code. Debugging was completed with ICE-80.

The software can be divided into two basic sections, the first controlling the flowmeter up through the point that a measurement is initiated, and the second controlling all operations from that time until a resulting flow rate is displayed. Functional flow charts for the two sections are shown in Figure 11 and Figure 12 respectively. The only path for reaching the second section of the software is through an interrupt generated either by the reset button, the lower liquid detector, or the upper liquid detector. More detailed flow charts are shown in Appendix B and the assembled code is shown in Appendix C.

Tests for error conditions are made at various points in the program to assist in troubleshooting any problems that might develop. When a problem does occur, an error code from Table 11 will be displayed. All of the error codes are flashed on and off except when oscillator failure is detected. Since the oscillator is used to time the flashing rate, its failure means 1.1.1.1. would be displayed without flashing. The flashing codes are displayed as four identical numbers with four decimal points for two seconds, and then the display indicates only the four decimal points for one-half second before repeating.

When power is applied to the flowmeter, an interrupt is generated which starts the program at address zero. It is different from those interrupts generated externally and utilized in later program control in that the external interrupts vector the program to hexadecimal address 38. Upon receiving the power-up interrupt, the system is first

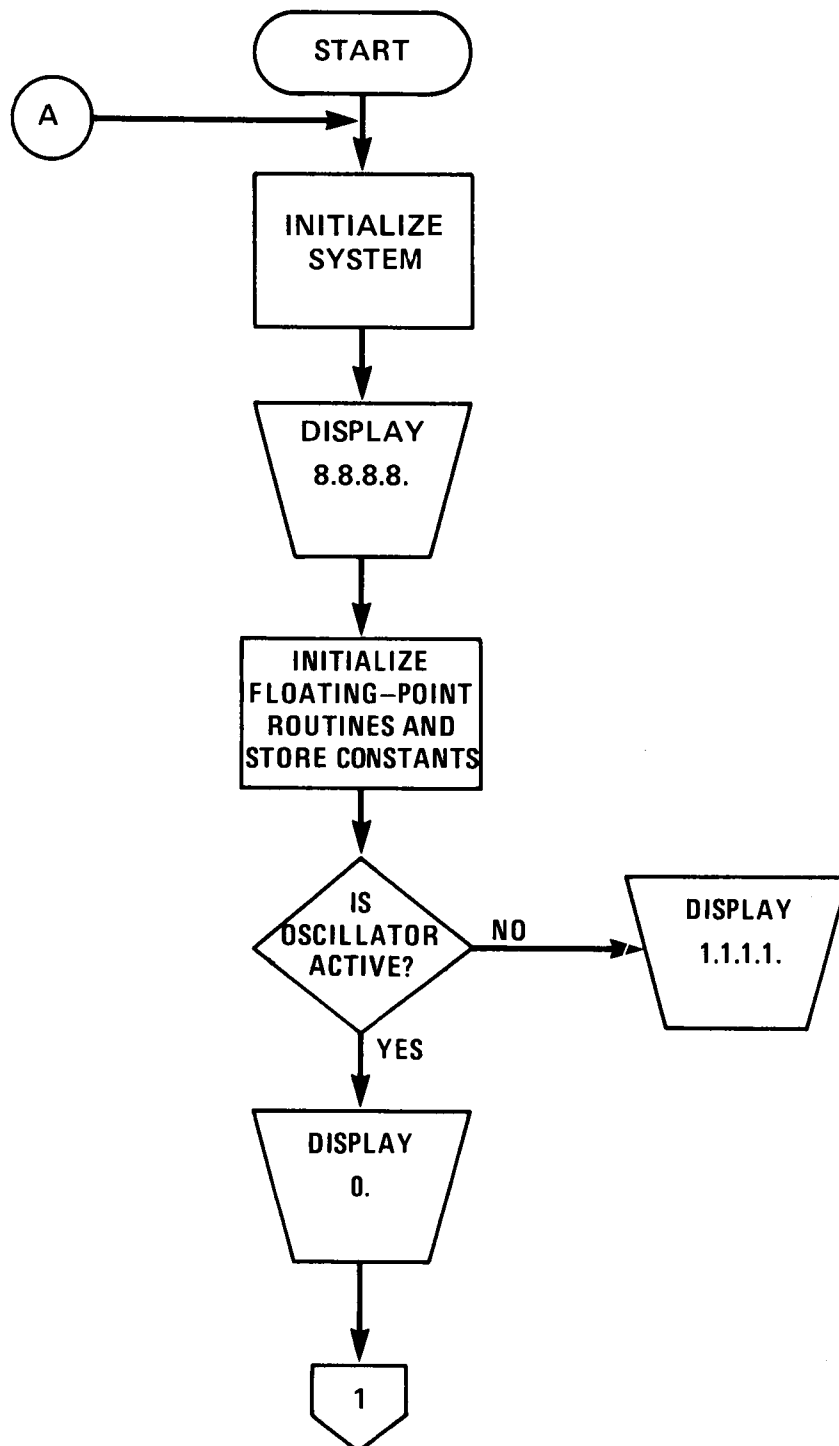


Figure 11. System Flow Chart, Segment One

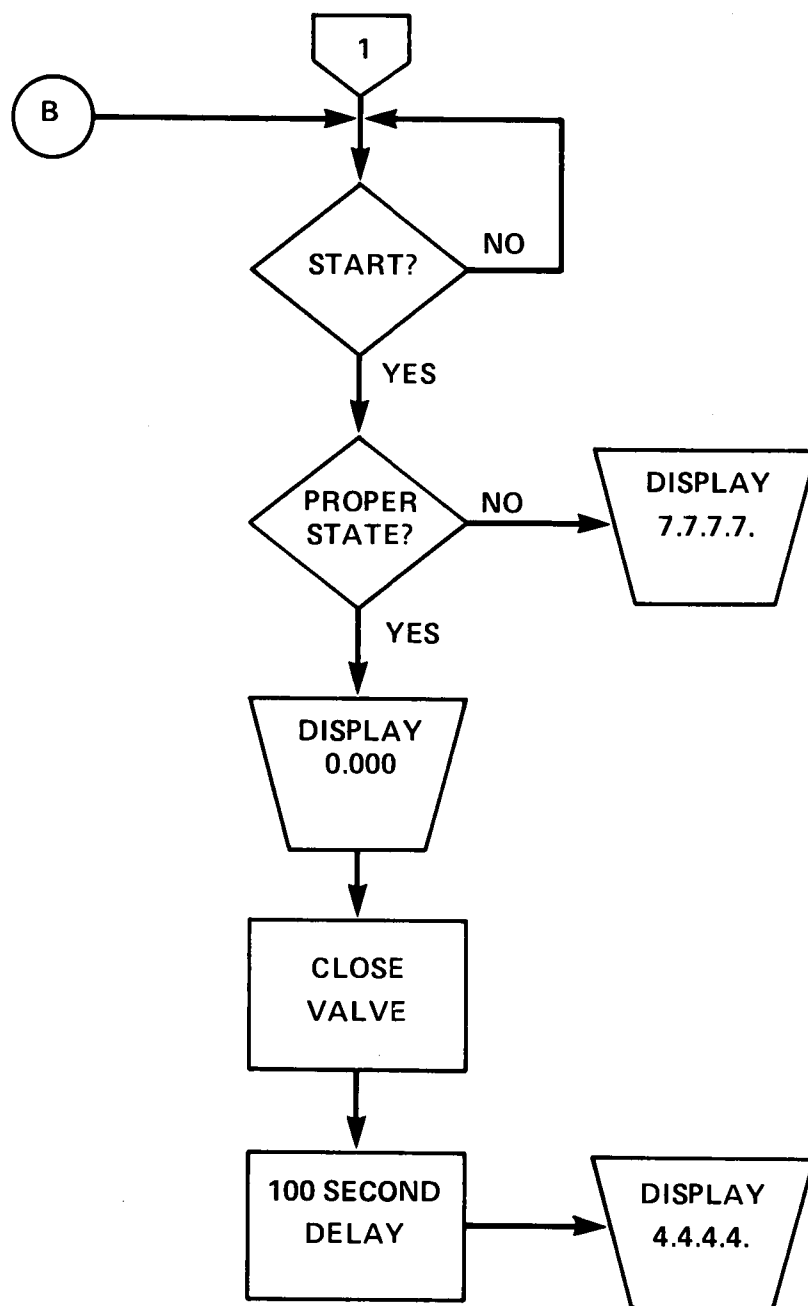


Figure 11. (Continued)

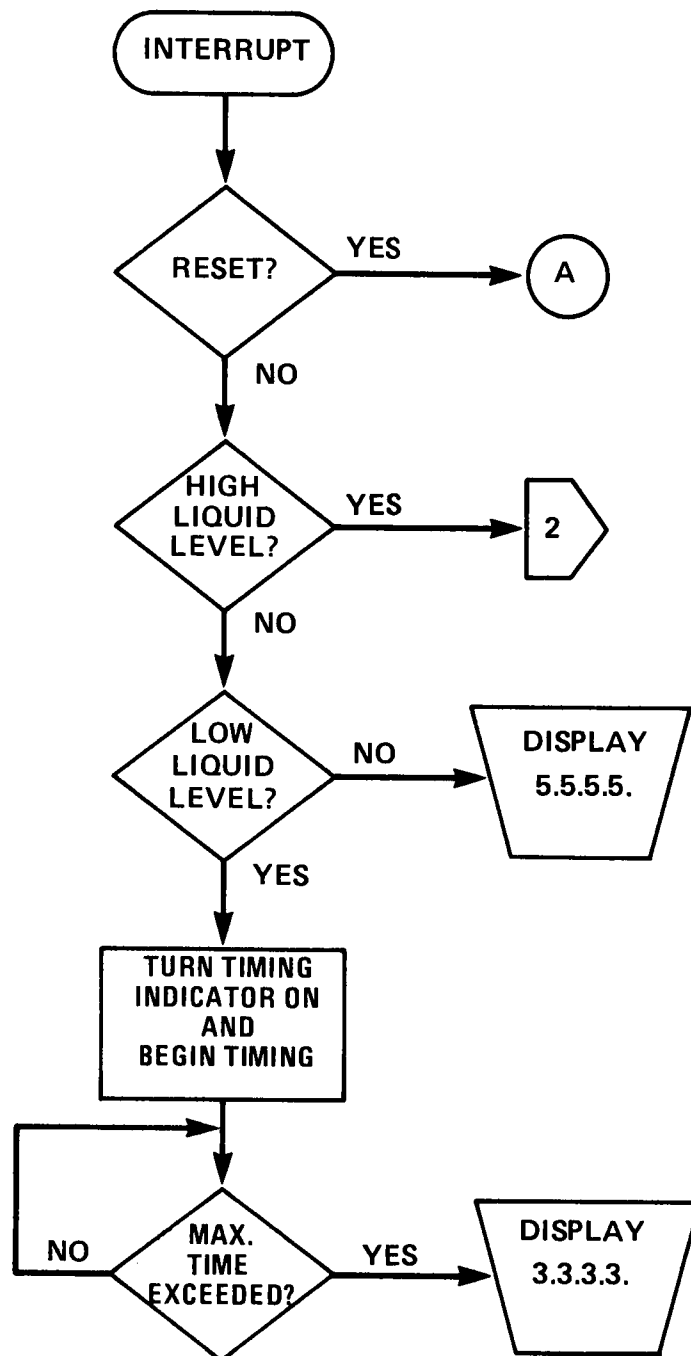


Figure 12. System Flow Chart, Segment Two

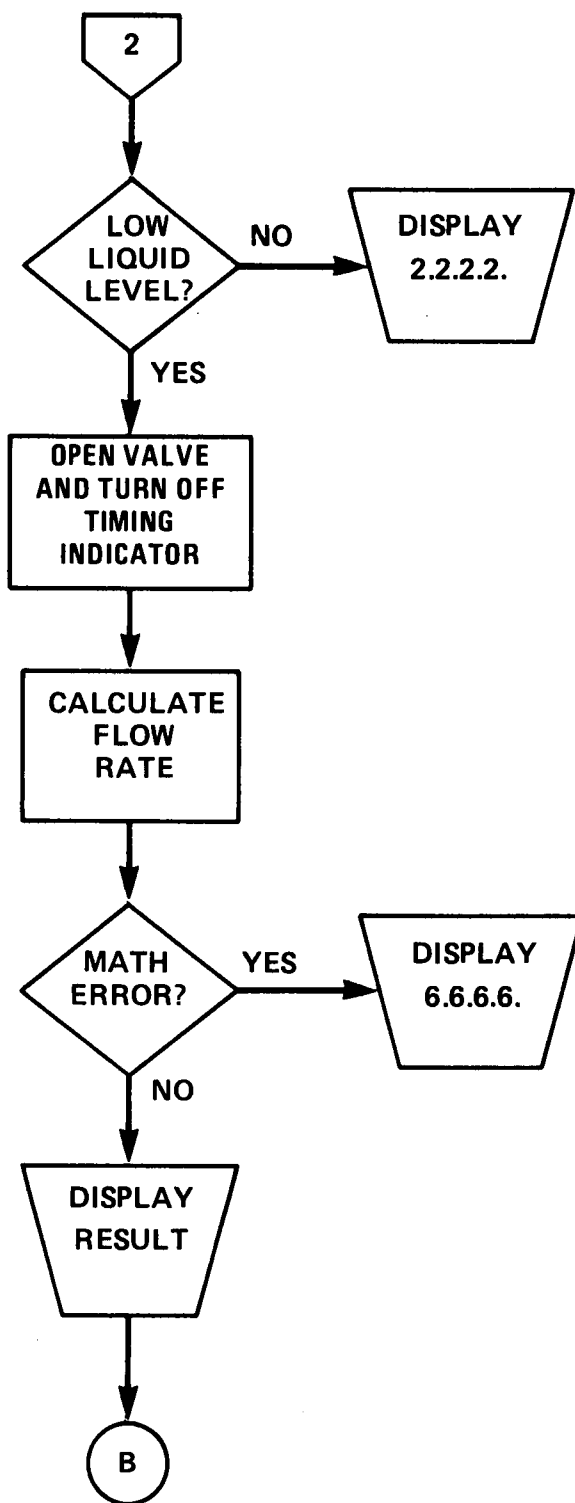


Figure 12. (Continued)

TABLE 11
DIAGNOSTIC ERROR CODES

Code	Error Condition
1.1.1.1.	Oscillator not functioning
2.2.2.2.	High liquid level sensed but not low
3.3.3.3.	Low liquid level sensed but not high
4.4.4.4.	Neither high nor low liquid level sensed
5.5.5.5.	False Interrupt
6.6.6.6.	Math Error
7.7.7.7.	Liquid level sensed before start

initialized by setting up the I/O ports to those modes described in Chapter V, then all display segments are illuminated (8.8.8.8.) for two seconds to indicate that they are functioning properly. While 8.8.8.8. is displayed, the floating-point software is initialized and the three constants required to calculate a flow rate from the model are stored as floating-point numbers.

Once the system is initialized, the oscillator signal is analyzed to verify that it is indeed oscillating. If oscillations are not detected, 1.1.1.1. is displayed. If oscillations are detected, then 0. is displayed and the program enters a loop to wait for the start signal.

After the start button is pushed, the status of the liquid detector outputs are checked to verify that they are low. Error code 7.7.7.7. is displayed if one of the detectors indicates the presence of fluid at this point. Assuming everything is satisfactory, the display is changed to 0.000 to indicate a flow measurement has been initiated and the flowmeter valve is closed. If an interrupt is not received within 100 seconds to indicate that fluid has reached one of the liquid detectors, then the measurement is discontinued and 4.4.4.4. is displayed.

Upon receiving an interrupt request, control passes to the second program section where the possible interrupt requesting devices are scanned to determine the source of the interrupt. The reset button has the highest priority, followed by the high liquid detector and the low liquid detector. If the source of the interrupt is not found, then error code 5.5.5.5. is displayed. Reset returns program control to the start and the system is completely reinitialized as though power had just been applied.

An interrupt generated by the lower liquid detector results in the illumination of the timing indicator and the start of an elapsed time measurement. If the upper liquid detector does not detect the fluid within approximately four minutes from the time it was detected by the lower probe, then 3.3.3.3. is displayed and the measurement is discontinued.

When fluid is detected by the upper liquid detector, the status of the lower liquid detector is immediately checked. Error code 2.2.2.2. is displayed and the measurement is discontinued if the upper

liquid detector interrupts without the lower liquid detector indicating the presence of liquid. If the status is satisfactory, then the valve is opened, the timing indicator is turned off, and the flow rate is calculated.

Immediately following the flow calculations, the floating-point error registers are examined to determine whether any math errors occurred during the calculations. Any of the following five errors will cause 6.6.6.6. to be displayed: invalid operand, overflow error, underflow error, attempted division by zero, or domain error. If no math errors are detected, the calculated flow rate is displayed and the program returns to wait for the start button to be pressed again.

The Floating-Point Arithmetic Library, which is utilized to provide floating-point procedures in the program, is supplied on the ISIS-II diskette. It provides such operations as addition, subtraction, division, multiplication, and conversion between decimal and binary floating-point representations. The error handler routine used to check for math errors is also provided. They all reside in an ISIS-II library file (FPAL.LIB) in object code form and must be linked to a calling program with the ISIS-II Linker. To call them from the program, they must also be declared as external using the EXTRN directive. The statements required to link and locate a program are shown with the assembled code in Appendix C.

CHAPTER VII

SUMMARY

A microcomputer-based flowmeter was developed to meter the average liquid phase flow in a two-phase fluid, where the two phases are liquid and gas. An experimental system was set up to test the flowmeter and to develop a mathematical model for the device. The resulting experimental model fits the data with a prediction error of less than 0.2 percent of flow rate over the tested span of zero to five gallons per minute. A microcomputer utilizes the model to make all flow rate calculations, and additionally, it controls flowmeter functions and displays diagnostic information.

Although the flowmeter was developed for two-phase flow, it will function equally well for liquid flow alone. It would be particularly suited for use as a calibration device for other flowmeters or for other applications where a high degree of precision is necessary. Requirements are that the metered fluid must be conductive enough for the liquid detectors to sense the fluid and should not be highly viscous. A fluid with high viscosity would not flow into the annular space of the flowmeter as easily and might create problems. It could also result in a significant quantity of the fluid being retained on the walls after a measurement.

As configured, the flowmeter program stores the constants used for flow calculations by converting ASCII characters to floating-point numbers. This was a programming convenience which utilized a library

program available for the purpose. In systems where it might be necessary to reduce the length of the program, this procedure could be eliminated and the memory requirements reduced from the current 5732 bytes to less than 4096 bytes. In that case, the constants would have to be stored directly as integer or floating-point constants.

With the current software, the flowmeter makes flow measurements only "on demand," but if required, the program could easily be altered to accommodate automatic measurements. This change could be implemented in a couple of ways. One method would be to interface the flowmeter to a central computer which would request flow measurements as needed. The other method would be to program the flowmeter to periodically and automatically measure flow rates. The results might then be communicated to a central computer, a data acquisition system, or the LED display.

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APPENDICES

APPENDIX A

Table A-1

TEST RESULTS FOR DAY 1

Run No.	Nominal Flow Rate (gpm)	Flowmeter (F) or Calibrator (C)	Flowmeter Output (Volts)	Water Temp. Range (°F)	Water Density (lb/gal)	Elapsed Time (Sec)	Actual Flow Rate (gpm)	Average Turbine Freq. (Hz)
1	1.1	C	3.457	73.50-73.79	8.3159	266.9600	1.0788	297.54
2	1.1	C	3.457	74.18-74.40	8.3152	266.8227	1.0795	297.03
3	1.1	F	3.457	74.45-74.61	8.3149	197.3100	-	-
4	1.1	F	3.457	74.59-74.74	8.3148	197.1100	-	-
5	4.5	F	7.973	75.23-75.37	8.3141	46.5500	-	-
6	4.5	C	7.973	76.75-76.76	8.3124	64.1662	4.4903	1210.50
7	4.5	C	7.973	77.48-77.49	8.3115	64.0314	4.5002	1210.80
8	4.5	F	7.973	77.99-78.00	8.3109	46.5800	-	-
9	2.0	C	4.744	78.26-78.37	8.3106	141.1450	2.0418	556.22
10	2.0	F	4.744	78.33-78.39	8.3105	103.6700	-	-
11	2.0	F	4.744	78.36-78.42	8.3105	103.6500	-	-
12	2.0	C	4.744	78.42-78.52	8.3104	141.1910	2.0411	556.30
13	2.9	F	5.871	78.58-78.61	8.3102	72.8800	-	-
14	2.9	F	5.871	78.63-78.66	8.3102	72.8800	-	-
15	2.9	C	5.871	78.67-78.72	8.3101	99.6835	2.8912	784.30
16	2.9	C	5.871	78.71-78.78	8.3101	99.6938	2.8909	784.44
17	3.8	F	7.070	78.96-78.99	8.3098	55.1000	-	-
18	3.8	C	7.070	79.13-79.17	8.3096	75.7673	3.8040	1026.99
19	3.8	F	7.070	79.23-79.26	8.3094	55.0800	-	-
20	3.8	C	7.070	79.33-79.37	8.3093	75.6082	3.81215	1027.12

Table A-2

TEST RESULTS FOR DAY 2

Run No.	Nominal Flow Rate (gpm)	Flowmeter(F) or Calibrator(C)	Flowmeter Output (Volts)	Water Temp. Range (°F)	Water Density (lb/gal)	Elapsed Time (Sec)	Actual Flow Rate (gpm)	Average Turbine Freq. (Hz)
21	3.8	F	7.070	74.30-74.33	8.3152	55.1400	-	-
22	3.8	F	7.070	74.50-74.54	8.3149	55.0900	-	-
23	3.8	C	7.070	74.78-74.82	8.3146	75.7651	3.8018	1027.80
24	3.8	C	7.070	75.01-75.05	8.3144	75.8091	3.8001	1028.00
25	3.8	F	7.070	75.34-75.37	8.3140	55.1600	-	-
26	3.8	C	7.070	75.52-75.56	8.3138	75.7265	3.8041	1028.30
27	3.8	F	7.070	75.91-75.93	8.3134	55.1300	-	-
28	3.8	C	7.070	76.08-76.11	8.3132	75.6688	3.8073	1028.00
29	1.1	C	3.457	76.60-76.81	8.3124	267.6706	1.0764	296.75
30	1.1	F	3.457	76.68-76.81	8.3124	197.3300	-	-
31	1.1	F	3.457	76.75-76.89	8.3123	197.5100	-	-
32	1.1	C	3.457	76.84-77.04	8.3122	267.1297	1.0786	296.57
33	1.1	C	3.457	76.91-77.06	8.3121	268.5038	1.0731	296.60
34	1.1	C	3.457	76.99-77.14	8.3120	267.8948	1.0756	296.54
35	1.1	F	3.457	77.08-77.21	8.3119	197.5800	-	-
36	1.1	F	3.457	77.16-77.29	8.3118	197.6200	-	-

Table A-2 (Continued)

Run No.	Nominal Flow Rate (gpm)	Flowmeter or Calibrator (F) (C)	Flowmeter Output (Volts)	Water Temp. Range (°F)	Water Density (lb/gal)	Elapsed Time (Sec)	Actual Flow Rate (gpm)	Average Turbine Freq. (Hz)
37	2.9	C	5.870	77.47-77.52	8.3115	99.7741	2.8880	784.13
38	2.9	F	5.870	77.56-77.60	8.3114	72.9800	-	-
39	2.9	C	5.870	77.63-77.68	8.3113	99.9511	2.8830	783.82
40	2.9	F	5.870	77.75-77.78	8.3112	72.9600	-	-
41	2.9	F	5.870	77.84-77.87	8.3111	72.9800	-	-
42	2.9	F	5.870	77.93-77.96	8.3110	72.9200	-	-
43	2.9	C	5.870	78.00-78.04	8.3109	100.0166	2.8813	783.89
44	2.9	C	5.870	78.07-78.12	8.3108	99.7618	2.8887	783.68
45	2.0	F	4.743	78.22-78.27	8.3106	103.8600	-	-
46	2.0	C	4.743	78.24-78.31	8.3106	141.2742	2.0399	555.98
47	2.0	F	4.743	78.28-78.33	8.3106	103.8600	-	-
48	2.0	C	4.743	78.32-78.38	8.3105	141.1702	2.0414	555.97
49	2.0	C	4.743	78.35-78.42	8.3105	141.2926	2.0397	555.86
50	2.0	F	4.743	78.41-78.46	8.3104	103.8800	-	-
51	2.0	F	4.743	78.45-78.50	8.3104	103.7800	-	-
52	2.0	C	4.743	78.48-78.55	8.3103	141.4431	2.0375	555.76
53	4.5	C	7.970	80.12-80.13	8.3083	64.2057	4.4897	1209.90
54	4.5	C	7.970	80.39-80.40	8.3080	64.1675	4.4925	1210.20
55	4.5	F	7.970	81.07-81.10	8.3071	46.6100	-	-
56	4.5	F	7.970	81.23-81.25	8.3069	46.5700	-	-
57	4.5	F	7.970	81.40-81.43	8.3067	46.6100	-	-
58	4.5	C	7.970	81.63-81.64	8.3064	64.2268	4.4893	1209.40
59	4.5	C	7.970	81.89-81.90	8.3060	64.2181	4.4901	1209.90
60	4.5	F	7.970	82.06-82.07	8.3058	46.5800	-	-

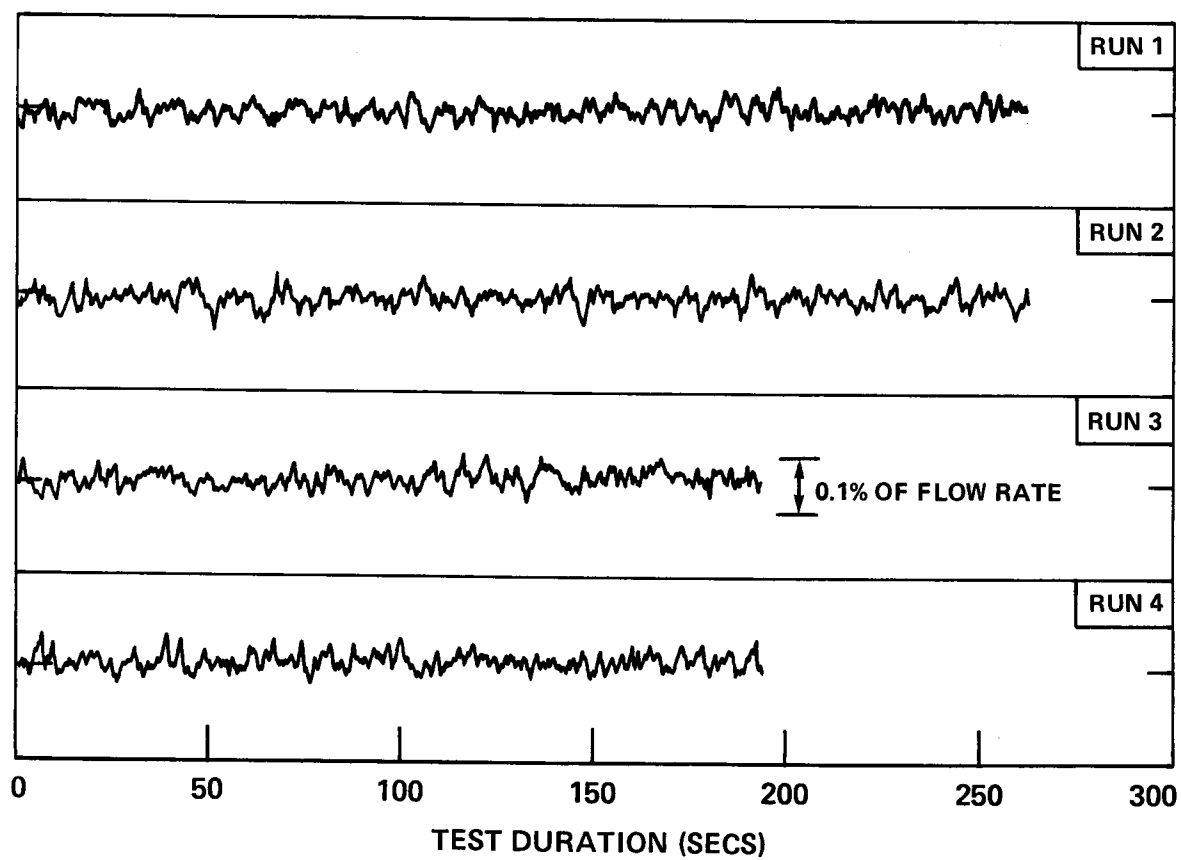


Figure A-1. Flow Records for Day 1

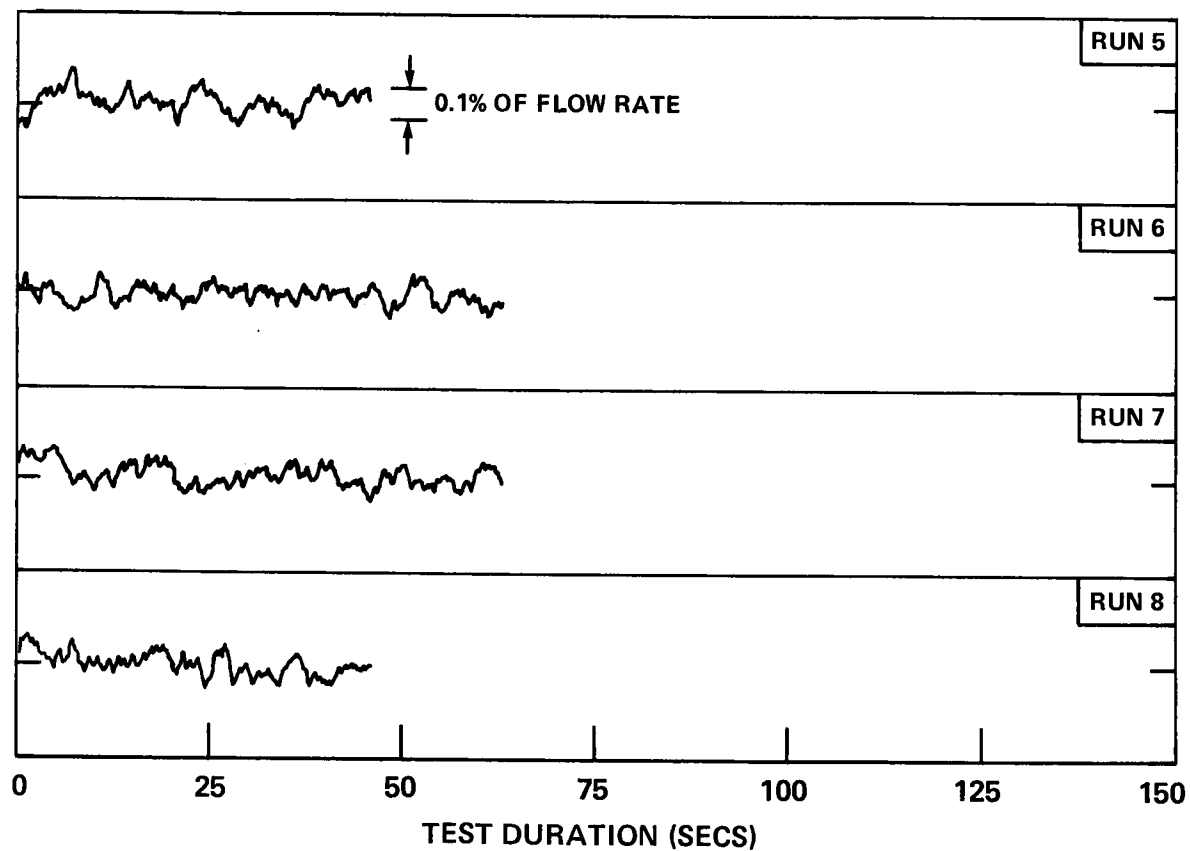


Figure A-1. (Continued)

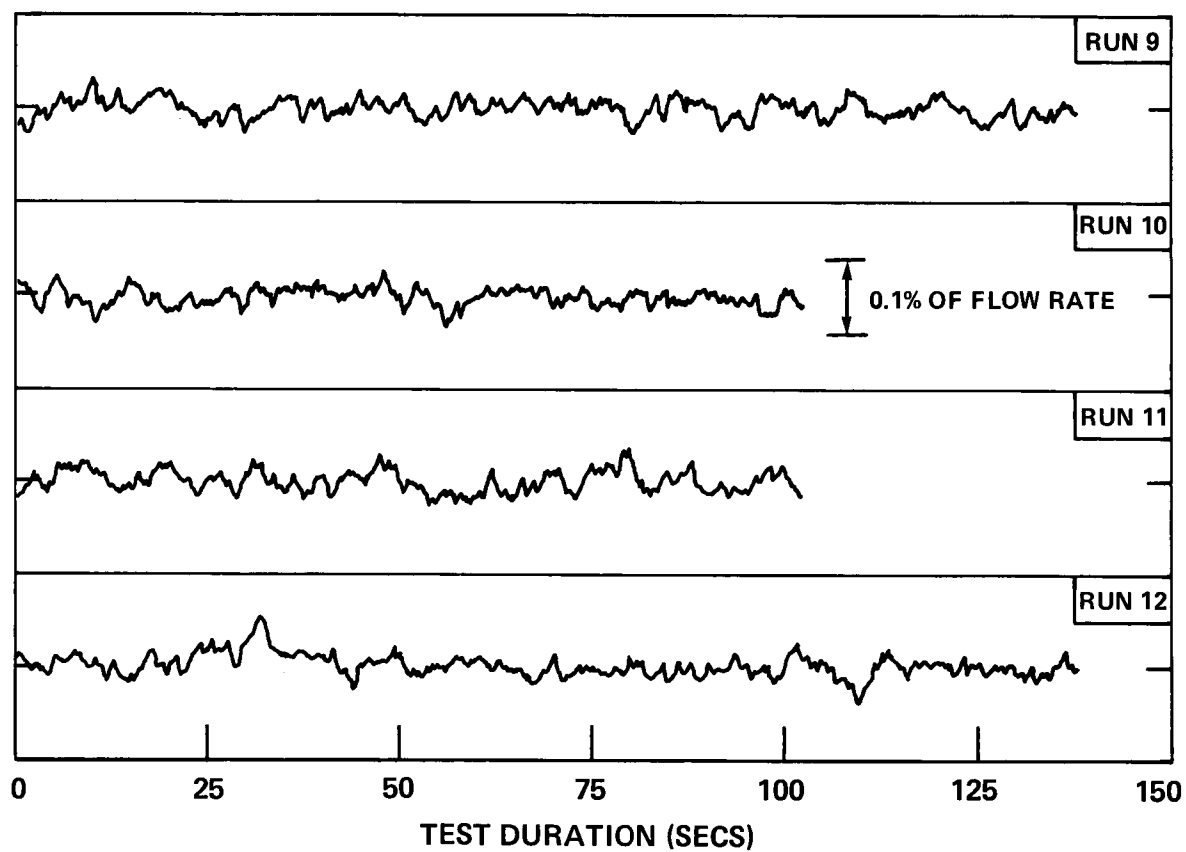


Figure A-1. (Continued)

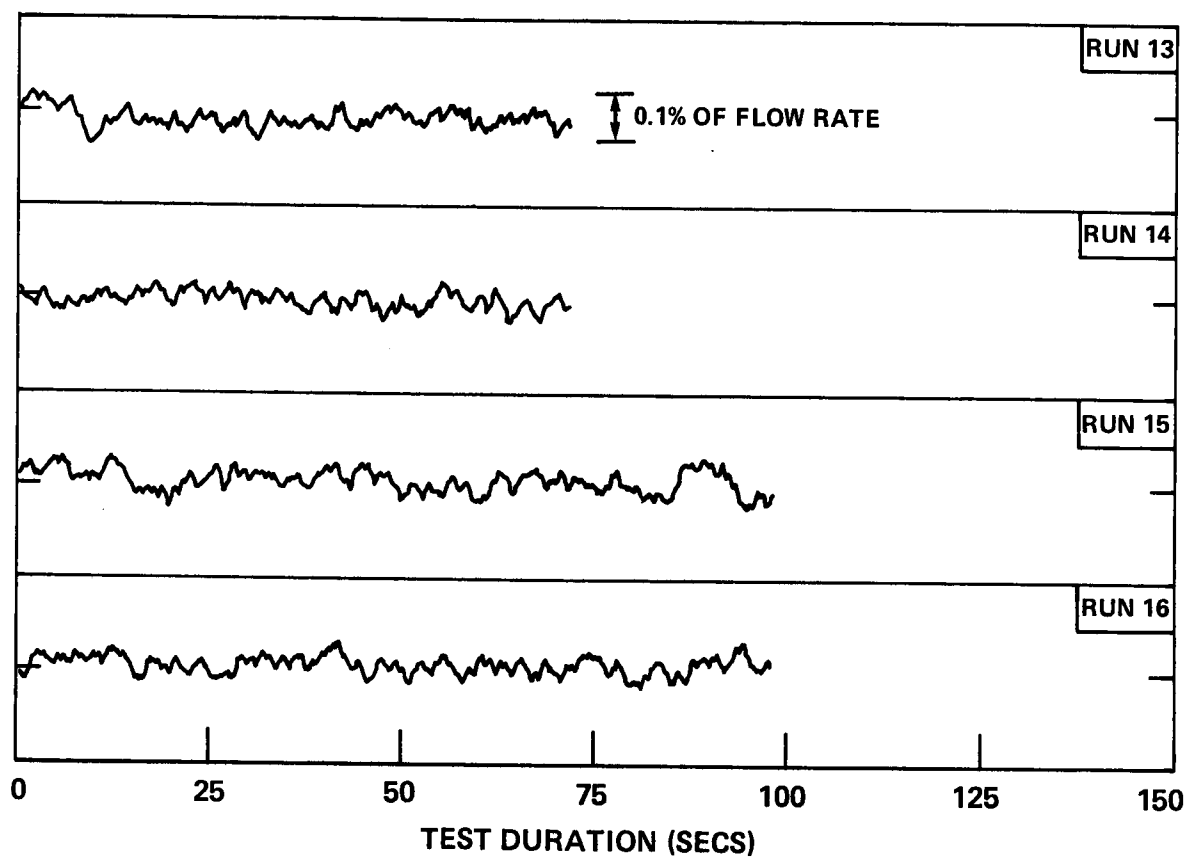


Figure A-1. (Continued)

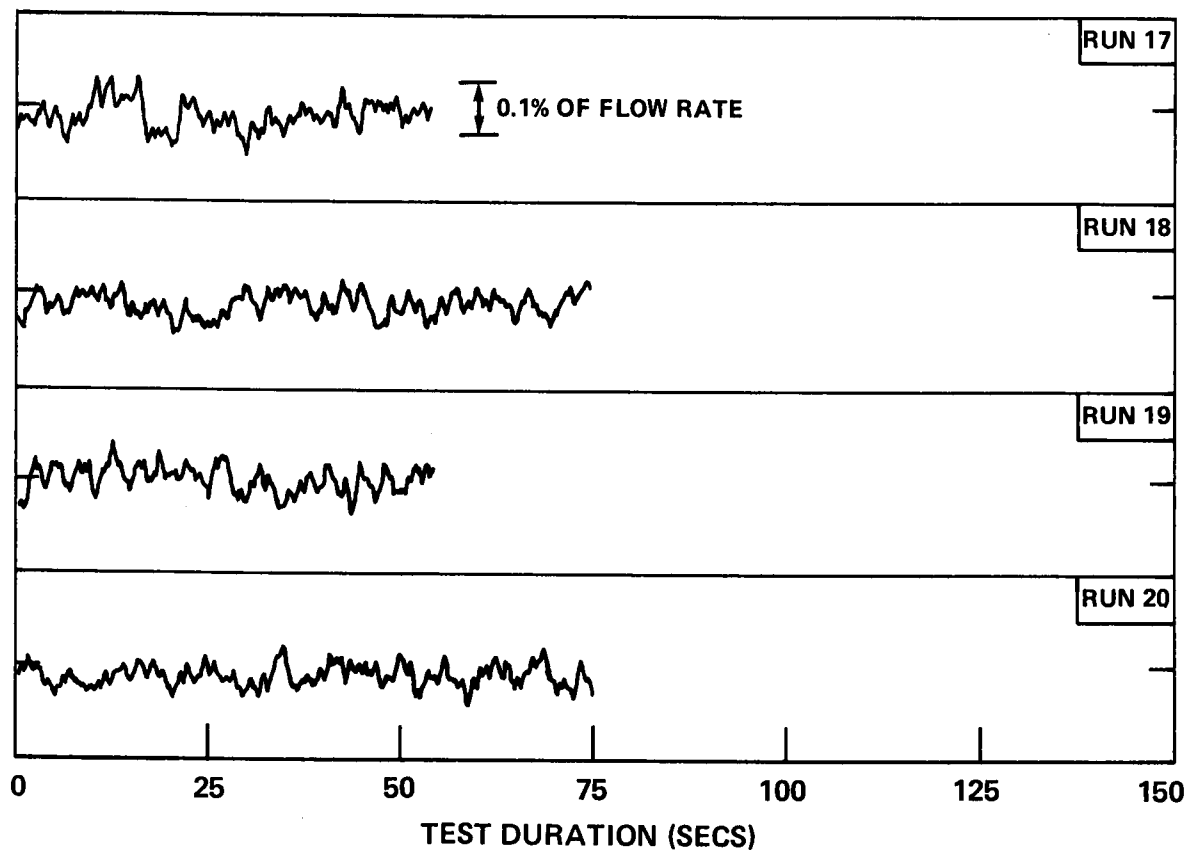


Figure A-1. (Continued)

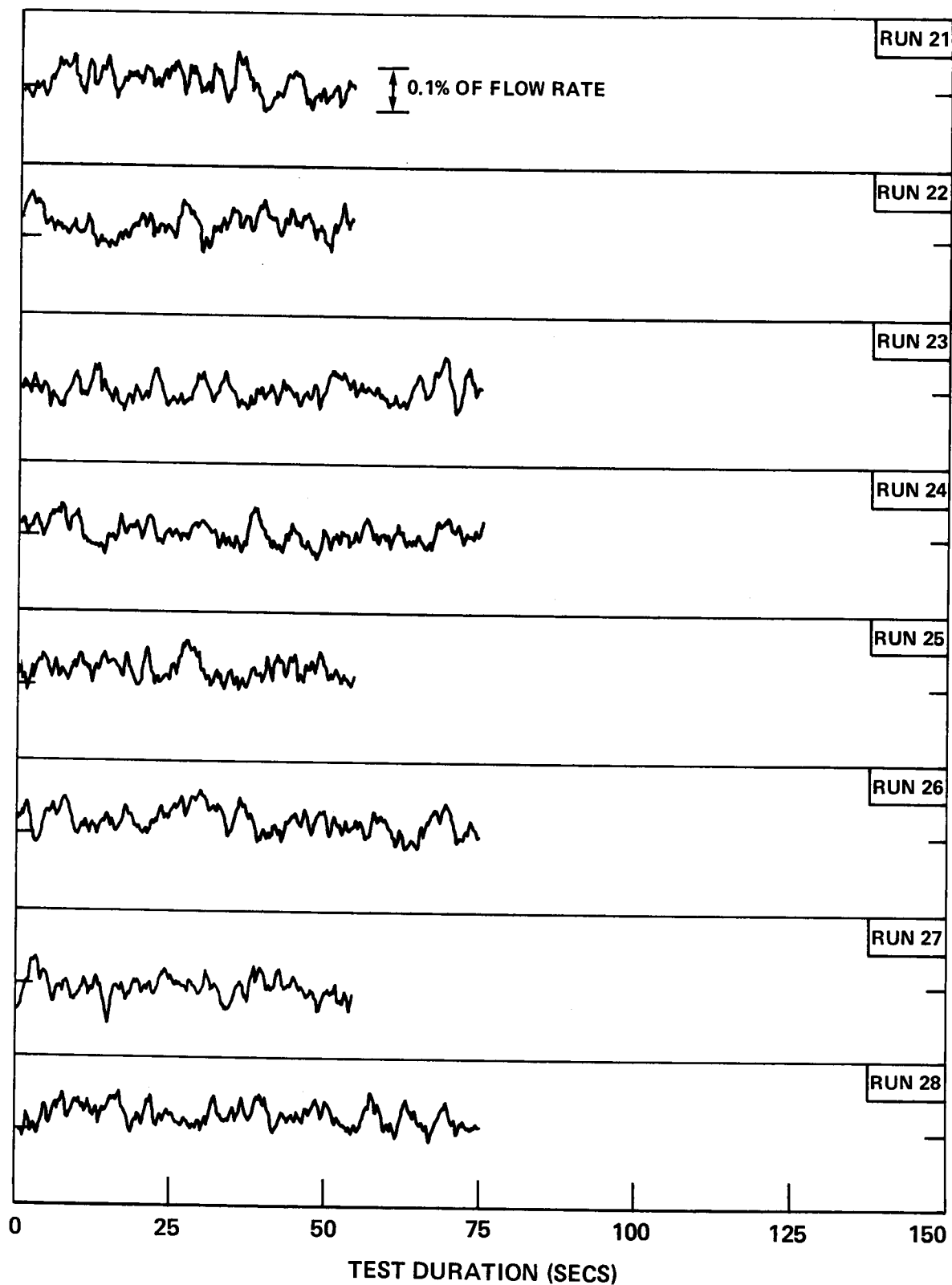


Figure A-2. Flow Records for Day 2

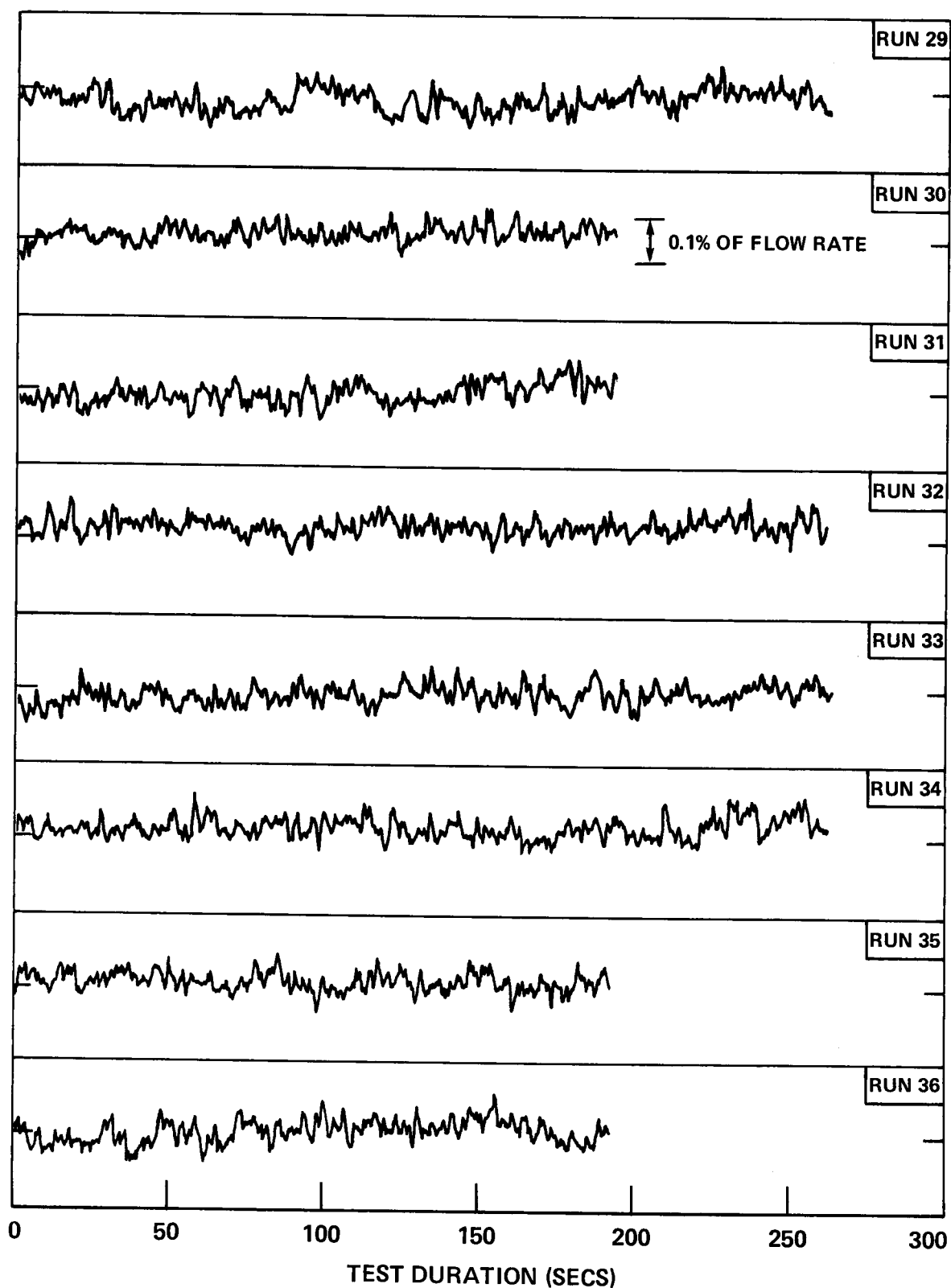


Figure A-2. (Continued)

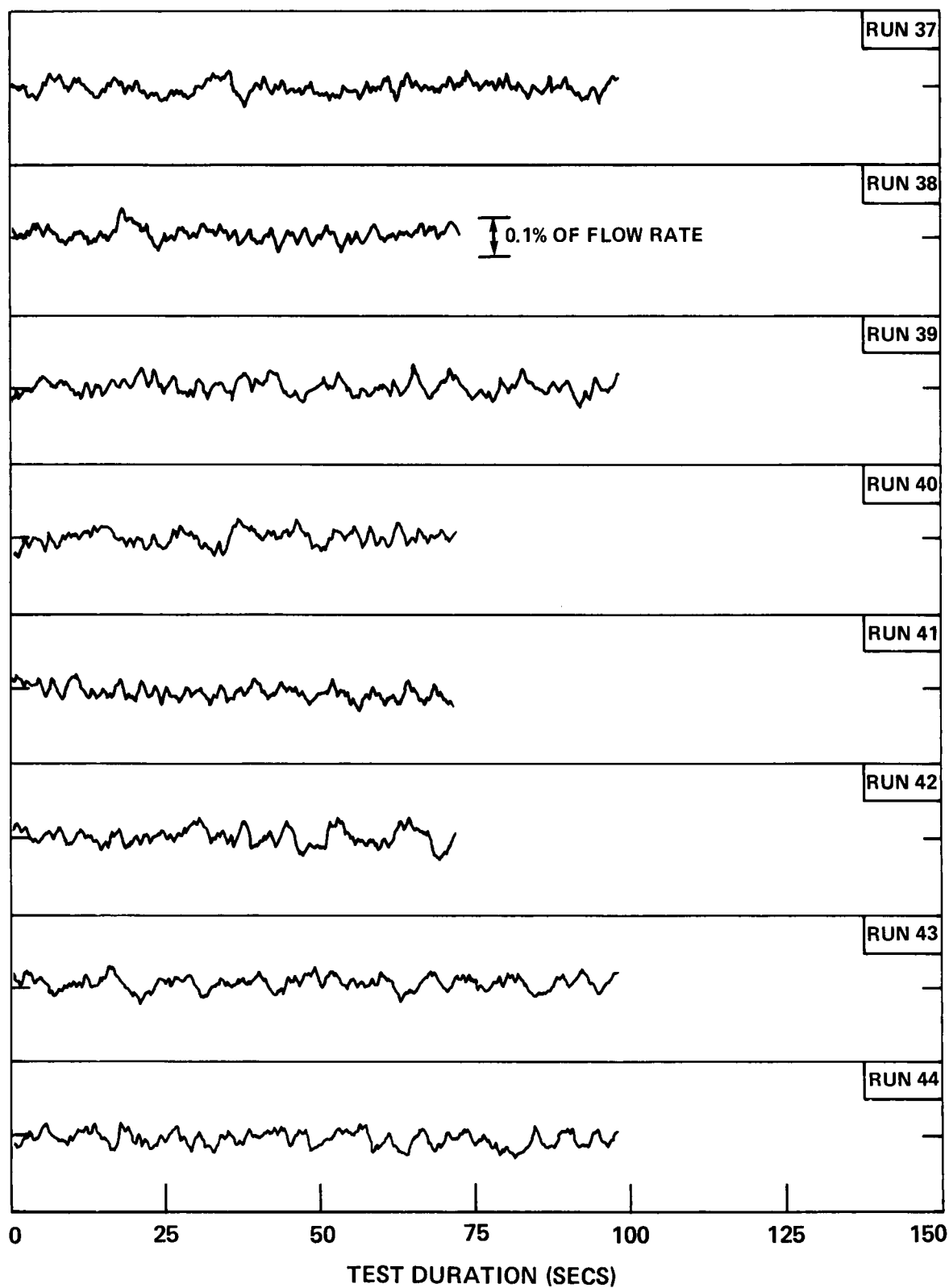


Figure A-2. (Continued)

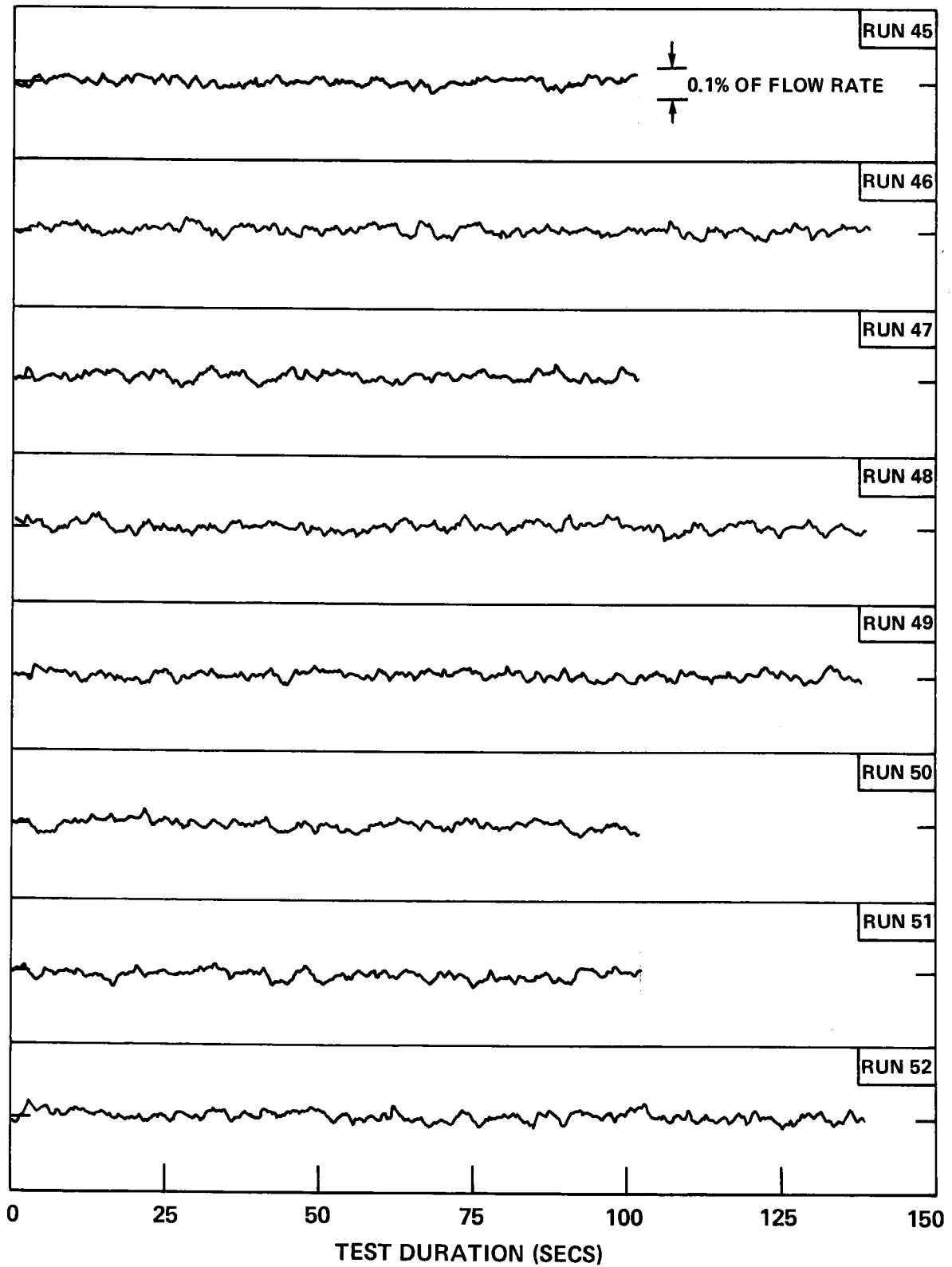


Figure A-2. (Continued)

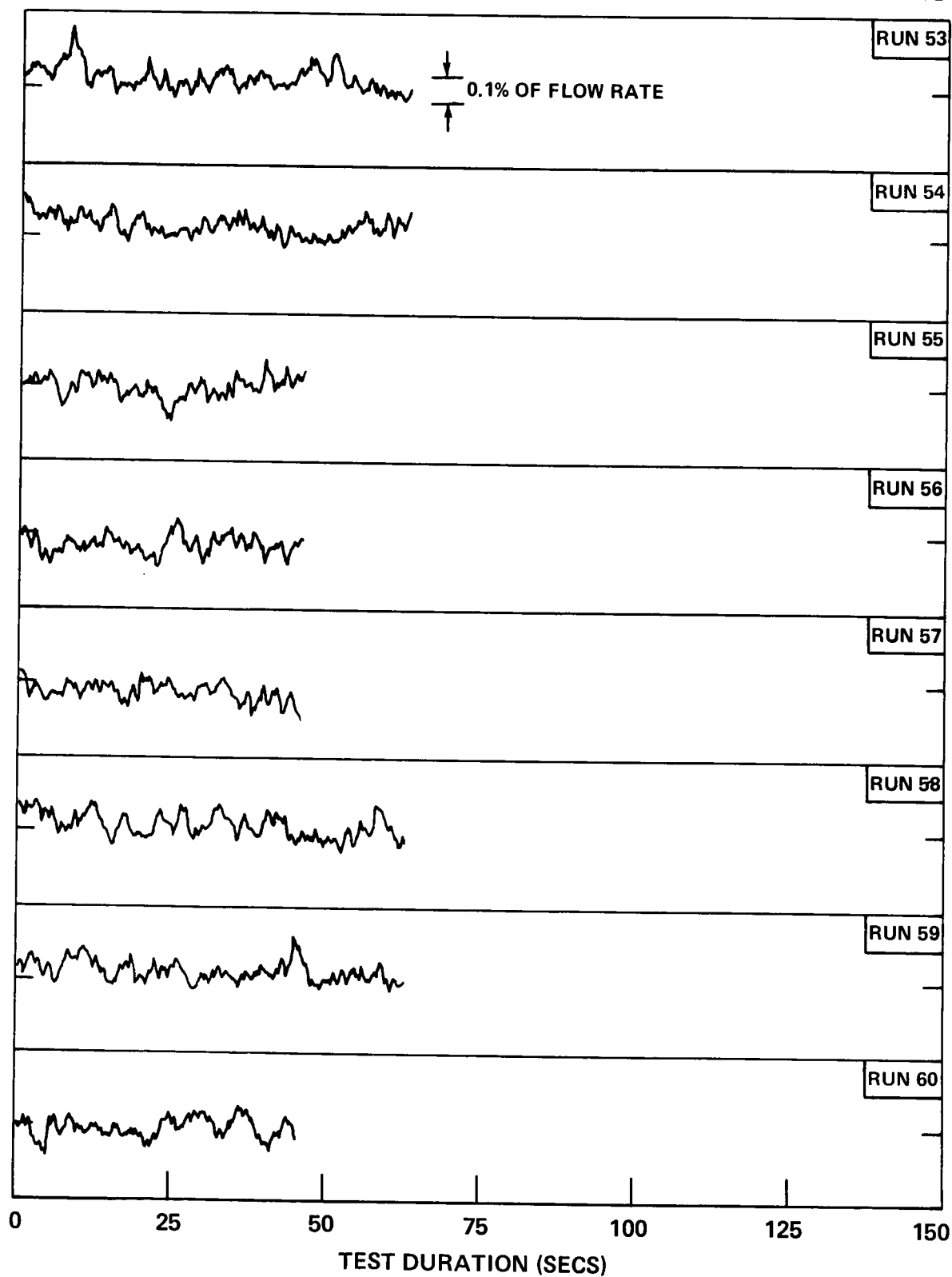


Figure A-2. (Continued)

APPENDIX B

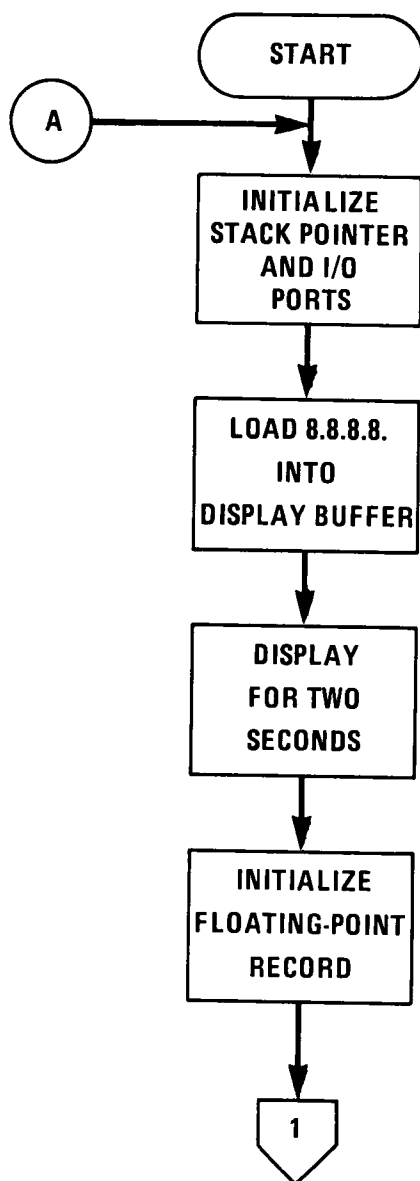


Figure B-1. Detailed System Flow Charts

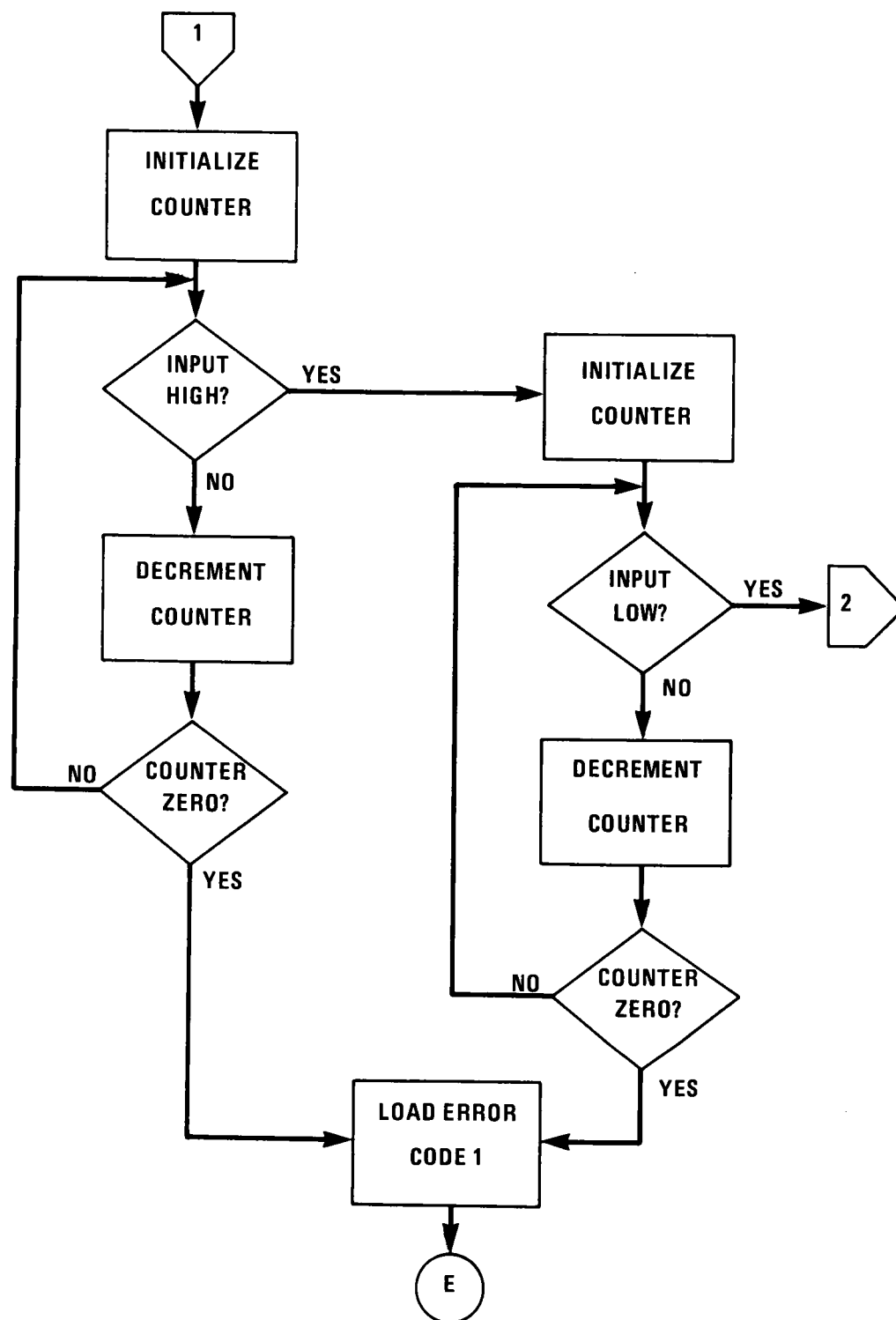


Figure B-1. (Continued)

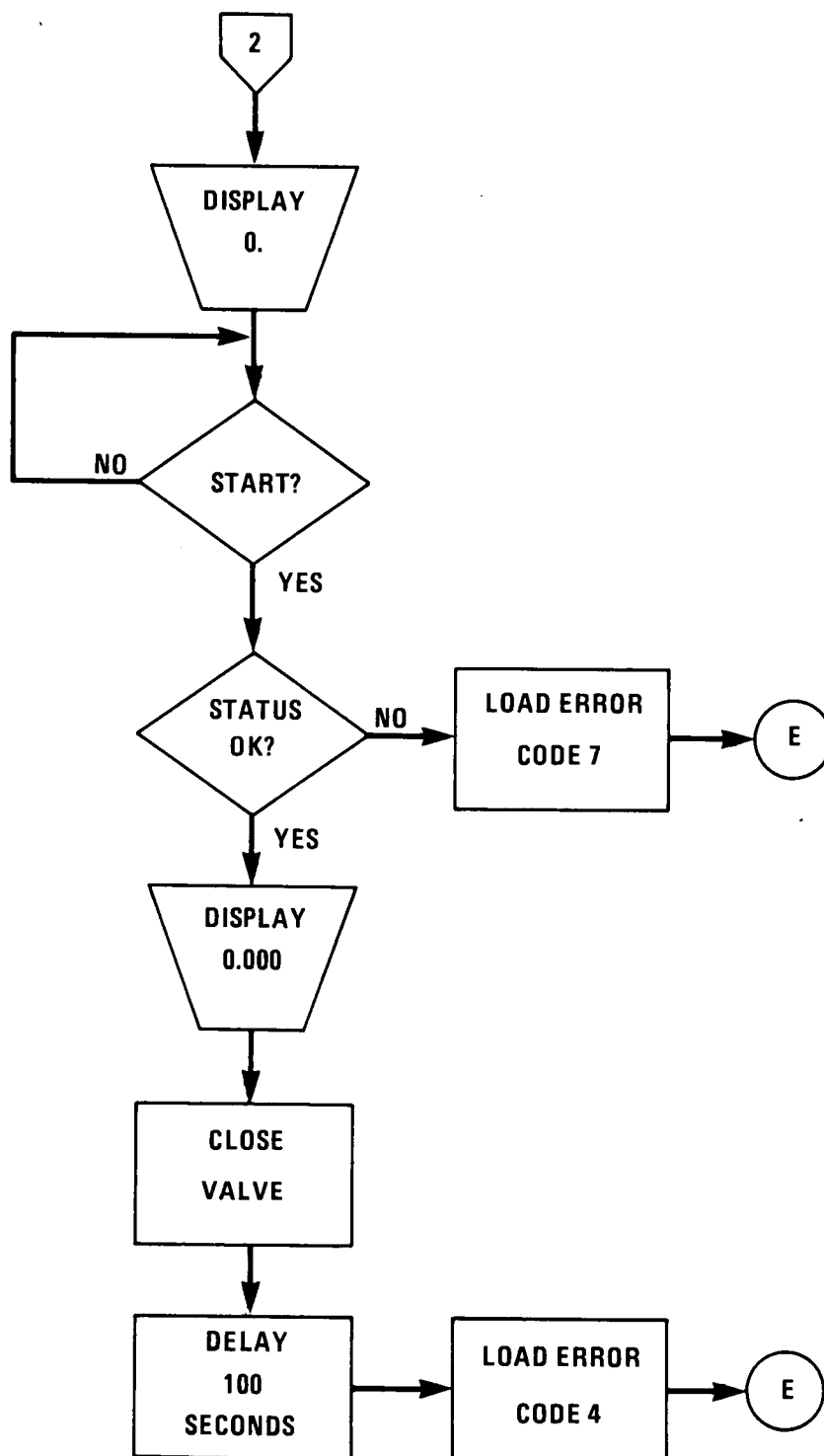


Figure B-1. (Continued)

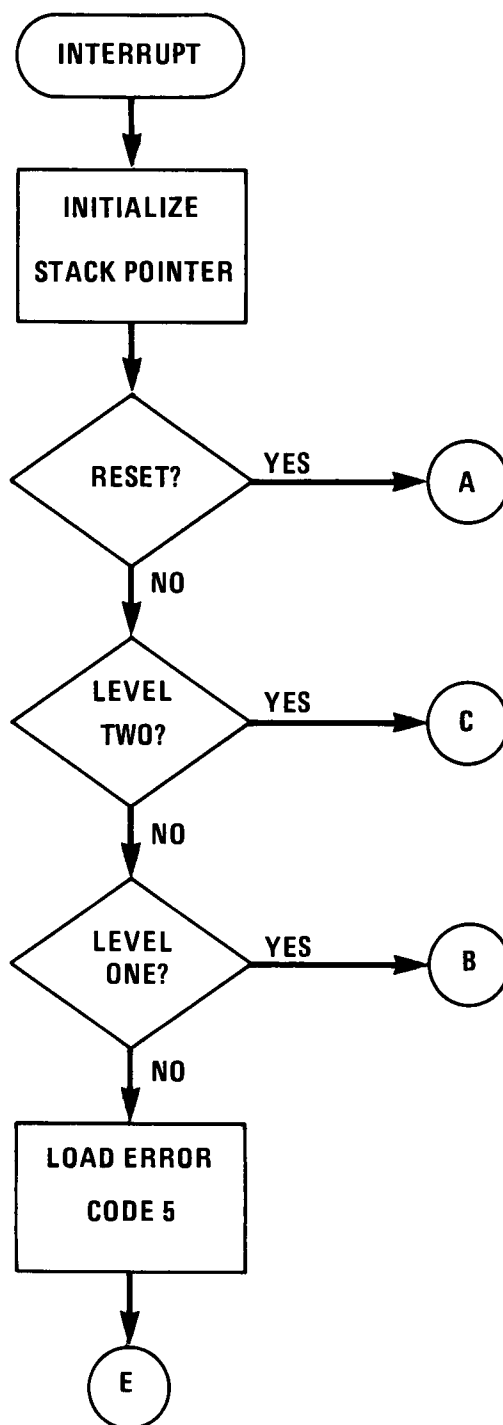


Figure B-1. (Continued)

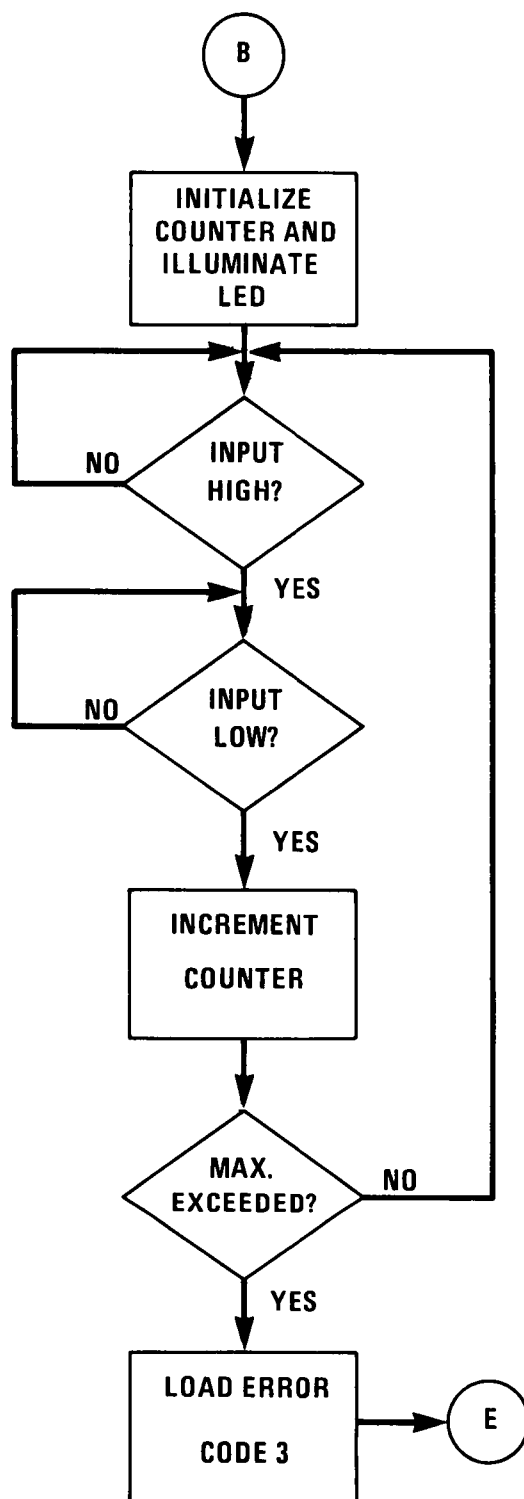


Figure B-1. (Continued)

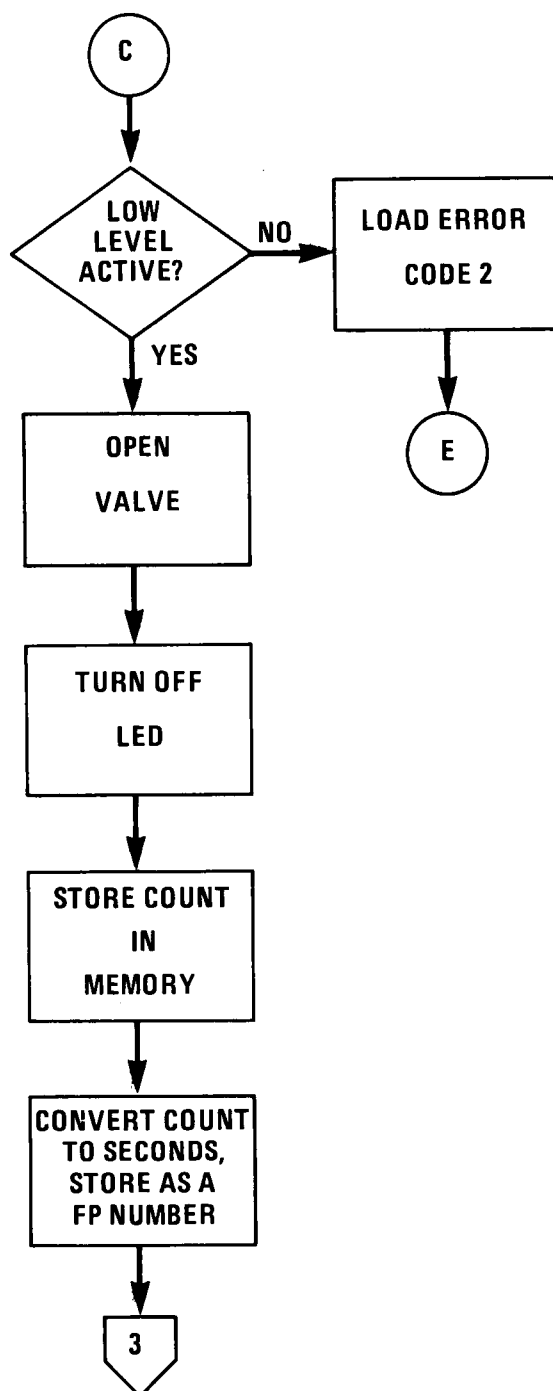


Figure B-1. (Continued)

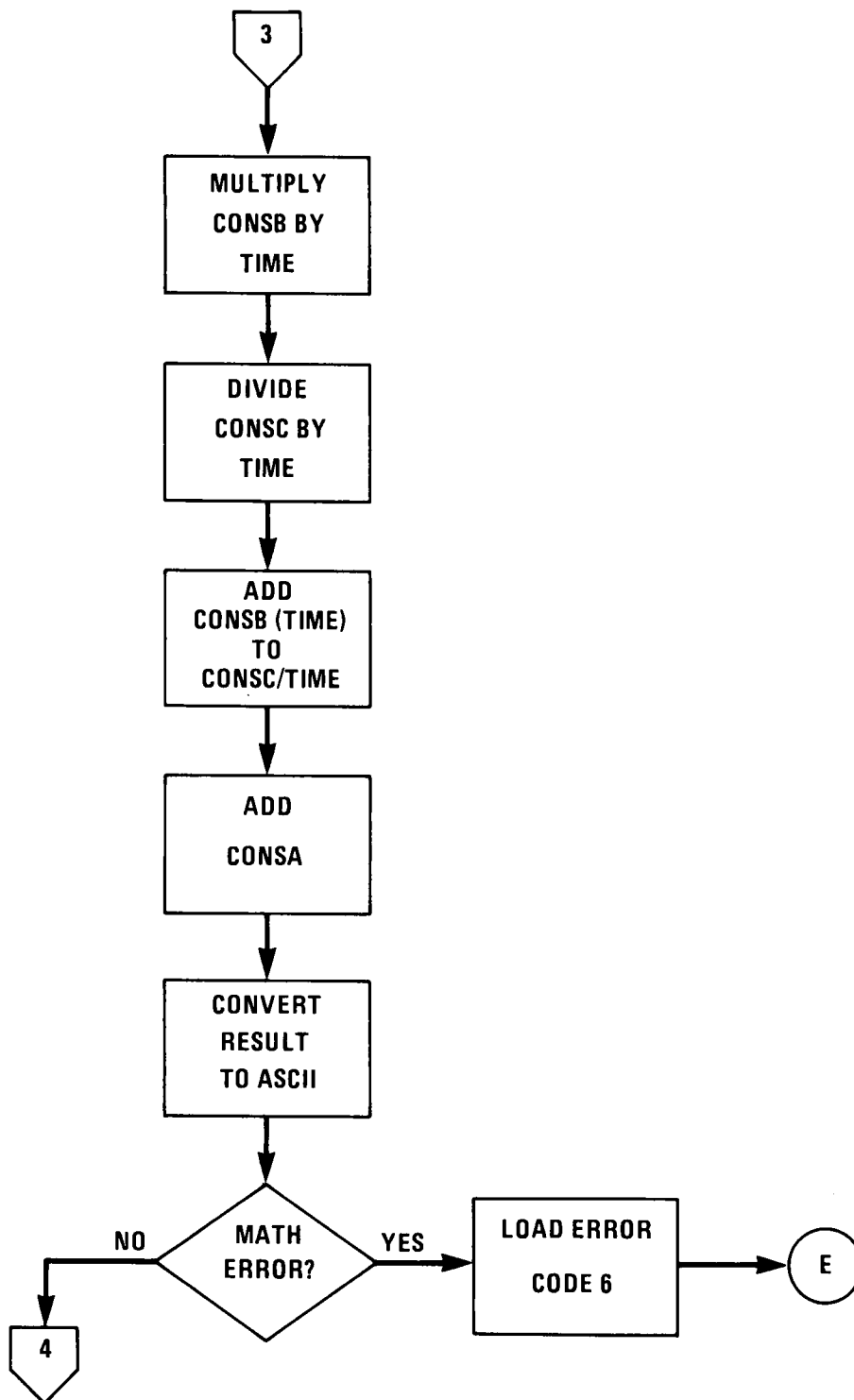


Figure B-1. (Continued)

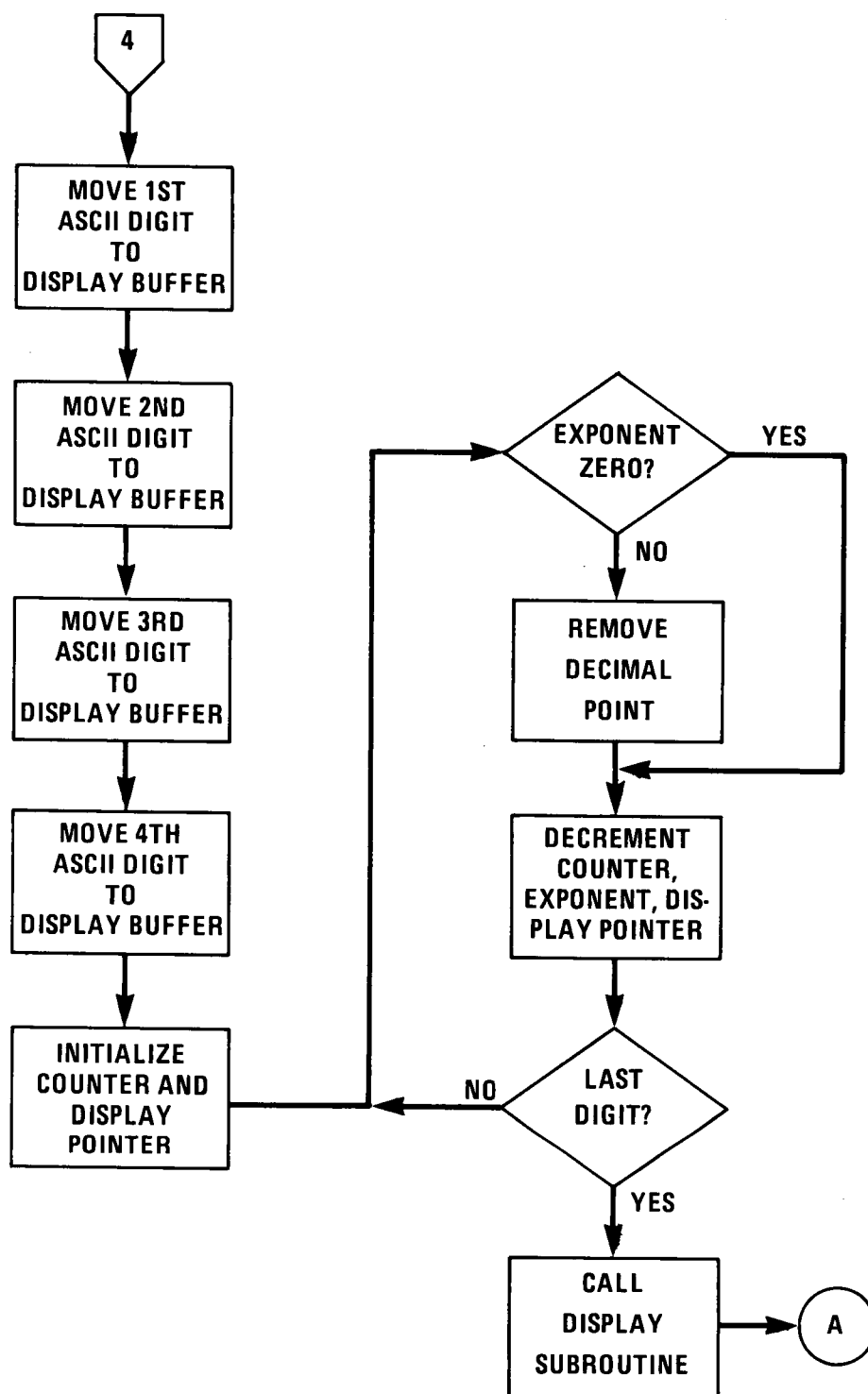


Figure B-1. (Continued)

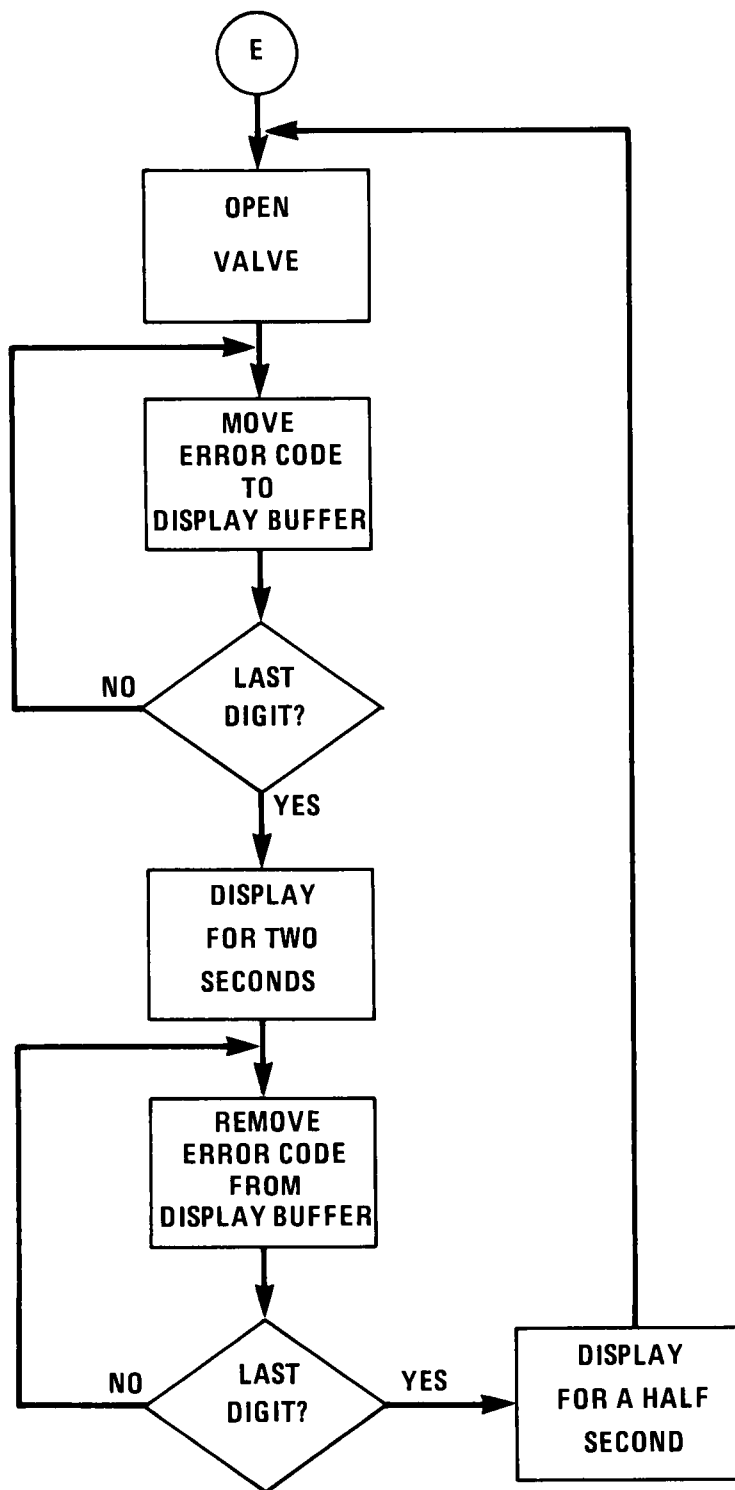


Figure B-1. (Continued)

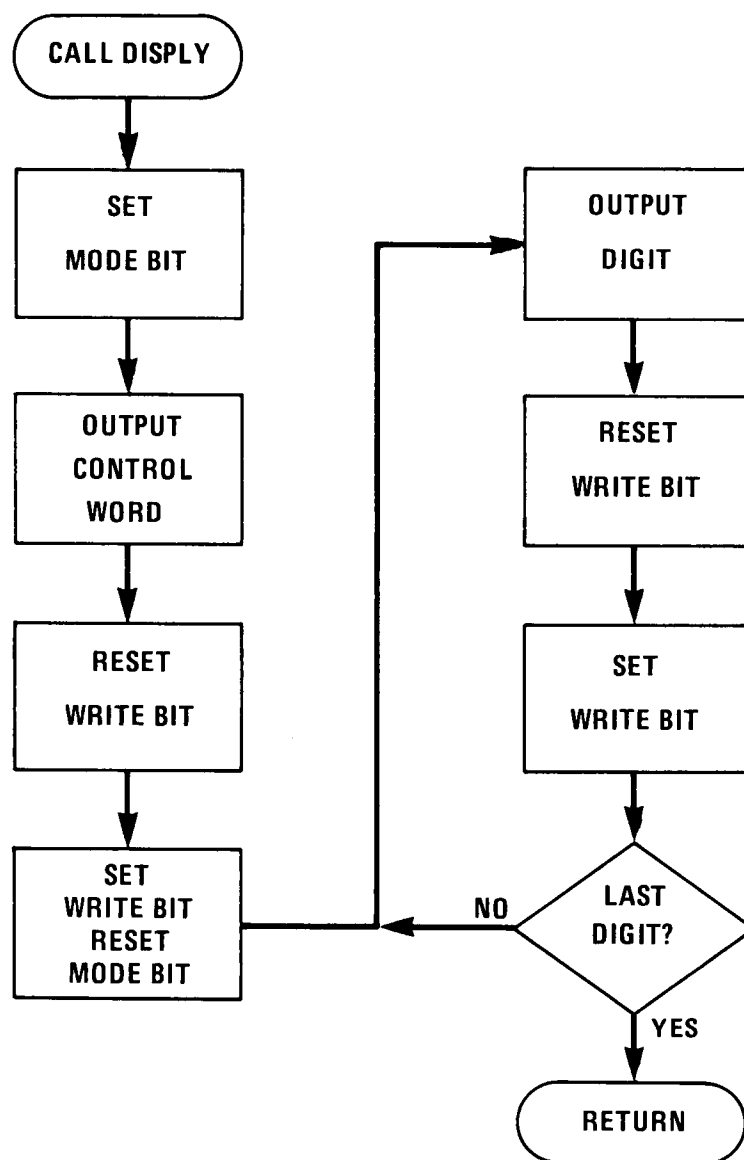


Figure B-1. (Continued)

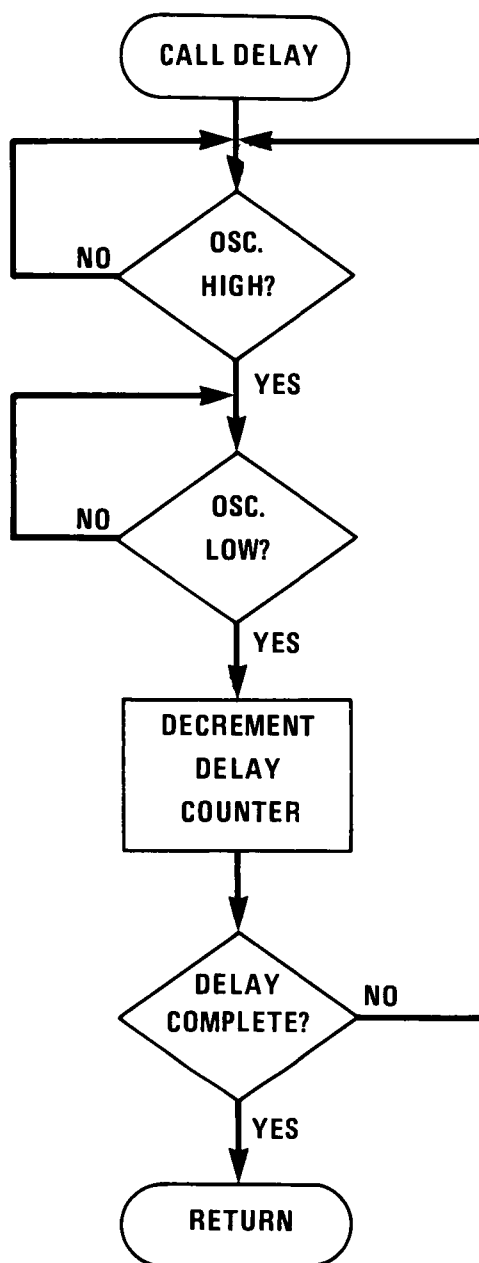


Figure B-1. (Continued)

APPENDIX C

ASMB0 :F1:FLOWT XREF PAGEWIDTH(84)

ISIS-II 8080/8085 MACRO ASSEMBLER, V2.0

FLWMTR

LOC	OBJ	SEQ	SOURCE STATEMENT
		1	NAME FLWMTR
		2 ;	
		3 ;	
		4	EXTRN FSET,FSTOR,FQFD2B,FQFB2D,FLOAD,FADD
		5	EXTRN FERHND,FCLR,FLTDS,FDIV,FHUL,FERROR
		6 ;	
		7 ;	
0000		8	HMODE EQU 00H
0001		9	LMODE EQU 01H
0003		10	LWRITE EQU 03H
0002		11	HWRITE EQU 02H
00E7		12	BITSET EQU 0E7H
006F		13	CONT1 EQU 6FH
00E4		14	DISPLA EQU 0E4H
0020		15	OSC EQU 20H
00E5		16	INPUT EQU 0E5H
0004		17	HVALVE EQU 04H
0005		18	LVALVE EQU 05H
0002		19	RESET? EQU 02H
0008		20	LEVL2? EQU 08H
0010		21	LEVL1? EQU 10H
0006		22	HLIGHT EQU 06H
0007		23	LLIGHT EQU 07H
		24 ;	
		25 ;	
		26	CSEG
		27 ;	
		28 ;	
		29 ;	POWER-UP SEQUENCE
		30 ;	
0000		31	ORG 0H
0000 F3		32	DI
0001 C34000	C	33	JMP INIT ;JUMP TO PROGRAM BEGINNING
		34 ;	
		35 ;	
		36 ;	INTERRUPT SERVICE
		37 ;	
0038		38	ORG 38H
0038 FB		39	EI
0039 310000	S	40	LXI SP,STACK ;RESET STACK POINTER
003C C3E700	C	41	JMP INTR ;JUMP TO INTERRUPT ROUTINE
		42 ;	
		43 ;	
		44 ;	INITIALIZE SYSTEM
		45 ;	
0040		46	ORG 40H
0040 310000	S	47	INIT: LXI SP,STACK ;INITIALIZE STACK POINTER
0043 3E82		48	MVI A,82H
0045 D3E7		49	OUT BITSET ;SET UP IO PORTS
0047 3EFD		50	MVI A,0FDH
0049 D3E6		51	OUT 0E6H ;INITIALIZE PORT 3 OUTPUTS
		52 ;	

Figure C-1. Flowmeter System Software

ISIS-II 8080/8085 MACRO ASSEMBLER, V2.0

FLWMTR

LOC	OBJ	SEQ	SOURCE STATEMENT
		53 ;	
		54 ;	
		55 ; DISPLAY 8.8.8.8.	
		56 ;	
004B	0604	57	MVI B,4H ;DIGIT COUNTER
004D	213500	58	LXI H,DIGIT1 ;DIGIT ADDRESS
0050	3608	59 LOOP1:	MVI M,08H ;LOAD DIGIT 8. INTO MEMORY
0052	23	60	INX H ;NEXT DIGIT
0053	05	61	DCR B
0054	C25000	62	JNZ LOOP1 ;LOAD FOUR 8.'S INTO MEMORY
0057	CD8702	63	CALL DISPLY
005A	01C800	64	LXI B,200 ;LOAD TWO SECOND DELAY
005D	CDE902	65	CALL DELAY
		66 ;	
		67 ;	
		68 ; INITIALIZE FLOATING-POINT RECORD	
		69 ;	
0060	010000	70	LXI B,FPR
0063	C5	71	PUSH B
0064	0600	72	MVI B,0
0066	CD0000	73	CALL FSET ;INITIALIZE FPR
0069	CD1602	74	CALL STORE ;STORE CONSTANTS
		75 ;	
		76 ;	
		77 ; CHECK OSCILLATOR FUNCTION	
		78 ;	
006C	01FFFF	79 CHKOSC:	LXI B,0FFFFH ;INITIALIZE TIMER
006F	DBE5	80 HICHK:	IN INPUT ;GET INPUTS
0071	E620	81	ANI OSC
0073	C28400	82	JNZ LOCHK1 ;INPUT HIGH?
0076	0B	83	DCX B
0077	AF	84	XRA A ;ZERO ACCUMULATOR
0078	B9	85	CMP C ;CHECK HALF OF BC TIMER PAIR
0079	C26F00	86	JNZ HICHK ;TIMER NOT ZERO
007C	AF	87	XRA A ;ZERO ACCUMULATOR
007D	B8	88	CMP B ;DELAY COMPLETE?
007E	C26F00	89	JNZ HICHK ;TIMER NOT ZERO
0081	C39900	90	JMP ERR1 ;TIMER ZERO,NO OSCILLATOR HIGH
0084	01FFFF	91 LOCHK1:	LXI B,0FFFFH ;INITIALIZE TIMER
0087	DBE5	92 LOCHK:	IN INPUT ;GET INPUTS
0089	E620	93	ANI OSC
008B	CA9E00	94	JZ DUN ;OSCILLATOR FUNCTIONING
008E	0B	95	DCX B
008F	AF	96	XRA A ;ZERO ACCUMULATOR
0090	B9	97	CMP C ;CHECK HALF OF BC TIMER PAIR
0091	C28700	98	JNZ LOCHK ;TIMER NOT ZERO
0094	AF	99	XRA A ;ZERO ACCUMULATOR
0095	B8	100	CMP B ;DELAY COMPLETE?
0096	C28700	101	JNZ LOCHK
0099	1E01	102 ERR1:	MVI E,01H ;LOAD ERROR 1 INTO REGISTER E
009B	C3E601	103	JMP ERROR
009E	00	104 DUN:	NOP
		105 ;	
		106 ;	
		107 ;	

Figure C-1. (Continued)

ISIS-II 8080/8085 MACRO ASSEMBLER, V2.0

FLWMTR

LOC	OBJ	SEQ	SOURCE STATEMENT
		108 ;	
		109 ;	
		110 ; DISPLAY 0.	
		111 ;	
009F	0603	112	MVI B,3H ;DIGIT COUNTER
00A1	213500	113	LXI H,DIGIT1 ;DIGIT ADDRESS
00A4	36FF	114	LOOP2: MVI M,0FFH ;LOAD BLANK INTO MEMORY
00A6	23	115	INX H ;NEXT DIGIT
00A7	05	116	DCR B
00AB	C2A400	117	JNZ LOOP2 ;MOVE THREE BLANK'S INTO MEMORY
00AB	3600	118	MVI M,0H ;MOVE 0. INTO MEMORY
00AD	CDB702	119	CALL DISPLY
00B0	FB	120	EI
		121 ;	
		122 ;	
		123 ; WAIT FOR START SIGNAL	
		124 ;	
00B1	DBE5	125	START?: IN INPUT ;GET INPUTS
00B3	E601	126	ANI 01H
00B5	CAB100	127	JZ START? ;LOOP UNTIL START SIGNAL
		128 ;	
		129 ;	
		130 ; CHECK SYSTEM STATUS	
		131 ;	
00B8	DBE5	132	STAT: IN INPUT ;GET INPUTS
00BA	E618	133	ANI 18H
00BC	CAC400	134	JZ ZERO ;STATUS OK
00BF	1E07	135	MVI E,07H
00C1	C3E601	136	JMP ERROR ;ERROR 7 DETECTED
		137 ;	
		138 ;	
		139 ; DISPLAY 0.000	
		140 ;	
00C4	0603	141	ZERO: MVI B,3H ;DIGIT COUNTER
00C6	213500	142	LXI H,DIGIT1 ;DIGIT ADDRESS
00C9	3600	143	MVI M,00H ;LOAD 0. INTO MEMORY
00CB	23	144	LOOP3: INX H ;NEXT DIGIT
00CC	36F0	145	MVI M,0F0H ;LOAD 0 INTO MEMORY
00CE	05	146	DCR B
00CF	C2CB00	147	JNZ LOOP3 ;LOAD THREE 0'S
00D2	CDB702	148	CALL DISPLY
		149 ;	
		150 ;	
		151 ; CLOSE VALVE AND WAIT FOR INTERRUPT TO START TIMER	
		152 ;	
00D5	3E04	153	VALVE: MVI A,HVALVE
00D7	D3E7	154	OUT BITSET ;CLOSE
00D9	011027	155	LXI B,10000 ;LOAD 100 SECOND DELAY
00DC	110000	156	LXI D,0H ;INITIALIZE TIMER
00DF	CDE902	157	CALL DELAY
00E2	1E04	158	MVI E,04H ;LOAD ERROR 4 INTO REGISTER E
00E4	C3E601	159	JMP ERROR ;TIME TOO LONG, INDICATE ERROR 4
		160 ;	
		161 ;	
		162 ;	

Figure C-1. (Continued)

ISIS-II 8080/8085 MACRO ASSEMBLER, V2.0

FLWMTR

LOC	OBJ	SEQ	SOURCE STATEMENT
		163 ;	
		164 ;	
		165 ;	
		166 ;	LOCATE INTERRUPT REQUEST
		167 ;	
00E7	DBE5	168	INTR: IN INPUT ;GET INPUTS
00E9	47	169	MOV B,A ;STORE INPUT
00EA	E602	170	ANI RESET? ;HAS RESET OCCURRED?
00EC	C24000	C 171	JNZ INIT
00EF	78	172	MOV A,B ;REPLACE INPUT
00F0	E608	173	ANI LEVL2? ;HAS LEVEL 2 BEEN REACHED?
00F2	C22101	C 174	JNZ LEVEL2
00F5	78	175	MOV A,B ;REPLACE INPUT
00F6	E610	176	ANI LEVL1? ;HAS LEVEL 1 BEEN REACHED?
00F8	C20001	C 177	JNZ LEVEL1
00FB	1E05	178	MVI E,05H ;LOAD ERROR CODE FOR FALSE INTERRUPT
00FD	C3E601	C 179	JMP ERROR
		180 ;	
		181 ;	
		182 ;	LEVEL 1 ROUTINE
		183 ;	START TIMING FLUID FLOW
		184 ;	
0100	110000	185	LEVEL1: LXI D,0H ;INITIALIZE TIMER
0103	3E06	186	MVI A,HLIGHT
0105	D3E7	187	OUT BITSET ;TURN ON TIMING INDICATOR
0107	DBE5	188	HLVL1: IN INPUT ;GET INPUTS
0109	E620	189	ANI OSC
010B	CA0701	C 190	JZ HLVL1 ;WAIT FOR OSCILLATOR HIGH
010E	DBE5	191	LLVL1: IN INPUT ;GET INPUTS
0110	E620	192	ANI OSC
0112	C20E01	C 193	JNZ LLVL1 ;WAIT FOR OSCILLATOR LOW
0115	13	194	INX D ;INCREMENT TIMER
0116	7A	195	MOV A,D
0117	FE60	196	CPI 60H ;COMPARE TIME TO MAXIMUM ALLOWED
0119	C20701	C 197	JNZ HLVL1 ;CONTINUE COUNTING
011C	1E03	198	MVI E,03H ;LOAD ERROR CODE
011E	C3E601	C 199	JMP ERROR ;ERROR 3 DETECTED
		200 ;	
		201 ;	
		202 ;	LEVEL 2 ROUTINE
		203 ;	HIGH FLUID LEVEL DETECTED
		204 ;	
0121	DBE5	205	LEVEL2: IN INPUT ;GET INPUTS
0123	E610	206	ANI LEVL1? ;LOWER LEVEL ACTIVE?
0125	C22D01	C 207	JNZ LVL2 ;NO ERROR, CONTINUE
0128	1E02	208	MVI E,02H ;LOAD CODE FOR ERROR 2
012A	C3E601	C 209	JMP ERROR
012D	3E05	210	LVL2: MVI A,LVALVE
012F	D3E7	211	OUT BITSET ;OPEN VALVE
0131	3E07	212	MVI A,LLIGHT
0133	D3E7	213	OUT BITSET ;TURN OFF TIMING INDICATOR
		214 ;	
		215 ;	
		216 ;	
		217 ;	

Figure C-1. (Continued)

ISIS-II 8080/8085 MACRO ASSEMBLER, V2.0

FLWMTR

LOC	OBJ	SEQ	SOURCE STATEMENT
		218 ;	
		219 ;	STORE TIME AT LOCATION TIME
		220 ;	
0135	212D00	D 221	LXI H,INTIME
0138	73	222	MOV M,E ;STORE LOW TIME BYTE
0139	23	223	INX H
013A	72	224	MOV M,D ;STORE HIGH TIME BYTE
013B	23	225	INX H
013C	3600	226	MVI M,0H ;STORE ZERO IN 3RD BYTE OF INTIME
013E	23	227	INX H
013F	3600	228	MVI M,0H ;STORE ZERO IN 4TH BYTE OF INTIME
0141	010000	D 229	LXI B,FPR
0144	112D00	D 230	LXI D,INTIME
0147	CD0000	E 231	CALL FLTDS ;CONVERT INTEGER TO FP
014A	114A00	D 232	LXI D,HUND
014D	CD0000	E 233	CALL FDIU ;CONVERT TO SECONDS
0150	113100	D 234	LXI D,TIME
0153	CD0000	E 235	CALL FSTOR ;STORE FP TIME
		236 ;	
		237 ;	CALCULATE FLOW
		238 ;	RESULT = CONSA+CONSB(TIME)+CONSC/TIME
		239 ;	
0156	114200	D 240	LXI D,CONSB
0159	CD0000	E 241	CALL FLOAD ;LOAD CONSB INTO FAC
015C	113100	D 242	LXI D,TIME
015F	CD0000	E 243	CALL FMUL ;MULTIPLY BY TIME
0162	113A00	D 244	LXI D,FPMEM
0165	CD0000	E 245	CALL FSTOR ;STORE TEMPORARY RESULT
0168	114600	D 246	LXI D,CONSC
016B	CD0000	E 247	CALL FLOAD ;LOAD CONSC INTO FAC
016E	113100	D 248	LXI D,TIME
0171	CD0000	E 249	CALL FDIU ;DIVIDE BY TIME
0174	113A00	D 250	LXI D,FPMEM
0177	CD0000	E 251	CALL FADD ;ADD CONSB(TIME)
017A	113E00	D 252	LXI D,CONSA
017D	CD0000	E 253	CALL FADD ;ADD CONSA
0180	3E04	254	MVI A,4
0182	321500	D 255	STA DLNGTH ;MOVE LENGTH TO CONTROL BLOCK
0185	212800	D 256	LXI H,RESULT
0188	221600	D 257	SHLD DADDR ;MOVE RESULT ADDR TO CONTROL BLOCK
018B	010000	D 258	LXI B,FPR
018E	111200	D 259	LXI D,DSIGN ;SIGN LOCATION
0191	CD0000	E 260	CALL FQFB2D ;CONVERT RESULT TO DECIMAL
		261 ;	
		262 ;	CHECK FOR MATH ERROR
		263 ;	
0194	010000	D 264	LXI B,FPR
0197	CD0000	E 265	CALL FERROR ;ERROR INFO TO REGISTERS H,L
019A	AF	266	XRA A ;ZERO ACCUMULATOR
019B	BD	267	CMP L
019C	CAA401	C 268	JZ NOERR ;NO MATH ERROR
019F	1E06	269	MVI E,6H ;LOAD ERROR CODE 6
01A1	C3E601	C 270	JMP ERROR
01A4	00	271	NOERR: NOP ;CONTINUE
		272 ;	

Figure C-1. (Continued)

ISIS-II 8080/8085 MACRO ASSEMBLER, V2.0

FLWMTR

LOC	OBJ	SEQ	SOURCE STATEMENT
		273 ;	
		274 ;	DISPLAY CALCULATED FLOW
		275 ;	
01A5	212800	D 276	LXI H,RESULT
01AB	113500	D 277	LXI D,DIGIT1
01AB	7E	278	MOV A,M ;GET 1ST ASCII CHARACTER
01AC	D630	279	SUI 30H ;CONVERT TO NUMBER
01AE	EB	280	XCHG
01AF	77	281	MOV M,A ;LOAD 1ST DIGIT IN DISPLAY BUFFER
01B0	EB	282	XCHG
01B1	23	283	INX H ;MOVE TO NEXT CHARACTER
01B2	13	284	INX D ;MOVE TO NEXT BUFFER LOCATION
01B3	7E	285	MOV A,M ;GET 2ND CHARACTER
01B4	D630	286	SUI 30H ;CONVERT TO NUMBER
01B6	EB	287	XCHG
01B7	77	288	MOV M,A ;LOAD 2ND DIGIT IN DISPLAY BUFFER
01B8	EB	289	XCHG
01B9	23	290	INX H ;MOVE TO NEXT CHARACTER
01BA	13	291	INX D ;MOVE TO NEXT BUFFER LOCATION
01BB	7E	292	MOV A,M ;GET 3RD CHARACTER
01BC	D630	293	SUI 30H ;CONVERT TO NUMBER
01BE	EB	294	XCHG
01BF	77	295	MOV M,A ;LOAD 3RD DIGIT IN DISPLAY BUFFER
01C0	EB	296	XCHG
01C1	23	297	INX H ;MOVE TO NEXT CHARACTER
01C2	13	298	INX D ;MOVE TO NEXT BUFFER LOCATION
01C3	7E	299	MOV A,M ;GET 4TH CHARACTER
01C4	D630	300	SUI 30H ;CONVERT TO NUMBER
01C6	EB	301	XCHG
01C7	77	302	MOV M,A ;LOAD 4TH DIGIT IN DISPLAY BUFFER
		303 ;	
		304 ;	POSITION DECIMAL POINT
		305 ;	DISPLAY BUFFER IS ALTERED TO SUPPRESS DECIMAL POINT
		306 ;	AT DIGITS NOT REQUIRING DECIMAL POINT
		307 ;	
01C8	2A1300	D 308	LHLD DSCALE ;LOAD EXPONENT
01CB	EB	309	XCHG
01CC	213800	D 310	LXI H,DIGIT1+3 ;LOAD ADDRESS OF 4TH DIGIT
01CF	0604	311	MVI B,4 ;DIGIT COUNTER
01D1	AF	312	DCPT?: XRA A ;ZERO ACCUMULATOR
01D2	BB	313	CMF E ;EXPONENT EQUAL ZERO?
01D3	CADA01	C 314	JZ DECPT ;DO NOT INHIBIT DECIMAL POINT
01D6	7E	315	MOV A,M ;GET DIGIT
01D7	F680	316	ORI 80H ;SET DECIMAL POINT INHIBIT
01D9	77	317	MOV M,A ;REPLACE DIGIT
01DA	2B	318	DECPT: DCX H
01DB	13	319	INX D
01DC	05	320	DCR B ;DECREMENT COUNTER
01DD	C2D101	C 321	JNZ DCPT? ;REPEAT FOR 4 DIGITS
		322 ;	
		323 ;	DISPLAY RESULT
		324 ;	
01E0	CDB702	C 325	CALL DISPLY
01E3	C3B100	C 326	JMP START? ;JUMP TO BEGINNING, RETAIN DISPLAY
		327 ;	

Figure C-1. (Continued)

ISIS-II 8080/8085 MACRO ASSEMBLER, V2.0

FLWMTR

LOC	OBJ	SEQ	SOURCE STATEMENT
		328 ;	
		329 ;	
		330 ;	
		331 ;	
		332 ;	ERROR DISPLAY ROUTINE
		333 ;	ENTER WITH ERROR CODE IN REGISTER E
		334 ;	
01E6	3E05	335	ERROR: MVI A,LVALVE
01E8	D3E7	336	OUT BITSET ;OPEN VALVE
01EA	1604	337	MVI D,04H ;DIGIT COUNTER
01EC	213500	338	LXI H,DIGIT1 ;DIGIT ADDRESS
01EF	73	339	BLINK1: MOV M,E ;MOVE ERROR CODE TO DISPLAY MEMORY
01F0	23	340	INX H ;NEXT ADDRESS
01F1	15	341	DCR D
01F2	C2EF01	342	JNZ BLINK1 ;LAST DIGIT?
01F5	CDB702	343	CALL DISPLY
01F8	01C800	344	LXI B,200 ;TWO SECOND DELAY
01FB	CDE902	345	CALL DELAY
01FE	1604	346	MVI D,04H ;DIGIT COUNTER
0200	213500	347	LXI H,DIGIT1 ;DIGIT ADDRESS
0203	360F	348	BLINK2: MVI M,0FH ;MOVE BLANK TO DISPLAY MEMORY
0205	23	349	INX H ;NEXT ADDRESS
0206	15	350	DCR D
0207	C20302	351	JNZ BLINK2 ;LAST BLANK?
020A	CDB702	352	CALL DISPLY
020D	013200	353	LXI B,50 ;HALF SECOND DELAY
0210	CDE902	354	CALL DELAY
0213	C3E601	355	JMP ERROR ;CONTINUE TO BLINK
		356 ;	
		357 ;	
		358 ;	
		359 ;	
		360 ;	STORE 100 AT HUND
		361 ;	
0216	3E2B	362	STORE: MVI A,'+' ;LOAD SIGN
0218	321200	363	STA DSIGN ;LOAD SIGN
021B	3E01	364	MVI A,1 ;LOAD LENGTH OF NUMBER
021D	321500	365	STA DLNGTH ;LOAD LENGTH OF NUMBER
0220	211403	366	LXI H,XHUND ;LOAD ADDRESS OF ASCII NUMBER
0223	221600	367	SHLD DADDR ;LOAD ADDRESS OF ASCII NUMBER
0226	210200	368	LXI H,2 ;LOAD EXPONENT
0229	221300	369	SHLD DSCALE ;LOAD EXPONENT
022C	010000	370	LXI B,FPR
022F	111200	371	LXI D,DSIGN
0232	CD0000	372	CALL FQFD2B ;CONVERT NUMBER TO BINARY
0235	010000	373	LXI B,FPR
0238	114A00	374	LXI D,HUND
023B	CD0000	375	CALL FSTOR ;STORE FP NUMBER
		376 ;	
		377 ;	
		378 ;	
		379 ;	
		380 ;	
		381 ;	
		382 ;	

Figure C-1. (Continued)

ISIS-II 8080/8085 MACRO ASSEMBLER, V2.0

FLWMTR

LOC	OBJ	SEQ	SOURCE STATEMENT
		383 ;	
		384 ;	STORE 0.077294 AT CONSA
		385 ;	
023E	3E2B	386	MVI A,'+' ;
0240	321200	387	STA DSIGN ;LOAD SIGN
0243	3E05	388	MVI A,5 ;
0245	321500	389	STA DLNGTH ;LOAD LENGTH OF NUMBER
0248	210303	390	LXI H,XCONSA ;
024B	221600	391	SHLD DADDR ;LOAD ADDRESS OF ASCII NUMBER
024E	21FAFF	392	LXI H,-6 ;
0251	221300	393	SHLD DSCALE ;LOAD EXPONENT
0254	010000	394	LXI B,FPR ;
0257	111200	395	LXI D,DSIGN ;
025A	CD0000	396	CALL FQFD2B ;CONVERT NUMBER TO BINARY
025D	010000	397	LXI B,FPR ;
0260	113E00	398	LXI D,CONSA ;
0263	CD0000	399	CALL FSTOR ;STORE FP NUMBER
		400 ;	
		401 ;	
		402 ;	STORE -0.00022543 AT CONSB
		403 ;	
0266	3E2D	404	MVI A,'-' ;
0268	321200	405	STA DSIGN ;LOAD SIGN
026B	3E05	406	MVI A,5 ;
026D	321500	407	STA DLNGTH ;LOAD LENGTH OF NUMBER
0270	210803	408	LXI H,XCONSB ;
0273	221600	409	SHLD DADDR ;LOAD ADDRESS OF ASCII NUMBER
0276	21F8FF	410	LXI H,-8 ;
0279	221300	411	SHLD DSCALE ;LOAD EXPONENT
027C	010000	412	LXI B,FPR ;
027F	111200	413	LXI D,DSIGN ;
0282	CD0000	414	CALL FQFD2B ;CONVERT NUMBER TO BINARY
0285	010000	415	LXI B,FPR ;
0288	114200	416	LXI D,CONSB ;
028B	CD0000	417	CALL FSTOR ;STORE FP NUMBER
		418 ;	
		419 ;	
		420 ;	STORE 206.1398 AT CONSC
		421 ;	
028E	3E2B	422	MVI A,'+' ;
0290	321200	423	STA DSIGN ;LOAD SIGN
0293	3E07	424	MVI A,7 ;
0295	321500	425	STA DLNGTH ;LOAD LENGTH OF NUMBER
0298	210D03	426	LXI H,XCONSC ;
029B	221600	427	SHLD DADDR ;LOAD ADDRESS OF ASCII NUMBER
029E	21FCFF	428	LXI H,-4 ;
02A1	221300	429	SHLD DSCALE ;LOAD EXPONENT
02A4	010000	430	LXI B,FPR ;
02A7	111200	431	LXI D,DSIGN ;
02AA	CD0000	432	CALL FQFD2B ;CONVERT NUMBER TO BINARY
02AD	010000	433	LXI B,FPR ;
02B0	114600	434	LXI D,CONSC ;
02B3	CD0000	435	CALL FSTOR ;STORE FP NUMBER
02B6	C9	436	RET
		437 ;	

Figure C-1. (Continued)

ISIS-II 8080/8085 MACRO ASSEMBLER, V2.0

FLWMTR

LOC	OBJ	SEQ	SOURCE STATEMENT
		438 ;	
		439 ;	
		440 ;	DISPLAY SUBROUTINE.
		441 ;	OUTPUTS THE DIGITS STORED AT THE FOUR
		442 ;	ADDRESSES BEGINNING WITH DIGIT1
		443 ;	
02B7	3E00	444	DISPLY: MVI A,HMODE
02B9	D3E7	445	OUT BITSET ;SET MODE BIT
02BB	3E6F	446	MVI A,CONT1
02BD	D3E4	447	OUT DISPLA ;OUTPUT DISPLAY CONTROL
02BF	3E03	448	MVI A,LWRITE
02C1	D3E7	449	OUT BITSET ;RESET WRITE BIT
02C3	3E02	450	MVI A,HWRITE
02C5	D3E7	451	OUT BITSET ;SET WRITE BIT
02C7	3E01	452	MVI A,LMODE
02C9	D3E7	453	OUT BITSET ;RESET MODE BIT
02CB	0604	454	MVI B,4H
02CD	0E02	455	MVI C,2H
02CF	213500	D 456	REPEAT: LXI H,DIGIT1
02D2	7E	457	DIGITS: MOV A,M
02D3	EEFF	458	XRI OFFH
02D5	D3E4	459	OUT DISPLA ;LOAD NTH DIGIT
02D7	3E03	460	MVI A,LWRITE
02D9	D3E7	461	OUT BITSET ;RESET WRITE BIT
02DB	3E02	462	MVI A,HWRITE
02DD	D3E7	463	OUT BITSET ;SET WRITE BIT
02DF	23	464	INX H
02E0	05	465	DCR B
02E1	C2D202	C 466	JNZ DIGITS ;LOOP FOR FOUR DIGITS
02E4	0D	467	DCR C
02E5	C2CF02	C 468	JNZ REPEAT ;REPEAT FOUR DIGITS
02E8	C9	469	RET
		470 ;	
		471 ;	
		472 ;	DELAY SUBROUTINE.
		473 ;	DESIRED DELAY IN HUNDREDTH'S OF SECONDS SHOULD
		474 ;	BE IN REGISTER PAIR B,C WHEN CALLED
		475 ;	
02E9	DBE5	476	DELAY: IN INPUT
02EB	E620	477	ANI OSC
02ED	CAE902	C 478	JZ DELAY ;WAIT FOR OSCILLATOR HIGH
02F0	DBE5	479	WAIT: IN INPUT
02F2	E620	480	ANI OSC
02F4	C2F002	C 481	JNZ WAIT ;WAIT FOR OSCILLATOR LOW
02F7	0B	482	DCX B
02F8	AF	483	XRA A
02F9	B9	484	CMF C
02FA	C2E902	C 485	JNZ DELAY ;CHECK HALF OF B,C COUNTER PAIR
02FD	AF	486	XRA A
02FE	B8	487	CMF B
02FF	C2E902	C 488	JNZ DELAY ;DELAY COMPLETE?
0302	C9	489	RET
		490 ;	
		491 ;	
		492 ;	

Figure C-1. (Continued)

ISIS-II 8080/8085 MACRO ASSEMBLER, V2.0

FLWMTR

LOC	OBJ	SEQ	SOURCE STATEMENT
0303	37373239	493	XCONSA: DB '77294'
0307	34		
0308	32323534	494	XCONSB: DB '22543'
030C	33		
030D	32303631	495	XCONSC: DB '2061398'
0311	333938		
0314	31	496	XHUND: DB '1'
		497	;
		498	DSEG
		499	;
0012		500	FPR: DS 18
0001		501	DSIGN: DS 1
0002		502	DSCALE: DS 2
0001		503	DLNGTH: DS 1
0012		504	DADDR: DS 18
0005		505	RESULT: DS 5
0004		506	INTIME: DS 4
0004		507	TIME: DS 4
0005		508	DIGIT1: DS 5
0004		509	FPMEM: DS 4
0004		510	CONSA: DS 4
0004		511	CONSB: DS 4
0004		512	CONSC: DS 4
0004		513	HUND: DS 4
0000		514	END OH

PUBLIC SYMBOLS

EXTERNAL SYMBOLS

FADD E 0000	FCLR E 0000	FDIV E 0000	FERHND E 0000
FERROR E 0000	FLOAD E 0000	FLTDS E 0000	FMUL E 0000
FQFB2D E 0000	FQFD2B E 0000	FSET E 0000	FSTOR E 0000

USER SYMBOLS

BITSET A 00E7	BLINK1 C 01EF	BLINK2 C 0203	CHKOSC C 006C
CONSA D 003E	CONSB D 0042	CONSC D 0046	CONT1 A 006F
DADDR D 0016	DCPT? C 01D1	DECPT C 01DA	DELAY C 02E9
DIGIT1 D 0035	DIGITS C 02D2	DISPLA A 00E4	DISPLY C 02B7
DLNGTH D 0015	DSCALE D 0013	DSIGN D 0012	DUN C 009E
ERR1 C 0099	ERROR C 01E6	FADD E 0000	FCLR E 0000
FDIV E 0000	FERHND E 0000	FERROR E 0000	FLOAD E 0000
FLTDS E 0000	FMUL E 0000	FPMEM D 003A	FPR D 0000
FQFB2D E 0000	FQFD2B E 0000	FSET E 0000	FSTOR E 0000
HCHK C 006F	HLIGHT A 0006	HLVL1 C 0107	HMODE A 0000
HUND D 004A	HVALVE A 0004	HWRITE A 0002	INIT C 0040
INPUT A 00E5	INTIME D 002D	INTR C 00E7	LEVEL1 C 0100
LEVEL2 C 0121	LEV1? A 0010	LEV12? A 0008	LLIGHT A 0007
LLVL1 C 010E	LMODE A 0001	LOCHK C 0087	LOCHK1 C 0084
LOOP1 C 0050	LOOP2 C 00A4	LOOP3 C 00CB	LVALVE A 0005
LVL2 C 012D	LWRITE A 0003	NOERR C 01A4	OSC A 0020
REPEAT C 02CF	RESET? A 0002	RESULT D 0028	START? C 00B1
STAT C 0088	STORE C 0216	TIME D 0031	VALUE C 00D5
WAIT C 02F0	XCONSA C 0303	XCONSB C 0308	XCONSC C 030D
XHUND C 0314	ZERO C 00C4		

Figure C-1. (Continued)

ISIS-II ASSEMBLER SYMBOL CROSS REFERENCE, V2.0

BITSET	12#	49	154	187	211	213	336	445	449	451	453
	461	463									
BLINK1	339#	342									
BLINK2	348#	351									
CHKOSC	79#										
CONSA	252	398	510#								
CONSB	240	416	511#								
CONSC	246	434	512#								
CONT1	13#	446									
DADDR	257	367	391	409	427	504#					
DCPT?	312#	321									
DECPT	314	318#									
DELAY	65	157	345	354	476#	478	485	488			
DIGIT1	58	113	142	277	310	338	347	456	508#		
DIGITS	457#	466									
DISPLA	14#	447	459								
DISPLY	63	119	148	325	343	352	444#				
DLNGTH	255	365	389	407	425	503#					
DSCALE	308	369	393	411	429	502#					
DSIGN	259	363	371	387	395	405	413	423	431	501#	
DUN	94	104#									
ERR1	90	102#									
ERROR	103	136	159	179	199	209	270	335#	355		
FADD	4	251	253								
FCLR	5										
FDIV	5	233	249								
FERHND	5										
FERROR	5	265									
FLOAD	4	241	247								
FLTDS	5	231									
FLWMTR	1										
FMUL	5	243									
FPMEM	244	250	509#								
FPR	70	229	258	264	370	373	394	397	412	415	430
	433	500#									
FQFB2D	4	260									
FQFD2B	4	372	396	414	432						
FSET	4	73									
FSTOR	4	235	245	375	399	417	435				
HCHK	80#	86	89								
HLIGHT	22#	186									
HLVL1	188#	190	197								
HMODE	8#	444									
HUND	232	374	513#								
HVALVE	17#	153									
HWRITE	11#	450	462								
INIT	33	47#	171								
INPUT	16#	80	92	125	132	168	188	191	205	476	479
INTIME	221	230	506#								
INTR	41	168#									
LEVEL1	177	185#									
LEVEL2	174	205#									
LEVL1?	21#	176	206								
LEVL2?	20#	173									
LLIGHT	23#	212									
LLVL1	191#	193									
LMODE	9#	452									

Figure C-2. Symbol Cross Reference Table

ISIS-II ASSEMBLER SYMBOL CROSS REFERENCE, V2.0

LOCHK	92*	98	101				
LOCHK1	82	91*					
LOOP1	59*	62					
LOOP2	114*	117					
LOOP3	144*	147					
LVALUE	18*	210	335				
LVL2	207	210*					
LWRITE	10*	448	460				
NOERR	268	271*					
OSC	15*	81	93	189	192	477	480
REPEAT	456*	468					
RESET?	19*	170					
RESULT	256	276	505*				
START?	125*	127	326				
STAT	132*						
STORE	74	362*					
TIME	234	242	248	507*			
VALVE	153*						
WAIT	479*	481					
XCONSA	390	493*					
XCONSB	408	494*					
XCONSC	426	495*					
XHUND	366	496*					
ZERO	134	141*					

Figure C-2. (Continued)

```
-LINK :F1:FLOWT.OBJ,FPAL.LIB,SYSTEM.LIB,PLM80.LIB TO :F1:FLOW.LNK MAP
ISIS-II OBJECT LINKER V3.0
```

```
LINK MAP OF MODULE FLOW
WRITTEN TO FILE :F1:FLOW.LNK
MODULE IS A MAIN MODULE
```

```
SEGMENT INFORMATION:
START  STOP LENGTH REL NAME
```

```
1664H  B  CODE
4EH    B  DATA
8EH    B  STACK
```

```
INPUT MODULES INCLUDED:
```

```
:F1:FLOWT.OBJ(FLOWMTR)
:FO:FPAL.LIB(FADD)
:FO:FPAL.LIB(FQFB2D)
:FO:FPAL.LIB(FCLR)
:FO:FPAL.LIB(FQFD2B)
:FO:FPAL.LIB(FDIV)
:FO:FPAL.LIB(FERHND)
:FO:FPAL.LIB(FERROR)
:FO:FPAL.LIB(FLOAD)
:FO:FPAL.LIB(FLTDS)
:FO:FPAL.LIB(FMUL)
:FO:FPAL.LIB(FSET)
:FO:FPAL.LIB(FSTOR)
:FO:FPAL.LIB(@CHECK)
:FO:FPAL.LIB(FABS)
:FO:FPAL.LIB(FCMFR)
:FO:FPAL.LIB(FIXSD)
:FO:FPAL.LIB(FNEG)
:FO:FPAL.LIB(FSTAT)
:FO:FPAL.LIB(FZTST)
:FO:FPAL.LIB(@MPLY)
:FO:FPAL.LIB(@NORML)
:FO:FPAL.LIB(FQFT10)
:FO:FPAL.LIB(FQFX10)
:FO:FPAL.LIB(@GROUND)
:FO:FPAL.LIB(@SHIFT)
:FO:PLM80.LIB(@P0011)
:FO:PLM80.LIB(@P0014)
:FO:PLM80.LIB(@P0036)
:FO:PLM80.LIB(@P0091)
:FO:PLM80.LIB(@P0094)
:FO:PLM80.LIB(@P0096)
:FO:PLM80.LIB(@P0098)
:FO:PLM80.LIB(@P0101)
:FO:PLM80.LIB(@P0103)
```

```
-LOCATE :F1:FLOW.LNK TO :F1:FLOW.RUN ORDER(CODE,DATA,STACK,MEMORY) &
**CODE(0H) DATA(3C00H) STACK(3F66H) MAP
ISIS-II OBJECT LOCATER V3.0
```

```
MEMORY MAP OF MODULE FLOW
READ FROM FILE :F1:FLOW.LNK
WRITTEN TO FILE :F1:FLOW.RUN
MODULE START ADDRESS 0000H
```

```
START  STOP LENGTH REL NAME
```

```
0000H 1663H 1664H B CODE
3C00H 3C4DH 4EH B DATA
3F66H 3FFFH 9AH B STACK
4000H F6BFH B6C0H B MEMORY
```

Figure C-3. Example of Linking and Locating Modules

VITA

John Carl Rowe was born on April 30, 1950, in Ardmore, Oklahoma. Following several years of elementary school in that city, he attended Ozark Academy in Gentry, Arkansas where he graduated in May of 1968. He received the 1974 Outstanding Scholarship Award in Engineering Physics while attending the University of Oklahoma and graduated with special distinction from that university in December 1974 receiving a Bachelor of Science degree in Engineering Physics. He entered the University of Tennessee Graduate School, Knoxville, in the spring of 1978.

Since 1975, he has been employed as a Development Engineer at the Oak Ridge Gaseous Diffusion Plant, which is operated by the Nuclear Division of Union Carbide Corporation for the United States Department of Energy. Responsibilities there have included process instrumentation development, instrumentation applications, and process support. Additionally, as technical liaison and consultant to a manufacturing facility, responsibilities involved product improvement, troubleshooting, process development, data management, and other functions.

He has been married to the former Janet Lile since 1975.