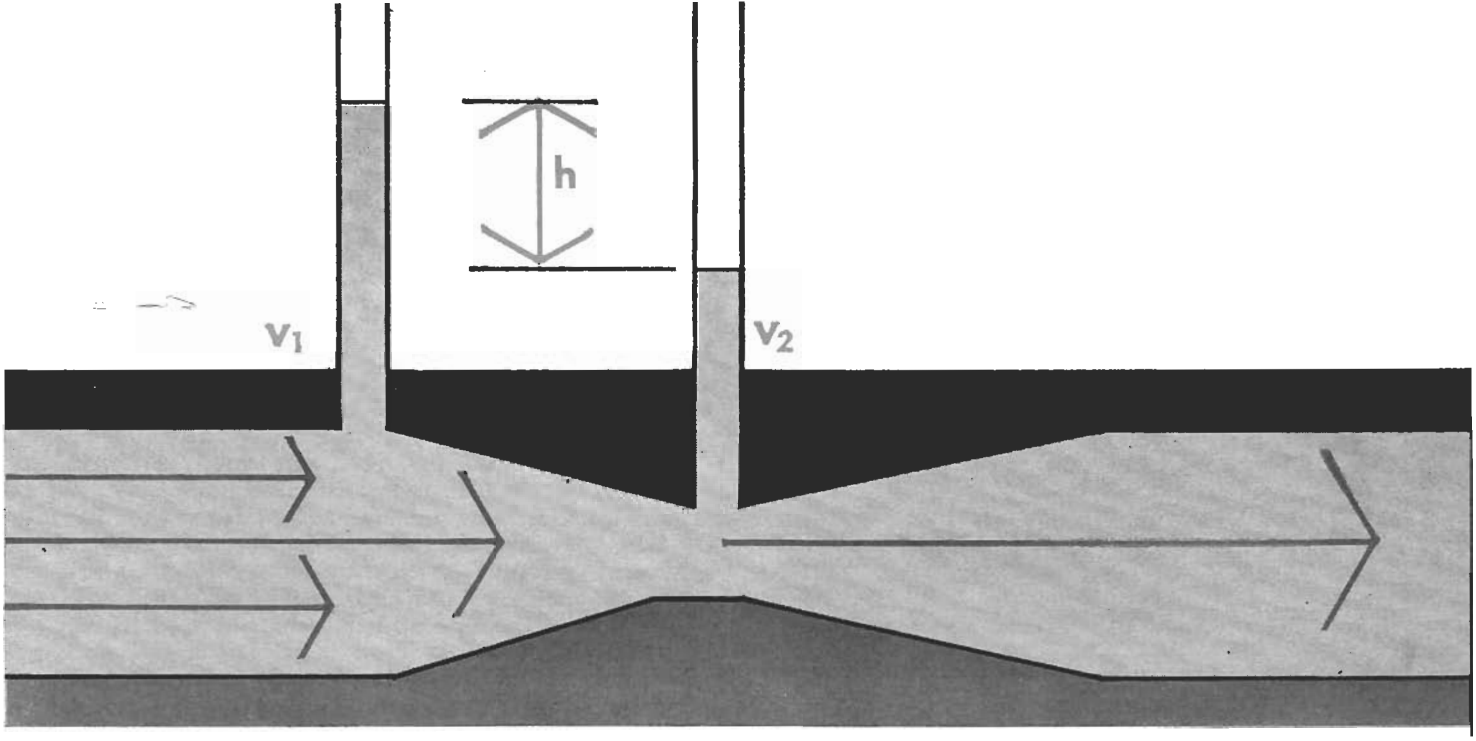


FLOW MEASUREMENT
ELECTRONIC TECHNIQUES & DEVICES

By WALTER H. BUCHSBAUM, Industrial Consultant, ELECTRONICS WORLD

Precise gauging of liquid flow is essential in many industrial processes and in such diverse applications as control of fuel to rocket motors and of blood during surgery.

ALTHOUGH not spectacular devices, electronic flowmeters are found in such widely divergent applications as regulating the fuel flow to the rocket motors of the "Nova" super-missile and in the delicate control system that governs the flow of human blood during an artificial-heart–lung operation. Flowmeters are not new devices and do not necessarily employ electronics. With the advent of automation, however, the measurement of flowing liquid had to be more precise and controllable by an electrical signal. A survey of the flowmeters now in use shows that there are two types that employ electronics: those which are really mechanical and convert a mechanical motion into an electrical signal and those that use electronic principles to measure the flow as well as indicate it with an electrical signal.

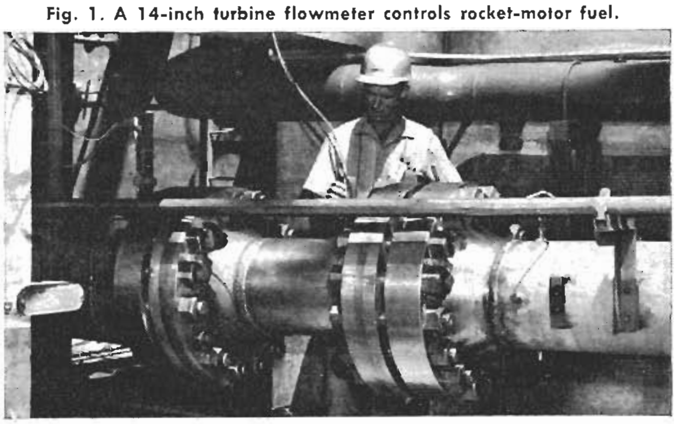
Many technicians who work in industrial electronics will come into contact with these flowmeters as part of an electronic control system. Understanding how a particular type of flowmeter works will enable you to at least determine if it is working correctly or not. The troubleshooting and repair of some specific flowmeters require special training in this type of equipment.

Mechanical Flowmeters

The most obvious way to measure the flow of a liquid is to insert a propeller or turbine into the stream and measure how fast the flowing liquid turns it. Turbine flowmeters combine a mechanical motion with an electronic sensing device to produce an electrical signal output. As shown in Fig. 2, the propeller inside the pipe is turned by the liquid or gas flowing through it. A sensing coil is located outside the pipe to pick up the magnetic flux variations due to the motion of the propeller vanes. When the flow is fast, the propeller turns rapidly and the frequency of the output signal is high. The stationary vanes at both ends of the metering section are necessary to prevent the swirling effects of the liquid which would affect the propeller speed and result in false, low readings. Turbine meters are available in a wide range of sizes from the miniature version shown in Fig. 2 to units several feet in diameter. They are used in many industrial installations, but one of the more spectacular applications is measuring the flow of liquid oxygen ("lox") to missile engines. A 14-inch turbine flowmeter which controls the fuel going to the F-1 engine, one of eight, of the new "Nova" super-rocket is shown in Fig. 1. One obvious drawback of turbine flowmeters is that the vanes and propeller obstruct the flow of liquid. Another is that they are limited in their applications to non-corrosive liquids because their bearings and the propellers will corrode.

Another mechanical-type flowmeter is the differential-diaphragm type shown in Fig. 4. By varying the cross-section of a length of pipe, making one section narrower than the rest, a pressure difference is developed. The magnitude of this difference, which determines the position of a sensitive

Fig. 1. A 14-inch turbine flowmeter controls rocket-motor fuel.



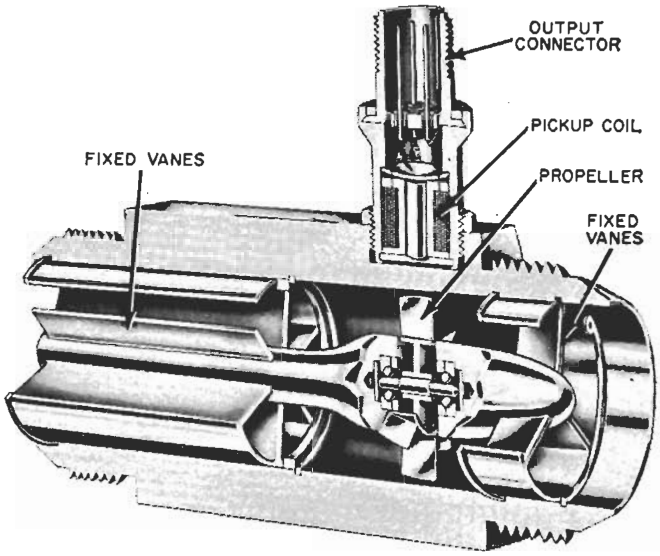


Fig. 2. Cutaway drawing of typical small turbine flowmeter.

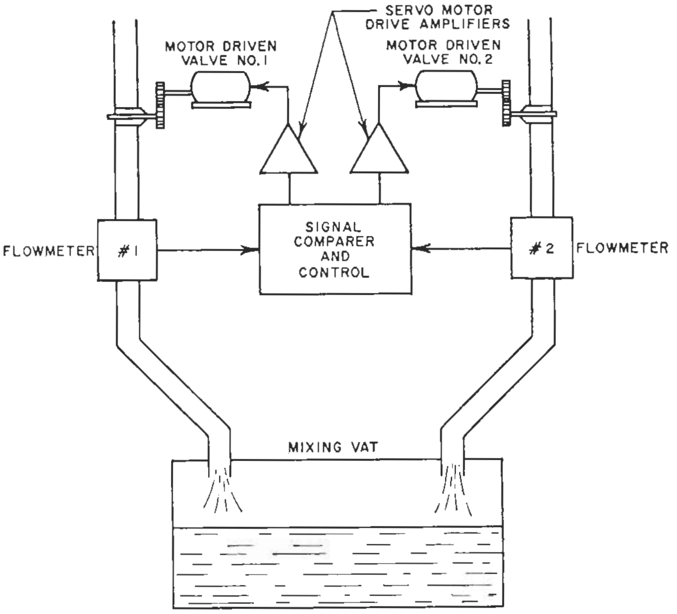


Fig. 3. Typical flowmeter application. Signals from flowmeters are compared to generate a control signal that adjusts valves 1 and 2 which maintain desired flow into mixing vat.

diaphragm, depends on the flow rate. An arm is attached to the diaphragm and the position of the arm is measured electronically. The most frequent method of measuring the arm displacement is by connecting it to the movable core of a differential transformer. Different circuits are in use but essentially they just measure the output-voltage variation between the two windings. If each of these windings is connected to the inputs of a differential amplifier, the amplifier output will be an a.c. signal whose magnitude is proportional to the diaphragm displacement or to flow of material in the pipe. The creation of an area of pressure difference means that the flow itself is reduced. This type of meter is suitable for non-corrosive liquids and gases.

In another type of mechanical flowmeter called a "rotameter," (Fig. 5) a specially shaped float rides within a tapered tube in which the differential pressure determines the position of the float. (The float guide-rod assembly is held in position in the pipe by perforated discs.) Flow determines the position of the float and, in electronically sensed rotameters, the float controls the inductance of an external coil so that either the frequency of an oscillator or the output amplitude of a transformer will be proportional to the flow rate. The rotameter is widely used for non-corrosive liquid metering and in relatively small-diameter pipes and tubes.

The electronic portions of the control and indicating systems usually contain a servo amplifier, differential amplifiers, milliammeters, and other conventional devices. Signals are either 60 cps or below 10 kc. which means that transmission over ordinary cables is possible and r.f. or high-frequency pulse techniques are not involved. This greatly simplifies system design, installation, and servicing.

Electronic Flowmeters

Although many types are in use and more are being developed, there are three basically different types of electronic flowmeters. One type is used for electrically conducting liquids, such as salt water, and is generally called a magnetic flowmeter. Another type uses ultrasonic techniques, and the third type is really a temperature-sensing device. The magnetic flowmeter's operation is based on the principle of the electric generator: when a conductor moves in a magnetic field, a current will be induced in the conductor. Fig. 6 shows the elements of a magnetic flowmeter. A magnetic flux B is produced between the upper and lower coils. When the conducting liquid V moves through this flux, a voltage E will be produced at right angles in that portion of the liquid moving through the field. With a fixed conductivity and cross-section, this voltage will be proportional to the speed of the liquid flow.

In order to measure a voltage across the liquid, the inside of the pipe must be insulated over a short length to avoid shorting out the small induced potential. The frequency of the excitation field will depend on the conductance of the metered liquid. For poorer conductors, a higher frequency will produce a greater signal voltage.

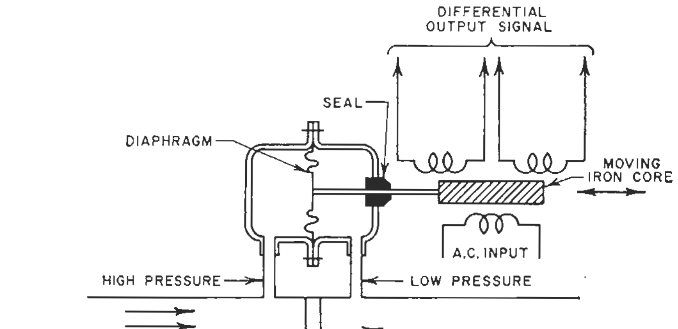
The flowmeter illustrated in Fig. 6 uses an a.c. field and is found in many liquid-flow control systems in the chemical industry especially where strong acids are used. The Teflon or fiberglass pipe lining and the lack of internal obstructions makes this flowmeter ideal for such applications. Surprisingly many liquids are sufficiently good electrical conductors to be measured with an a.c. flowmeter. Human blood, for example, is an electrical conductor and is monitored by magnetic flowmeters during artificial-heart–lung operations.

In addition to a.c. magnetic flowmeters there are also some that use a d.c. excitation field, usually produced by permanent magnets. In order to be effective, the liquid, such as liquid sodium, must have a relatively high electrical conductance. One of the more recent applications of d.c. flowmeters has been in nuclear reactors where the flow of liquid metal is to be measured.

The second type of electronic flowmeter uses ultrasonic techniques to measure flow. In this area there are several different designs and many meters in the field are custom-made rather than mass produced. Ultrasonic techniques have been applied to flowmeters only recently and it seems too early for standardization. The principle underlying any of these meters, however, is basically the same: a flowing liquid produces changes in a beam of ultrasonic energy.

The simplest configuration of ultrasonic flow measurement

Fig. 4. Principle of operation of a differential flowmeter.



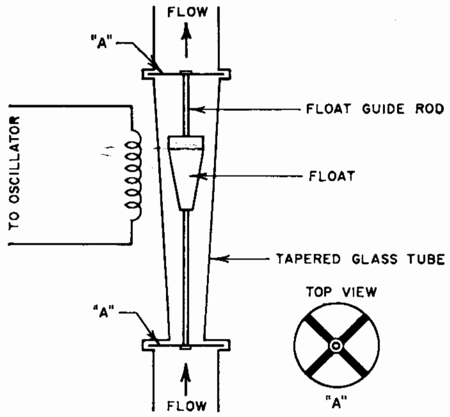
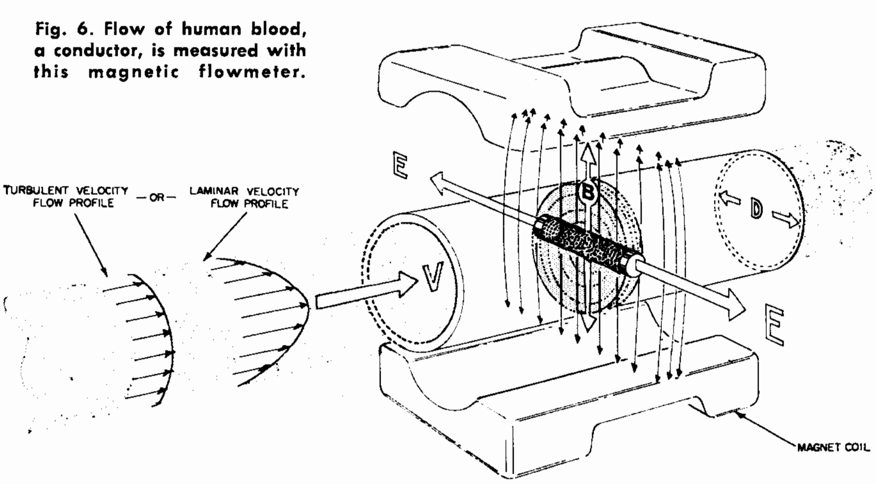


Fig. 5. Schematic shows principle of operation of electronically sensed rotameter.

Fig. 6. Flow of human blood, a conductor, is measured with this magnetic flowmeter.



is shown in Fig. 7. An ultrasonic signal is beamed from the transmitter to the receiver. The transit time is simply the distance divided by the speed of sound in the particular liquid. If the liquid flows in the direction of propagation then the transit time is modified by adding the velocity of the flow to the speed of sound. This is somewhat similar to the well-known Doppler principle and, in fact, the measuring circuits are similar to those used in Doppler radar systems. The transmitted and the received signals are compared in frequency; the difference signal is proportional to flow in the pipe.

Because the transit time changes over a distance of ten inches are relatively small, a more sophisticated arrangement than the one shown in Fig. 7 is usually used. Fig. 8 is typical of a more complex measuring system. This system is pulsed, with the pulse-repetition rate dependent on the transit time since each received pulse starts a new transmission.

Each received pulse is fed to an amplifier which drives the transmitter. This closed loop oscillates at a frequency dependent on the transit time through the liquid. Note that the two sets of transmitters and receivers are opposed in direction so that one pulse rate will increase as the other decreases. The measurement of flow is a function of the difference between the two pulse-repetition rates.

Still another configuration is shown in Fig. 9 where one transmitter feeds two receivers. The difference in signal amplitude between the two receivers is then a measure of the flow. Naturally this arrangement will be most effective in larger diameter pipes.

All ultrasonic flowmeters suffer from one major drawback: The liquid must be homogeneous because air or gas bubbles or particles of any kind alter the sound transmission characteristic of the liquid and cause considerable inaccuracy. On the other hand, most ultrasonic flowmeters do not have internal flow obstructions and can be used with any liquid irrespective of its electrical conductance or viscosity. In actual practice, ultrasonic flowmeters have so far been used mostly in defense applications and special purpose industrial installations. They have not yet found universal industrial acceptance.

Electro-Caloric Flowmeters

The third type of electronic flowmeter is generally referred to as an electro-caloric or boundary-layer type and is little more than a thermocouple and a heat source.

A heated element is cooled by the flow of liquid or gas which itself has a lower temperature. If we measure the amount of this cooling effect, a measure of the flow is obtained. Fig. 10 shows the basic circuit of a widely used thermal-flowmeter. Inside the pipe are three thermocouple junctions two of which, *A* and *B*, are heated by the a.c. source. The cooling effect of the gas or liquid in the pipe causes a change in the temperature of thermocouple *A* and *B* and therefore causes a change in the d.c. voltage across the meter. The third element, *C*, is unheated and is included to compensate for slight changes in ambient temperature. Since it is unheated, any change in ambient temperature will have the opposite effect on *C* and tend to cancel d.c. changes which are due only to ambient temperature. Element *C* is at whatever temperature the metered liquid or gas is and is therefore not part of the actual flow measurement.

Fig. 11 shows a complete thermal flowmeter, typical of those used in small pipes. These flowmeters are especially useful for gases, including pneumatic systems, and are found mostly in laboratory, pilot plant, and special metering installations. They are not suitable for outdoor piping where large temperature variations can occur, nor will they be found in industries where the liquids contain coarse particles, are corrosive, or where large pipe diameters are used.

(*Continued on page* 85)

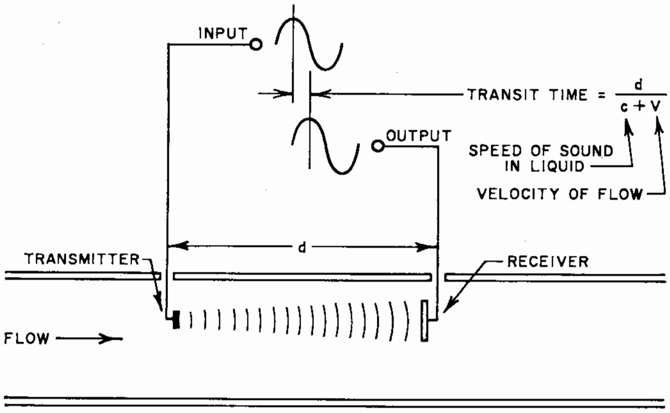
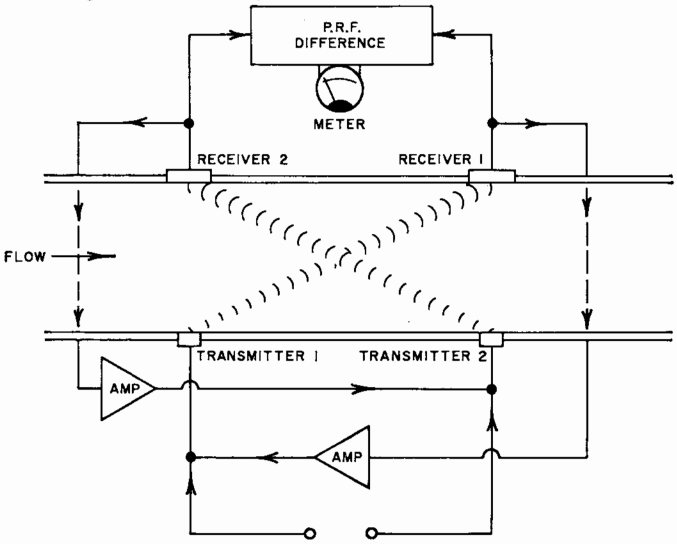


Fig. 7. Simplified schematic of the ultrasonic flowmeter.

Fig. 8. Circuit of pulse-difference ultrasonic flowmeter.



Flow Measurement
(Continued from page 47)

Flowmeters and their electrical output signals form the sensing elements for complex automatic process control systems in the oil and chemical industry. Most of the servicing of such systems is concentrated in the computing and control circuits, but an understanding of how flowmeters work helps when their output signals must be evaluated. Once the flowmeter is eliminated as the possible source of trouble, you should consider the system as a whole.

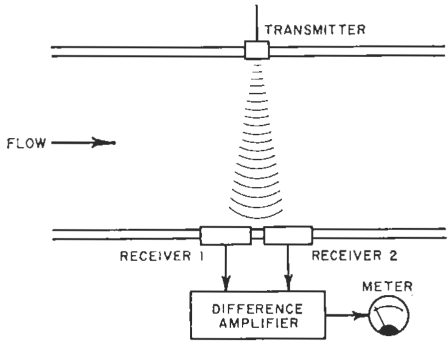


Fig. 9. Dual-receiver ultrasonic flowmeter. Signal difference is proportional to flow.

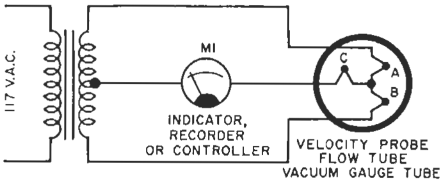


Fig. 10. Thermal flowmeter. Flow is determined by cooling effect of gas, liquid.

In the typical flowmeter application shown in Fig. 3, you will note that there are several spots to consider, namely: the motor-driven valves, the servo-motor drive amplifiers, or the signal comparer and control circuits.

Several different principles are used to measure flow in various applications. Knowing the application will often enable you to judge what kind of flowmeter is probably used and how its signals should behave. ▲

Fig. 11. Thermal flowmeters are often used for gas measurement and in laboratories.