NBS TECHNICAL NOTE 943

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Evaluation of Automotive Fuel Flowmeters

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EVALUATION OF AUTOMOTIVE
FUEL FLOWMETERS

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Fuel economy measurement procedures being developed by the Transportation Systems Center of the Department of Transportation require flowmeters to measure the gasoline consumed by the engine of an automobile either on the road or on a dynamometer. The contribution of the National Bureau of Standards to this work was to ascertain the environment in which the flowmeters will probably be used, to develop procedures for measuring their performance in a laboratory simulation of that environment, and to carry out illustrative measurements on a number of flowmeters.

This report discusses: (1) the environment of the flowmeter in an automobile, i.e., flowmeter temperature; fuel temperature, pressure, density, viscosity, color, opacity, flow pulsations, back flow, and swirl due to elbows; line voltage fluctuations; electromagnetic radiation from ignition; vehicle attitude with respect to the vertical; and vibration, (2) the test set-up and procedure used for eavluating and calibrating these meters in the laboratory under conditions simulating the automotive environment, (3) a discussion of possible sources and magnitudes of errors in the calibration, and (4) results of illustrative tests on seven flowmeters.

Keywords: automotive environment; automotive fuel flowmeters; effect of environment on flowmeter performance; flowmeter calibration; flowmeter evaluation; procedure for testing flowmeters.

1. INTRODUCTION

The Automotive Energy Efficiency Program of the Department of Transportation (DoT) has needed reliable calibration and evaluation of flowmeters in order to study various proposed schemes for conserving automobile fuel. The Fluid Meters Section of the National Bureau of Standards (NBS) was asked to develop a procedure for doing this because of its experience with the calibration of flowmeters suitable for liquid hydrocarbons.

The flowmeters to be tested are of the kind used by DoT to measure the flow of gasoline to the carburetors in fleets of automobiles as well as in special test vehicles and on engine test stands. The procedure involves using gasoline under conditions that simulate the environment expected for flowmeters in automobiles. This is necessary because the hostile conditions that can exist in an automobile may cause the flowmeter to give a reading that is incorrect by a factor of two or more.

For example, engine heat causes vapor bubbles to form in the gasoline. If they are metered along with the liquid, a substantial increase in flowmeter indication will result. But even if bubbles form only downstream of the meter, they cause backflow through the flowmeter when they expand during the backstroke of the automobile fuel pump. Some flowmeters count the backflow as if it were forward flow and hence make a large error in measuring the net flow.

In the procedure the basic test of a flowmeter is a calibration performed at room temperature by weighing the amount of gasoline collected during a measured time interval. The apparatus used is designed so that although the flow is steady where it goes into the weigh tank, it pulsates where it is metered as in the automotive environment. This is done by using an automotive fuel pump and the float bowl assembly from a carburetor. Flowrates used range from 0.2 to 20 g/s, and precision attained is better than 0.05 percent.

Other laboratory tests to be performed involve simulating a variety of operating conditions which may be adverse to dependable meter performance. These include: unsteady flow to simulate the effects of throttle opening and closing; fuel pump speed changes from 190 to 1900 pulses per minute to simulate changes in engine speed; horizontal and vertical vibration of meter and float bowl at the smaller of 2.5 cm displacement or 0.5 x 980 cm/s^2 acceleration over frequencies from 1 to 1000 Hz to simulate road and engine vibration; supply voltage changes to simulate battery discharge, accessory switching, or alternator output changes; electromagnetic radiation from a spark plug wire to simulate radiation from ignition wiring; and temperatures from 20°C to 65°C to simulate the effects of ambient temperature changes and engine heating. The last test required elaborate precautions in order to minimize the chance of explosion during the tests.

Seven flowmeters were tested to illustrate the use of the procedure. They include four of the larger more expensive commercially available flowmeters and three smaller ones, which are inexpensive enough to be considered for installation in every automobile sold. It should be emphasized that only selected results are reported here, that only one meter of each kind was tested, and that the present results may not reliably indicate how other meters made by the same manufacturer will perform. Because only limited time was available, a comprehensive series of tests to fully characterize the dynamic performance of these flowmeters has not been performed. Some of the tests, e.g. the high temperature test, which is one of the most important tests, have been carried out on only one flowmeter. As a result the present data should not be used in an estimation of how a particular flowmeter will perform on an automobile under actual driving conditions.

Section 2 describes the automotive environment that may be expected to possibly affect flowmeter accuracy. Section 3 describes the apparatus used for determining flowmeter accuracy in a laboratory simulation of that environment. Section 4 describes the test procedure. Section 5 discusses potential sources of error and gives estimates for the magnitudes of errors that do occur. Section 6 presents test results for seven flowmeters. Section 7 gives a brief discussion. The Appendix gives a functional description of the flowmeters that were tested, and gives Reports of Test of the thermister probes used for measuring temperature.

2. FLOWMETER ENVIRONMENT

The flowrate of gasoline to the carburetors of automobiles can be as low as .4 mℓ/s (.4 gallons/hour) for a small car at idle. It can be as high as 22 mℓ/s (22 gallons/hour) for a large car at full load going up hill at high speed. This is a range of over 50 to 1. The flowmeters available to measure this flow range in mass from .5 to 11 kg and in size from those that fit in your hand up to a cube about 30 cm on a side. In addition some have remote readouts that are to be put on the dash to make it easy to record the measured results.

The larger flowmeters are intended to be placed on the floor in front of the right front seat of the car. The fuel lines lead out the window over the fender, through the grill, and to the engine. Smaller flowmeters are to be mounted on the front bumper, elsewhere outside the car, or on a long bracket attached to the automobile body under the hood. The smallest flowmeters are supported by the fuel line itself; one is to be near the fuel pump, and one near the carburetor.

Regardless of where the flowmeter is placed in or on the car, its input and output lines usually have to be connected between the fuel pump and the carburetor. Many cars have a fuel pump with three fuel lines connected to it. One line comes from the tank, one goes to the carburetor, and a vapor diverter line goes back to the tank. The vapor diverter line is connected to a small orifice at the top of the output fuel passage. Bubbles which rise to the top of the gasoline in the passage go through the orifice and are carried by the diverter line back to the tank. This helps prevent vapor lock. However, the diverter line also carries a large flow of liquid gasoline back to the tank. If the flowmeter were connected into the line from the tank to the pump, it would measure the flow to the carburetor plus the flow back to the tank. On these cars the flowmeter must be connected so that the fuel flows from the pump to the flowmeter and then to the carburetor. Only then will it measure just the flow to the carburetor.

On some cars the diverter is mounted on the fuel line just a short distance from the carburetor. The diverter line leads from there back to the tank. For these cars the flowmeter must be connected between the diverter and the carburetor.

The environment of the flowmeters in an automobile is complex and rather hostile. It is complex because there are several possible locations in which to place the flowmeters, quite a few physical variables to be considered, many different makes and models of cars, and a broad range of conditions under which the cars will be operated. In principle, the environment could be expressed more simply in terms of the flowmeter locations, the physical variables, and the range of values that these variables take for these locations. However, the problem remains in getting the data for the normal operating conditions that occur in the tests by DoT.

Unfortunately we could not solve the problem by just going out and measuring the variables we want to know. First, many of the measurements would have to be made on 1976 cars since they differ in several important ways from earlier ones. Second, the tests would have to be performed on a representative sample of makes and models of cars. Third, they would have to be performed under a complete range of weather conditions. Fourth, we did not have the time nor all of the instruments. The time and expense involved is obviously enormous. We must rely on measurements taken by others, and these appear to be somewhat limited.

We do have the recommended standards and test methods published by the Society of Automotive Engineers[1] and other sources.[2] Unfortunately, much of the data either applies to 1972 or earlier cars or applies to test conditions that are much more extreme than occur in the tests by DoT. However, conversations with several people[3] in the research laboratories of automobile manufacturers as well as with others provided some data that applies to the conditions of the DoT tests. The following data was obtained from these sources.

2A Fuel Temperature and Vapor

The temperature of the fuel in the fuel lines can range at least between −10° C (15°F) and 65 to 77°C (150 to 170°F). The result is a 10 percent change of density and a change by a factor of 2 in the kinematic viscosity. This will certainly affect the performance of some of the flowmeters. However, there are potentially much larger effects at the higher temperatures. Depending on what week of the year and in what part of the country the gasoline is purchased, vapor bubbles can form in the fuel line at temperatures above 50°C (120°F) to 70°C (160°F). These bubbles or even ordinary air bubbles in the fuel reduce the average density of the fuel much more than ordinary thermal expansion of the liquid. If the bubbles are in the fuel that is measured, they can cause large errors in the reading of most flowmeters, even apart from the backflow effect to be described later. Some flowmeters have vapor diverters, which are intended to eliminate the bubbles just before the fuel is metered. Even so, bubbles will form again inside the meter. If they do, the measured flowrate can be in error by a factor of two or so.

But even if there are no bubbles in the fuel that is measured there can be a substantial effect due to bubbles formed in the fuel line between the meter and the carburetor, i.e., downstream of the meter. On hot days it is not unusual to find 50 to 80 percent of the volume inside the fuel line occupied by the bubbles. The effect of this on the flowmeter is due to the pulsating fuel pump pressure, which can vary in the range from 20 to 50 kPa (3 to 7 psi) on cars with a vapor diverter. When the pressure drops due to flow back through the vapor diverter, the gas bubbles get larger according to the gas law. New bubbles may even form since the solubility of the more volatile components in the gasoline has been lowered by the decrease in pressure. The increase in volume of the fuel because of the bubbles causes fuel to flow backwards through the meter. Some flowmeters will not count this backflow, others will count it as if it were ordinary forward flow. Then on the next fuel pump stroke, the pressure increases, the bubbles collapse and may even disappear, and the fuel that once flowed backward now flows forward through the flowmeter, getting counted once again.

The effect is particularly large when the engine is shut off. Then the fuel line pressure drops to zero, and the bubbles and gravity can cause the entire contents of the fuel line (more than 100 cm^3) to flow backwards through the flowmeter.

There is another possible cause of pulsations in fuel flow that can occur even when bubbles are not present at all. The needle valve in the float bowl of the carburetor may tend to be either appreciably open or closed entirely, rather than somewhere in between. Thus the flow may tend to stop and start and this may affect the accuracy of some meters.

Besides the change in fuel density and viscosity due to temperature, there can be a change of roughly 3 percent in density and 25 percent in kinematic viscosity depending on the week and place of purchase.

2B Fuel Color

Another property of the gasoline may also affect flowmeter performance— its opacity due to its color: red for premium, orange for regular, clear for unleaded, and brown for tax-free off-road use. If the gasoline is unusually strongly colored, the light beam going through it in some flowmeters may not be intense enough to be detected. These flowmeters will then give erratic readings or record no flow at all.

2C Swirl in Fuel Flow

Turbine meters may be affected by swirl in the fuel flow. The swirl can be generated by centrifugal force if the fuel flows through elbows. This swirl may add to the rotating motion of a turbine rotor.

2D Electrical Environment

All but one of the meters described use electrical power from a 12-volt battery. If this is the car battery there may be undesirable effects due to fluctuation in the voltage supplied to the meter. On a normally operating automobile, the DC line voltage can range between 9 and 16 volts depending on the condition and state of charge of the battery and the rate of charge by the alternator. In addition there can be undesirable noise voltages on the line. Automobile accessory and normal ignition noise on the line can be as big as 3 volts peak. Also when the ignition switch is shut off there can be a -100 volt pulse on the line due to an inductive load on the line such as the alternator or an accessory. These voltage fluctuations may affect flowmeter accuracy. However, the effect of the noise and transient voltages can be reduced if the flowmeter is connected directly to the battery.

Another possible source of flowmeter inaccuracy is the electromagnetic radiation from electronic ignition systems in normal operation. This may disturb the electronic circuitry in some flowmeters that are not properly shielded.

2E Flowmeter Attitude

Some meters may have their accuracy affected by a change in attitude of the meter with respect to the vertical as the car goes up or down hill or around a banked turn. The maximum grade on a hill is usually 9 percent, and the maximum banking on a curve is usually 6 percent (10 percent if in a location where ice and snow is unlikely).[4]

2F Vibration Environment

The vibration environment of the flowmeters is complex. Assuming that the flowmeter as a whole is a rigid body it has six vibrational degrees of freedom: three translational and three rotational, one about each of the three axes. Each of these modes of vibration can have many frequencies and intensities. The details depend strongly on the exact location of the flowmeter in the car, the make and model of the car, the balancing of the wheels, the smoothness of the road, the speed of the engine, and the speed of the car. There are a lot of variables, and very little data is available.

The SAE publication[1] characterizes the vibration caused by driving on a very rough test track: the Belgium Block Road, the Hop, the Tramp, the Square Block Test Course, and other complex surfaces. It specifies sinusoidal test vibration levels of 2.5 cm peak to peak displacement from 1 Hz to 5 Hz and 1.5×980 cm/s^2 acceleration from 5 Hz to 1000 Hz to simulate interior and under hood vibration, and a similar sweep at 2.5 cm and 4×980 cm/s^2 for the exterior and chassis. These vibration levels are probably much more severe than those to be expected during the TSC tests on smooth roads or test tracks.

A lower vibration level has been proposed by the Packaging Committee of ASTM in a test procedure for packages shipped on a truck. This test procedure specifies vibrating at $.5 \times 980\ cm/s^2$ acceleration. However, the suspension of an unloaded truck is much stiffer than that of an automobile. So the amplitude of the vibration is probably larger than expected for a flowmeter inside the car during the DoT tests.

A much lower vibration level has been measured by the Noise, Vibration and Harshness Division of an automobile manufacturer. They[5] report a peak acceleration of $.05 \times 980\ cm/s^2$ on the dash of a car on a nearly perfectly smooth road with wheels balanced dynamically. However, wheel balancing for mass production is static rather than dyamic, and since the test road may not be perfectly smooth, the vibration levels during the DoT tests could be much higher.

Some understanding of the vibration of an automobile on a smooth road can be gained by the following general considerations. The most obvious of the low frequency resonances observable on the floor of an automobile are reported to be at roughly 1 Hz, 10 Hz, 14 Hz, and 20 Hz. The exact values vary substantially from car to car. The approximately 1 Hz resonance is due to the vertical motion of the entire car on its four springs and tires. Even on a particular car, this resonant frequency can change since it depends upon the pressure. The 10 Hz and 14 Hz resonances are associated with bending and torsion of the car body. The 20 Hz resonance occurs in the vibration of the floor pan itself. Of course there are many other possible resonances that appear throughout a broad frequency band.

All these resonances are excited to varying degrees depending upon the degree of balance of the wheels, the smoothness of the road, and the speed of the car. For just one example, at 24.5 m/s (55 MPH) the speed of a 76 cm (2.5 ft) diameter tire is about 10 rev/s. Thus if the wheel is even slightly out of balance, there will be a 10 Hz vibration source, which will resonate with the car. Of course the numbers vary from car to car, and the frequency of the vibration source obviously varies with speed. Also, there are many other resonances that can be excited.

Only a very sketchy discussion of the relevant vibration environment has been presented. A realistic characterization of vibration at the different flowmeter locations in a car on a smooth road is not available.

2G Flowmeter Installation

One last comment should be made on the installation of flowmeters. It is desirable that the flowmeter not affect the performance of the car. There are three ways this might happen. First, the pressure drop across the meter might be an appreciable fraction of the fuel pump pressure. Whether this happens with steady fuel flow or only when the flow suddenly increases by a sudden opening of the throttle, the engine could be deprived of fuel, and its performance affected. Second, some flowmeters smooth out the pressure pulses from the fuel pump. The effect of this might be to lower the fuel level in the carburetor float bowl, and that could affect engine performance or fuel economy. Third, the extra load on the engine due to the electric power drawn from the car's electric system by one of the flowmeters is about one horsepower. This will affect fuel economy measurements. It can be avoided by powering the flowmeter by separate batteries. But then the mass of these batteries plus the flowmeter and its converter might affect the performance of the car, especially if it is a small car.

3. APPARATUS

It is essential to use gasoline for the tests in order for the metered fluid to have the correct density, viscosity, lubricity, and volatility. Because of this the tests must be done in a special laboratory that has forced ventilation with exhaust inlets at floor level. In order to meet the electric code, every electrical part must be either in an explosion-proof enclosure with explosion-proof fittings, in an ordinary enclosure that is purged with fresh air, or in a nearby room in which there is no gasoline and which is ventilated with fresh air at a small positive pressure. In addition special precautions should be taken to prevent evaporation of the gasoline.

A schematic of the test set-up is shown in Fig. 3.1. The flowmeter under test is connected between an automobile fuel pump and the float bowl of a carburetor. The fuel pump pumps gasoline from the storage tank through the meter and the needle valve into the float bowl. Another pump pumps the gasoline from the float bowl through the transfer standard meter and the flow adjusting valve into the weigh tank. When the dump valve is open the gasoline flows by gravity from the weigh tank into the storage tank.

The automotive fuel pump is a mechanical one that is normally driven by a cam on the cam shaft of an engine. This rotates at half engine speed, and hence the pump operates in the range from 225 ppm (pulses per minute) to 1800 ppm. For the laboratory tests, the

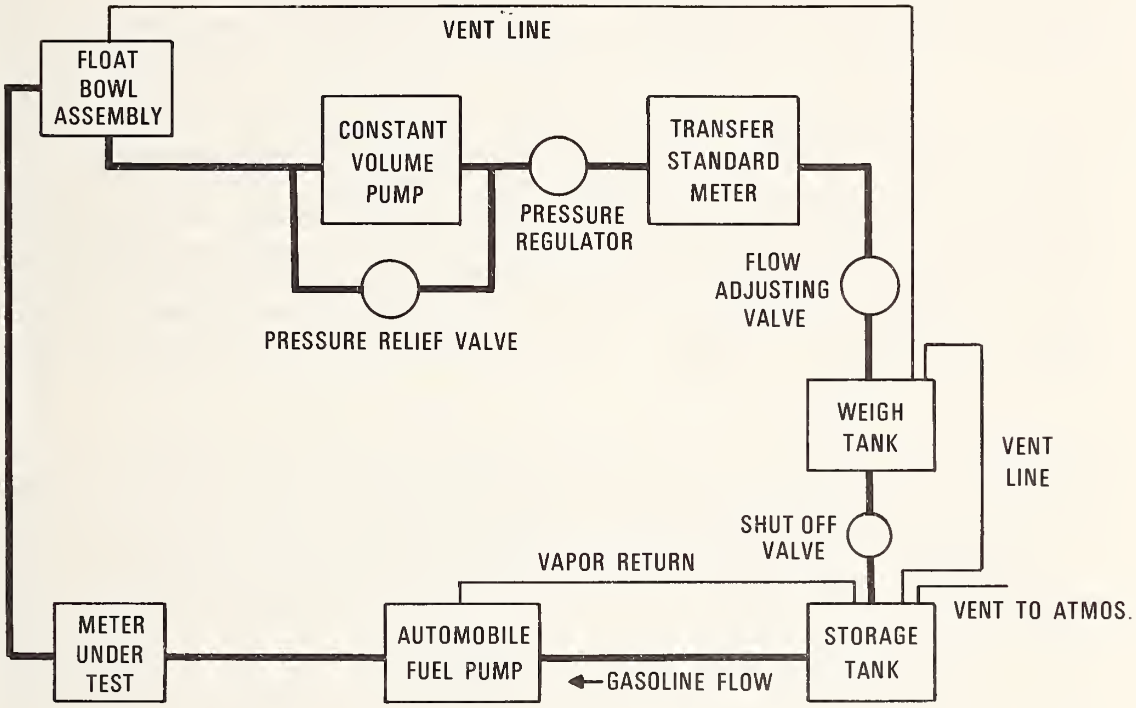

Fig. 3.1. Test Set-up Schematic. The flowrate through the meter under test is set using the flow adjusting valve.

automotive fuel pump is driven by an explosion-proof motor connected to a variable speed drive with an automobile cam on it. The speed range possible is 190 ppm to 1900 ppm. The speed is measured using a 160 tooth gear on the output shaft with a magnetic sensor to detect the passage of each tooth and an electronic counter to count the resulting pulses. The fuel pump has a 1/4 inch diverter line leading back to the storage tank. This line can be closed off in order to simulate automobiles without a diverter.

The gasoline lines are either 3/8 inch stainless steel tubes or 3/8 inch hard flexible plastic tubing connected together with stainless steel or nylon fittings. Copper or brass can not be used because they cause gasoline to form gum especially at higher temperatures. Soft distensible tubing can not be used between the automotive fuel pump and the float bowl because it might affect flowmeter performance. The gasoline lines should slope upward everywhere in order to encourage bubbles to be carried along with the liquid flow.

The needle valve, float, and bowl assembly is one that can be purchased separately as a replacement part for an automobile carburetor. The open side where the bowl normally attaches to the carburetor is covered with a transparent plastic plate so that the liquid level can be observed during nonsteady flow experiments. For steady flow, at least, the fuel pump supplies enough fuel so that the liquid level in the float bowl remains nearly constant regardless of the flowrate.

Since the pressure regulator maintains a constant pressure at its output, the flowrate for the entire flow around the system is set by the flow adjusting valves. These are needle valves, one 3/8 inch and one 1/4 inch size, in parallel just upstream of the weigh tank. The flow from each valve spills separately into the weigh tank and drains into the storage tank when the shut off valve is open. The pipes leading into and out of the tank are arranged so that they do not interfere with the weighing.

Substitution weighing (to be described in the next section) is used to determine the mass of the fuel collected. The tank is suspended from one pan of an equal arm balance with a distance of 16 cm from the center to either pan. A weight whose mass equals the mass of gasoline to be measured is placed on the pan from which the tank is hung. A set of Class C brass weights including 200 g, 500 g, and 1 kg masses is used for this purpose. A counter weight is kept on the pan that hangs from the other end of the balance arm. This weight is more than large enough to balance the weigh tank plus the substitution weight so that with no gasoline in the tank the tank end of the balance arm is up and the other end down.

Tilting of the balance arm is detected by a photon coupled interrupter module. This consists of a light emitting diode shining light onto a photo-Darlington. With the weigh tank empty, a tab on the balance pointer blocks the light beam. When the tank fills and the balance arm swings, the tab moves unblocking the light. This causes the output voltage of the photo-Darlington to decrease monotonically with the lowering of the weigh tank. The output voltage is connected to the gating circuit of an electronic counter, which is set up so that the decreasing voltage starts the counter the first time the voltage decreases and stops the counter the second time. The photo-Darlington output is also amplified and used to energize a relay that turns on a 100 Watt light bulb when the weigh tank is down. The light helps remind the operator to remove the substitution weight the first time it turns on and to open the shut-off valve and replace the substitution weight the second time it turns on.

3A Vapor Seals, Vent Lines, and Bypass Lines

The weigh tank is equipped with two vapor seals designed to minimize the escape of vapor during the measurement and at the same time leave the tank unhindered for weighing. There are two seals, one at the top and one underneath the tank. Each consists of an oil filled circular moat with the edges of a concentric inverted cup immersed in the oil (Fig. 3.2). At the top of the tank, the inverted cup has rigid tubing going through it and so is fixed. The moat it dips into is attached to the top of the weigh tank. Underneath the tank, the inverted cup has the rigid tube from the shut-off valve going through it. So it will swing-free with the tank and shut-off valve. Here, it is the oil filled moat that is fixed since it is attached to the discharge stand-pipe. The empty tank and the valve altogether have a mass of 2545 g.

A vent line connects the weigh tank, the stand-pipe, and the storage tank. This is necessary to provide a return for the vapor that is displaced when the weigh tank is dumped by opening the shut-off valve. The vapor volume flowrate from the storage tank to the weigh tank must be at least as large as the liquid volume flowrate, which can be large when a full tank is dumped. In addition vapor will be entrained by the liquid jetting into the weigh tank from the flow adjusting valve. This vapor is carried with the liquid into the storage tank and released when the liquid settles down. The pressure drop in the vent line due to the (total) vapor flow must be kept small enough so that air does not gurgle through the oil filled moat. The gurgling would cause oil to spill into the weigh tank and mix with the gasoline. A 3/8 inch vent line is large enough to prevent gurgling when using the tank of Fig. 3.2 provided the 3/4 inch shut-off ball valve is not opened all the way at first when a full weigh tank is dumped. A 3/8 inch ball valve would probably have been large enough and probably could be opened completely without causing gurgling when dumping.

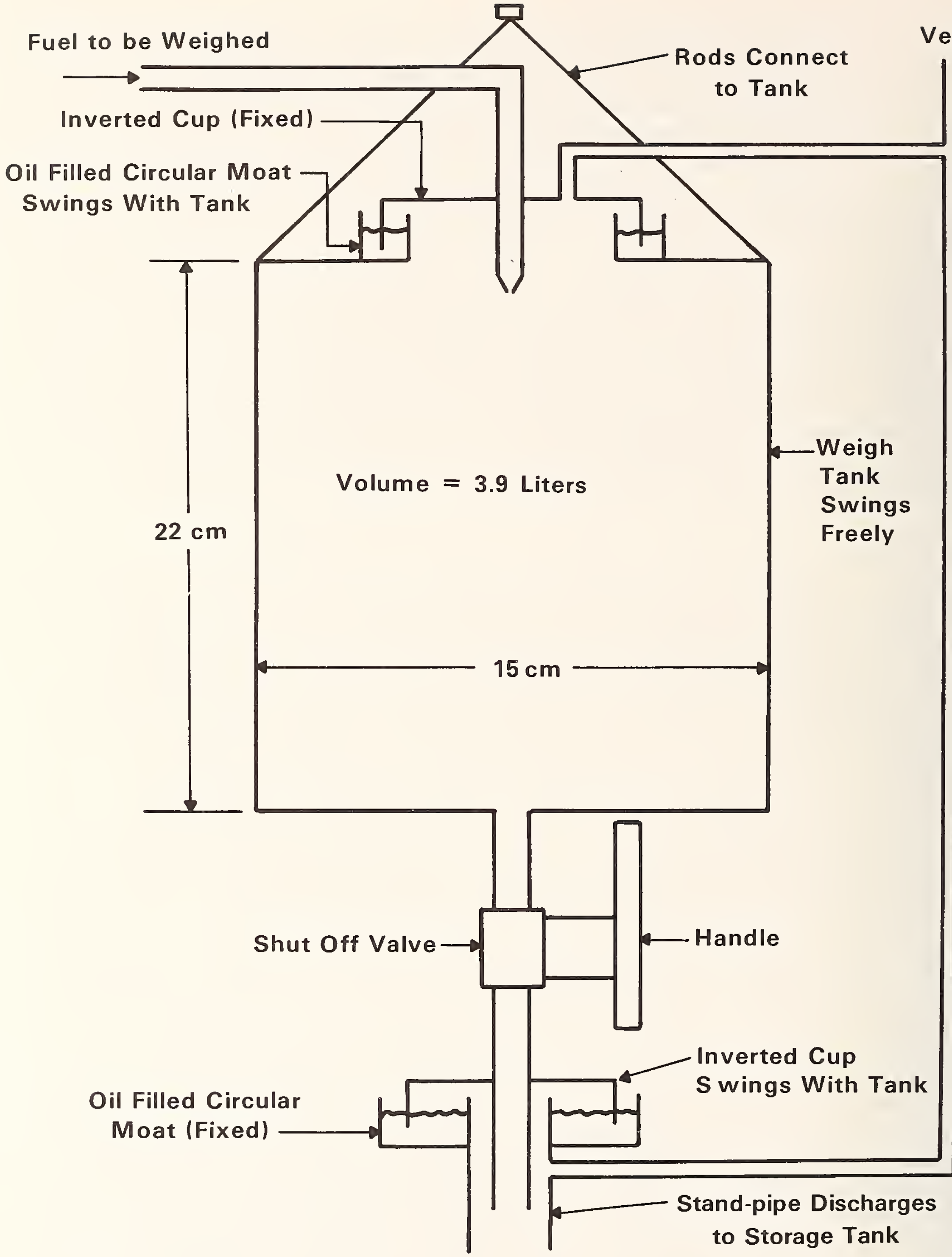

Fig. 3.2. Weigh tank and Vapor Seals. The oil filled moats prevent vapor from escaping and do so without interfering with the weighing.

A vent line is connected between the float bowl assembly and the weigh tank, and a 1 meter long vent line is connected from the weigh tank and storage tank vent line to the atmosphere. The open end of the latter is placed inside the explosion-proof room-exhaust duct in order to keep gasoline vapor out of the room. The line to the atmosphere is long enough that after the entire system settles to a steady state only gasoline vapor (and no air) will be in the vent lines.

In addition to the vent lines, there are bypass lines from the main gasoline line just above the flow adjusting valves, from the bypass outlet of the transfer standard meter, and from the bypass or vapor diverter outlet (if one exists) of the meter under test. These lines (not shown in Fig. 3.1) all lead to the storage tank. The vapor diverter line is left connected according to the instructions of the manufacturer of the meter under test. The bypass lines, on the other hand, are used only momentarily to bleed air and vapor bubbles out of the gasoline lines when the system is turned on. Hence they normally are closed off by valves, which are located at the gasoline-line end of the bypass lines. All the bypass and diverter lines are made of clear plastic to permit visual inspection for bubbles, e.g., to determine when the lines have been bled enough.

3B Apparatus for Other Tests

The Four Orifice Flowmeter described in Appendix A is used for the transfer standard flowmeter in Fig. 3.1. It is included in the test set-up in order to increase the rate of taking data during tests other than the calibrations. The tests involve changing fuel temperature, vibrating the flowmeter under test, etc., and observing whether the indication of the flowmeter under test changes while the flowrate, as measured by the transfer standard flowmeter, is held constant. The transfer standard flowmeter operates at room temperature and is not vibrated or otherwise disturbed. Of course the accuracy of the data taken in these tests is limited by the accuracy of the transfer standard flowmeter, which is not as accurate as weighing and timing. But the transfer standard used, when its voltage output is connected to a voltage-to-frequency converter, gives one pulse for each milligram of gasoline passing through it. This fine resolution makes it possible to determine quickly the effect on flowmeter indication of changing many variables one at a time over a large range. This is necessary when the effect on flowmeter indication is small and turns out to occur only over a small part of the range of only one variable. Such a small effect, in spite of its importance, would probably be missed altogether if only weighing and timing were possible because the latter is so time consuming and so would be done for only a few widely-spaced selected values of the variables.

The pulse output of the transfer standard is connected to the A input of an electronic counter, the pulse output of the flowmeter being tested is connected to the B input, and the counter is set to count the number of A pulses between one B pulse and the first, tenth, or one hundredth B pulse that follows. The counter thus displays the ratio of flowrates, and this display is automatically updated at an adjustable rate. Any three adjacent digits of this ratio are converted into a voltage by a digital-to-analog converter built into the counter. The voltage is connected to the Y input of an XY recorder as shown in Fig. 3.3. By choosing three digits other than the most significant ones and by increasing the Y axis gain of the recorder, the vertical scale of the graph can be expanded as much as desired. A voltage proportional to the variable being changed in the test is connected to the X input. Thus the recorder will plot the ratio of the "actual" flowrate to the indicated flowrate of the flowmeter being tested on the Y axis versus the changing variable on the X axis, where the "actual" flowrate is given by the undisturbed transfer standard flowmeter.

X inputs to the recorder that are possible with the present apparatus include:

- Flowrate, 0.2 to 20 grams per second

- Logarithm of vibration frequency, 1 to 5000 Hz.

- Peak acceleration, 0 to 10 x 980 cm/s^2.

- Automobile fuel pump speed, 190 to 1900 pulses per minute

- DC supply voltage, 8-16 volts

- Amplitude of 60 Hz voltage superposed on supply.

The pump-speed voltage is obtained from a digital-to-analog converter in the counter used to measure the speed.

3C Vibration Apparatus

The vibration exciter is shown at the lower right of Fig. 3.4. It is an electrodynamic exciter mounted with a 61 cm square granite slab for a slip plate all on a reinforced concrete seismic base. The entire assembly weighs 5200 lbs (23,131 N) and is supported on inflated air mounts. The air mounts are connected to an air tank with damping orifices in order to permit operation down to 1 Hz without excessive excursion of the seismic base. The peak force available is 800 lbs (3559 N), and the armature suspension stiffness is 400 lbs/inch (700 N/cm). Thus a 30 lb (133N) flowmeter, which is mounted on a 41 cm square by 5 cm thick fixture weighing 50 lbs (222 N) and attached to the 20 lb (89 N) armature, can be vibrated vertically without overwhelming the exciter. The mounting hole pattern on the 61 cm square by 3.18 cm slip plate is identical to the 20.32 cm diameter pattern on the armature so that after a flowmeter is vibrated vertically, the flowmeter and fixture can be remounted on the slip plate for horizontal vibration.

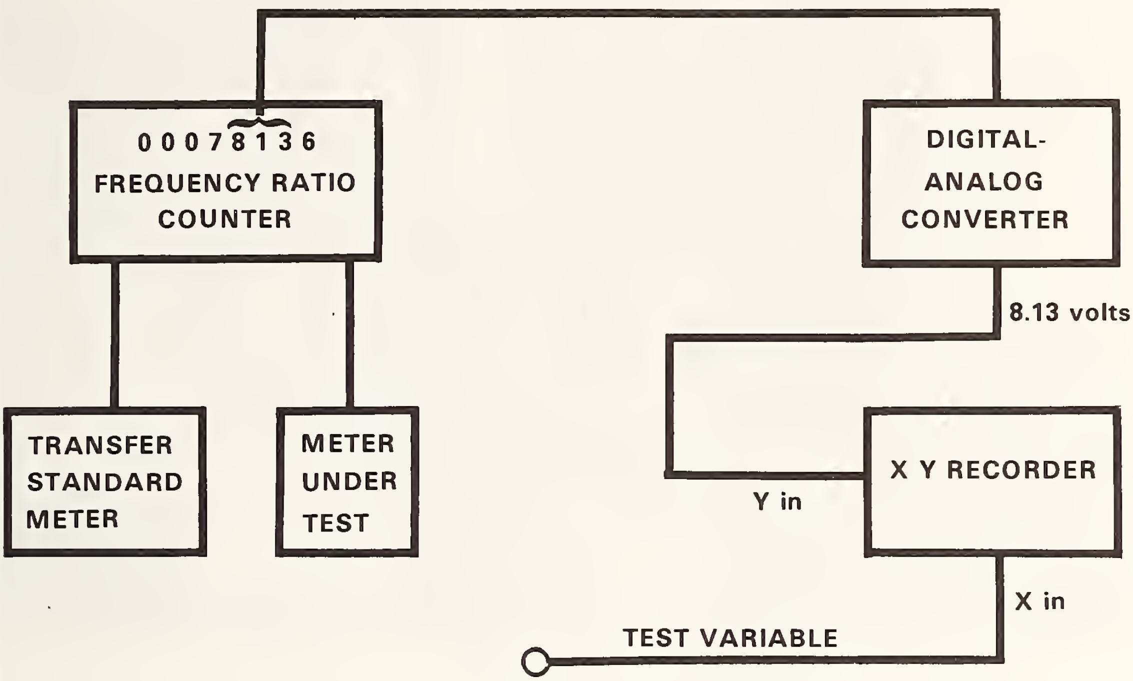

Fig. 3.3. Wiring Schematic for Vibration, Supply Voltage, Fuel Pump Speed, and other tests.

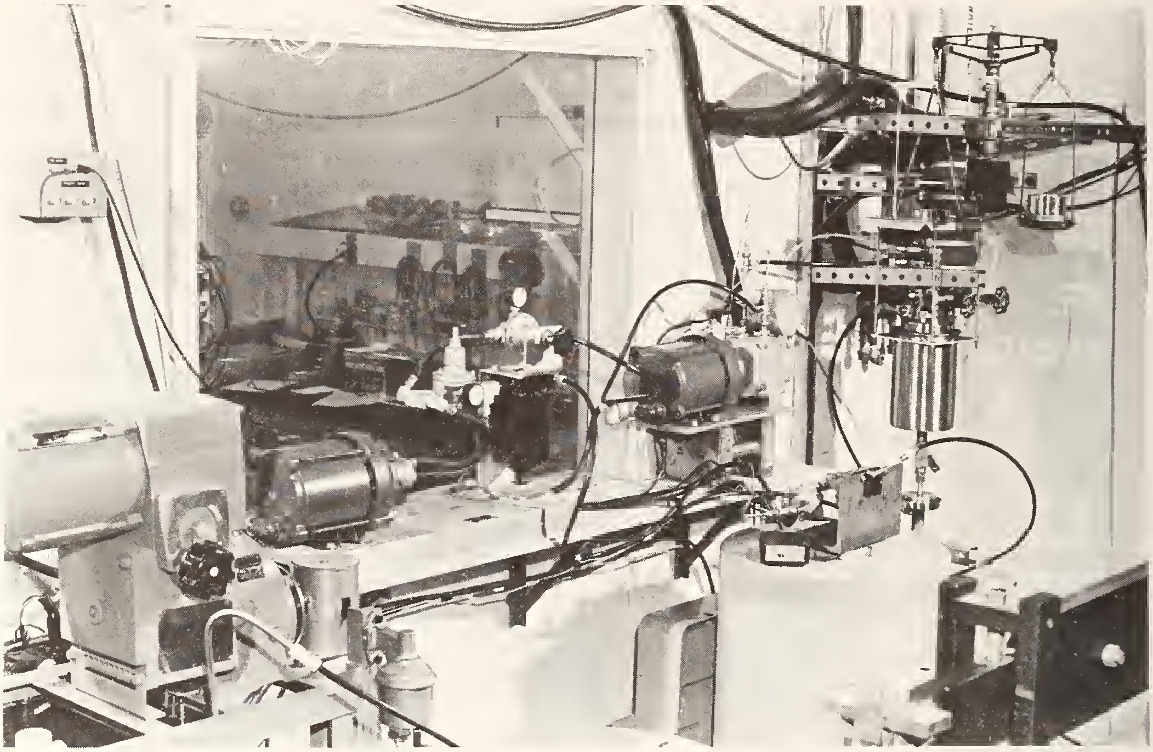

Fig. 3.4. Test Set-Up for Vertical Vibration. The flowmeter being tested is connected directly to the float bowl assembly, which is mounted on an angle iron on top of the exciter (lower right). For horizontal vibration, the angle iron is remounted on the slip table (one corner just visible at lower center), and the exciter is rotated 90° on its trunnion and attached to the slip table. The variable speed motor (lower right) has the automotive fuel pump attached to it. The four orifice flowmeter is just right of center, and the pressure regulator and supply pump used with it are to its left. The stainless steel weigh tank (center right) hangs from a pan with a substitution weight on it. The pan hangs from a balance arm (upper right) which has another pan on the other end with a counter weight on it. Electronic counters etc. are behind the window and to the left (not visible in the picture) and can be seen by the operator when standing at the weigh tank. The counters can be reset remotely by pushing explosion-proof pushbuttons.

The sinusoidal vibration can be swept automatically from 1 Hz to 1000 Hz or from 5 Hz to 5000 Hz or over an arbitrary range within either of these. In this frequency range, the vibration level can be up to 2.54 cm peak-to-peak displacement, 71 cm per second velocity, or 800 lbs (3559 N) force, whichever is smallest considering the frequency and the weight of the flowmeter, fixture, and armature. The displacement, velocity, or acceleration can be automatically controlled at presettable levels in each of two segments in the range from 1 to 5000 Hz with automatic crossover between segments at a presettable frequency, all presettable before vibrating. The vibration test system has overload and over driving protection and interlocked controls for damage protection. Vibration frequency is displayed to .1 Hz once every second or to 1 Hz ten times a second. Two vibration monitors each display displacement, velocity, or acceleration with an accuracy of 1 percent of reading in the range from 1 to 5000 Hz. The accelerometers used with the monitors are: one high sensitivity (100 mv per 980 cm/s^2, rms) accelerometer, and one subminiature one with a total mass of 1 gram, both of them the shear mode piezoelectric kind.

The shaker and slip table assembly are modified for use in an explosive atmosphere. The field power supply, power amplifier, and other vibration system electronics are mounted in a standard electronics rack located in a room adjacent to the explosion-proof laboratory.

Once a flowmeter has been fixtured to the armature the shaker can also be used to tilt the flowmeter 10 degrees or any other angle from the vertical. The shaker is designed to be rotated on its trunnion from the vertical position to the horizontal position for attaching it to the horizontal slip table. However, the shaker can be locked at any angle and can be used just as a mechanical support without any power supplied to it to make it vibrate.

3D Electrical Test Apparatus

Three automotive 6 volt lead storage batteries provides voltages in 2 volt increments up to 18 volts for flowmeters that require a large current. A regulated power supply provides a continuously variable voltage up to 18 volts for flowmeters that require less than 3 amperes. A 120 volt to 12 volt transformer with the primary connected to a variac and the secondary wired in series with the dc supply provides a 60 Hz sinusoidal voltage of variable amplitude superposed on the dc supply voltage. An automotive spark plug, coil, and capacitive discharge ignition source driven by a +5 volt pulse generator and a transistor provide a spark for testing the effect of electromagnetic radiation on flowmeter performance. An "antenna" made of ignition wire is attached to the hot side of the spark plug and taped to the window near the flowmeter. Radio noise suppression ignition wire and, alternatively, insulated metallic ignition wire are used for the antenna.

3E High Temperature Apparatus

For high temperature measurements heat exchangers are installed as shown in Fig. 3.5. The one used for heating the gasoline just upstream of the meter under test consists of three single pass sections, two of them each 100 cm long and one 130 cm long, connected in series in a Z configuration using 3/8 inch elbow tubing fittings. Each section consists of a long straight 3/8 inch stainless steel tube (with the gasoline flowing inside it) and a shorter concentric 5/8 inch stainless steel tube (with hot water flowing in the annular region between the tubes. The water enters through the branch of a 5/8 inch stainless steel T fitting at one end and leaves through a similar setup at the other end. A bored through 5/8 to 3/8 inch reducing fitting keeps water from leaking out the end and holds the 3/8 inch tube concentric with the run of the T and hence with the 5/8 inch tube. The hot water circulates at 15 ℓ/min through 1/2 inch plastic tubing from a constant temperature circulator consisting of a 1000 watt heater, a pump, and a thermostat. The circulator is located in the next room in order to meet the explosion-proof requirements. All tubes are covered with two layers of 1.25 cm thick foam pipe insulation.

The three heat exchangers used to cool the gasoline liquid and vapor each consist of 28 straight-through 1/4 inch tubes in parallel. One fluid flows inside the tubes and the other passes back and forth around the outside of the tubes and inside a 5.14 cm diameter jacket. The two heat exchangers used to cool vapor in the vent lines each have 20 cm long tubes, and the one used to cool the main gasoline flow has 45 cm long tubes. The heat exchanger in the vent line from the float bowl assembly to the weigh tank is higher than the weigh tank and has the vapor from the float bowl assembly entering the 28 straight tubes at the top so that any condensate will flow into the weigh tank. A transparent tube connects the heat exchanger to the weigh tank so that liquid drops can be seen in the tube. A circulator with a 1/2 horsepower cooler in the next room supplies 15 ℓ/min of water and ethelene glycol at -15°C for cooling in this heat exchanger. In-house chilled water at 12°C is used for cooling in the other two heat exchangers.

An electronic thermometer probe is located in the gasoline line just upstream of the flowmeter under test, another in the gasoline line just downstream of the cooling heat exchanger, and a third in the float bowl vent line between the heat exchanger and the weigh tank, all as shown in Fig. 3.5. When possible a fourth is located in the gasoline line just downstream of the flowmeter under test. Because the probe is inserted into the flow through a T fitting, the fourth probe can not be installed when the flowmeter manufacturer specifies mounting the flowmeter as close as possible to the float bowl, e.g. as with the Turbine Flowmeter described in Section II. The probes each consist of two thermistors inside an 11 cm long 1/8 inch stainless tube. The probes are inserted through a bored-through 3/8 to 1/8 inch reducing fitting connected to one run of a 3/8 inch T fitting. The gasoline flows between the branch of the T and the other run. Thus

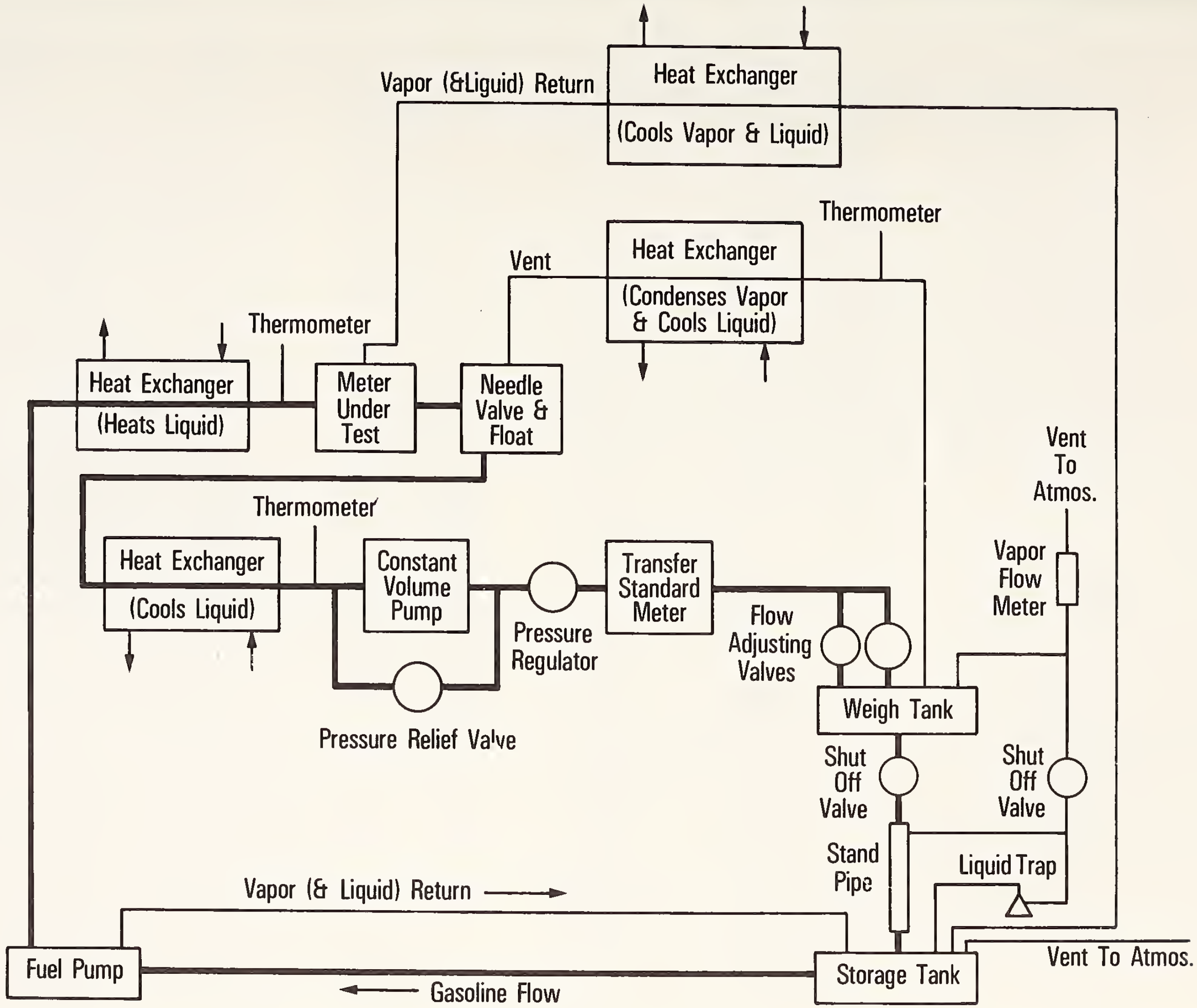

Fig. 3.5. Schematic of high temperature test set-up.

the sensitive end of the probe is well into the flowing gasoline. The electronic digital displays for these probes are located in the adjacent room because of the explosion hazard. Reports of test of the thermometers are reproduced in Appendix H.

A 1 mℓ-10 mℓ-100 mℓ soap bubble flowmeter is connected to the weigh tank vent line for use in measuring the flowrate of vapor displaced by the tank filling plus the flowrate of evaporation of the gasoline not recondensed. A liquid trap is located in the vent line between the storage tank and the weigh tank in order to keep liquid splashing out of the storage tank from entering the vent line near the weigh tank. This is necessary because the liquid would clog the soap bubble flowmeter.

An ASTM No. 83-H specific gravity 60°/60°F hydrometer[6] is used for measuring gasoline density, and a 1/4 size Reid vapor pressure bomb[7] and two constant temperature baths are used for measuring the Reid vapor pressure of the gasoline. A T fitting in the fuel line just downstream of the automotive fuel pump is used for drawing gasoline from the system for these tests. A valve connected to the T is opened to fill a container with gasoline and closed during the flowmeter tests. A similar T fitting in the fuel line just upstream of the automotive fuel pump is used for returning the gasoline to the system after the tests are completed. A valve connected to this T is opened to suck gasoline from the container and closed during the flowmeter tests.

4. PROCEDURE

4A. Scope.

4A.1 This section describes the procedures for set-up and testing of the automotive fuel flowmeters.

4B. Summary of Procedure.

4B.1 The flowmeters are mounted securely in the test set-up and all or some of the tests are performed on them. All data pertinent to the testing of the flowmeter are recorded: fuel temperature at the flowmeter, flowmeter indication obtained from flowmeter display, flowmeter indication obtained by counting flowmeter output pulses, mass of fuel collected, collection time, specific gravity of a fuel sample, number of cycles of unsteady flow, frequency span of vibration, duration of vibration, ratio of actual flowrate to indicated flowrate, voltage supplied to the flowmeter, voltage level of superposed sinusoidal signal, repetition rate of electromagnetic radiation from spark ignition circuit, flowmeter pressures, fuel pump speed, and temperature and pressure for determining the Reid Vapor pressure of a fuel sample.

4C. Apparatus.

4C.1 The apparatus used in the tests is described in Section 3.

4D. Preparation for Tests.

4D.1 If vibration tests are to be performed, a substantial fixture is constructed and used to secure the flowmeter under test to the armature of the vibration exciter or to the horizontal slip table. This mounting will also be satisfactory for the other tests. If no vibration tests are to be performed, a less massive mounting will suffice. The flowmeter is connected into the flow system of Fig. 3.1 as described in Section 3. If the flowmeter to be tested has a bleed outlet, a valve is connected between it and a transparent return line to the storage tank.

4D.2 All electrical connections are made and tested to insure proper functioning of the flowmeter and the other apparatus. The storage tank is emptied and filled with fresh gasoline. Fuel flow is started, and the system is checked for leakage. If leaks are found they are repaired. Air bubbles are bled from the system by momentarily opening the bleed valves until bubbles no longer are seen in the return lines.

4E. Procedure for Steady Flow Tests.

4E.1 Fuel is withdrawn from the system, its 60/60°F specific gravity is measured using ASTM Method D287,[8] and the fuel is returned to the system.

4E.2 The flowrate is set at one of the seven flowrates: 0.2, 0.5, 1, 2, 5, 10, or 20 g/s, as measured by the transfer standard flowmeter. The automotive fuel pump is operated at a low speed that is sufficient to supply the desired flowrate. Five collections of fuel are made at each of the above flowrates on each of two days.

4E.2.1 For flowmeters with more than ten output pulses per gram of fuel metered (100 mg per pulse) the mass collected is as follows. At the three lowest flowrates, 0.2, 0.5, and 1 g/s, the mass collected is 200 g. At 2 and 5 g/s it is 500 g, and at 10 and 20 g/s it is 1 kg.

4E.2.2 For flowmeters with ten or fewer output pulses per gram of fuel metered, the minimum mass collected must be larger than 2000 times the mass per pulse except for the following.

4E.2.3 For flowmeters that indicate in .01 gallon increments, 300 g is collected for .2 to 2 g/s flowrates, and 3 kg is collected for 5, 10, and 20 g/s. These flowmeters require a special procedure that is described in Subsection 4.E.4.

4E.3 Collections of fuel are weighed and timed using the substitution weighing procedure graphed in Fig. 4.1. For this procedure the weigh tank is attached to a pan on one side of an equal arm balance. At the start of a measurement a (substitution) weight of known mass is placed on the pan. Sufficient tare weight is on the pan on the other side of the balance to tilt the second pan down. With the gasoline flowing through the system in a steady state, the shut-off valve is closed so that the tank will fill. When sufficient gasoline is collected to swing the balance arm, it interrupts a light beam. This starts a timer and two counters that record the total number of electrical pulses from both the flowmeter under test and the transfer standard flowmeter. Then the substitution weight is removed, and the arm swings back. When sufficient additional gasoline is collected to swing the balance arm again, it again interrupts the light beam, which stops the timer and counters. Finally, the shut-off valve is opened draining the tank, and the substitution weight is replaced. The average actual flowrate is the substituted mass divided by the collection time interval.

4E.4 For flowmeters that indicate in .01 gallon increments, an additional timer is used for obtaining the indicated flowrate. The closing of the shut off valve in Subsection 5E.3 is timed so that the collection of the 300 g or 3 kg of gasoline in the weigh tank starts as nearly as possible to the time a pulse from the flowmeter starts the timer. The collection will then end at about the time the tenth or one hundredth subsequent pulse stops the timer. The output of the transfer standard flowmeter is plotted as a function of time during the collection in order to establish that the flowrate is constant. The indicated flowrate is obtained from the indicated volume and the time required for it to pass through the flowmeter.

4E.5 The data recorded after each collection of fuel includes:

- substitution mass
- collection time
- flowmeter indication (if available)
- total number of flowmeter output pulses (if available)
- total number of transfer standard flowmeter output pulses
- time required for 10 flowmeter pulses (if flowmeter indicates in .01 gallon measurements)
- fuel pump speed
- fuel temperature into flowmeter

4E.6 The 60/60°F specific gravity is measured again as in Subsection 4E.1.

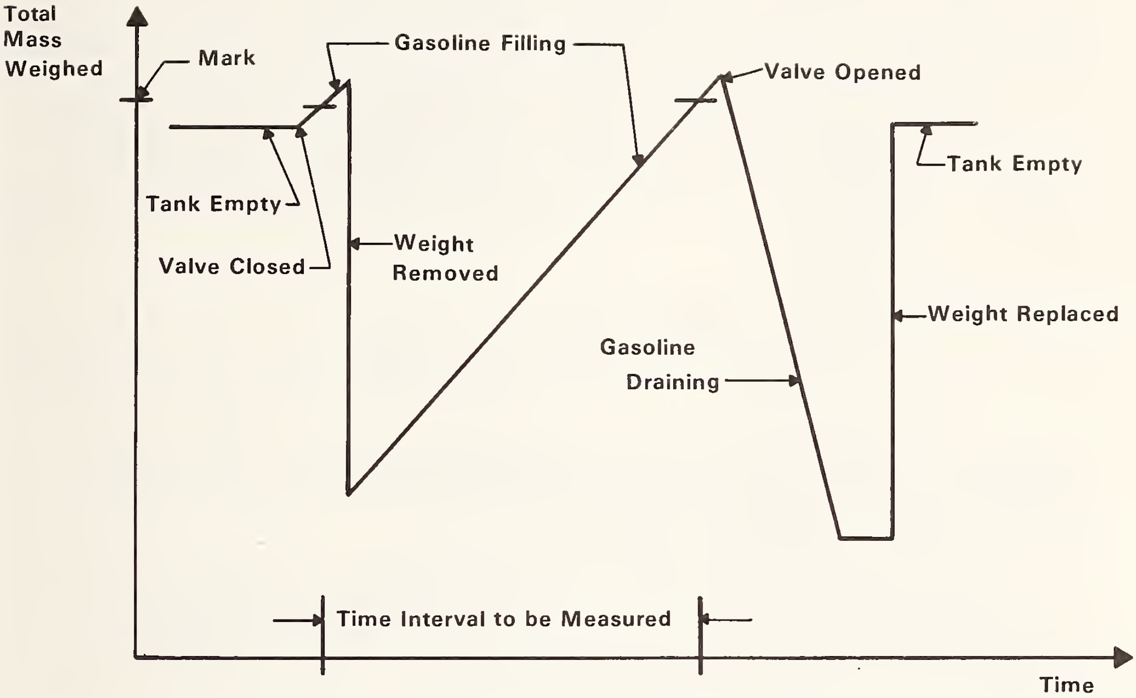

Fig. 4.1. Graph of total mass weighed versus time, illustrating the substitution weighing procedure.

4E.7 The actual mass flowrate is computed by dividing the substitution mass by the collection time and multiplying the result by 1.0036. As described in Section 5, this factor corrects for the lost mass of the gasoline vapor that is displaced by the collected liquid. The "indicated" mass flowrate is computed from the indicated volume flowrate and the average measured specific gravity using Tables 23, 24, and 26 of Ref. 9. Since the tables include a correction to give weight as if it were measured in air without a correction for buoyancy, the result must be multiplied by 1.0017 in order to compare it with the actual mass flowrate. The ratio of the actual mass flowrate to the indicated mass flowrate is computed for each collection. This ratio should be equal to one. Both the mean and the relative standard deviation of the five ratios are computed. The relative standard deviation or relative repeatibility is the standard deviation divided by the mean.

4F. Procedure for Unsteady Flow Tests.

4F.1 The 60/60°F specific gravity is measured as in Subsection 4E.1.

4F.2 The automotive fuel pump is operated at a low speed that is sufficient to supply the maximum desired flowrate. The test is started by setting a steady flowrate of about 10 g/s as measured by the transfer standard flowmeter.

4F.3 During the collection of a mass of fuel the flowrate is cycled between 0 and 20 g/s or between 5 and 10 g/s or between other appropriate rates a number of times and returned to 10 g/s before the end of the collection time.

4F.4 Five collections are made for each cycled range.

4F.5 The data recorded are the same as in Subsection 4E.5 plus the following:

- time period over which the flow is cycled
- the number of times the flow is cycled.

4F.6 The 60/60°F specific gravity is measured again as in Subsection 4E.1.

4F.7 The data is analysed as in Subsection 4E.7.

4G. Procedure for Vibrational Tests.

4G.1 The flowmeter or the flowmeter and float bowl assembly (if the manufacturer specifies attaching one to the other) is fixtured for either vertical or horizontal vibration.

4G.2 The pulse output of the transfer standard flowmeter is connected to the A input of an electronic counter, the pulse output of the flowmeter being tested is connected to the B input, and the counter is set to count the number of A pulses between one B pulse and the first, tenth, or one hundredth B pulse that follows. The circuit used is shown in Fig. 3.3 and described in Sec. 3. The LOG-DC output of the sweep sine generator is connected to the X input of the XY recorder. This output is a voltage proportional to the logarithm of the frequency of vibration.

4G.3 The 60/60°F specific gravity is measured as in Subsection 4E.1.

4G.4 The flowrate is set to 10 g/s as measured by the transfer standard flowmeter. The automotive fuel pump is operated at a low speed that is sufficient to supply this flowrate.

4G.5 The flowmeter is vibrated through the frequency range of 1 to 1000 Hz. From the low frequency limit to the crossover frequency the displacement is held constant at 2.5 cm peak-to-peak. From the crossover frequency to the high frequency limit the peak acceleration is held constant. For most tests the peak acceleration used is 1.5 x 980 cm/s^2, for which the crossover frequency is 5.4 Hz. If the flowmeter is to be installed in a location with relatively little vibration, the peak acceleration used is 0.5 x 980 cm/s^2, for which the crossover frequency is 3.1 Hz.

4G.6 The XY recorder is used to plot the ratio of the actual to indicated flowrates versus the logarithm of the frequency of vibration.

4G.7 The data recorded with the plotted graph are:

- direction of vibration
- peak-to-peak displacement
- crossover frequency
- peak acceleration
- time chosen for the duration of the sweep of the frequency range
- flowrate indicated by transfer standard meter
- fuel pump speed
- which digits on counter are selected to be plotted
- number of tested flowmeter pulses over which the counter averages
- fuel temperature.

4G.8 If as a result of the test the flowmeter indication is suspected to be affected by vibration over a portion of the frequency range, additional shorter frequency range tests are performed over a longer period of time in order to obtain more precise data describing the effect.

4G.9 Test for effect of increasing acceleration in order to establish a very small vibration effect.

4G.9.1 The oscillator is set to the frequency at which the maximum effect on flowmeter indication occurred.

4G.9.2 A DC voltage proportional to peak acceleration is connected to the X input of the XY recorder.

4G.9.3 The acceleration is increased slowly from zero to 2×980 cm/s^2.

4G.9.4 The XY recorder is used to plot the flowrate ratio versus peak acceleration.

4G.9.5 The data recorded with the graph are:

- direction of vibration
- frequency
- flowrate indicated by transfer standard flowmeter
- automotive fuel pump speed
- which digits on counter are selected to be plotted
- number of tested flowmeter pulses over which the counter averages
- time period over which acceleration is increased
- fuel temperature.

4G.10 Test for effect of flowrate on vibration effect.

4G.10.1 The same maximum effect frequency is used.

4G.10.2 The voltage output of the transfer standard flowmeter is connected to the X input of the XY recorder.

4G.10.3 The automotive fuel pump is operated at a low speed that is sufficient to supply 20 g/s.

4G.10.4 The acceleration is set to 1.5×980 cm/s^2.

4G.10.5 The flowrate is increased slowly from zero to 20 g/s.

4G.10.6 The XY recorder is used to plot the flowrate ratio versus flowrate.

4G.10.7 The data recorded with the graph are:

- direction of vibration
- frequency
- peak acceleration
- automotive fuel pump speed
- which digits on counter are selected to be plotted
- number of tested flowmeter pulses over which the counter averages
- time period over which flowrate is increased
- fuel temperature.

4G.11 The vibration tests are repeated for vibration in the other spatial directions so that tests are completed for vibration in each of the three perpendicular directions.

4G.12 The 60/60°F specific gravity is measured again as in Subsection 4E.1.

4G.13 The average fuel density is calculated as in Subsection 4E.7.

4H. Procedure for Electrical Tests.

4H.1 The flowrate is set at a steady rate of about 10 g/s.

4H.2 First, with the electrical connections the same as in Subsection 5G.3, the voltage supplied to the flowmeter under test is varied from 8 to 16 volts dc. The supplied voltage is connected to the X axis for the XY recorder, and the indicated to actual ratio is plotted versus the supply voltage.

4H.3 Second, a 4 volt zero-to-peak 60 Hz sinusoid is superposed on a fixed 12 volt supply connected to the flowmeter under test. The difference in flowmeter indication due to the superposed sinusoid is recorded.

4H.4 Third, a spark ignition circuit is connected to ignition wire taped to the window, and the circuit is turned on. Both radio noise suppression ignition wire and insulated metallic ignition wire are used, first one then the other. The effect of the spark on the tested flowmeter's indication is recorded for spark repetition rates up to 240 Hz.

4I. Procedure for Variable Pump Speed Test.

4I.1 The flowmeters are connected as in Subsection 5G.1 except that the pump speed is applied to the X input of the XY recorder. This is done by connecting the magnetic sensor that counts gear teeth to an electronic counter. The analog output of the counter is connected to the X input of the XY recorder.

4I.2 With a constant flowrate of about 10 g/s, the automobile fuel pump speed is varied from 190 to 1900 pulses per minute.

4I.3 The XY recorder is used to plot the flowrate ratio versus pump speed.

4I.4 The data recorded with the plotted graph are:

- flowrate indicated by the transfer standard meter
- fuel pressure.

4J. Procedure for High Fuel Temperature Tests.

4J.1 A heat exchanger is connected to heat the fuel upstream of the flowmeter under test, another heat exchanger to cool the fuel downstream of the float bowl, another heat exchanger to condense the vapors vented from the float bowl, and the bubble flowmeter to measure the vapor flowrate, all connected as shown in Fig. 3.5 and as described in Section 3. The -15°C coolant circulator is turned on.

4J.2 The storage tank is emptied and filled with fresh gasoline.

4J.3 The 60/60°F specific gravity is measured as in Subsection 4E.1. The Reid vapor pressure is measured using ASTM Method D323.

4J.4 The flowrate is set at 5 g/s, the fuel temperature at the flowmeter input is set initially at 25°C, and the fuel temperature upstream of the transfer standard flowmeter is set to room temperature by adjusting the house cooling water flowrate.

4J.5 The tests are conducted in the same manner as in Subsection 4E.3. In addition the condensate and vapor temperature is measured. Also the vent shut off valve must be open whenever the gasoline filling the weigh tank is about to tilt the balance arm at the beginning of a collection or at the end. This is necessary so that vapor can pass quickly from the stand pipe into the weigh tank without causing the oil to gurgle out of the moats. Immediately after the substitution weight is removed, the shut off valve is closed, and the bubble flowmeter is used to measure the vapor flowrate in the vent volume line. As soon as this measurement is completed, the vent shut off valve is opened, in time for the balance to tilt again. If necessary the vapor flow measurement can be made immediately following the completion of each collection.

4J.6 Five collections of fuel are made at each temperature.

4J.7 The data recorded after each collection are the same as in Subsection 4E.5 plus the following:

- vapor flow through the bubble flowmeter
- fuel temperature upstream of the constant volume pump
- condensate and vapor temperature.

4J.8 The measurements of Subsection 4J.3 are repeated.

4J.9 The fuel temperature at the flowmeter under test is increased by 10°C, the flowrate is reset to 5 g/s, the fuel temperature upstream of the transfer standard flowmeter is reset to room temperature, and Steps 4J.5 to 4J.8 are repeated.

4J.10 Step 4J.9 is repeated until all measurements at 65°C have been completed.

4J.11 The condensate flowrate is measured as follows when the fuel at the flowmeter input is at 65°C. The bleed valve upstream of the flow adjusting valves is opened, both flow adjusting valves are closed, and the bleed valve is used to set the gasoline flowrate to 5 g/s. The only flow into the weigh tank will be the condensate flow. The condensate flowrate is measured by weighing and timing with a 50g substitution weight. The condensate flow pulsations are characterized by noting the rate at which drops pass through the transparent tube from the heat exchanger to the weigh tank. The mass of the condensate drops can thus be estimated and used to estimate the error caused by the drops during the weighing of the main fuel flow.

4J.12 The data is analysed as in Subsection 4E.7 with the following exception. The vapor mass flowrate is calculated assuming a density of 2.6 g/ℓ. This mass flowrate is added to the substitution mass divided by the collection time. The ratio is not multiplied by 1.0036 here because adding the vapor mass flowrate already takes the buoyancy effect into account.

5. ERROR ANALYSIS

A significant source of error is shown in Fig. 5.1. The mass of liquid in the falling column is equal to the collected mass times the cross sectional area of the column divided by the cross sectional area of the weigh tank. The resulting error is not negligible. Also there is another significant source of error: The force exerted on the liquid in the tank by the liquid jet is larger at the initial level than at the final level due to the acceleration of the jet by gravity. Fortunately the difference between the initial and final force is exactly equal to the weight of the liquid in the column, and so the two errors cancel exactly. This is true even though the column tapers, becoming smaller in diameter at the bottom as the fluid speed increases the farther it falls.

Another source of error occurs in correcting for the buoyant force on the liquid due to the gas in the weigh tank. The density of the liquid is about .74 g/mℓ, and the density of air is about 1.2 g/ℓ. Hence, if the gas were air, the correction would be +.17 percent. However, because the weigh tank is completely enclosed as described in Section 3, the gas inside eventually becomes just gasoline vapor. The most volatile component of gasoline is usually butane. The density of butane at atmospheric pressure and room temperature is about 2.6 g/ℓ. This leads to a correction of about + .36 percent to the mass collected. Since the tables used for density are for weighings in air, a correction

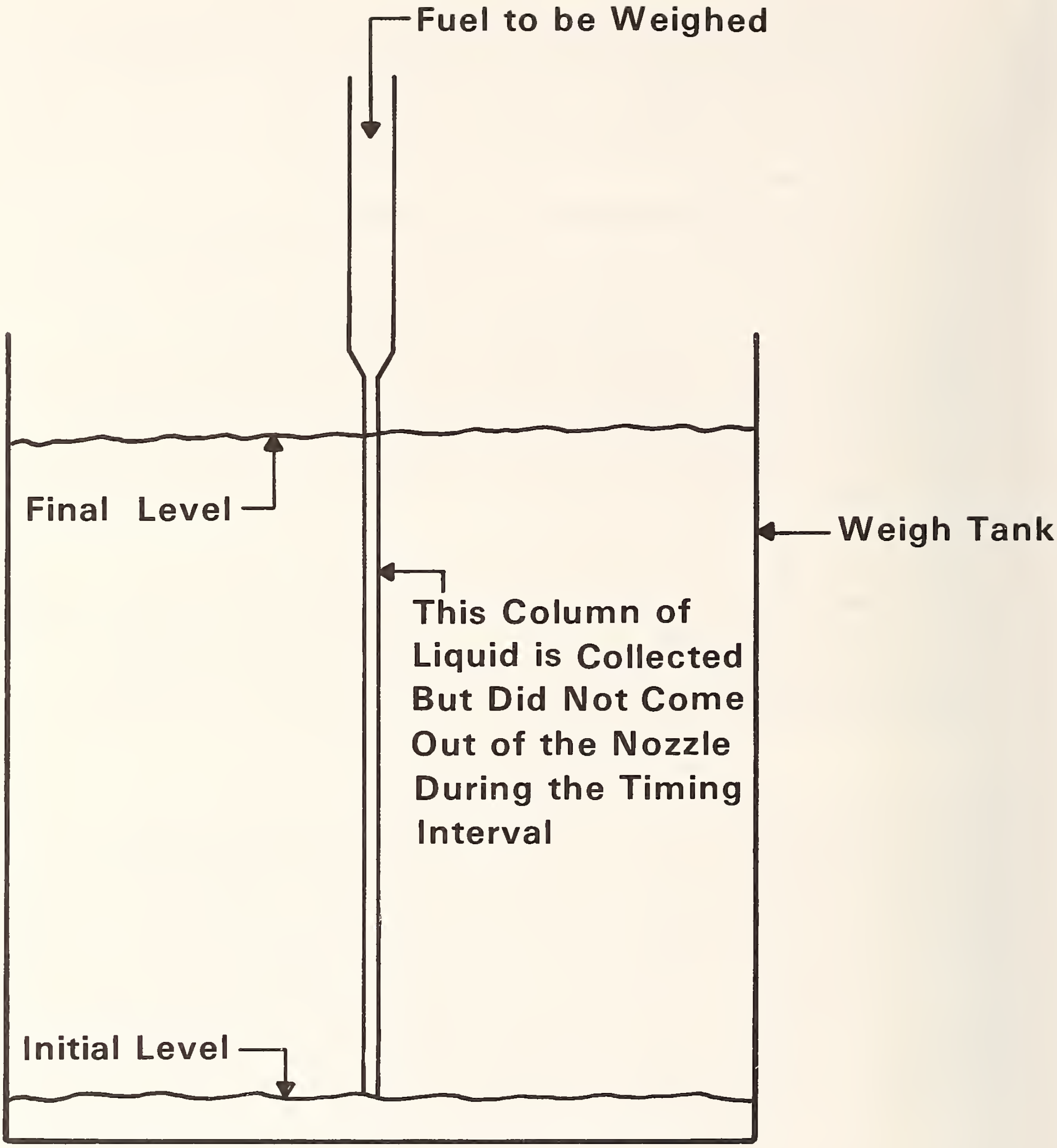

Fig. 5.1. Error due to the additional fuel collected.

equal to the difference (.36 - .17 = .19 percent) is applied to the data. The buoyant force of air on the brass weights used for substitution weighing is negligible.

Butane is not the only component of gasoline that evaporates. Gasoline is a mixture of a number of components with different boiling points and densities (and viscosities). As time passes, or as the temperature is raised, other of the more volatile components will also escape or be driven off. As a result the properties of the gasoline will change. Hence the .19 percent correction is only approximately correct, and the uncertainty is probably within the precision of the test system.

The precision of the flowrate calibration can be estimated as follows. The sensitivity of the balance is better than 0.1 gram, and the smallest mass collected is 200 grams (for the three lowest flowrates). This gives a readibility of .05 percent for each calibration at the lowest flowrates.

Note that the substitution weighing procedure eliminates any error due to the inertia being different at the two marks. This error occurs with the alternative procedure where the weight is placed on the counter balance pan after the collection is started rather than being removed from the weigh tank pan at that time as in the substitution procedure. In the first case the moment of inertia of the balance arm, weights, pans, and weigh tank is larger at the full tank mark than it is at the empty tank mark. Since the rate of change in torque due to the gasoline entering the tank is the same at both marks, the rotational acceleration of the balance arm would be less at the full tank mark than at the empty tank mark. However, this effect would be small for the present system because of the low flowrates involved.

Although enclosing the weigh tank with vapor seals reduces one source of error, it can introduce another if the vent lines are small. When the balance arm swings, the vapor volume inside the tank is suddenly increased by a small amount equal to the area of the inverted cup multiplied by the vertical distance the tank moves. This volume of vapor must pass quickly through the vent line in order to prevent distortion of the liquid level in the oil moat. If the vent lines are not sufficiently large the pressure inside the tank will decrease enough to cause a substantial force on the balance arm. At the lower seal a similar effect occurs but in the opposite direction. Unfortunately the forces do not cancel because they depend upon the vapor volume in each closed region, and these are not equal. For the same reason the effect is different when the tank is full and when it is empty. With the vent lines used at first this caused a small difference in the response time of the balance arm at the upper and lower fill marks. To minimize this effect the vent lines were increased from 4 mm to 7 mm inside diameter.

A measurement was made of the effectiveness of the 7 mm vent line, which was approximately 1 meter long between the weigh tank and the storage tank. The flowrate was set at 20 g/ℓ, and weights were chosen so that the vapor volumes at the lower and upper marks were 3.9ℓ and 0.5ℓ, respectively. The ratio of these volumes is much larger than the ratio for the upper and lower marks used when calibrating flowmeters so the measurement reliably establishes an upper limit for the error. The resulting response is seen in Fig 6.2 to be sufficiently similar at the two marks to result in a negligible error since the shortest collection time was 50 seconds.

Another potential source of error arises from evaporation of the gasoline from the float bowl and the weigh tank. At room temperature the error is negligible since after the system reaches a steady state the enclosed space over the liquid is filled with gasoline vapor, which tends to reduce further evaporation, and since the collection time does not exceed 1000 seconds. At higher temperatures the evaporation from the float bowl increases. Much of this vapor is condensed by the heat exchanger in the float bowl vent line, and the resulting condensate drips into the weigh tank and gets weighed. The flowrate of the vapor that is not condensed plus the vapor displaced by the liquid filling the weigh tank is measured by the bubble flowmeter. For a float bowl temperature near 65°C the net vapor flowrate measured is about 12 mℓ/s for gasoline with a Reid vapor pressure of about 8.9 psi. If the measured vapor density is assumed to be about 2.6 g/ℓ, the vapor mass flowrate is about .03 g/s. Because the composition of the vapor and hence its density is not certain, the vapor mass flowrate is uncertain by about .01 g/s. This leads to an uncertainty of .2 percent in the 5 g/s liquid flowrate measured at 65°C.

The uncertainty caused by the condensate dripping into the weigh tank rather than flowing smoothly can be estimated as follows. For a float bowl temperature near 65°C and a Reid vapor pressure of about 8.9 psi, the condensate flowrate is about .2 g/s. The condensate pulses through the transparent tube to the weigh tank about once a second. Hence, the condensate drops that fall into the weigh tank in one burst have a total mass of about .2 g, and so the uncertainty in the mass collected caused by the dripping is about .2g. For a substitution mass of 500 g, the resulting readibility for each flowrate measurement is .04 percent.

5A Summary of Potential Errors

Three kinds of errors have been discussed: 1) errors that exactly cancel other errors, 2) errors that are negligible for the conditions of the tests, and 3) errors that although they are quite small are not definitely negligible and whose magnitude is uncertain and cannot be corrected.

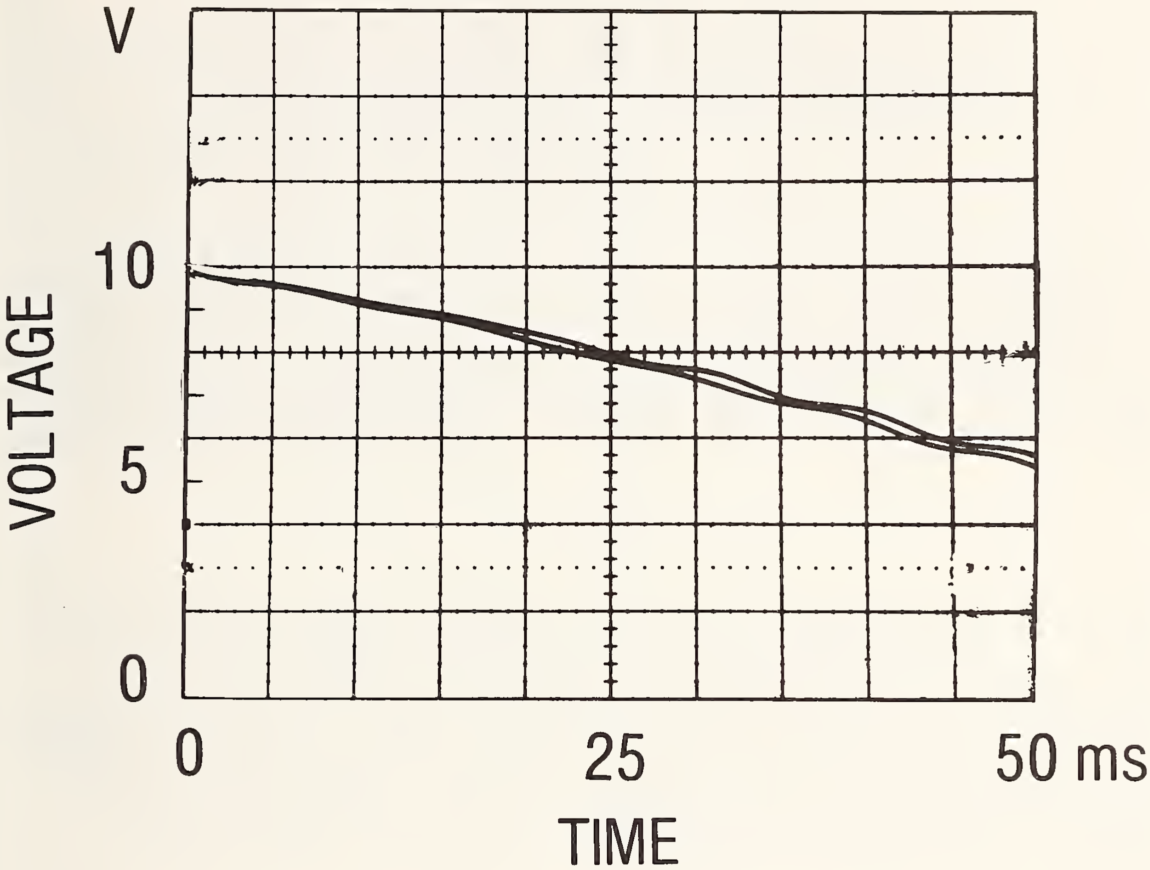

Fig. 5.2. Response of the beam balance with the weigh tank nearly empty and again with the tank full. The vertical axis is the output of the photo-Darlington, which is normally used to start and stop counters when the balance arm swings. The 60 Hz ripple just visible on these curves was not eliminated because it leads to a negligble error since the shortest collection time is 50 seconds.

Errors of the first kind are: some of the liquid collected did not come out of the nozzle during the timing interval, the force exerted by the jet is different at the initial and final levels, and the inertia of the balance system could be different at the two levels.

Errors of the second kind are due to: the buoyant force of air on brass weights, the sensitivity of the balance system, the number of flowmeter output pulses per gram of fuel metered as described in Sec. 5E.2, the difference in response of the balance arm at the two levels because of the finite size of the vent line between the weigh tank and the stand pipe, and the magnitude of the condensate pulses.

The error of the third kind is due to not knowing the mass flowrate of the vapor leaving the float bowl and weigh tank. This arises because of inaccuracy in the volume flowrate measurement and because of a lack of knowledge of the vapor density. At low temperatures the volume flowrate of the vapor is probably equal to the volume flowrate of the liquids. But the vapor density remains unknown for converting the volume flowrate to mass flowrate or equivalently for making the buoyancy correction.

6. TEST RESULTS

Results of tests on seven flowmeters are presented in order to illustrate the use of the procedure of Sec 4. It should be emphasized that only one of each of the seven kinds of flowmeters was tested. Hence the results may not reliably indicate how other flowmeters made by the same manufacturer will perform. Also, a complete series of tests to determine flowmeter performance has not been carried out. Some of the tests have been performed on only one flowmeter. Hence the present test results should not be used as an indication of how a given flowmeter would perform in an automobile on the road.

In the following graphs of the flowmeter calibration curves, each data point is the average of five collections, and the vertical bar shows plus and minus one standard deviation from these five collections. The actual flowrates for the different day points are: 0.2, 0.5, 1, 2, 5, 10, or 20 g/s. However, in order to avoid superposing data points for the two successive days, the two points are displaced slightly from the above values, with the first day's data point shifted slightly to the left and the second slightly to the right.

6A. Four Orifice Flowmeter

The first meter calibrated is described in Appendix A. It was tested in a set-up similar to Fig. 3.5. and connected into the fuel line in the place labeled "transfer standard meter." The vapor flowmeter, the automotive fuel pump, the float bowl assembly, and the "meter under test" that are shown in Fig. 3.5 were not in the flow loop.

The particular meter tested gave an 11.5 percent error when first calibrated because its voltage output had too high an impendance for the 100 kΩ input impedance of the voltage-to-frequency converter (VFC) used. This 100 kΩ input impedance is typical for VFCs and should have been anticipated in the design of the flowmeter. In order to eliminate the change in flowmeter calibration factor when a VFC is connected, the electronic circuit of the flowmeter was redesigned lowering its output impedance, a VFC was permanently connected, and the span and linearity were readjusted.

The calibration curve for the modified flowmeter is shown in Fig. 6A.1 with the data given in Table 6A.1. The results of unsteady flow tests for the flowmeter are given in Table 6A.2. Even though this flowmeter is not perfect, it is useful as a transfer standard for testing other flowmeters because it gives one pulse for each milligram of gasoline passing through it. Its calibration was rechecked when it was used in the evaluation of the other flowmeters, and the results were consistent with the data reported here.

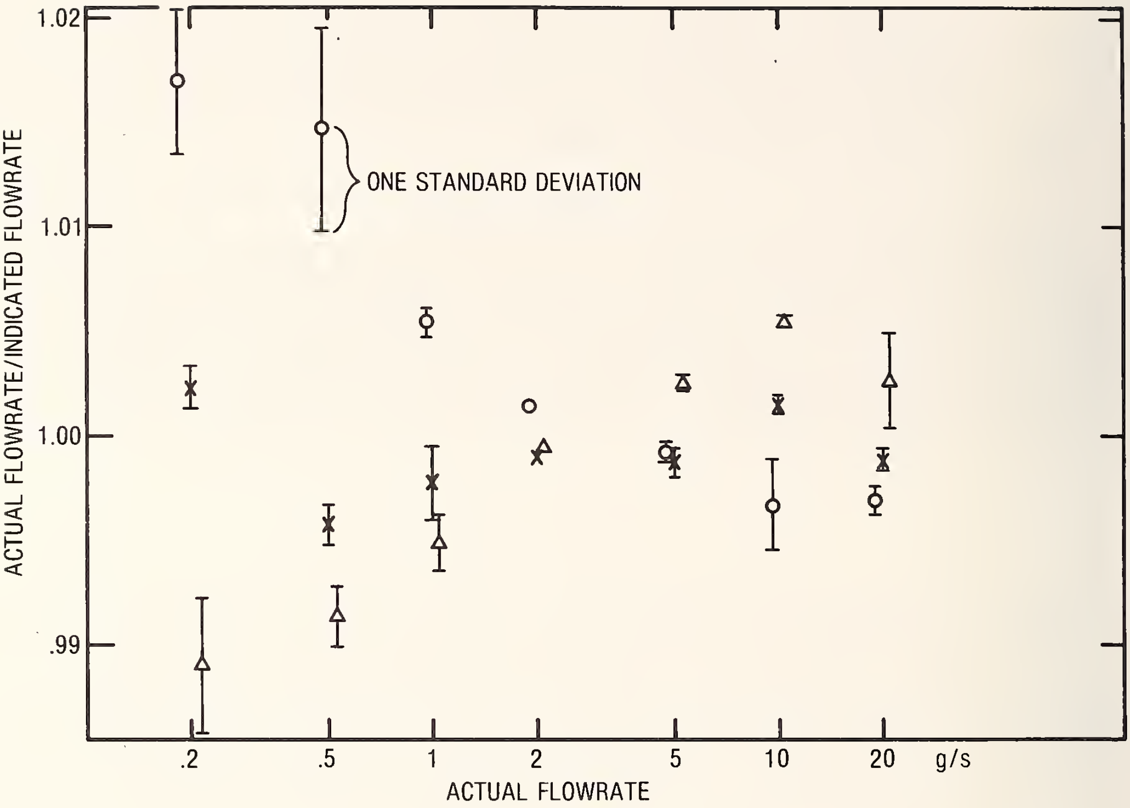

Fig. 6A.1. Four Orifice Flowmeter calibration curve. The actual flowrate is obtained by weighing and timing. The circles indicate data taken at 20°C, the x's at 30°C, and the triangles at 40°C. The actual flowrates are nominally 0.2, 0.5, 1, 2, 5, 10, and 20 g/s, and the points on the graph are slightly displaced horizontally from these values only to avoid overlapping them.

Table 6A.1

Four Orifice Flowmeter

Steady Flow Test

Actual Flowrate (g/s)	Indicated Flowrate (g/s)	Meter Factor* (Ideally = 1)	Relative Repeatability** (Percent)
0.202	0.199	1.0169	0.34
0.515	0.507	1.0148	0.48
1.015	1.010	1.0055	0.07
2.008	2.004	1.0014	0.02
5.057	5.060	0.9993	0.05
9.981	10.035	0.9946	0.28
9.995	10.006	0.9989	0.16
19.84	19.95	0.9943	0.04
19.97	19.98	0.9998	0.11
Average Temperature ≃ 20°C			
0.199	0.199	1.0023	0.10
0.498	0.501	0.9958	0.10
0.998	1.000	0.9978	0.18
1.999	2.001	0.9990	0.03
4.991	4.997	0.9988	0.07
10.01	9.998	1.0016	0.04
19.97	19.99	0.9988	0.08
19.98	20.00	0.9991	0.03
Average Temperature ≃ 30°C			
0.198	0.200	0.9891	0.33
0.495	0.500	0.9914	0.15
0.994	0.999	0.9949	0.14
1.998	1.998	0.9995	0.02
5.014	5.001	1.0023	0.02
5.014	4.999	1.0029	0.06
10.05	9.996	1.0055	0.03
20.05	19.99	1.0027	0.23
Average Temperature ≃ 40°C			

* Actual flowrate divided by flowmeter indication, averaged over five measurements at each flowrate.

** Standard deviation of the five flowrate ratios divided by the mean of the ratios.

Table 6A.2

Four Orifice Flowmeter

Unsteady Flow Test

Number of Flowrate Cycles	Period of Cycle (seconds)	Cycled Flow range (g/s)	Average Flowrate (g/s)	Meter Factor* (Ideally = 1)	Relative Repeatability** (Percent)
10	13	5-10	7.6	1.0007	0.01
5	25	0-20	8.0	1.0189	4.45
5	24	6.5-9.9	8.3	1.0010	0.02
5	22	1-20	8.9	1.0028	0.95
5	18	4-20	11.1	0.9992	0.11
3	26	0-20	11.5	1.0004	0.03
3	26	0-20	12.94	1.0035	0.03
4	21	0-20	12.14	1.0020	0.17
5	18	0-20	10.90	1.0018	0.02

* Actual flowrate divided by the meter indication, averaged over five measurements at each flowrate.

** Standard deviation of the five ratios of actual to indicated flowrate divided by the mean of the ratios.

6B Four Piston Flowmeter

This flowmeter is described in Appendix B. Its calibration curve is shown in Fig. 6B.1 with the data given in Table 6B.1. The indicated flowrate for the calibration was obtained from a digital readout, which gives total flow in 1 mℓ increments and total time in 1 s increments.

Table 6B.1

Four Piston Flowmeter

Steady Flow Test

Actual Flowrate (mℓs)	Indicated Flowrate (mℓ/s)	Meter Factor* (Ideally = 1)	Relative Repeatability** (Percent)
	First Day		
0.2652	0.2640	1.0047	0.15
0.6624	0.6596	1.0043	0.18
1.338	1.331	1.0049	0.11
2.663	2.656	1.0029	0.03
6.550	6.631	1.0028	0.13
13.35	13.32	1.0015	0.02
26.34	26.28	1.0022	0.15
Average Temperature = 26°C, Average Density = 0.7501 g/mℓ			
	Second Day		
0.2730	0.2708	1.0081	0.27
0.6761	0.6726	1.0051	0.38
1.373	1.363	1.0069	0.06
2.750	2.740	1.0040	0.07
6.872	6.846	1.0037	0.11
13.73	13.69	1.0027	0.06
27.37	27.30	1.0026	0.13
Average Temperature 26°C, Average Density = 0.7277 g/mℓ			

* Conversion factor times the actual flowrate divided by the meter indication, averaged over five measurements at each flowrate.

** Standard deviation of the fire ratios of actual to indicated flowrates divided by the mean of the ratios.

Some of the scatter in the data can be understood as follows. The displayed total flow for this flowmeter increases by 1 mℓ for each pulse from the flowmetering element except that occasionally the display increases by 2 mℓ in the normal operation of the flowmeter. This occurs because the volume per pulse from the flowmetering element is not exactly 1 mℓ, and the electronic circuit in the display unit corrects for this by occasionally increasing the display by 2 mℓ instead of 1 mℓ. For the particular flowmeter tested, the display always skips the values shown in Table 6B.2.

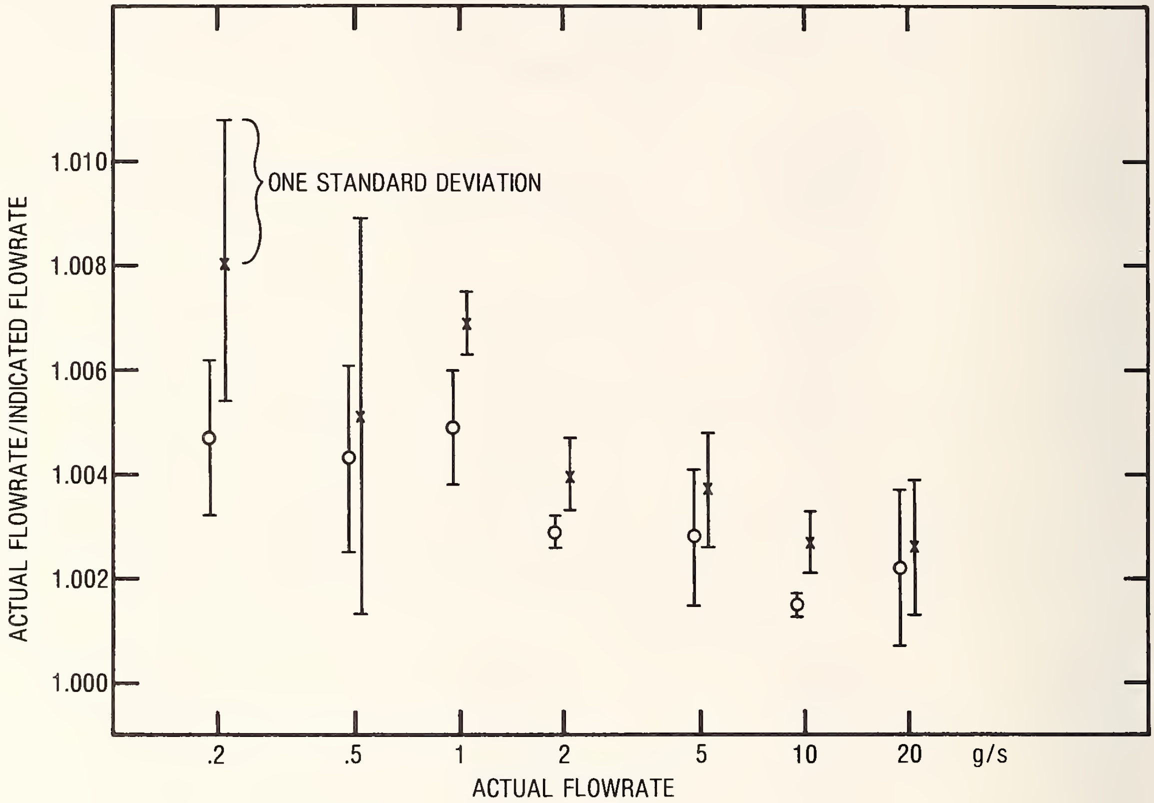

Fig. 6B.1. Four Piston Flowmeter calibration curve. The circles are for data taken on the first day of testing, and the x's the second day. The actual flowrates are nominally 0.2, 0.5, 1, 2, 5, 10, and 20 g/s, and the points on the graph are displaced from these values only to keep the data points and flags from overlapping.

Table 6B.2

Four Piston Flowmeter

Display Values (mℓ) Skipped				Differences
15	122	229	336	15
30	137	244	351	15
45	152	259	366	15
61	168	275	382	15
76	183	290	387	15
91	198	305	412	15
106	213	320	427	16
				107

It is apparent that the pattern repeats every 107 mℓ and so the table has not been continued past 427 mℓ. It follows that on the average the calibration of this flowmeter is approximately 1.07 mℓ per pulse from the flowmetering element. One can also see that due to the occasional skipping the displayed total flow can be too small by as much as .99 mℓ.

In addition there is another noncumulative error that occurs with this flowmeter. The flowmeter calibration differs slightly from pulse to pulse because the 10 pulses that occur in one revolution of the crank do not correspond to equal displacements. The volumes for the first five pulses are 1.10 mℓ, 1.10 mℓ, 0.91 mℓ, 1.09 mℓ, and 1.16 mℓ, and the second five pulses repeat this pattern. Thus, one time out of five, as much as 1.15 mℓ can flow before the next pulse comes. The sum of these two errors can make the total flow displayed by this flowmeter too small by as much as 0.99 mℓ + 1.15 mℓ = 2.14 mℓ even if the flowmetering element were perfectly accurate. This contributed to the scatter in Fig. 6B.1.

Note that another flowmetering element made by the same manufacturer could have a calibration less accurate than this one. It could be off as much as 1/2 percent because the volume per pulse could be as large as 1.075 mℓ and the nominal calibration would still be 1.07 mℓ. Only if the volume per pulse were larger than 1.075 mℓ would the nominal calibration of the readout be changed to 1.08 mℓ.

The flowmeter evaluated has no pulse output for use in the other tests described previously. So its cover was removed, and pulses were taken from a convenient point at the input of the readout circuit. Some results of vibrating this flowmeter and using the technique described previously are shown in Figs. 6B.2 to 6B.5, which show an error that occurs at a frequency near 16 Hz. The factor 1.07 appears in the ordinate because the flowmeter gives a pulse for each 1.07 mℓ. The meter factor is averaged over a multiple of 10 pulses in order to smooth out the differences in the volume per pulse described previously. The last graph shows an immense error at low flowrates.

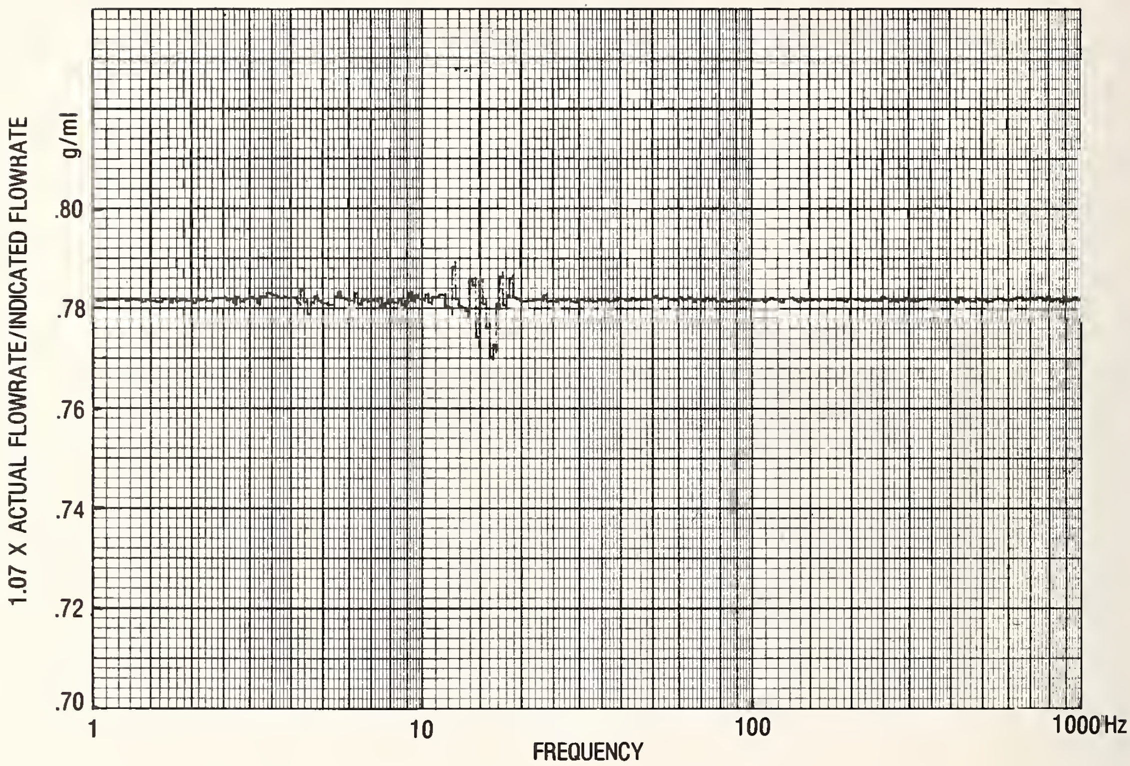

Fig. 6B.2. Vertical vibration test of the Four Piston Flowmeter. The peak-to-peak displacement is 2.54 cm from 1 to 5.4 Hz, and the peak acceleration is 1.5 x 980 cm/s^2 from 5.4 to 1000 Hz. The time required for sweeping from 1 to 1000 Hz is 10 minutes. The flowrate ratio times 1.07 is averaged over 107 mℓ. The factor 1.07 occurs because the flowmeter on the average has one pulse per 1.07 mℓ indicated on its digital display, and the pulses are used to obtain the vertical display. The actual flowrate is 10 g/s, the indicated flowrate is in mℓ/s, and the average density is .73 g/mℓ, so the ordinate should be .78 g/mℓ.

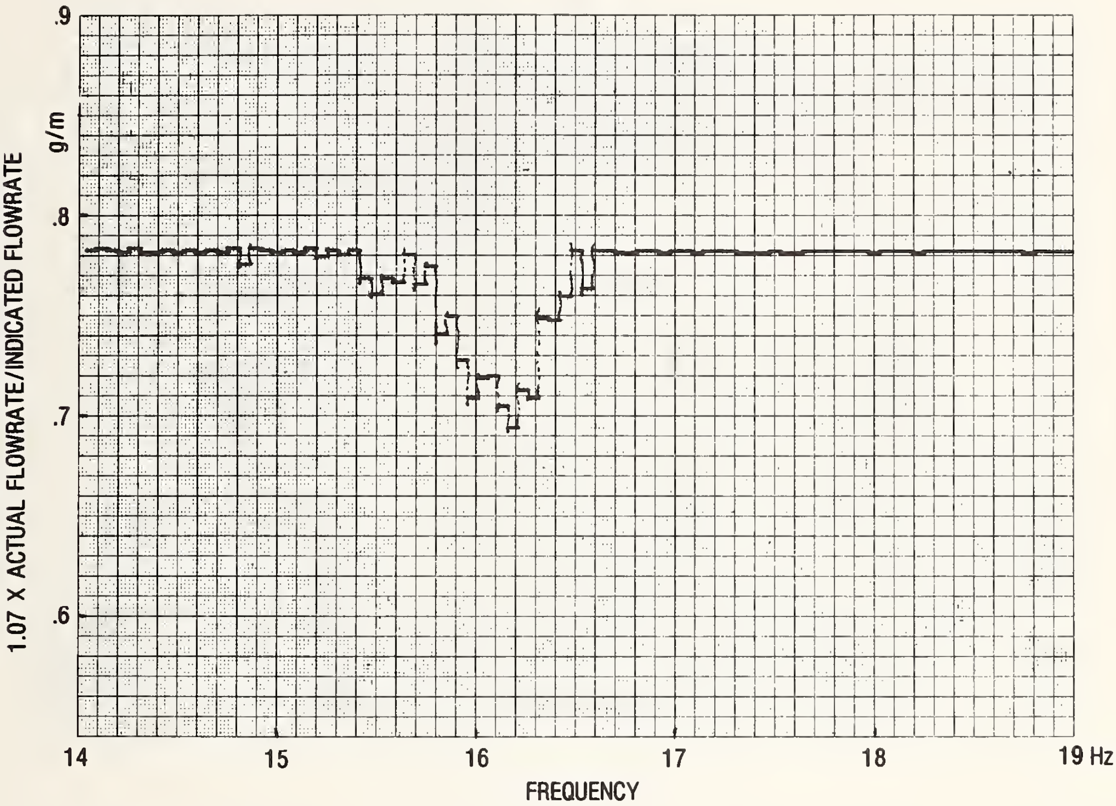

Fig. 6B.3. Vertical vibration test of Four Piston Flowmeter. The conditions are the same as in Fig. 6B.2 except the frequency is swept from 14 to 19 Hz in 10 minutes, and the ratio times 1.07 is averaged over 10.7 mℓ. The effect is more clearly shown here than in Fig. 6B.2.

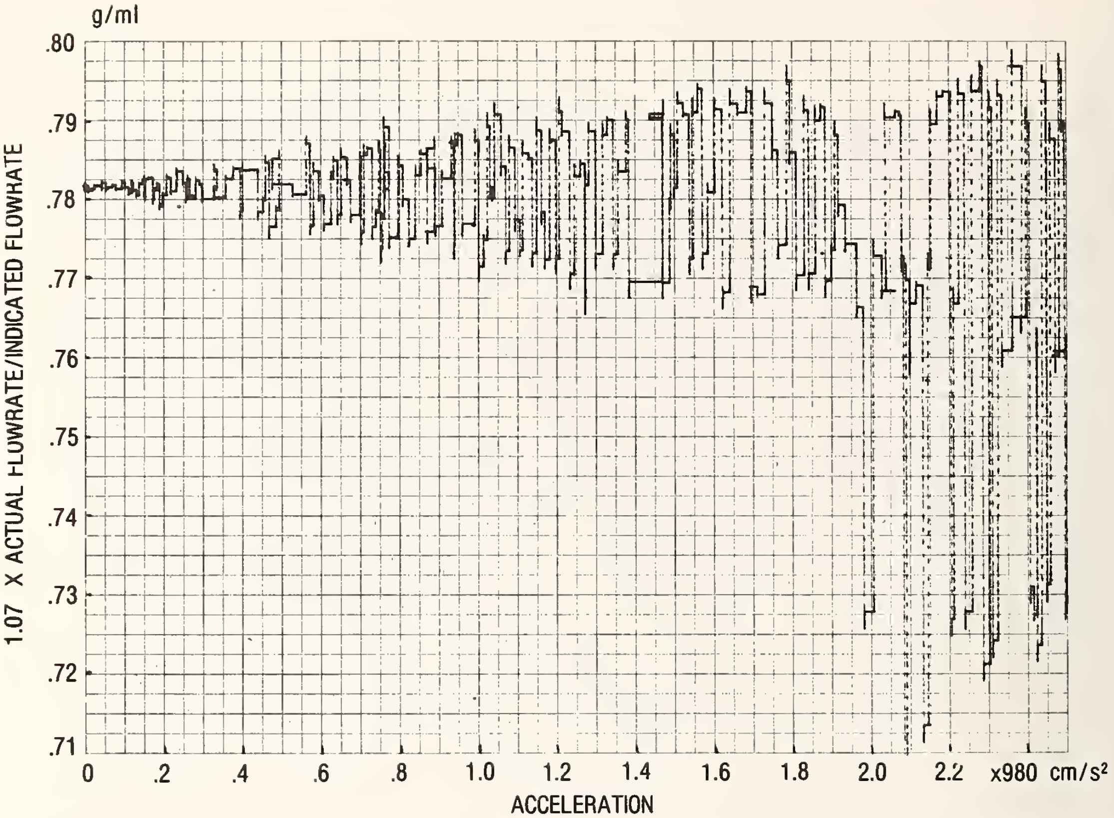

Fig. 6B.4. Vertical vibration test of Four Piston Flowmeter. The conditions are the same as in Fig. 6B.3 except the frequency is fixed at 16.1 Hz and the peak acceleration is increased smoothly over a 10 minute interval. The wide excursions in the graph above 2 x 980 cm/s^2 are due to the ratio exceeding the maximum range of the digital to analog converter. Below 2 x 980 cm/s^2 the effect is clearly shown to increase with increasing acceleration.

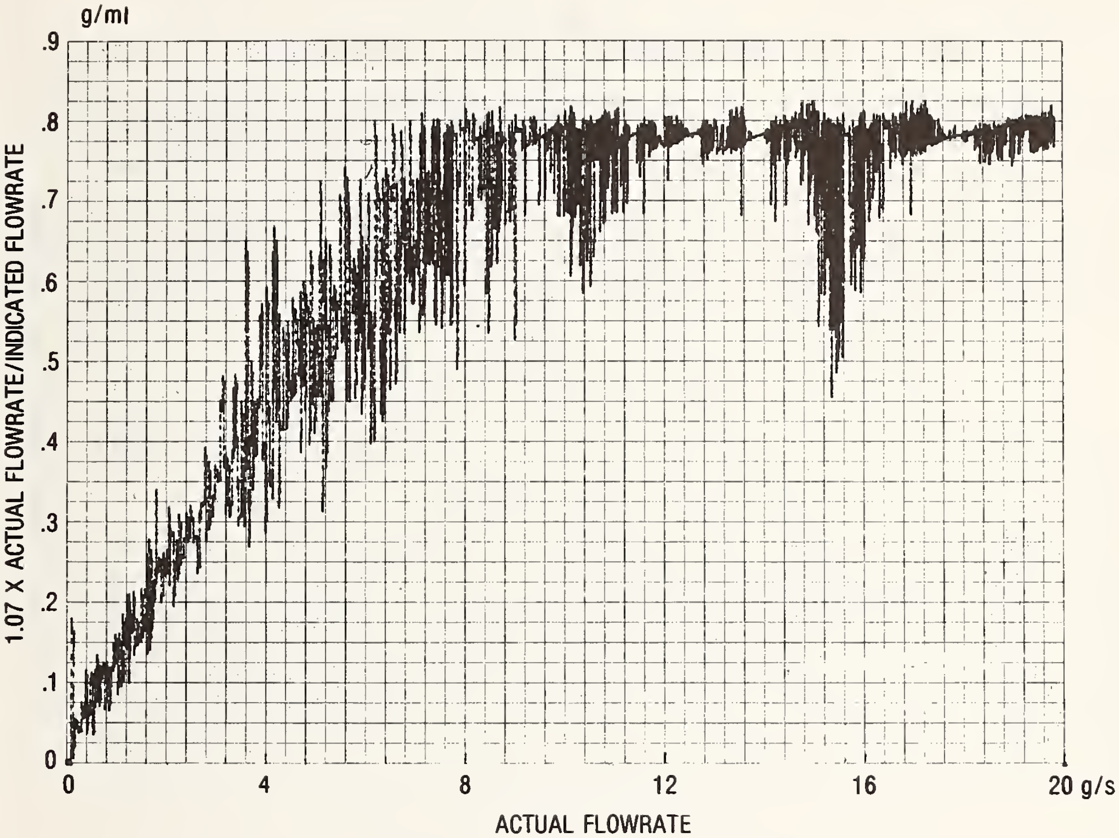

Fig. 6B.5. Horizontal vibration test of Four Piston Flowmeter. The conditions are similar to those in Fig. 6B.3 except the frequency is fixed at 16.0 Hz and the flowrate is increased smoothly over a 20 minute interval.

However, the error shown in these figures was not observed on the digital display because the readout electronics incorporated an up-down counter. The display was observed to count up and down between adjacent values many times before advancing permanently to the next value. Thus the error did not accumulate, and this was confirmed by comparing the indicated flowrate obtained from the digital display with the actual flowrate from weighing and timing.

Other tests were made on this flowmeter. The input voltage was varied from 8 V to 16 V. An 8 V peak-to-peak 60 Hz sinusoidal voltage was added to a constant 12 V. Also, 1 V rectangular pulses were added to a constant 12 V. None of these caused the flowmeter to make an error. But when a spark was discharged within several meters of the flowmeter (with its cover on), an essentially infinite error occurred. Fortunately, when resistive ignition wire is used instead of solid wire, no noticable error occurred.

6C Positive Displacement Pump Flowmeter

This flowmeter is described in Appendix C. The flowmeter has both an electrical pulse output and an electromagnetic counter built into it. The built in counter was started and stopped manually at the beginning and end of a collection. Because of this the two indications agree only approximately with each other. The calibration data for the pulse output is given in Table 6C.1, and the calibration curve for the built-in counter is shown in Fig. 6C.1. The collections that gave rise to the large scatter in both of these at 20 g/s were taken at the beginning of the second day. The first two collections gave results that agreed with the previous day's results. The last three at that flowrate gave much higher indications. During these three collections the flowmeter made slightly more noise then it had before. When the flowrate was decreased to 10 g/s for the next set, the noise went away, and all results from subsequent collections that day agreed with the results of the previous day as shown. However, on occasion on subsequent days the flowmeter was similarly erratic at 20 g/s and also at other flowrates. The cause for the erratic readings and for the associated increase in noise has not been determined.

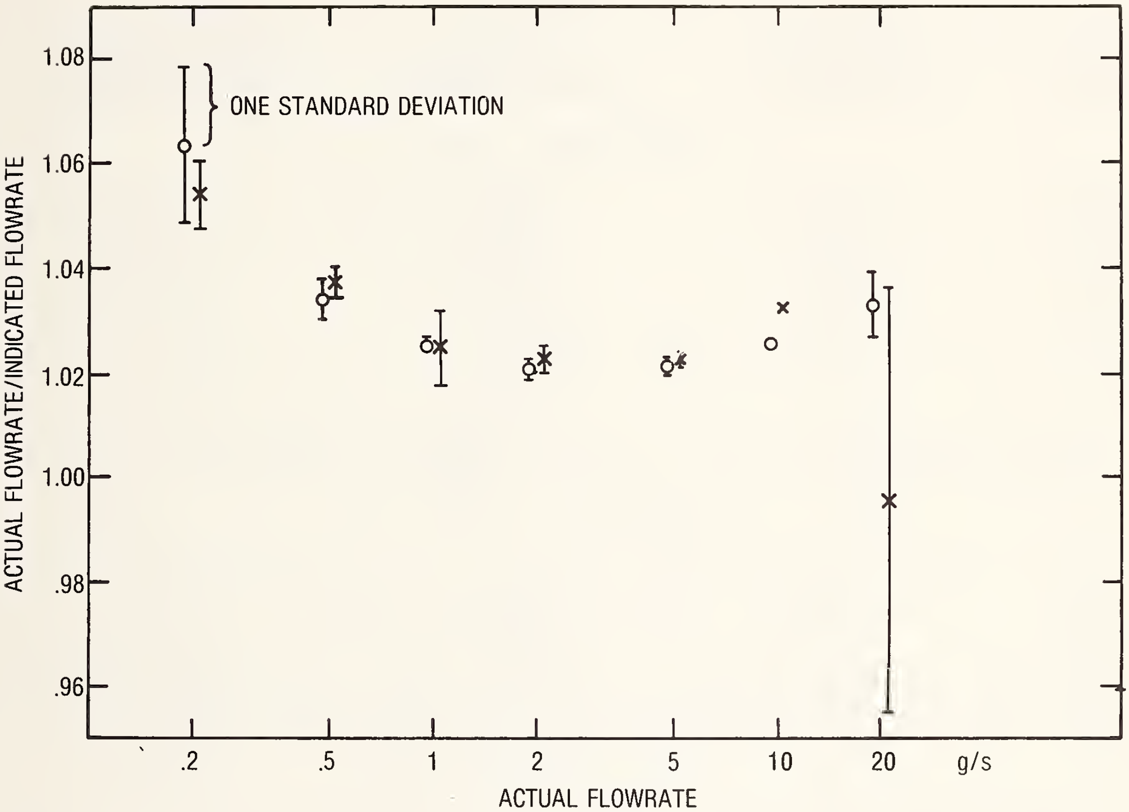

Fig. 6C.1. Calibration curve for the Positive Displacement Pump Flowmeter. The indicated flowrate is obtained from the counter supplied with the flowmeter. Similar but not identical results were obtained from the electrical pulse output and are reported in Table 6C.1. The flowrate ratio should be equal to one. The large scatter at 20 g/s on the second day is due to the flowmeter and is discussed in the text.

Table 6C.1

Positive Displacement Pump Flowmeter
(Pulse Output)

Steady Flow Test

Actual Flowrate (mℓ/s)	Meter Indication (mℓ/s)	Meter Factor* (Ideally = 1)	Relative Repeatability** (Percent)
First Day			
0.2700	0.2534	1.0653	1.41
0.6777	0.6542	1.0359	0.38
1.363	1.326	1.0273	0.13
2.733	2.673	1.0223	0.20
6.858	6.704	1.0229	0.14
13.71	13.35	1.0273	0.03
27.30	26.38	1.0349	0.61
Average Temperature = 2.6°C, Average Density = 0.7308 g/mℓ			
Second Day			
0.2684	0.2541	1.0561	0.61
0.6835	0.6577	1.0392	0.29
1.363	1.330	1.0264	0.72
2.730	2.665	1.0245	0.26
6.857	6.695	1.0242	0.9
13.72	13.26	1.0343	0.09
27.32	27.39	0.9974	4.08
Average Temperature = 26°C, Average Density = 0.7305 g/mℓ			

The effect of supply voltage on the pulse output on two separate days is given in Table 6C.2, and the effect of supply voltage on both outputs is compared in Fig. 6C.2. Vibration and other tests on this meter were difficult to analyze because of the erratic output shown in Figs. 6C.3 and 6C.4. This erratic output seemed to occur at all times and appears to be unrelated to that shown in Table 6C.1 and Fig. 6C.1. Because of the erratic behavior, no further tests were made on this meter.

Table 6C.2

Positive Displacement Pump Flowmeter
(Pulse Output)

Supply Voltage Test

Supply Voltage (Volts DC)	Meter Factor* (Ideally=1)	Relative Repeatability** (Percent)
	First Day	
9.6	1.0292	0.27
11.9	1.0425	0.14
14.1	1.0392	0.29
16.4	1.0426	0.06
	Second Day	
9.5	1.0294	0.19
11.8	1.044	0.09
14.0	1.0314	0.10
16.4	1.0446	0.06

Average Temperature = 28°C, Average Density = 0.7444 g/mℓ
Actual Flowrate = 10 g/s

* Conversion factor times the actual flowrate divided by the meter indication, averaged over five measurements at each flowrate. The conversion factor includes the manufacturer's recommended calibration of 12,000 pulses per gallon.

** Standard deviation of the five ratios of actual to indicated flowrates divided by the mean of the ratios.

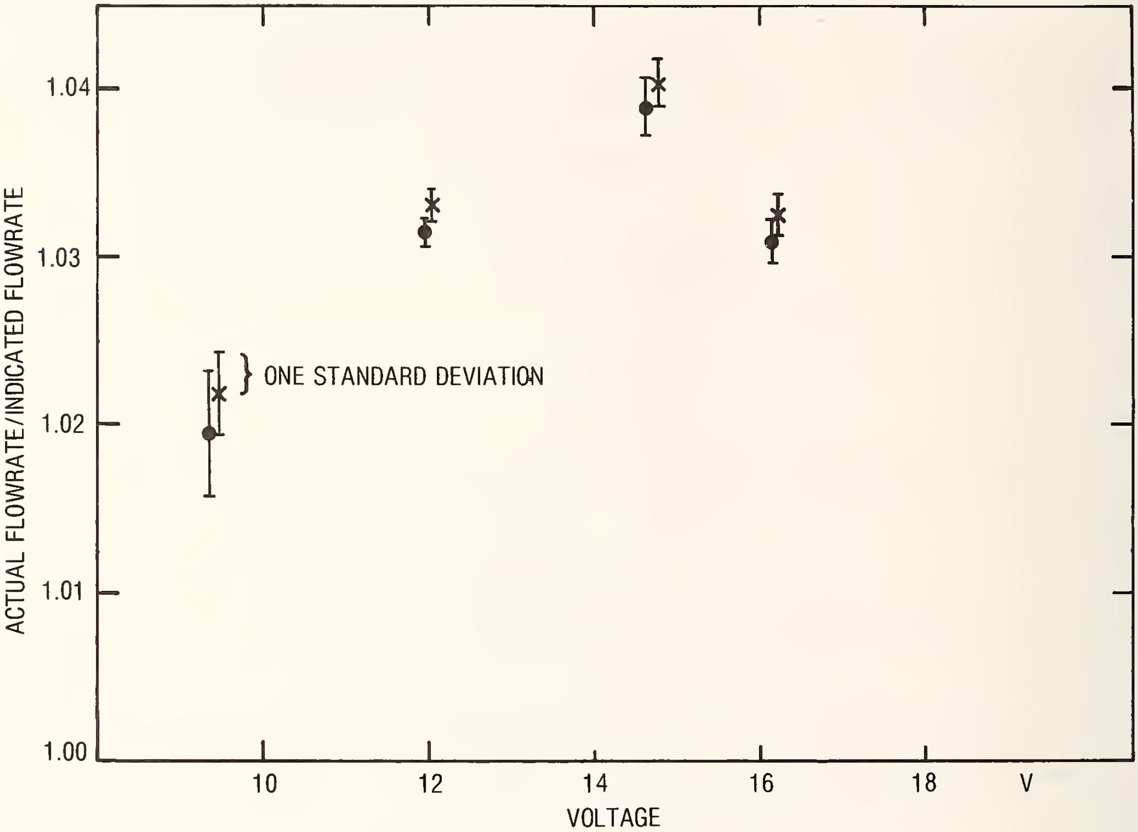

Fig. 6C.2. Effect of supply voltage on the Positive Displacement Pump Flowmeter with an actual flowrate of 10 g/s. The solid circles are from the flowmeter's built-in counter and the x's are from the pulse output at 1/12000 gallon per pulse. For both sets of data the flowrate ratio should be equal to one.

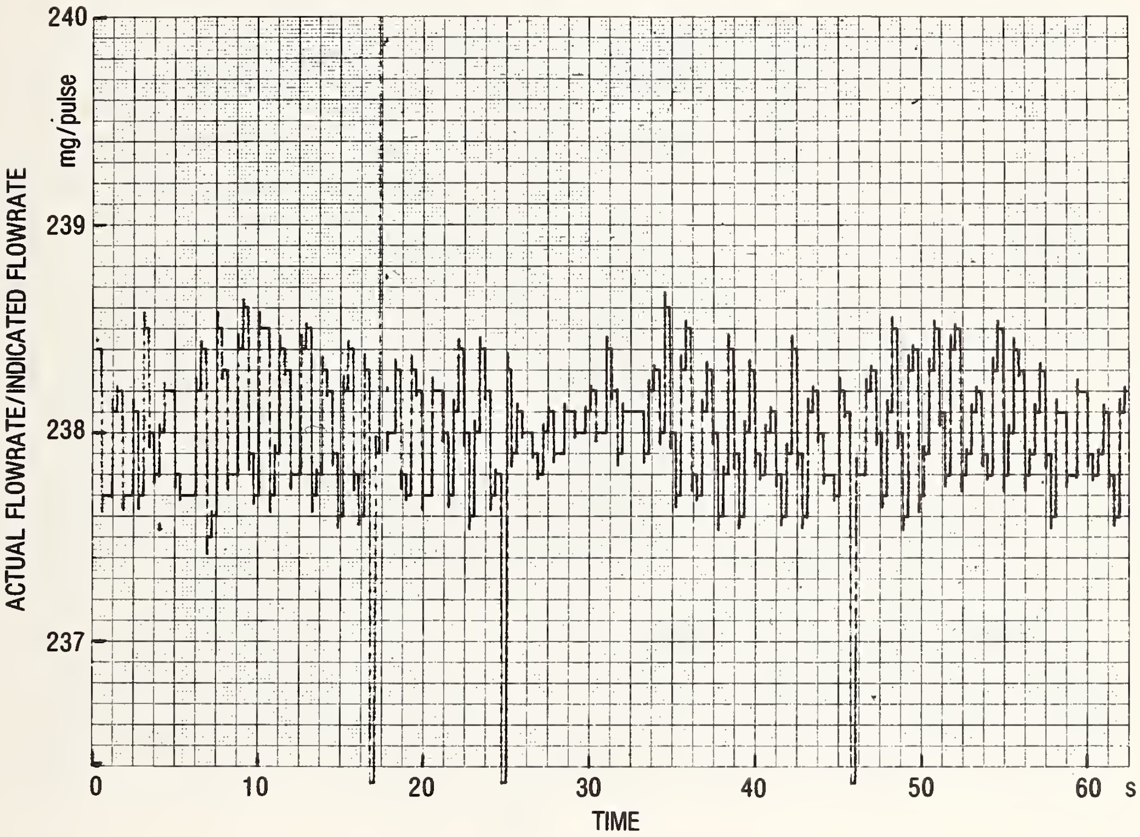

Fig. 6C.3. Erratic pulse output of the Positive Displacement Pump Flowmeter. The actual flowrate is 10 g/s, and the flowrate ratio is averaged over 10 pulses of the flowmeter under test.

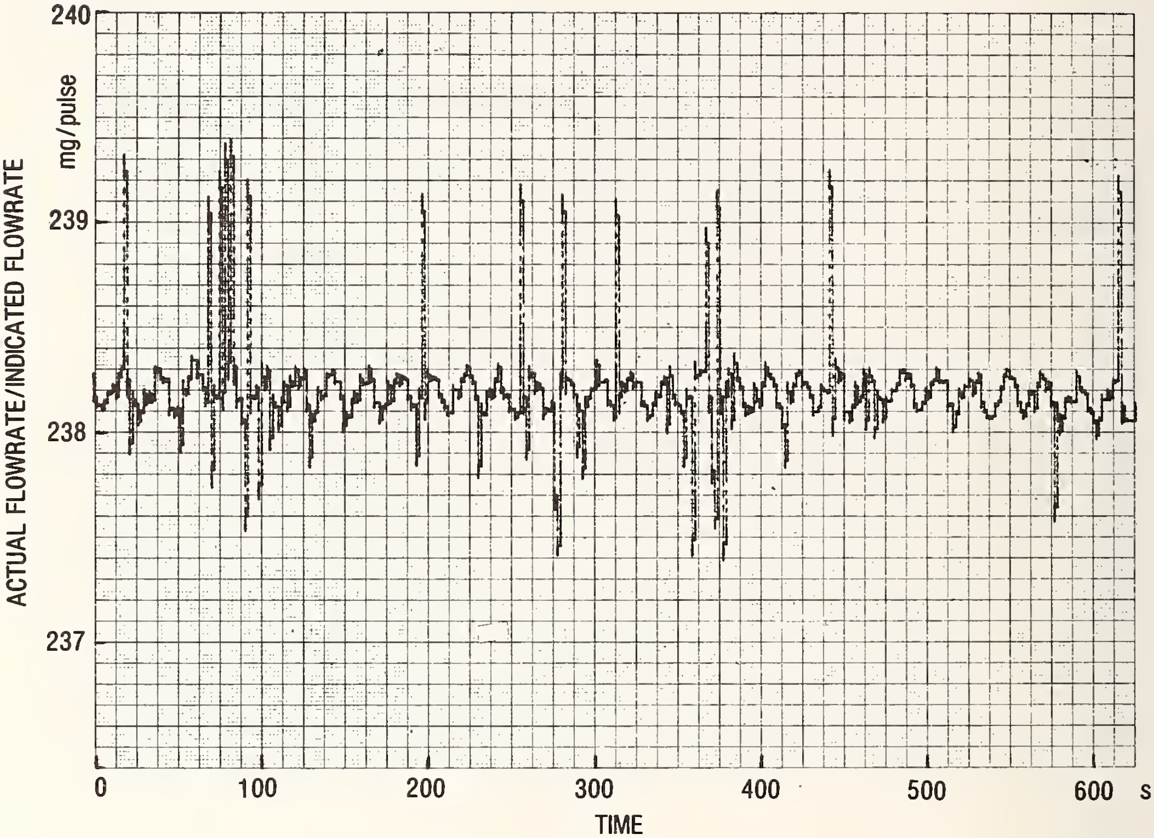

Fig. 6C.4. Erratic pulse output of the Positive Displacement Pump Flowmeter. The conditions are the same as for Fig. 6C.3 except that 100 pulses are averaged. A substantial improvement results, but the averaged output is still not usable.

6D TURBINE FLOWMETER

This flowmeter is described in Appendix D. In accordance with the manufacturer's recommendation, it was connected to the fuel line as close as possible to the float bowl. The automobile fuel pump was operated at 320 pulses per minute for all tests except one in which the pump speed was varied.

The flowmeter calibration curve is graphed in Fig. 6D.1 using the steady flow data in Table 6D.1, and the unsteady flow test results are in Table 6D.2. Even though .2 g/s and .5 g/s are below the manufacturer's recommended range, measurements were taken at these flowrates because some automobiles sometimes use fuel at these flowrates.

Even though the pulse output of this flowmeter is erratic as shown in Fig. 6D.2, vibration tests were performed. In these tests the float bowl assembly was vibrated along with the flowmeter. The results are shown in Figs. 6D.3 to 6D.5.

The erratic pulse output of the flowmeter also made it difficult to detect small effects in the electrical tests. The input voltage was varied from 8 to 16 V. Also an 8V peak-to-peak 60 Hz sinusoidal voltage was added to a constant 12V supply. These did not cause the flowmeter to make an observable error. The results of the ignition radiation tests are given in Table 6D.3.

For the high fuel temperature tests a .04" bit was used to drill a vapor return hole in a port at the top of the flowmeter as recommended by the manufacturer. At 25°C the vapor return bypass line was entirely full of liquid. As the temperature increased more and more vapor bubbles appeared in the bypass line, and at 45°C and higher the bypass line was entirely full of vapor.

Also at 42°C, condensate could just be seen to flow from the bottom of the heat exchanger installed in the float bowl vent line. The condensate flow pulsed through the transparent tubing and into the weigh tank about once every second. The condensate flow increased with temperature to about .2 g/s at 65°C.

At about 52°C the liquid in the float bowl had an abundance of bubbles as if it were boiling even though the float bowl was heated only by the gasoline entering it. The space over the liquid was filled with a fog, and droplets formed on the plexiglass window and ran down it.

The high fuel temperature tests are reported in Table 6D.4. The Reid vapor pressure measurements were made just after the five weighing and timing collections were made. The sharp decrease in the meter factor and increase in the repeatibility at 55°C and 65°C are apparently due to vapor bubbles in the liquid flow measured by the Turbine Flowmeter. The vapor return hole was not large enough to remove all of the vapor bubbles from the flow.

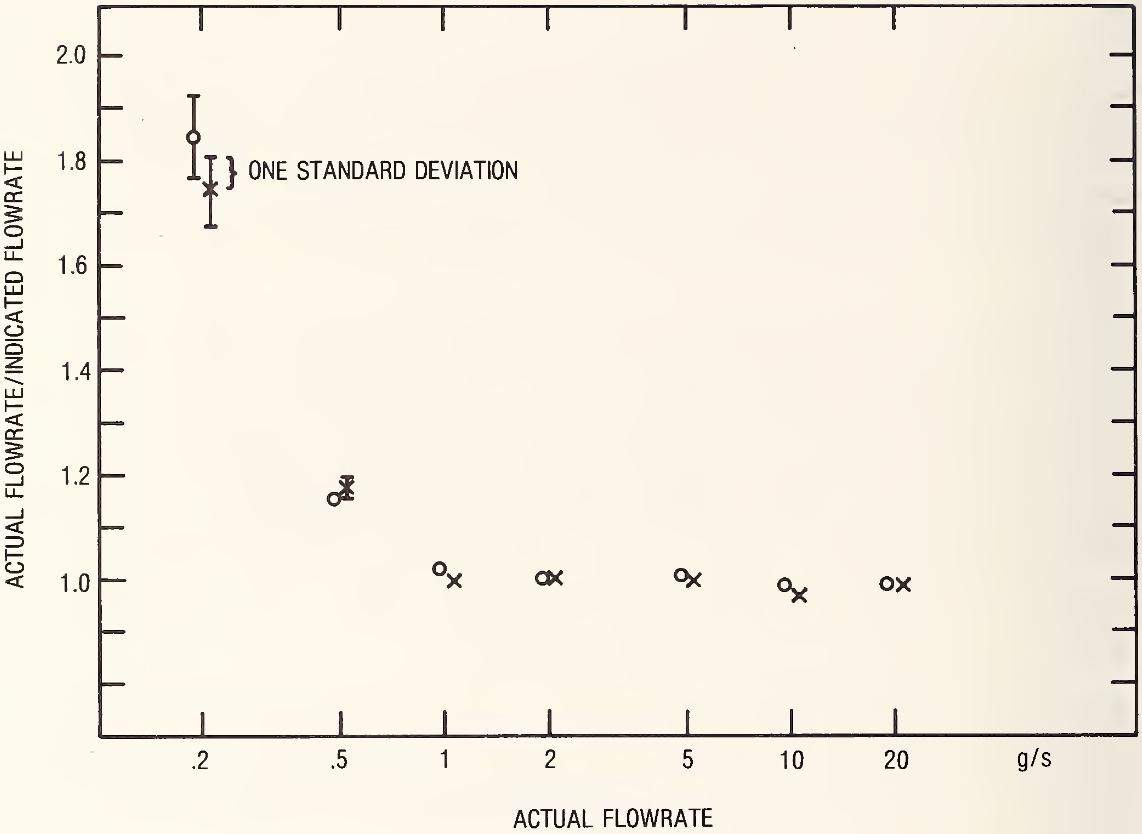

Fig. 6D.1. Turbine Flowmeter calibration curve. The average fuel density is .758 g/mℓ, and the manufacturer's recommended conversion factor is 7200 pulses per gallon. These were used to obtain the flowrate ratio, which should be equal to one.

Table 6D.1

Turbine Flowmeter

Steady Flow Test

Actual Flowrate (ml/s)	Pulse Repetition Rate (Hz)	Meter Factor* (Ideally=1)	Relative Repeatability** (Percent)
		First Day	
0.270	2.77	1.8490	4.13
0.65	10.9	1.1523	0.54
1.31	24.5	1.0221	0.37
2.64	50.0	1.0050	0.13
6.62	125.	1.0044	0.08
13.1	256.	0.9865	0.19
26.4	508.	0.9894	0.14
		Second Day	
0.265	2.90	1.7464	3.72
0.657	10.6	1.1791	1.83
1.31	25.0	1.9992	0.11
2.63	50.0	1.0044	0.27
6.57	125.	1.0000	0.08
13.2	258.	0.9719	0.63
26.3	507.	0.9872	0.05

Average Temperature = 24°C, Average Density = 0.7580 g/mℓ

Table 6D.2

Turbine Flowmeter

Unsteady Flow Test

Number of Flowrate Cycles	Period of Cycle (Seconds)	Flow Range (ml/s)	Average Flowrate (ml/s)	Meter Factor* (Ideally=1)	Relative Repeatability** (Percent)
5	25	0 - 26	10.5	0.9663	0.37
5	22	1.3 - 26	11.7	0.9590	0.44
5	18	5.3 - 26	14.6	0.9657	0.36
10	13	6.6 - 13	9.98	0.9914	0.17
5	24	8.6 - 12	10.9	0.9794	0.10
4	17	13 - 26	19.0	0.9766	0.67

Average Temperature = 24°C, Average Density = 0.7599 g/mℓ

Table 6D.3

Turbine Flowmeter

Ignition Radiation Test

Spark Frequency (Hz)	Actual Flowrate (mℓ/s)	Pulses Repetition Rate (Hz)	Indicated Flowrate (mℓ/s)
		Solid Ignition Wire	
0	13.8	280	14.5
33	13.8	500	540.
100	13.8	1290	407.
250	13.8	2250	573.
365	13.8	2750	68.7
		Resistive Ignition Wire	
0	13.7	270	14.5
32	13.7	278	13.9
101	13.7	276	14.5
252	13.7	283	14.5
380	13.7	290	14.5

Average Temperature = 23°C

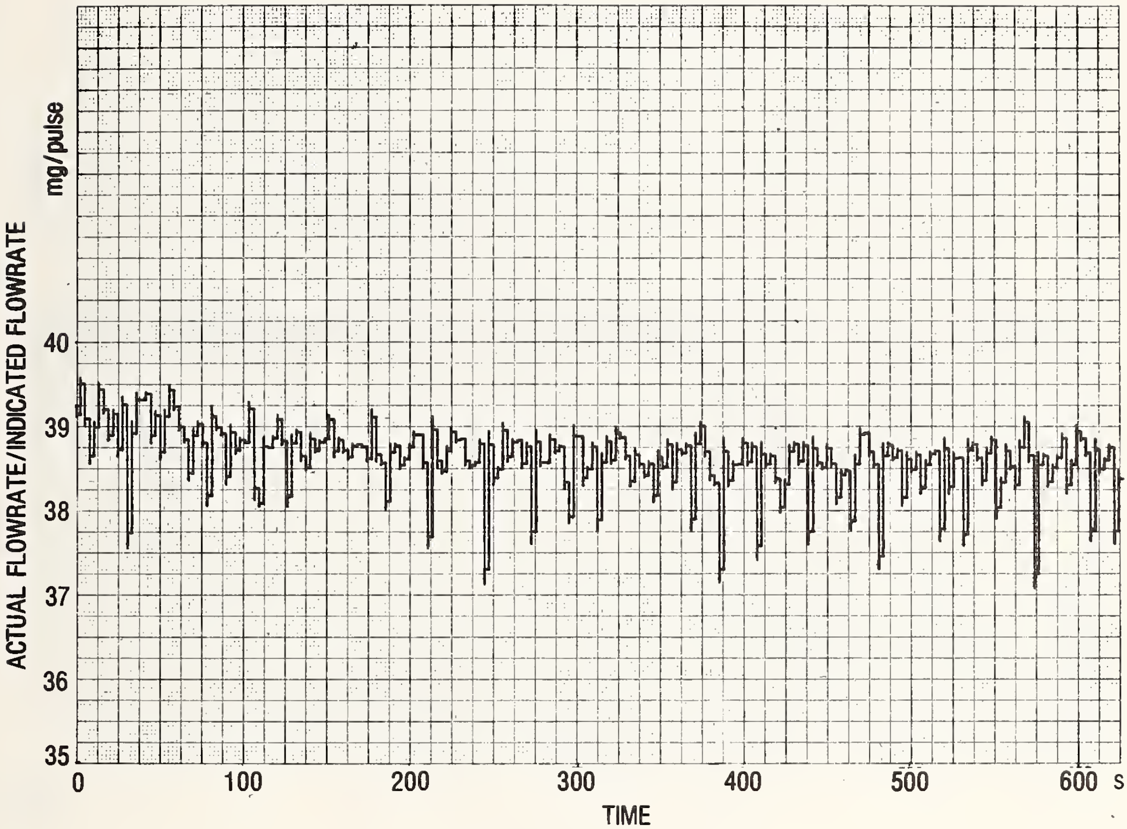

Fig. 6D.2. Erratic pulse output of the Turbine Flowmeter. The actual flowrate is 10 g/s, and the flowrate ratio is averaged over 1000 pulses of the Turbine Flowmeter.

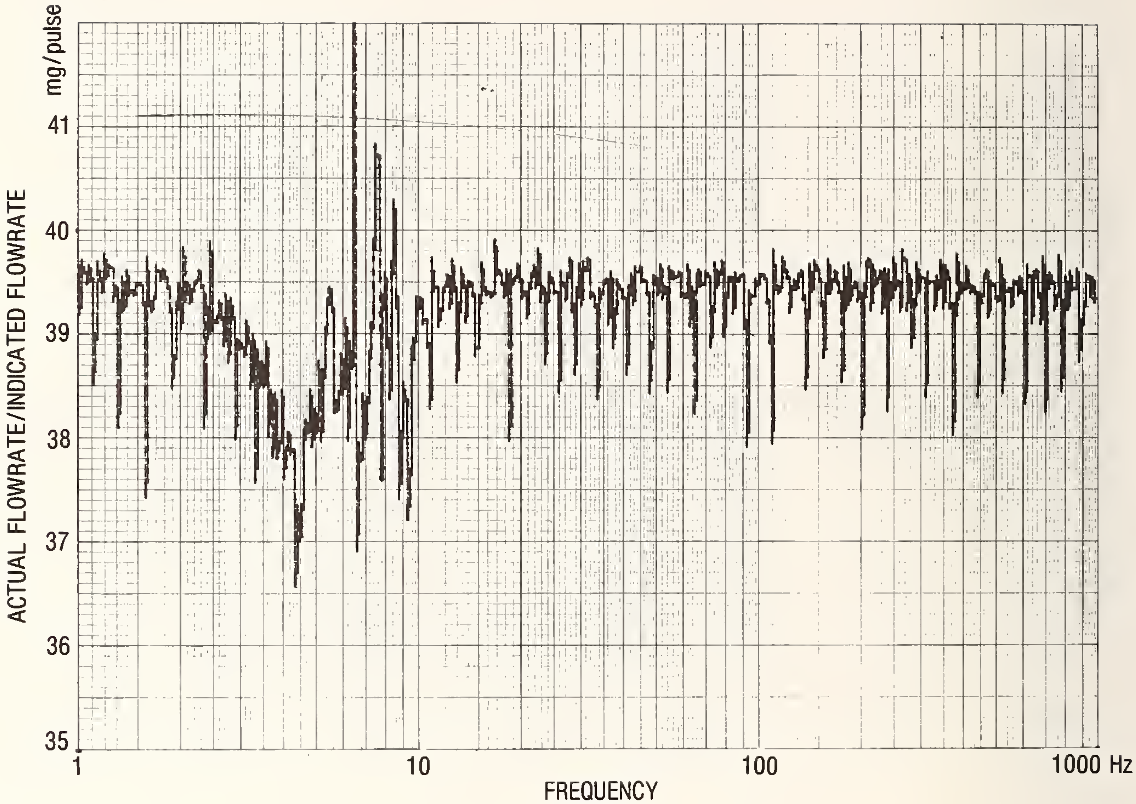

Fig. 6D.3. Vertical vibration test of the Turbine Flowmeter. The actual flowrate is 10 g/s, and the flowrate ratio is averaged over 1000 pulses. The peak-to-peak displacement is 2.54 cm from 1 to 5.4 Hz, and the peak acceleration is 1.5 x 980 cm/s^2 from 5.4 to 1000 Hz. The time required for sweeping from 1 to 1000 Hz is 30 minutes, and the average density is .76 g/mℓ.

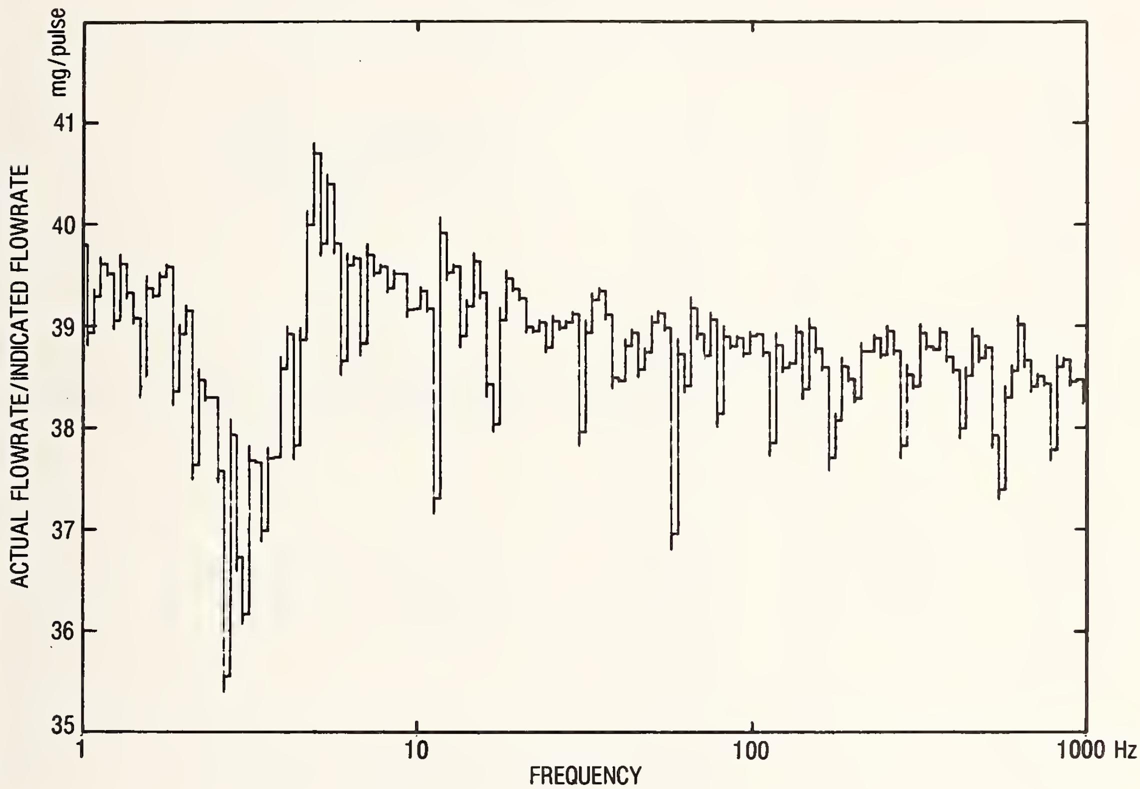

Fig. 6D.4. Effect of vibrating the Turbine Flowmeter horizontally and perpendicular to the flow direction. Other conditions are the same as in Fig. 7D.3 except the sweep time is 10 minutes.

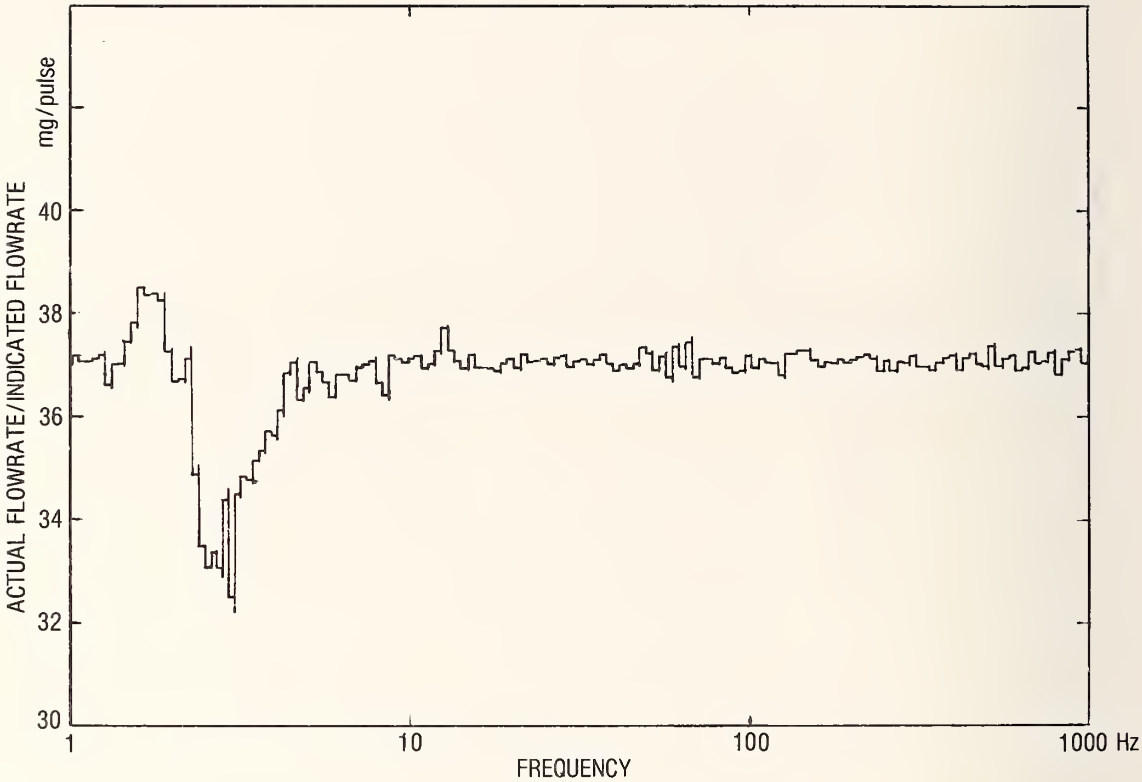

Fig. 6D.5. Effect of vibrating the Turbine Flowmeter horizontally and parallel to the flow direction. Other conditions are the same as in Fig. 6D.4.

Table 6D.4

Turbine Flowmeter

High Fuel Temperature Test

Fuel Temperature (°C)	Reid Vapor Pressure (psi)	Fuel Density (g/mℓ)	Actual Flowrate (mℓ/s)	Vapor Flowrate (mℓ/s)	Pulse Repetition Rate (Hz)	Meter Factor* (Ideally=1)	Relative Repeatability* (Percent)
25.47	9.65	0.7314	6.845	9.36	129.3	1.0071	0.39
35.10	9.28	0.7242	6.942	9.03	133.1	0.9922	0.49
45.08	8.95	0.7154	7.026	8.86	132.8	1.0065	0.16
55.24	8.85	0.7077	7.226	10.22	177.2	0.7759	1.93
65.69	8.85	0.7025	7.562	10.03	171.6	0.8437	4.63

* Conversion factor times the actual flowrate divided by the meter indication, averaged over five measurements at each flowrate. The conversion factor includes the manufacturer's recommended calibration of 72,000 pulses per gallon.

** Standard deviation of the five ratios of actual to indicated flowrates divided by the mean of the ratios.

That the meter factor at 65°C is larger than the one at 55°C can be explained as follows. The test at 65°C was performed on October 22 using regular gasoline purchased on October 21. The gasoline was heated to 45°C on October 21 and permitted to cool. It was heated to 65°C on October 22 for several hours before the measurements were made. On the other hand the tests at 45°C and 55°C were made on October 27 using gasoline purchased that day. After the test at 45°C was completed the gasoline was heated to 55°C, and the test at 55°C was performed without delay. The explaination is that the rate of evaporation from gasoline that has been at 65°C for several hours is lower than the rate from gasoline that was just raised to 55°C. Thus more vapor was in the gasoline metered at 55°C than that at 65°C, and this explains the difference in meter factors.

6E Automatic Burrette Flowmeter

This flowmeter is described in Appendix E. Since each flowmeter pulse indicates .01 gallon (38 mℓ) a huge error would occur if the indicated flowrate were obtained by counting the flowmeter pulses that occur while only 200 g (270 mℓ at .74 g/mℓ) is weighed and timed. Hence the procedure of Subsection 4E must be modified.

The easiest way to do this involves the assumption that once the system has settled to a steady flow, the flowrate will remain constant long enough for about .1 gallon to flow. The indicated flowrate is obtained from the time for ten periods (or the time interval between a pulse and the tenth one following it) and is converted to mass flowrate as in Subsection 5E.7. The actual flowrate is obtained by timing the weighing of 300 g of fuel at about the same time the .1 gallon passes through the Automatic Burrette Flowmeter and is corrected as in Subsection 5E.7.

The first Automatic Burrette Flowmeter that was tested did not permit a flowrate above 6 g/s. The manufacturer replaced it with one that permitted a flowrate of 12 g/s and that also was modified to reduce its sensitivity to vibration. The flowmeter performed satisfactorily for a while, but then started to leak profusely. On the recommendation of the manufacturer an attempt was made to seal the leak with epoxy. It was not successful, and so the tests were halted. The data that was obtained in the few measurements that were performed is not presented here because the flowmeter failure prevented confirmation of some questionable results.

6F Ball-in-Race Flowmeter

This flowmeter is described in Appendix F. The first Ball-in-Race Flowmeter that was tried gave no indication of flow and was replaced by the manufacturer. The flowmeter that was tested was inserted in the fuel line just upstream of the float bowl. The flowmeter was mounted so that the fuel flow into and out of it was horizontal, and the ball inside it travelled in a vertical plane. The automotive fuel pump was operated at 312 strokes per minute.

The results of the steady flow tests are given in Table 6F.1 and graphed in Fig. 6F.1. The data was obtained from the electrical pulse output. The counter supplied with the flowmeter was reset manually as quickly as possible at the start of a collection and read immediately at the end. The reading was always within one count of the total number of pulses divided by 32. The maximum possible flowrate was 15.6 g/s, while the advertised range was .5 to 20 gallons per hour (.5 to 21 mℓ/s), which is equivalent to .4 to 16 g/s. The mass collected was 3 kg for all flowrates except that it was 1 kg for 1 g/s and on the second day it was 2 kg for 2 g/s. At .5 g/s the flowmeter indication was incorrect by a factor about 10 and so data was not taken below 1 g/s.

The large scatter in the data at 2 g/s and the large difference in means at 5 g/s may be attributed to the flowmeter tested. The scatter and difference occurred because the time required for one gallon to be indicated by the flowmeter showed a similar scatter and difference. There was not an appreciable change in the density, temperature, or flowrate, and there were no bubbles in the fuel as is apparent from the following. At 2 g/s on the first day, the relative repeatibility of the actual flowrate was .20 percent, and that of the transfer standard flowmeter's indicated total mass was .03 percent. At 5 g/s the mean actual flowrate differed by .07 percent from day to day, and the mean indication of the transfer standard flowmeter differed by .04 percent from day to day.

Table 6F.1

Ball-in-Race Flowmeter

Steady Flow Test

Actual Flowrate (mℓ/s)	Flowmeter Indication (GPH)	Meter Factor* (Ideally=1)	Relative Repeatability** (percent)
		First Day	
1.35	0.96	1.192	0.28
2.70	2.25	1.028	12.8
6.75	6.29	0.909	0.24
13.5	11.1	1.028	0.49
21.0	16.9	1.057	0.30

Actual Flowrate (mℓ/s)	Flowmeter Indication (GPH)	Meter Factor* (Ideally = 1)	Relative Repeatability** (percent)
		Second Day	
1.35	0.95	1.198	0.45
2.70	1.97	1.157	0.05
6.75	5.33	1.078	0.14
13.5	10.8	1.060	0.05
21.0	17.1	1.039	0.25

Average Temperature = 23°C, Average Density = 0.7423 g/mℓ

*Conversion factor times the actual flowrate divided by the indicated flowrate, averaged over five measurements at each flowrate. The conversion factor includes the manufacturer's recommended calibration of 3200 pulses per gallon.

**Standard deviation of the five ratios of actual to indicated flowrates divided by the mean of the ratios.

The flowmeter and float bowl assembly were vibrated together, and the results are shown in Figs. 6F.2 and 6F.3. The effect of ignition radiation on the indication of the counter supplied by the flowmeter manufacturer is shown in Table 6F.2.

Table 6F.2

Ball-in-Race Flowmeter

Ignition Radiation Test

Spark Repetition Rate(Hz)	Actual Flowrate (mℓ/s)	Indicated Flowrate (mℓ/s)
	Solid Ignition Wire	
0	13.2	12.0
33	13.2	16.4
118	13.2	21.4
318	13.2	34.7
338	13.2	Erratic
	Resistive Ignition Wire	
33	13.2	12.0
99	13.2	12.0
215	13.2	12.0
328	13.2	12.0

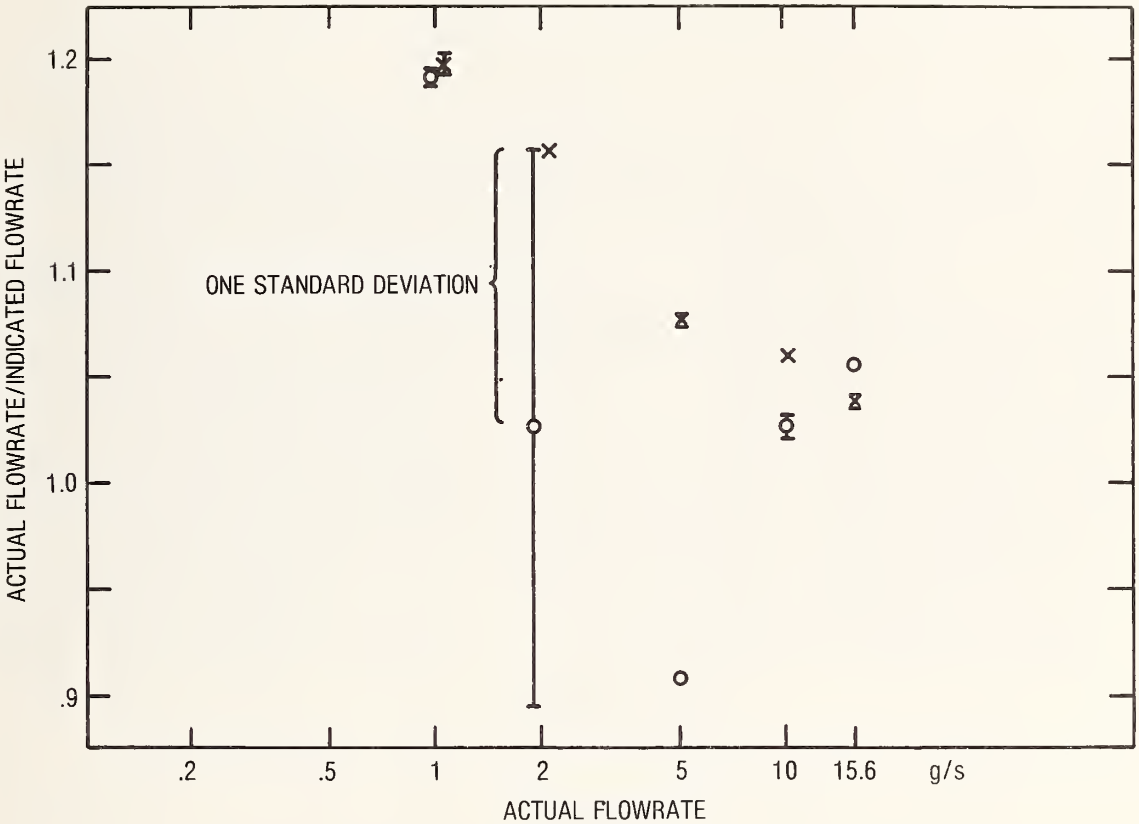

Fig. 6F.1. Ball-in-Race Flowmeter calibration curve. The circles are for data taken on the first day of testing, and the x's the second day. The omission of data at low and high flowrates, the large scatter at 2 g/s, and the discrepancy at 5 g/s are due to the flowmeter and are discussed in the text.

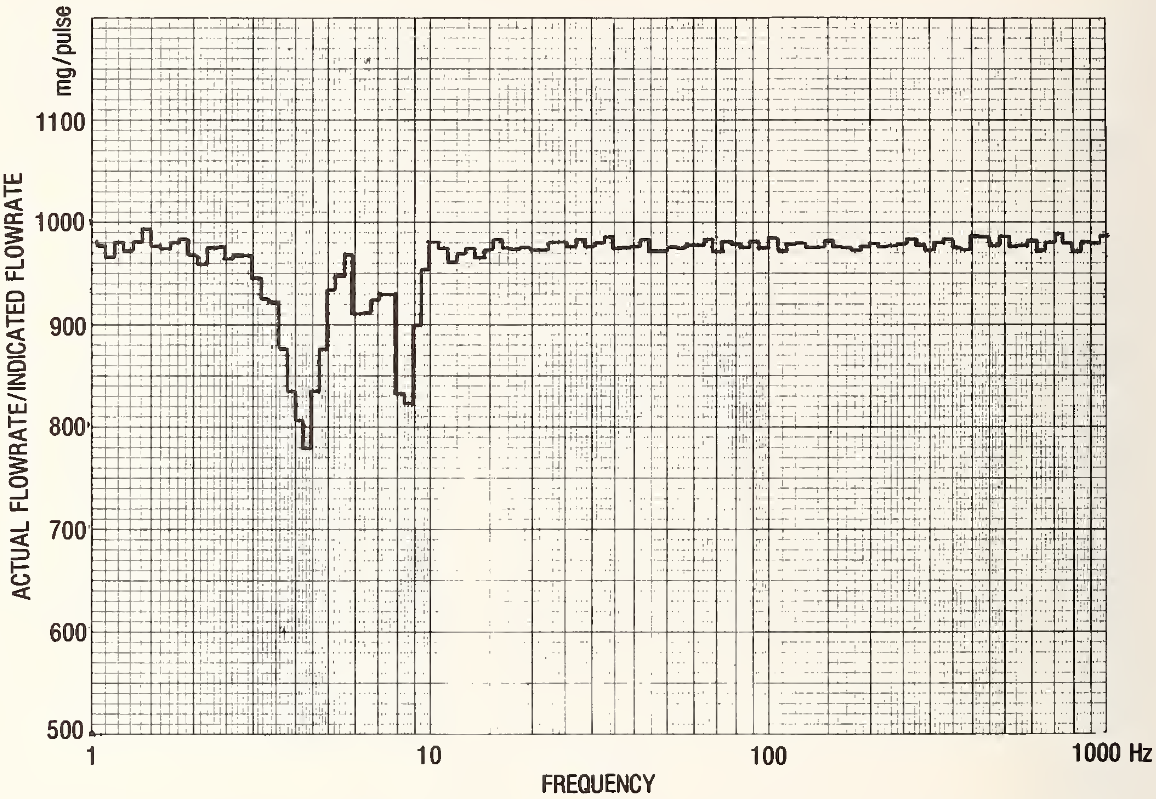

Fig. 6F.2. Vertical vibration test of Ball-in-Race Flowmeter. The actual flowrate is 10 g/s, and the flowrate ratio is averaged over 100 pulses from the Ball-in-Race Flowmeter. The sweep from 1 to 1000 Hz took 20 minutes.

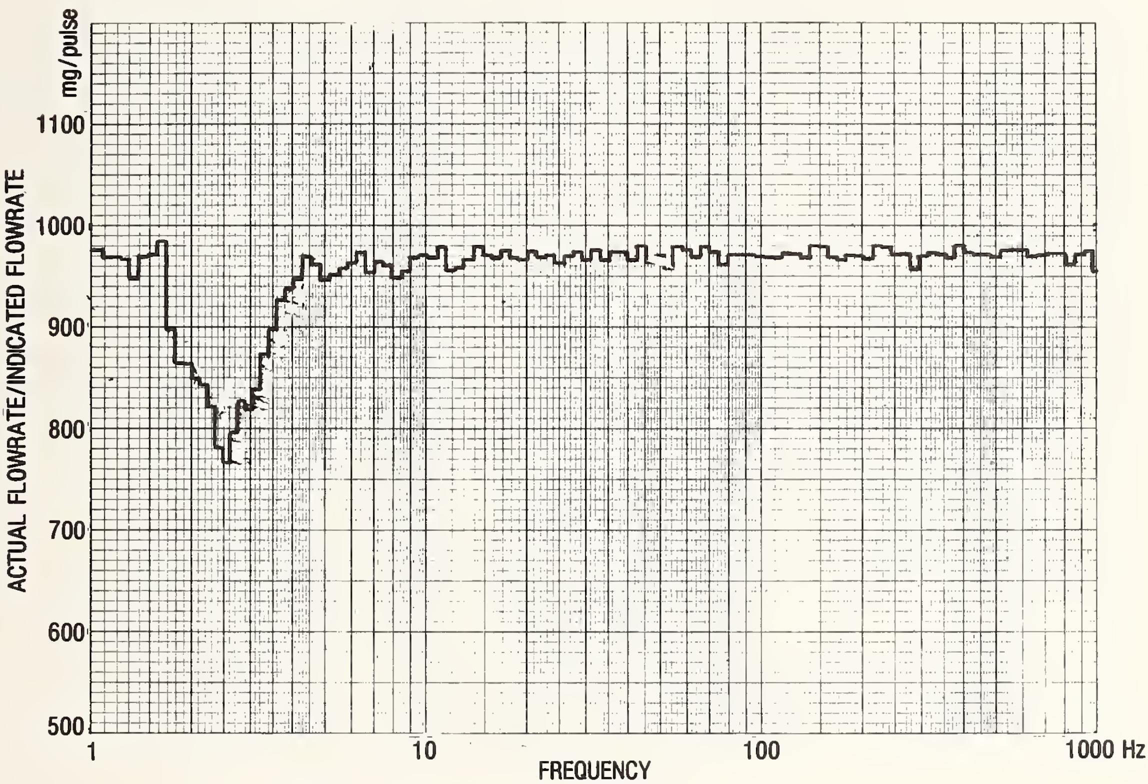

Fig. 6F.3. Ball-in-Race Flowmeter vibrated horizontally in direction of inlet and outlet fuel lines. Other conditions are the same as in Fig. 6F.2.

6G Ball and Spring Flowmeter

This flowmeter, described in Appendix G, leaked around the inlet fitting when it was first installed. The leak was stopped with epoxy, but after the flowmeter was used for a while, leaking again occurred around the outlet and around the photodiode mounting. These leaks were stopped with epoxy, and the flowmeter was tested.

A calibrator supplied with the flowmeter was used as shown in Fig. 6G.1 to verify that the flowmeter was properly adjusted. The adjustment was checked before the steady flow tests started and again after the steady flow tests were completed and found to meet the manufacturer's specification. Thus incorrect adjustment does not explain the day-to-day change in the steady flow data reported in Table 6G.1 and Fig. 6G.2. The day-to-day change is not due to bubbles in the flow either. This follows from the transfer standard flowmeter's total mass indication, which did not change more than .3 percent from day to day, and that was only at the lowest flowrate.

The effect of supply voltage on flowmeter indication is shown in Table 6G.2. The flowmeter is useful, however, as a real time indicator of the fuel flowrate through the needle valve and into the float bowl as shown in Fig. 6G.3. Although the flowmeter may not give a completely accurate indication of the time dependence of the fuel flow, it does show that the flow itself is quite erratic.

Table 6G.1

Ball and Spring Flowmeter

Steady Flow Test

Actual Flowrate (mℓ/s)	Flowmeter Indication (GPH)	Indicator Fluctuation (GPH)	Meter Factor* (Ideally=1)
	First Day		
1.66	1.5	± 0.2	1.06
2.66	3	± 0.2	.84
4.77	6	± 0.2	.76
6.05	9	± 0.3	.64
7.81	12	± 0.3	.62
9.00	15	± 0.5	.57
	Second Day		
3.18	1.5	± 0.4	2.01
4.73	3	± 0.1	1.50
7.19	6	± 0.4	1.14
9.51	9	± 0.5	1.00
11.8	12	± 0.5	.94
13.4	15	± 0.5	.85

Average Temperature = 23°C, Average Density = 0.7474 g/mℓ

*Conversion factor times the actual flowrate divided by indicated flowrate.

Table 6G.2

Ball and Spring Flowmeter

Supply Voltage Test

Actual Flowrate = 7.60 mℓ/s (7.23 GPH)

Supply Voltage (Volts DC)	Indicated Flowrate (GPH)
9.3	0
10.0	1.7
10.5	3.1
10.95	4.6
11.45	6.6
11.9	8.6
12.5	9.2
12.9	9.5
13.5	10.0
14.0	10.3
14.6	10.5
15.0	11.5

Average Temperature = 22°C, Average Density = 0.7259 g/mℓ

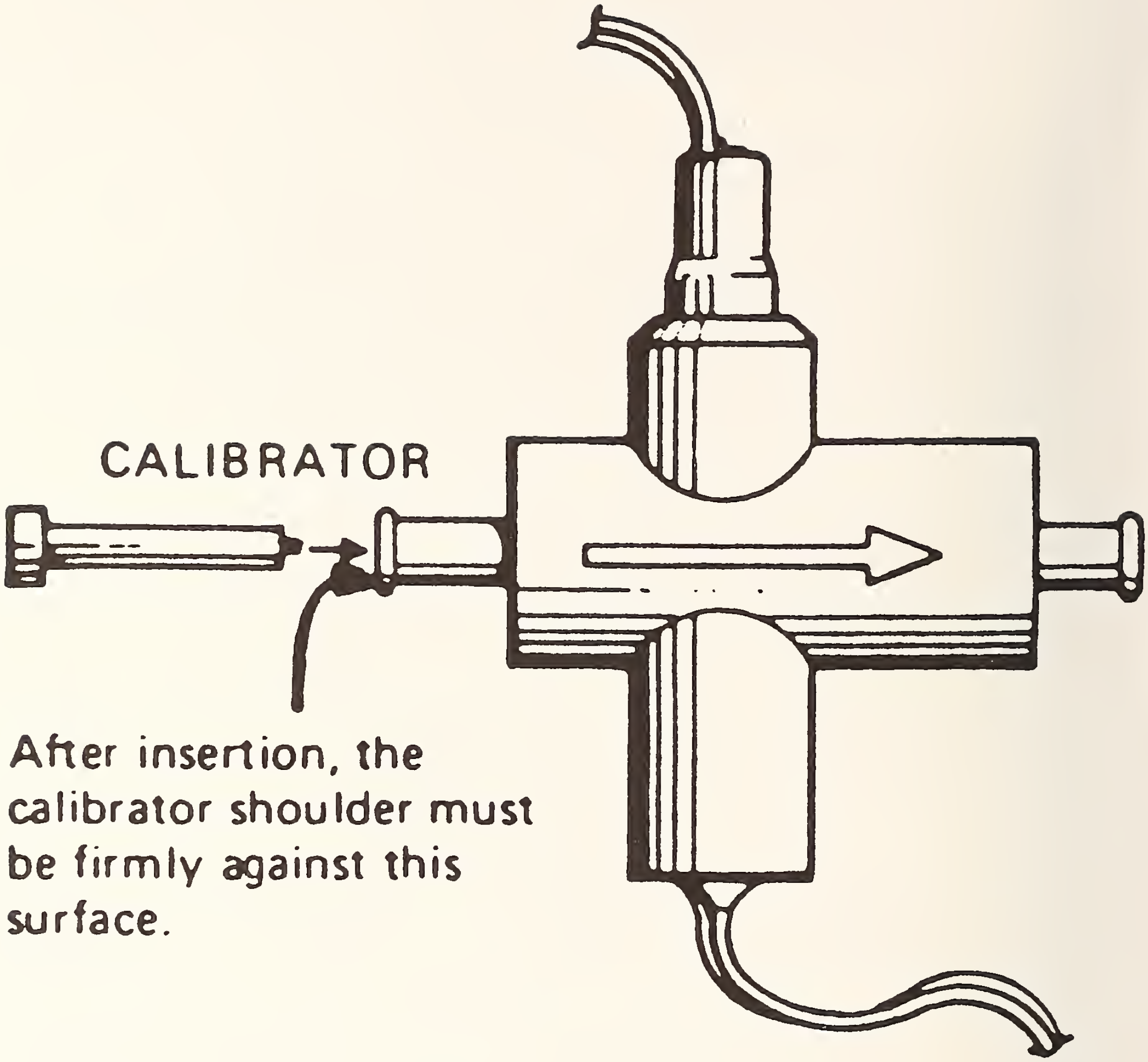

Fig. 6G.1. Ball and Spring Flowmeter calibrator.

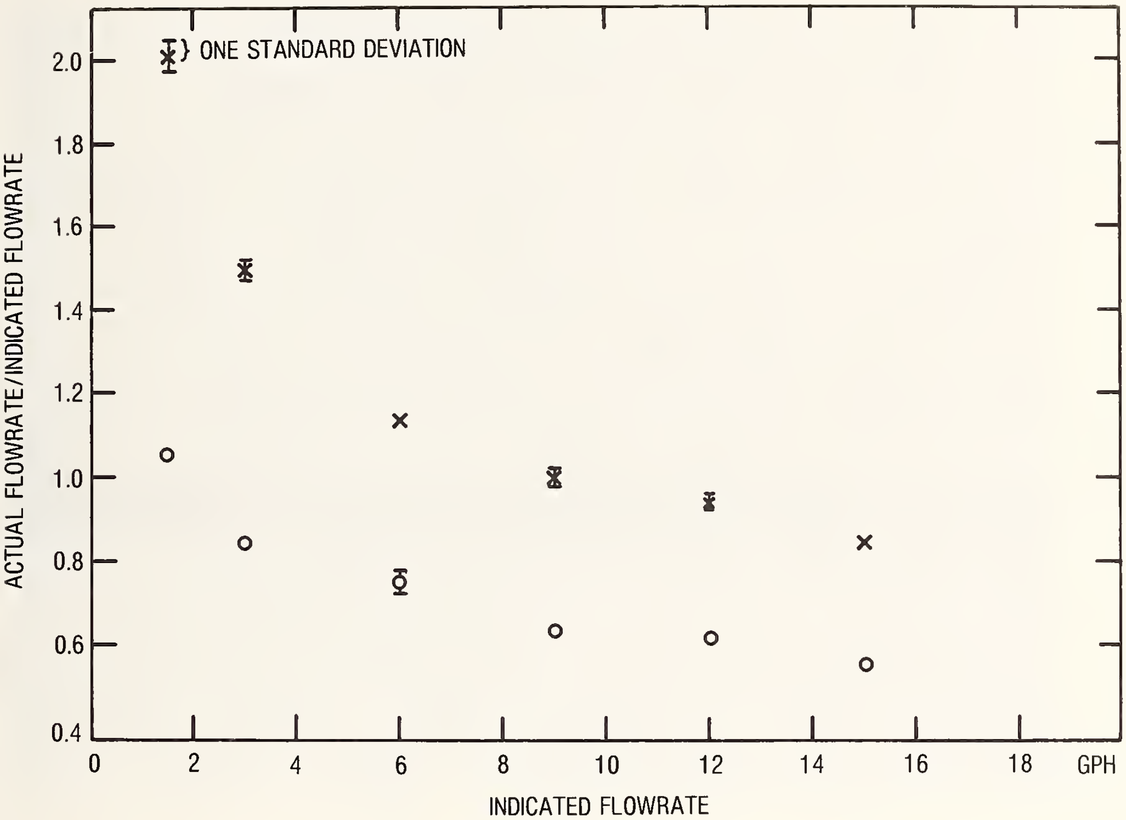

Fig. 6G.2. Ball and Spring Flowmeter calibration curve. The flowrate ratio should be equal to one. The circles are for data taken on the first day of testing, and the x's the second day. The day-to-day change is due to the flowmeter as discussed in the text.

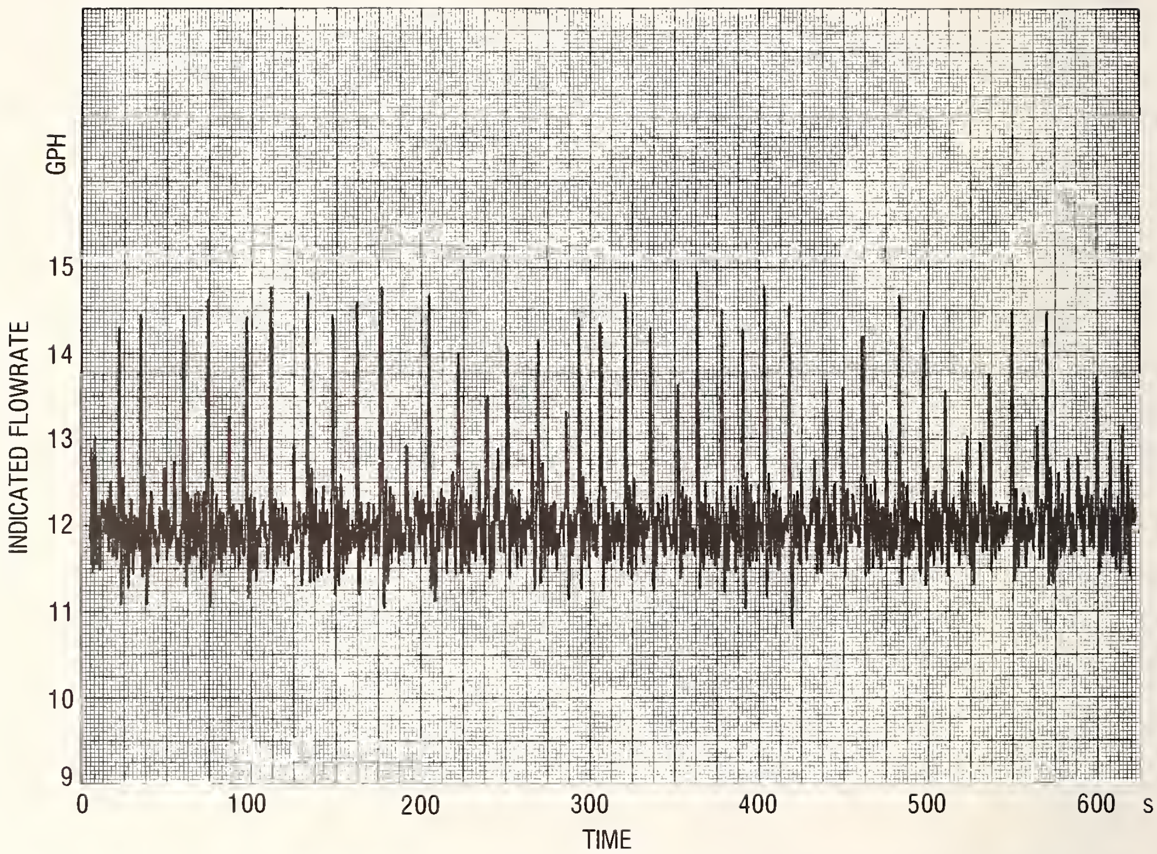

Fig. 6G.3. Ball and Spring Flowmeter indicated flowrate versus time. This shows that the fuel flow through the needle valve into the float bowl is erratic.

7 DISCUSSION AND CONCLUSION

In the present work, flowmeter environment in an automobile was surveyed. In light of this information, a procedure was developed to test flowmeter performance in a laboratory simulation of that environment. Sources of error in the tests were examined and eliminated as much as possible. Tests on six flowmeters were performed illustrating the results of the evaluation procedure.

Time and staff limitations prevented complete testing of all available automotive fuel flowmeters. Tasks left undone include the following:

- Defining more completely the conditions of some of the tests, e.g. characterizing the vapor bubble content in the fuel at high temperatures.

- Extending the tests, e.g., to lower flowrates at high temperatures, or e.g., vibrating the float bowl independently.

- Completing all of the present tests not performed here, e.g., tilting the Automatic Burrette Flowmeter.

- Determining the long term effect of wear on flowmeter performance, e.g., for the Four Piston Flowmeter.

- Testing with fuel injection rather than with a float bowl.

- Carrying out all tests on other kinds of automotive fuel flowmeters, e.g., an $8000 flowmeter, which was not obtained for the present tests because of its cost.

- Testing more than one automotive fuel flowmeter of a given model to determine how typical the flowmeter defects are.

- Determining the causes for automotive fuel flowmeter inaccuracy.

- Modifying or redesigning flowmeters to eliminate defects and testing the new version.

Testing as extensive as this would best be approached by a screening process in which further tests would be made on a flowmeter only if it performed satisfactorily on all previous tests. The tests would not be performed in a fixed order; tests which the flowmeter is expected to fail most significantly would be performed first.

APPENDIX. FLOWMETERS

The environment of a flowmeter in an automobile is sufficiently hostile that it is not likely to measure fuel accurately unless specially designed for this purpose. So, only flowmeters that are advertised for automotive use were considered.

The advertised prices of flowmeters range from about \$50 to \$4000 and have a claimed accuracy as good as 0.25 percent. Not all of them cover the necessary 50 to 1 flow range. Several of them are available as miles-per-gallon (MPG) meters as well as instantaneous gallons-per-hour or total fuel used meters. Only the fuel consumption versions will be discussed.

A. Four Orifice Flowmeter

The flowmeter used for the transfer standard is the Four Orifice Flowmeter, shown schematically in Fig. A. It uses four matched orifices in a Wheatstone bridge arrangement. An orifice is in each of the fuel lines that form the sides of the square. An internal pump maintains a constant volume flow Q of fuel in a line that goes diagonally from one corner of the square to the opposite one. The fuel then flows back along the perimeter of the square in equal amounts on both sides. The fuel to be measured enters at another corner of the square with volume flowrate q, and the same quantity of fuel leaves to the carburetor from the last corner. The pressure drop ΔP divided by the internal pump volume flowrate Q is proportional to the mass flowrate G of the fuel to be measured.

This can be seen as follows. Since the orifices are made as nearly identical as possible and then selected from a large batch to form a matched set of four, the flow divides reasonably accurately as shown in Fig. A. The flowrate through the lower left orifice for example is

$$\frac{Q + q}{2} = C \sqrt{\frac{P_{in} - P}{\rho}},$$

where P_{in} is the flowmeter inlet pressure, P is the pump inlet pressure, ρ is the fuel density, and C is a constant. The flowrate through the lower right orifice is

$$\frac{Q - q}{2} = C \sqrt{\frac{P_{out} - P}{\rho}},$$

where P_{out} is the flowmeter outlet pressure, and the constant C is the same because the orifices are matched. The difference between the squares of these equations yields the mass flowrate

$$G = \rho Q = C^2 \Delta P/Q,$$

where $\Delta P = P_{in} - P_{out}$ is the measured pressure difference.

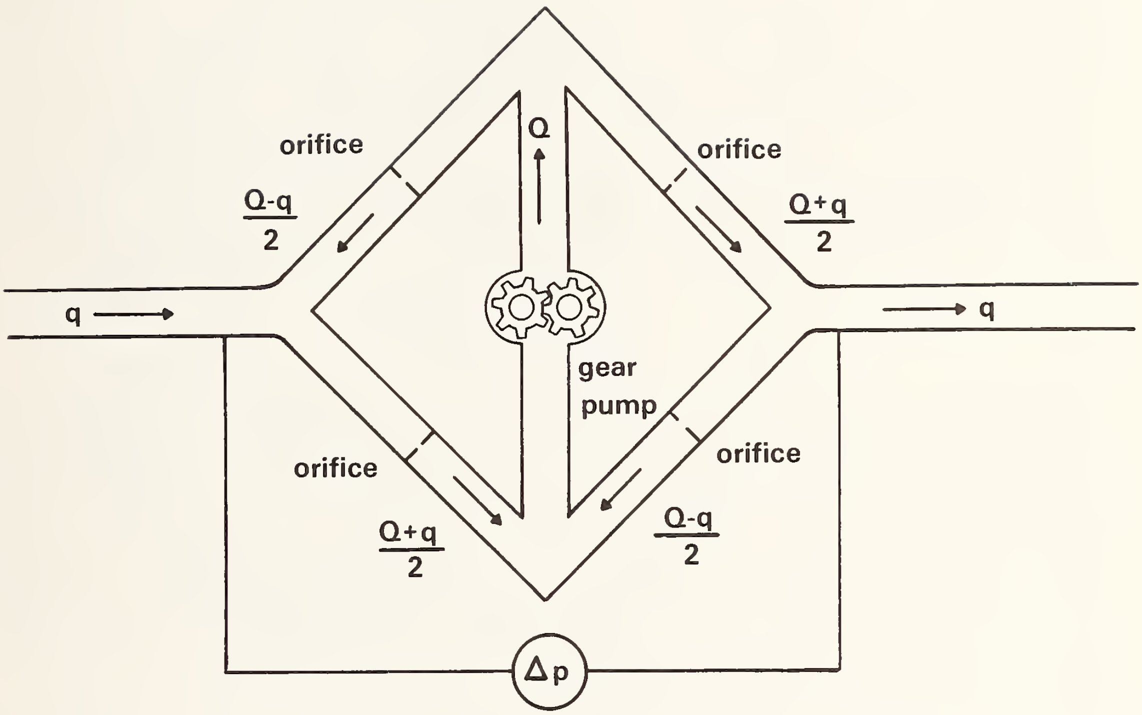

Fig. A. Four Orifice Flowmeter. The pump in the center maintains a constant volume flowrate Q. If the four orifices are identical, the total mass flow rate is given by $G = \rho q = \text{constant} \times \Delta P/Q$, where ΔP is the pressure drop across the meter.

This flowmeter is the only one that reads mass flow directly. All others respond to volume flow. However, since the internal pump rate must be held constant, a synchronous motor is used, which requires 115 V, 60 Hz A.C. This is easily supplied if the meter is used for dynamometer testing. For mobile testing, a converter must be used, which has a mass of 25 kg and draws about 50 A at 12 V.

B. Four Piston Flowmeter

The Four Piston Flowmeter has four pistons in a radial arrangement as shown in Fig. B. The four pistons are connected to the same crank shaft. No valves are used; fuel flows through ports uncovered by the pistons as they move. The ports are arranged so that the fuel flow causes the crank to turn continuously. A vapor eliminator is incorporated in the inlet. The magnitude and direction of rotation of the crank shaft is determined by two light beams that each are interrupted ten times per revolution. The resulting pulses from two light detectors are combined to determine direction of rotation and counted by an up-down counter so that back flow is subtracted automatically. The readout displays total fuel used in milliliters with 1 mℓ increments and also displays fuel temperature and pressure.

C. Positive Displacement Pump Flowmeter

The Positive Displacement Pump Flowmeter uses a piston pump run by a variable speed motor. The piston is rigidly attached to its connecting rod, and the axis of the cylinder is at a slight angle to the shaft of the motor. The connecting rod is coupled to the shaft by a pin travelling in a wavy groove, and this causes the piston to move back and forth in the cylinder as the shaft turns. Calibration can be adjusted by changing the angle. The volume displaced per piston stroke times the number of strokes gives the flow measurement. The speed of this calibrated pump is automatically varied to maintain constant output pressure. A schematic diagram is shown in Fig. C. Input pressure is boosted and held constant by another pump. A vapor diverter purges bubbles from the fuel before metering. An electromagnetic counter records total fuel used in 0.001 gallon increments. The average current used at 12 volts is 3 to 6A depending on flowrate. However, peak current can be as high as 20 A.

D. Turbine Flowmeter

The Turbine Flowmeter has a bypass line around it and a diaphragm blocking the bypass line. Because of the diaphragm no fuel flows in the bypass on the average. But the fuel does flow back and forth in it pushing the diaphragm back and forth. Meantime fuel is flowing through the turbine meter causing its rotor to rotate. The bypass line is intended to smooth out the flow through the turbine meter. A light beam is interrupted by the blades of the turbine rotor every time one goes by. The resulting signals are counted and displayed digitally with 0.01 gallon increments.

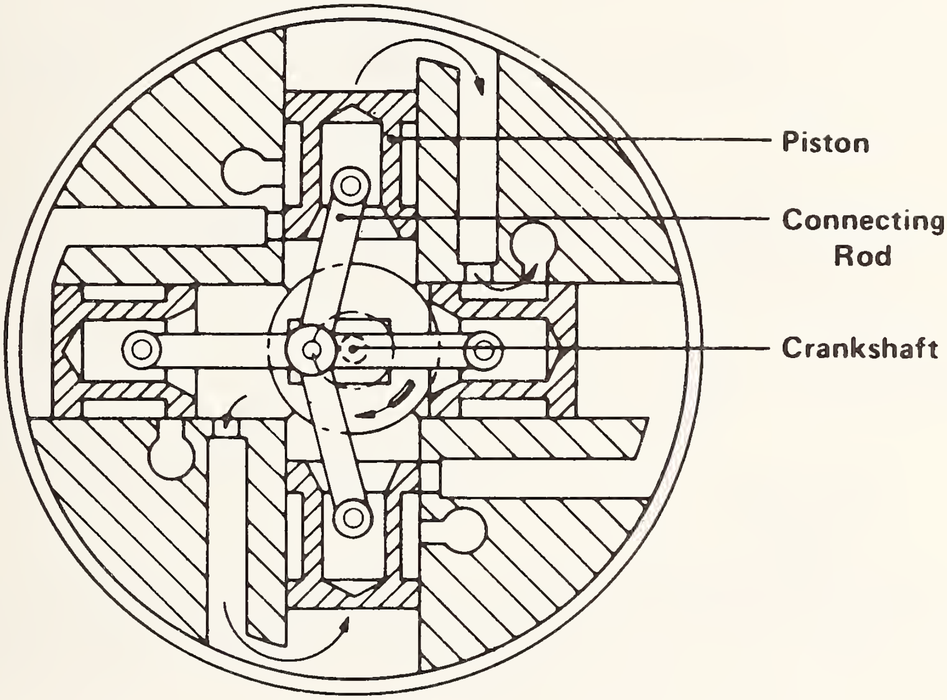

Fig. B. Four Piston Flowmeter. The crankshaft is caused to rotate by the flowing fluid. The rotation is detected optically.

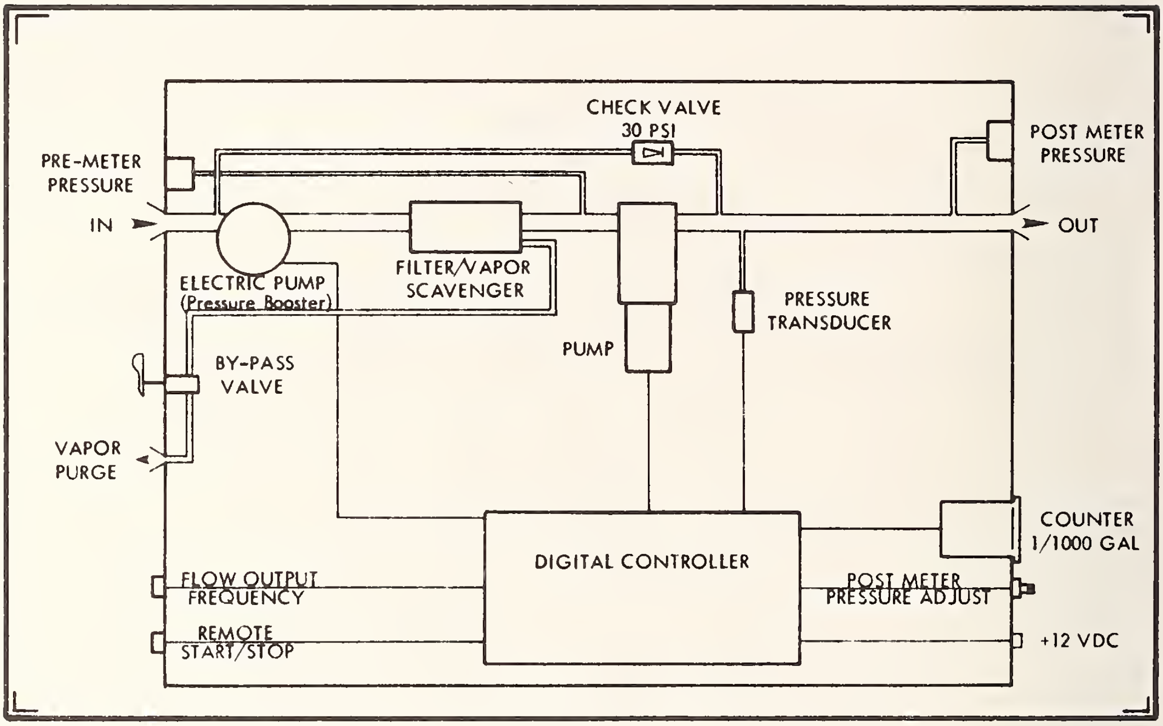

Fig. C. Positive Displacement Pump Flowmeter. When the pressure transducer detects a decrease (increase) in the output pressure, the digital controller causes the pump to increase (decrease) the flow-rate. The pulses to the pump are divided by 12 and used to advance the counter 1/1000 gallon.

E. Automatic Burrette Flowmeter

The Automatic Burrette Flowmeter has an automatically filled .01 gallon container as shown in Figs. E.1 and E.2. The contents of the container are dumped on demand into a reserve tank that holds three times as much as the container. A pump at the outlet of the reserve tank pumps the fuel to the carburetor. When the fuel level in the reserve tank drops far enough, a level sensor initiates the cycle. The container is then filled by incoming fuel until a level sensor set for .01 gallon is actuated. This stops the flow of the incoming fuel and causes the container contents to be dumped into the reserve tank. The number of times the container is filled is counted by an electromagnetic counter, which records total fuel used in .01 gallon increments.

F. Ball-in-Race Flowmeter

The Ball-in-Race Flowmeter has an opaque ball that travels through a toroidal passage, i.e. a passage shaped like the dough of a donut. The ball is pushed along by a jet of fuel every time it comes around the toroid. The fuel travels three fourths of the way around the toroid behind the ball and then exits while the ball coasts along to where it gets pushed again. Each time the ball goes around the toroidal passage it interrupts a light beam. This interruption is turned into an electric pulse, which is counted. The readout gives a digital reading in .01 gallon increments of the total fuel used.

G. Ball and Spring Flowmeter

The Ball and Spring Flowmeter is a variable area flowmeter. A spring pushes an opaque ball into a tapered translucent tube whose diameter decreases with distance into the tube as shown in Fig. G. The farther into the tube the ball goes, the tighter it fits. At the end of the tube is an orifice, and the spring pushes the ball against it covering it. The fuel flows out of the orifice pushing the ball away so it can flow through the annular area around the ball. This annular area increases continuously as the ball moves along the tube. The faster the fuel flows, the more cross sectional area needed for the fuel, and so the farther along the tube the ball gets pushed. As the ball moves back it increasingly uncovers a beam of light so that more light shines on a photodiode decreasing its electrical resistance. The resistance is measured to give the flowrate. The light bulb is powered through a voltage regulator so that changes in the car battery voltage will not affect the flow measurement. A red filter is used to prevent errors due to gasoline color changes. The flowrate is displayed on an analog readout with a readability of about 0.2 gallon/hour.

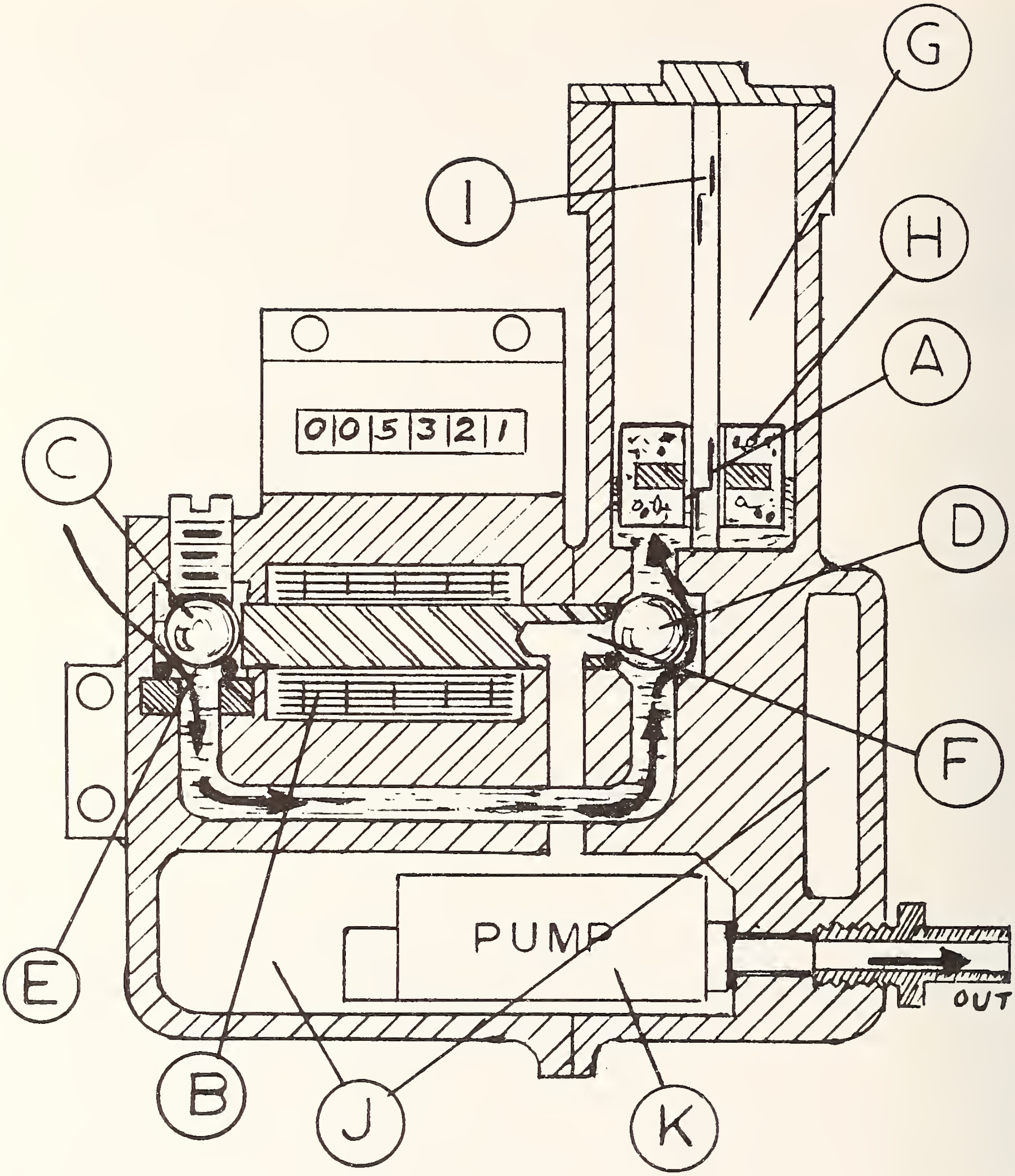

Fig. E.1. Automatic Burette Flowmeter, just before filling the measuring chamber. In this illustration, the level sensor at (A) has activated the magnetic coil at (B) and the balls at (C) and (D) are raised, opening the port at (E) and closing the outlet at (F). Fuel enters the measuring chamber at (G) and the float (H) raises toward the level sensor (I).

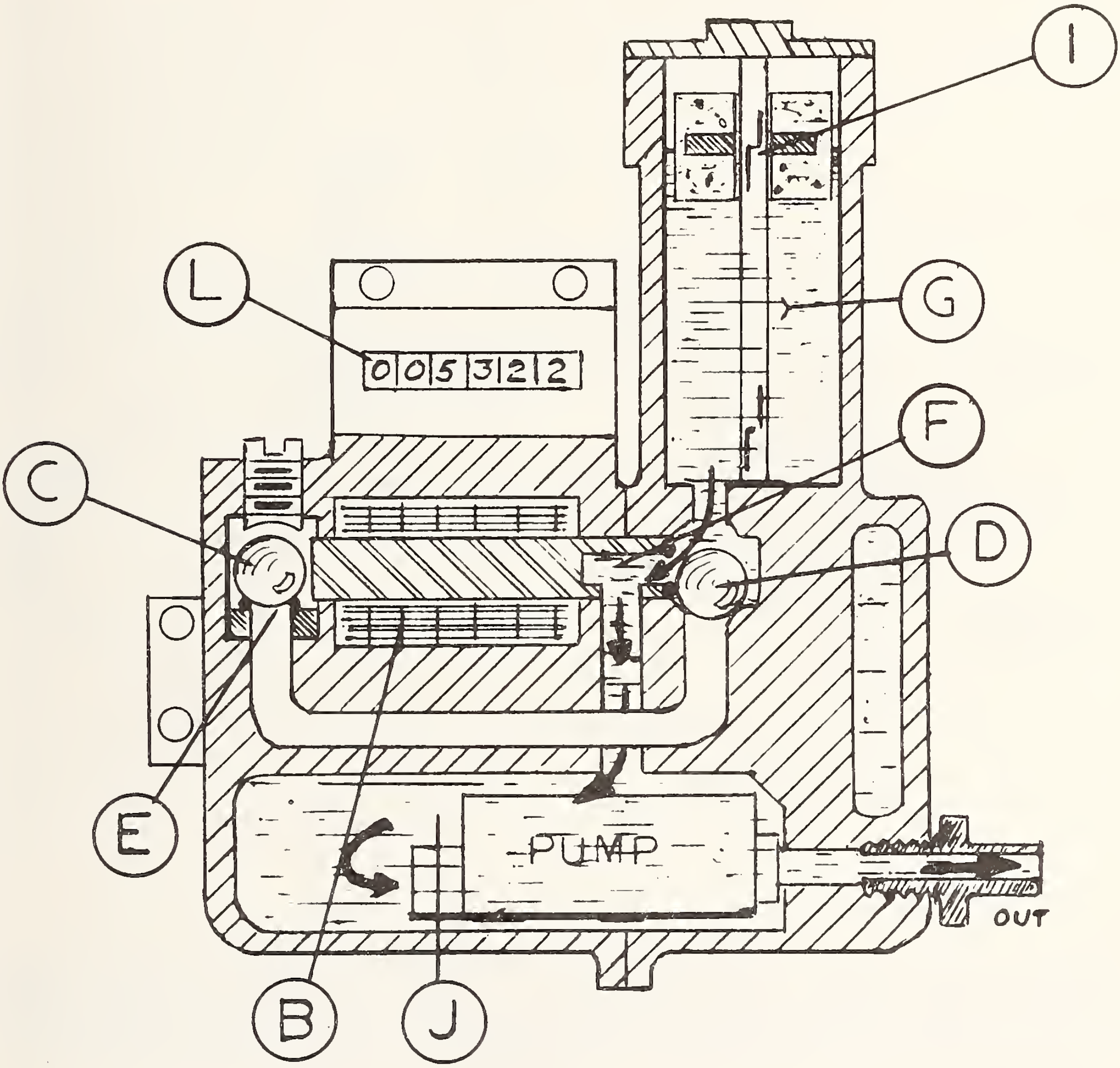

Fig. E.2. Automatic Burette Flowmeter just after filling the measuring chamber. In this illustration, the coil (B) has been discharged by the action of the liquid level sensor at (I), and the balls at (C) and (D) have fallen back, closing the port at (E) and opening outlet at (F). Fuel in the measuring chamber (G) will now flow into the reservoir (J). The counter at (L) records the addition of this increment as it passes into the reservoir.

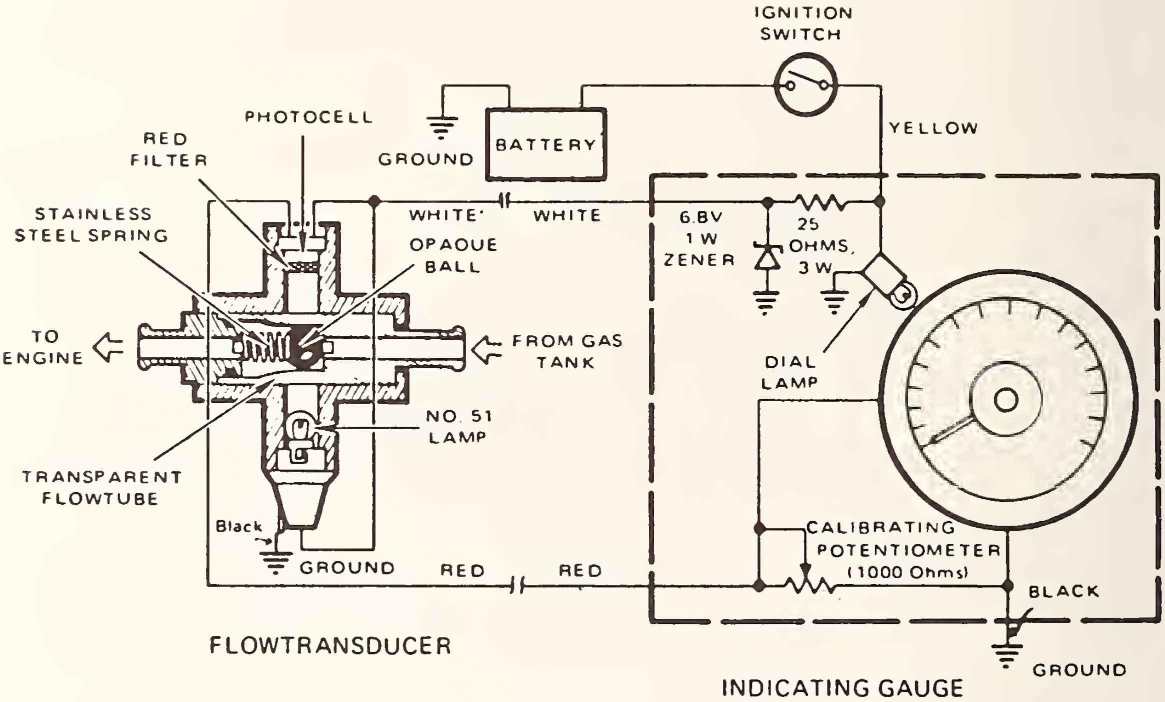

Fig. G. Ball and Spring Flowmeter. The flowing fluid pushes the ball against the spring. The farther back the ball is pushed, the more light from the lamp strikes the photodiode, the lower its resistance, the more current flows in the circuit, and the greater the indicated flowrate on the gauge.

APPENDIX H. THERMISTOR CALIBRATION

The thermistor probes used for each test are as follows:

Meter	Probe Numbers
- Four Orifice Flowmeter	1 & 4
- Four Piston Flowmeter	1 & 4
- Positive Displacement Pump Flowmeter	1 & 4
- Turbine	1 (#2 during heated test)
- Automatic Burrette Flowmeter	1 & 2
- Ball and Race Flowmeter	1
- Ball and Spring Flowmeter	1

The Reports of Test for these probes follow .

FORM NBS-259
(3-66)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF TEST

Thermistor Probes #1 and #5
Digital Display Unit S/N 559

Submitted by

National Bureau of Standards
Division 213, Section 06

The thermistor probes were calibrated by intercomparison with a standard platinum resistance thermometer in stirred liquid baths at 13 temperatures. An ice point was taken by immersing the probes in an ice bath. The probes were immersed to a depth of 4 1/2 inches and the zero was checked before each reading. For temperatures below 0 °C the readings were taken on the -30 °C to +50 °C range, and for temperatures at 0 °C through 100 °C the readings were taken on the 0-100 °C range. The results obtained are given in tabular form below.

Temperature °C	Probe No.	Correction (IPTS-68) 1	5
-30.00		-0.20	-0.28
-20.00		+ .14	+ .07
-10.00		- .07	- .11
0.00		- .26	- .30
10.00		+ .20	+ .15
20.00		+ .03	.00
30.00		- .14	- .17
40.00		- .11	- .14
50.00		+ .06	+ .04
60.00		+ .18	+ .16
70.00		+ .13	+ .11
80.00		- .02	- .05
90.00		- .10	- .13
100.00		+ .22	+ .19

All temperatures in this report are based on the International Practical Temperature Scale of 1968, IPTS-68. This temperature scale was adopted by the International Committee of Weights and Measures at its meeting in October, 1968, and is described in "The International Practical Temperature Scale of 1968," Metrologia, Vol. 5, No. 2, 35 (April, 1969).

For the Director
Institute for Basic Standards

James F. Schooley
Chief, Temperature Section
Heat Division

Test No. 311-9-75
Completed: October 28, 1975
JAW:NMcB

FORM NBS-259
(3-66)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF TEST

Thermistor Probes #2 and #6
Digital Display Unit S/N 705

Submitted by

National Bureau of Standards
Division 213, Section 06

The thermistor probes were calibrated by intercomparison with a standard platinum resistance thermometer in stirred liquid baths at 13 temperatures. An ice point was taken by immersing the probes in an ice bath. The probes were immersed to a depth of 4 1/2 inches and the zero was checked before each reading. For temperatures below 0 °C the readings were taken on the -30 °C to +50 °C range, and for temperatures at 0 °C through 100 °C the readings were taken on the 0-100 °C range. The results obtained are given in tabular form below.

Temperature °C	Probe No.	Correction (IPTS-68) 2	6
-30.00		-0.19	
-20.00		+ .18	
-10.00		- .03	
0.00		- .14	-.18
10.00		+ .28	+.25
20.00		+ .10	+.07
30.00		- .08	-.12
40.00		- .07	-.11
50.00		+ .09	+.04
60.00		+ .20	+.14
70.00		+ .14	+.07
80.00		- .03	-.11
90.00		- .12	-.22
100.00		+ .19	+.13

All temperatures in this report are based on the International Practical Temperature Scale of 1968, IPTS-68. This temperature scale was adopted by the International Committee of Weights and Measures at its meeting in October, 1968, and is described in "The International Practical Temperature Scale of 1968," Metrologia, Vol. 5, No. 2, 35 (April, 1969).

For the Director
Institute for Basic Standards

James F. Schooley
Chief, Temperature Section
Heat Division

Test No. 311-9-75
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FORM NBS-259
(3-66)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF TEST

Thermistor Probes #3 and #7
Digital Display Unit S/N 706

Submitted by

National Bureau of Standards
Division 213, Section 06

The thermistor probes were calibrated by intercomparison with a standard platinum resistance thermometer in stirred liquid baths at 13 temperatures. An ice point was taken by immersing the probes in an ice bath. The probes were immersed to a depth of 4 1/2 inches and the zero was checked before each reading. For temperatures below 0 °C the readings were taken on the -30 °C to +50 °C range, and for temperatures at 0 °C through 100 °C the readings were taken on the 0-100 °C range. The results obtained are given in tabular form below.

Temperature °C	Correction (IPTS-68) Probe No. 3	Correction (IPTS-68) Probe No. 7
-30.00	-0.24	-0.30
-20.00	+ .14	+ .10
-10.00	- .05	- .08
0.00	- .22	- .20
10.00	+ .24	+ .26
20.00	+ .08	+ .11
30.00	- .09	- .07
40.00	- .06	- .03
50.00	+ .13	+ .14
60.00	+ .25	+ .26
70.00	+ .20	+ .22
80.00	+ .03	+ .06
90.00	- .06	- .02
100.00	+ .26	+ .33

All temperatures in this report are based on the International Practical Temperature Scale of 1968, IPTS-68. This temperature scale was adopted by the International Committee of Weights and Measures at its meeting in October, 1968, and is described in "The International Practical Temperature Scale of 1968," Metrologia, Vol. 5, No. 2, 35 (April, 1969).

For the Director
Institute for Basic Standards

James F. Schooley
Chief, Temperature Section
Heat Division

Test No. 311-9-75
Completed: October 28, 1975

FORM NBS-259
(3-66)

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234

REPORT OF TEST

Thermistor Probe #4
Digital Display Unit S/N 634

Submitted by

National Bureau of Standards
Division 213, Section 06

The thermistor probe was calibrated by intercomparison with a standard platinum resistance thermometer in stirred liquid baths at 13 temperatures. An ice point was taken by immersing the probe in an ice bath. The probe was immersed to a depth of 4 1/2 inches and the zero was checked before each reading. For temperatures below 0 °C the readings were taken on the -30 °C to +50 °C range, and for temperatures at 0 °C through 100 °C the readings were taken on the 0-100 °C range. The results obtained are given in tabular form below.

Temperature °C	Correction (IPTS-68) Probe No. 4
-30.00	-0.19
-20.00	+ .18
-10.00	.00
0.00	- .11
10.00	+ .35
20.00	+ .18
30.00	.00
40.00	.00
50.00	+ .15
60.00	+ .25
70.00	+ .19
80.00	+ .01
90.00	- .08
100.00	+ .23

All temperatures in this report are based on the International Practical Temperature Scale of 1968, IPTS-68. This temperature scale was adopted by the International Committee of Weights and Measures at its meeting in October, 1968, and is described in "The International Practical Temperature Scale of 1968," Metrologia, Vol. 5, No. 2, 35 (April, 1969).

For the Director
Institute for Basic Standards

James F. Schooley
Chief, Temperature Section
Heat Division

Test No. 311-9-75
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REFERENCES

1. "Preliminary Recommended Environmental Practices for Electronic Equipment Design" proposed by the Environmental Standards & Test Methods Subcommittee of the Electronic Systems Committee, Society of Automotive Engineers and presented at the International Colloquium on Automotive Electronic Technology, October, 1974, (SAE, 1974).

2. H. I. Wilson, "Fuel System Time-Temperature Histories During Specified Car Use Patterns." Paper No. 720080, Trans. SAE (1974).

3. Milton Baker, James Callison, (private communication).

4. American Association of State Highway and Transportation Officials.

5. Ernest Johnson (private communication).

6. ASTM Specification E100-72 (American Society of Testing Materials, Philadelphia, Pa., 1972).

7. ASTM Method D323-72 (American Society of Testing Materials, Philadelphia, Pa., 1972).

8. ASTM Method D287-67 (American Society of Testing Materials, Philadelphia, Pa., 1972).

9. ASTM-IP Petroleum Measurement Tables. (American Society of Testing Materials, Philadelphia, Pa., 1952).

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Fuel economy measurement procedures being developed by the Transportation Systems Center of the Department of Transportation require flowmeters to measure the gasoline consumed by the engine of an automobile either on the road or on a dynamometer. The contribution of the National Bureau of Standards to this work was to ascertain the environment in which the flowmeters will probably be used, to develop procedures for measuring their performance in a laboratory simulation of that environment, and to carry out illustrative measurements on a number of flowmeters.

This report discusses: (1) the environment of the flowmeter in an automobile, i.e., flowmeter temperature; fuel temperature, pressure, density, viscosity, color, opacity, flow pulsations, back flow, and swirl due to elbows; line voltage fluctuations; electromagnetic radiation from ignition; vehicle attitude with respect to the vertical; and vibration, (2) the test set-up and procedure used for evaluating and calibrating these meters in the laboratory under conditions simulating the automotive environment, (3) a discussion of possible sources and magnitudes of errors in the calibration, and (4) results of illustrative tests on seven flowmeters.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Automotive environment; Automotive fuel flowmeters; Effect of environment on flowmeter performance; Flowmeter calibration; Flowmeter evaluation; Procedure for testing flowmeters

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