A New Electro-Mechanical Velocity Meter

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ONE OF THE most primitive ways of estimating how fast water is flowing is by dropping small bits of paper or other readily visible material into a stream and timing its travel over a known distance. Under certain conditions such a system is perfectly suitable for engineering purposes, particularly where the object is not to have precise measurements but rather a comprehensive indication of a trend, a relative velocity pattern.

Some of the more sophisticated approaches to fluid velocity measurements include the Pitot tube, the Bentzel tube, the thermistor device, the bridge-electronic method, the pressure cell, and the utilization of Sonar in conjunction with the Doppler Effect. These devices have one feature in common. They are invariably of either a delicate construction and thus require great handling care, or they involve elaborate setups requiring skilled technicians for their operation. The range of these instruments is usually restricted. The Pitot tube, for example, is meant to record the higher velocities with good accuracy, while a thermistor device is extremely precise at very low velocities.

Desirable Features of a Fluid Velocity Meter

A meter designed to measure fluid velocities should have the following features:

1. Be able to give reproducible results with a degree of accuracy consistent with that required for a particular test.
2. Exhibit a stable, long-term operational characteristic.
3. Not be dependent on the physical properties of fluids.
4. Be of physical dimensions suited to the requirements imposed by different tests .
5. Possess a wide velocity range.
6. Be simple in operation and in maintenance.
7. Have provisions for the automatic recording of velocity data.
8. Be competitively priced.

The Conventional Current Meter

The need for a relatively wide-range instrument to measure fluid velocities has been met only partially with the development of the propeller-type meters, also known as current meters. These devices have cups, a screw, or a propeller whose rotation is definitely related to the fluid velocity. The usual way of recording rotation is by means of an audible signal in the form of "clicks" produced by a brush and commutator arrangement that energizes a pair of headphones through the application of a low voltage in the circuit.

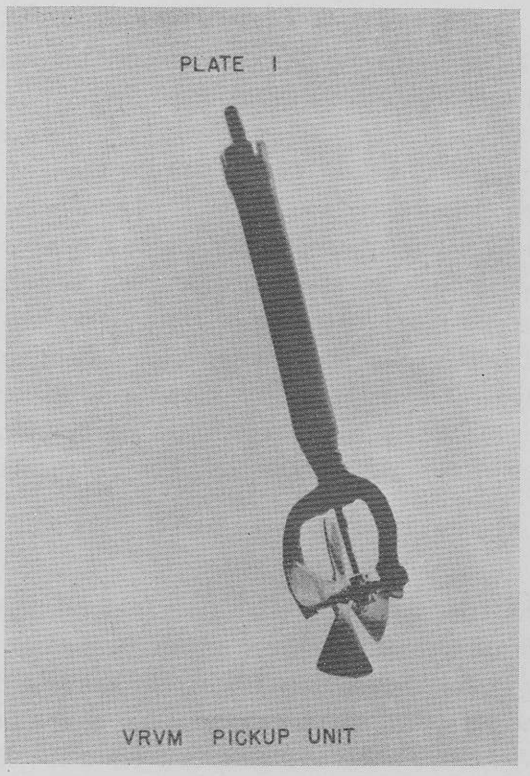
The propeller-type meter has an inherently linear relationship between rotation and fluid velocity, and it maintains this relationship over a relatively great velocity range. The meter can be made in almost any size. With a reasonable amount of care, it will give excellent performance for many years. Yet, certain limitations of use unfortunately exist, particularly if the unit is made very small.

Limitations of the Current Meter

It is not difficult to understand that when a mechanical contact is used to generate an electrical impulse, which in turn is used to relay the rate of rotation of the propeller, the accuracy of the instrument will depend directly on how steady and unvarying the contact pressure of the brush on the commutator remains. Furthermore, assuming that for a reliable and consistent electrical contact any brush or "collector wire" has to be set to exert a basic, minimum force against the commutator, it is easy to see that propeller size will also be limited to a particular minimal dimension that will always be *greater than if the propeller had been absolutely free-wheeling.* Any propeller, no matter what its size, will respond to lower velocities, when unimpeded by other restrictive forces in the friction of contact elements, than any other identical propeller having to make and break an electrical contact through a mechanical device.

An Improved Type of Velocity Meter

In 1957 the idea was first conceived to use a magnetic field to translate the rotation of a propeller free of any mechanical contacts except for the inevitable but relatively minute amount of friction between shaft and jewel bearings. Three years later a prototype model was built that possessed most of the desirable characteristics that a velocity meter should have. The meter, shown on Plate I, is called the Variable Reluctance Velocity Meter, or VRVM in short. The over-all length of the unit is only four inches, although it could easily have been made smaller with more precise manufacturing equipment.



The electromagnetic part of the VRVM pickup consists basically of a low-impedance coil encased within a mu-metal shell, a magnetic core that protrudes through the base of the shell, and a very small steel sprocket.

The sprocket is mounted on the propeller shaft and rotates with it. As each tooth of the sprocket passes by the tip of the magnetic pole piece (see Figure 1), the reluctance of the air gap undergoes a change. It is minimum when a tooth is exactly under the pole. It is maximum when any two teeth adjacent are equally positioned on each side of the pole. The rotation of the sprocket induces an alternating voltage in the coil. This signal is then fed into a preamplifier of suitable gain. As is shown in Figure 2, the actual meaningful translation of the A.C. signal that originates at the propeller occurs with the use of a frequency meter such as is made by Hewlet-Packard. This easily portable piece of electronic equipment will accept auxiliary recording devices such as the Esterline-Angus automatic recorder and electronic counter.

Operational Features

The sensitivity of the VRVM to very low velocities will depend on the mass and the geometry of the propeller as well as on the quality of its two jewel bearings. A lightweight propeller, such as the one used on the

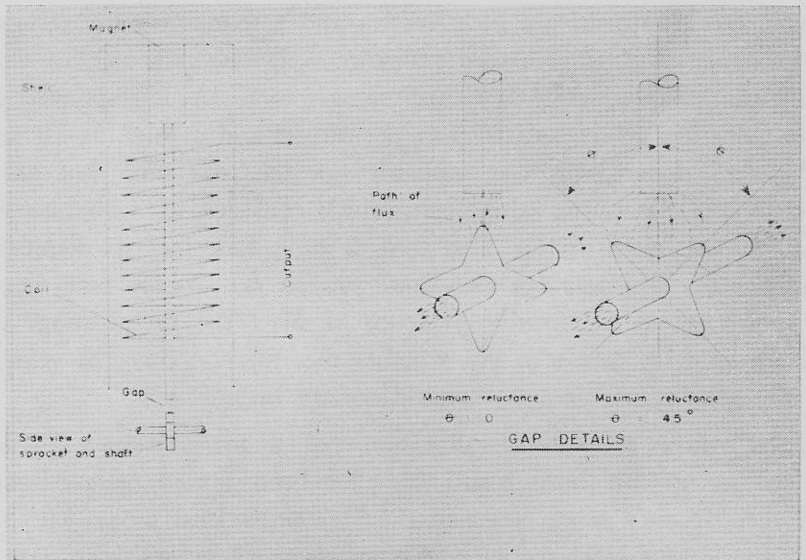
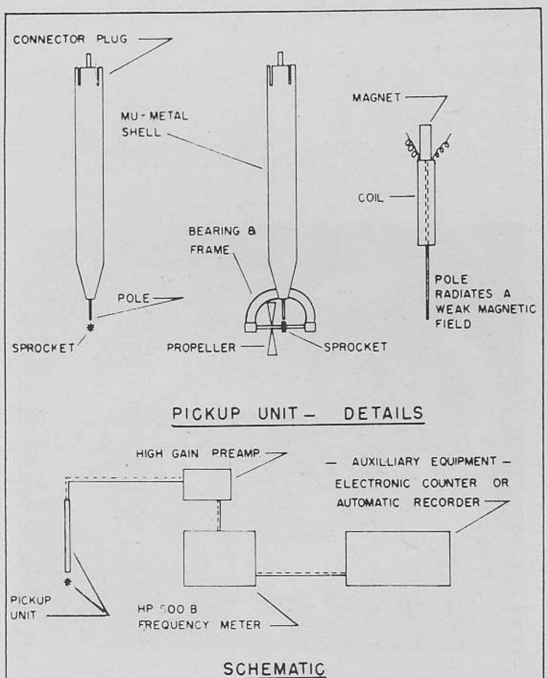


FIG. I SCHEMATIC & DETAILS

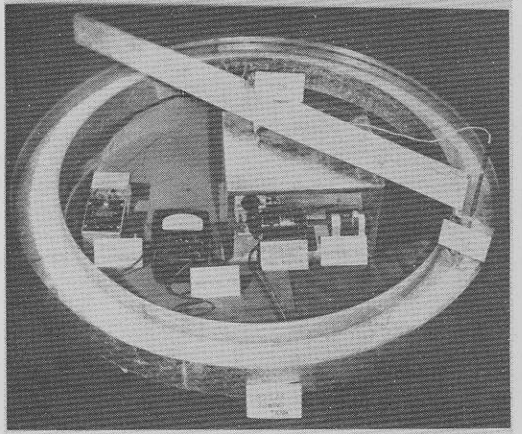


VRVM
GENERAL PLAN
FIG. 2

prototype, has comparatively little inertia and responds almost instantly to velocity changes. A three-bladed propeller only one-half inch in diameter and weighing approximately 500 milligrams was used. It responded unfailingly to velocities as low as 0.05 feet per second and as high as 10 feet per second. This upper limit was probably not the true limit but only one dictated by the calibrating equipment, which consisted of a circular towing tank, as shown in Plate II. This tank is only four feet in diameter and designed for the calibration of very small propellers. At the time these tests began there existed no positive evidence of what the useful range of the propeller would be, that is to say, whether the response curve of velocity vs. rps or the velocity vs. frequency would remain linear.

Figure 3 shows the VRVM calibration chart at low velocities. The velocity of the pickup unit through still water has been plotted against frequency, as read directly on a large meter of the Hewlet-Packard model HP 500 B. This electronic unit gives a choice of nine frequency ranges from 3 to 100,-000 cps. In actual operation, the meter would be covered with a decal calibrated in feet per second instead of frequency. Should anyone be interested in the actual rate of rotation of the propeller, he needs only divide the fre-

PLATE II



CALIBRATION APPARATUS

quency by the number of teeth on the sprocket. Thus, for eight teeth, a velocity of 1.33 feet per second gives a frequency of 80 cps, which means the propeller is turning at 10 rps.

Figure 4 is a plot of the complete frequency vs. velocity range of the VRVM as measured with the limited equipment available at the time. The upper velocity appearing on the graph is 5.35 feet per second at a frequency of 300 cps. For an eight-tooth sprocket, this means a propeller speed of 37.5 rps or 2,250 rpm. It may be of interest here to note that the same propeller was checked at 10,000 rpm in air.

Figure 5 again shows the linear response of the pickup voltage output vs.

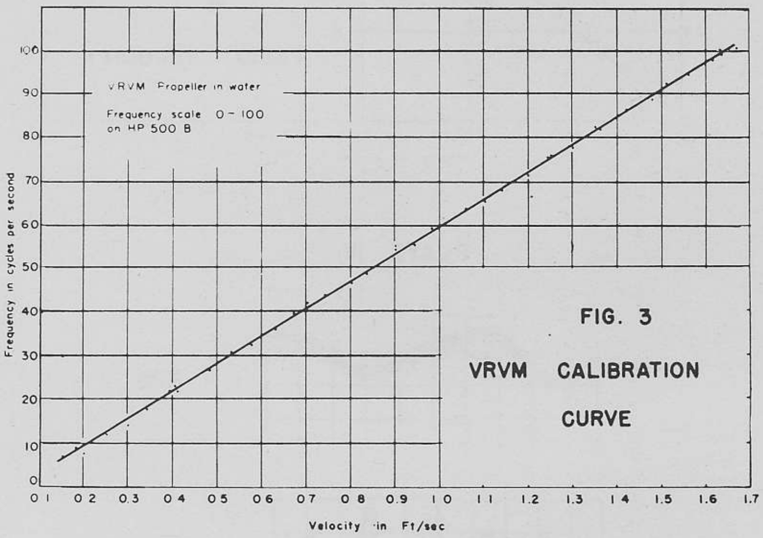


FIG. 3
VRVM CALIBRATION CURVE

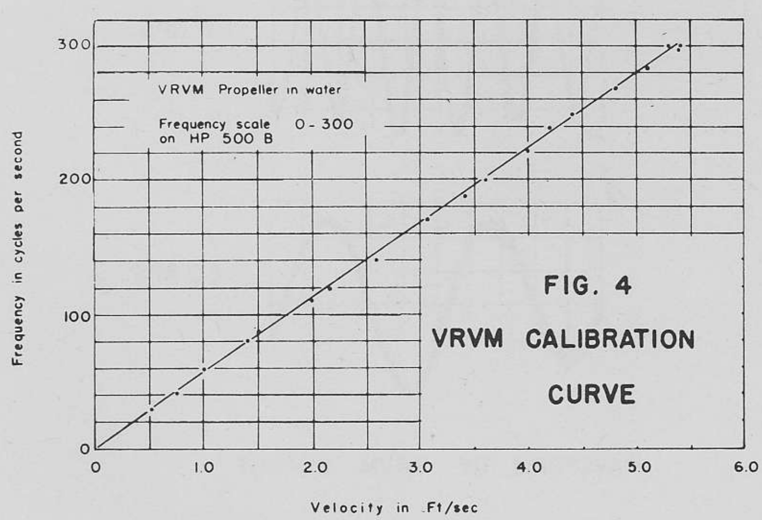


FIG. 4
VRVM CALIBRATION CURVE

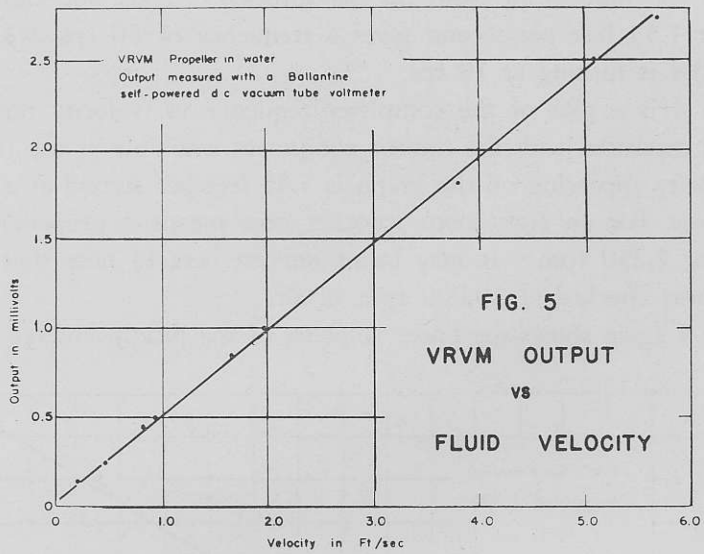
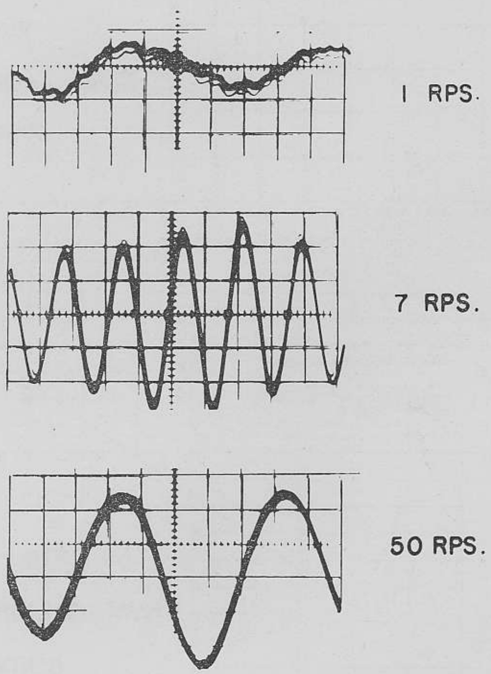


PLATE III



WAVEFORM OF VRVM OUTPUT

velocity. Note that the signal measures only 0.2 millivolts at the lowest recorded velocity of 0.15 feet per second. When designing a VRVM, one must consider the factors of coil output voltage and preamplifier gain, in relation with the propeller speed requirements. Insufficient voltage at the lowest rps will not produce reliable readings with the Hewlet-Packard frequency meter.

The sinusoidal waveform of the VRVM output signal is shown on Plate III.

Summary

The Variable Reluctance Velocity Meter is a new propeller-type meter that can be made in virtually any size down to a propeller diameter less than one-half inch. Its small size makes the instrument adaptable to the study of shallow-draft flow conditions. The VRVM has but one moving part, which revolves freely on two jewel bearings. Operation of the meter is not dependent on the fluid's electrical conductivity, and it may be used with any gas or liquid. The response of the VRVM to fluctuating velocities may be minimized by using a heavy propeller with an inherent degree of self-integration, or it can be maximized through the use of a very lightweight propeller. Suited for either laboratory or field work, the VRVM is adaptable to automatic recording. This is an asset whenever a long-term velocity study is required, as in the correlation of biological responses to flow conditions. The Hewlet-Packard HP 500 B accepts any EsterlineAngus I ma. pen recorder. An electronic counter can also be used to advantage to record average velocities.

In the field, the VRVM pickup may be used with a subminiature, transistorized preamplifier and small, transistorized, portable tape recorder. Both of these units are commercially available. Complete records of the water or air velocity data are filed on tape, later to be played back in the office through the application of the taped signal into the frequency meter and, better yet, into an automatic pen recorder. The use of the latter equipment allows leisurely examination of all the data collected in the field.

In conclusion, the possibilities of the Variable Reluctance Velocity Meter have just begun to be discovered. It is hoped that the versatility, modest cost, and ease of operation of this instrument will activate interest among all those who seek better and more practical instrumentation.