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THE DEVELOPMENT OF A TURBULENCE INDICATOR
LIQUIDS UTILIZING MAGNETIC INDUCTION

by
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THE DEVELOPMENT OF A TURBULENCE INDICATOR FOR LIQUIDS UTILIZING MAGNETIC INDUCTION

INTRODUCTION

In an effort to develop an instrument for measuring turbulence in water a study was made of the electromagnetic velocity meter developed by A. Kolin (1)*. This instrument consists of a double-wire probe which registers small currents set up in water flowing between the poles of an electromagnet. Alternating magnetic fields are used to reduce polarization of the probe. Since Kolin's instrument in its present form responds only to velocity changes of low frequency and relatively large amplitude, it would be necessary to increase the frequency response of the instrument and improve its sensitivity if it is to be used as a turbulence indicator. This report discusses the difficulties which would be encountered and the feasibility of adopting this instrument for turbulence measurements. Only instruments utilizing alternating magnetic fields are considered here.

SPECIFICATIONS FOR A TURBULENCE INDICATOR

In turbulent flow the motion of fluid particles becomes very irregular with high frequency fluctuations in velocity occurring not only in the direction of flow but also across the flow. Characterization of turbulence depends upon the measurement of the magnitude and frequency of the velocity fluctuations in three mutually perpendicular directions. From measurements of these quantities it is possible to derive the intensity of turbulence, the spectrum of turbulence, velocity correlations and the scale of turbulence.

As the velocity fluctuations are only a few per cent of the velocity of the main flow the measuring instrument must be highly sensitive to detect small variations in velocity. Furthermore, since the frequency of the velocity fluctuations ranges from zero to several hundred cycles per second (2) the instrument must have a high frequency response. In addition, the instrument must be small in physical dimensions to avoid disturbing the flow.

THEORY OF KOLIN'S INSTRUMENT

The operation of Kolin's instrument is based on electromagnetic induction (1). When a conductor, in this case a fluid, moves with a velocity U through a uniform magnetic field of

* Numbers in parentheses indicate references on page 6.

intensity H , a difference in potential is developed in the conducting medium perpendicular to both the field and the velocity. The potential gradient set up is given by

$$\text{grad } \varphi = \frac{\mu}{c} \vec{U} \times \vec{H} - \gamma \vec{I} \quad [1]$$

Here μ is the magnetic permeability of the medium and c the velocity of light. Owing to the difference in potential induced in the fluid, eddy currents are set up which produce an opposing potential. In Equation [1] i is the current density and γ the specific resistance of the fluid. As will be explained later, special attention must be given to the eddy currents, either to correct for them or eliminate them by appropriate shielding of the electrodes.

In Kolin's apparatus the induced potential difference is picked up by a pair of electrodes oriented parallel to the flow and perpendicular to the magnetic field, as shown in Figure 1. The potential difference measured by the probe is

$$E = \frac{\mu}{c} \int_0^1 (\vec{U} \times \vec{H}) \cdot d\vec{l} - \int_0^1 \gamma \vec{I} \cdot d\vec{l} \quad [2]$$

where l is the effective distance between the electrodes or the equivalent length of a metallic conductor.

Detection of small potential differences in an electrolyte is a very difficult problem. Not only do the electrodes become polarized but local galvanic potentials may introduce large errors. The latter difficulty may be eliminated by using platinum electrodes while an alternating magnetic field would reduce the polarization. In general, the higher the frequency of the alternating field the better the correction of polarization will be. The polarization might be reduced further by platinum plating the platinum electrodes or by coating the electrodes with aquadag.

With an alternating field, Equation [2], for the difference in potential measured by the probe, becomes

$$E = \int_0^1 \frac{\mu}{c} (\vec{U} \times \vec{H}) \cdot d\vec{l} - \iint \frac{\partial \vec{H}}{\partial t} \cdot d\vec{S} - \int_0^1 \gamma \vec{I} \cdot d\vec{l} \quad [3]$$

The second term, which is 90 degrees out of phase with the first, represents the electromotive force induced in the circuit by the changing flux and is present even when there is no flow. Kolin eliminates the effects of this term by using a phase compensating circuit with which this undesirable component of the potential difference is balanced out when the fluid is at rest (3). If a suitable correction is made for the last term of Equation [3] the velocity of flow, as a function of the time, is proportional

to the envelope of the induced potential difference curve. Since Kolin used a 60 cycle alternating magnetic field his apparatus was limited to the measurement of steady velocities of low frequency fluctuations.

In the case of flow in a tube eddy currents, which affect the potential difference measured by the probe, may be set up because of the distortion of the potential field across the tube by the non-uniform velocity distribution. If the flow were uniform everywhere across the tube, the equipotential lines would be a set of parallel straight lines. With a parabolic velocity distribution, which is characteristic of laminar flow, the equipotential lines are distorted and eddy currents are set up, as shown in Figure 2 (4). A complete analysis of the eddy currents induced in a tube is given in reference (4).

Kolin was able to shield his probe from eddy currents by mounting a suitable shield about the electrodes which prevented extraneous currents from crossing the space between them. With this shielded probe Kolin was able to explore the velocity distribution across a tube and also in the region near the mouth of a nozzle. Readings with an unshielded probe, on the other hand, gave spurious effects due to eddy currents (1).

ADAPTATION OF KOLIN'S INSTRUMENT FOR THE MEASUREMENT OF TURBULENCE

In order to adapt Kolin's instrument for the measurement of turbulent fluctuations it would be necessary to increase both its sensitivity and its frequency response. The frequency response might be increased either by using a steady magnetic field or by using a high frequency alternating field. Since no method is known for eliminating polarization in a steady field only the second alternative is considered here. A new phase shift circuit would have to be devised because Kolin's circuit would not be sensitive enough when used with the high frequency field.

For energizing the magnetic field it would be necessary to design and build a power oscillator which would maintain a constant frequency and amplitude to a high degree of accuracy. Although an accuracy of about 0.1 per cent would be adequate for the frequency, the amplitude would have to be controlled more precisely. To maintain an accuracy of 1 per cent in measuring velocity fluctuations, which are 2 to 5 per cent of the main velocity, an accuracy of 0.02 to 0.05 per cent would be needed in the amplitude of the carrier wave.

To eliminate the component of the emf induced by the changing flux of the magnetic field it would be necessary to introduce

an emf of the same amplitude and 90 degrees out of phase with the induced emf. This might be accomplished in a number of ways with the use of a phase shift network in an electronic circuit. As this component of the emf would be large owing to the high frequency field, the circuit should be efficient and be capable of sharp tuning.

The induced emf would be balanced out while the flow of water was zero. Once the flow started the induced emf would be due entirely to the velocity of flow and the strength of the magnetic field. Since the magnetic field would alternate about 5000 times per second, the induced emf would alternate with an amplitude proportional to the instantaneous velocity. Velocity fluctuations would be measured from the variations in the envelope of the carrier wave.

If an instrument of this type were to be used for measuring turbulent fluctuations the electrodes would have to be entirely free of polarization. The use of a 60 cycle field in Kolin's instrument did not completely solve this difficulty. Kolin coated his electrodes with aquadag, which seemed to give satisfactory results. Although a high frequency field would help eliminate polarization it is particularly important that the bubbles be completely eliminated. If aquadag should not prove completely successful, electroplating the platinum electrodes with platinum could be tried.

The development of eddy currents due to potential differences existing in the fluid would add to the difficulty in measuring turbulence. Kolin devised shields for his electrodes and thereby eliminated the effects of eddy currents and was able to measure velocity distributions across a pipe. It is feared that, although such a shield did not appreciably disturb the average flow, it would undoubtedly obscure small velocity fluctuations in the flow.

For measuring velocity correlations it would be necessary to use two probes. If one were placed downstream from the other the flow would undoubtedly be seriously disturbed. As long as one probe was not in the wake of the other the method might be successful.

Even though suitable electronic circuits were procured and a successful method were devised for eliminating or correcting for eddy currents, the usefulness of such an instrument would be limited to the measurement of flow in pipes or channels narrow enough to fit between the poles of an electromagnet. Although the magnetic field need not be very strong the cost of construction increases rapidly with the size of the air gap. Application, therefore, would be limited to tubes of small diameter.

SELF-CONTAINED INSTRUMENT

If suitable electronic equipment could be obtained it might be practicable to build a self-contained unit, consisting of a field coil and electrodes in a streamlined case or built into the surface of some special hydrodynamic form. Such an instrument could be used in a wide channel to study the turbulence of the water or could be used to study the boundary layer about a hydrodynamic form. The auxiliary equipment would include an oscillator for energizing the field and a phase compensating circuit. Although the oscillator might be less powerful it should have the same precision for maintaining frequency and amplitude.

CONCLUSION

Although Kolin's electromagnetic induction instrument has been used successfully for measuring uniform flow of liquids and for low frequency velocity fluctuations, many difficulties arise when attempts are made to adapt the instrument for measuring high frequency turbulent velocity fluctuations. The equipment needed includes: an electromagnet with laminated iron core and wide air gap, a power oscillator which would provide a constant amplitude within 0.02 per cent and an efficient phase shift circuit for a frequency of about 5000 cycles. All these items would be expensive to design and build. In addition, it would be necessary to devise a means of eliminating or correcting for eddy currents.

In this study the use of an alternating magnetic field was the only method considered for eliminating polarization of the electrodes. Recently L. Grossman (5) of the University of California has reported the successful development of an electromagnetic instrument using a steady magnetic field. His probe was constructed of No. 28 insulated copper thermocouple wire. The tips of the wires were treated with colloidal graphite burnt on to form a graphite layer at the points of contact with the liquid. He does not mention any difficulties with polarization. With a steady field it is not necessary to build a power oscillator or phase compensating circuit and it would cost less to procure a steady-field magnet. The problem of eliminating or correcting for eddy currents would still have to be considered.

Other methods for measuring turbulent velocity fluctuations in liquids are being studied at the Taylor Model Basin and at least one shows promise of being successful (5,6). This instrument is small in physical dimensions and is not limited in application to flow in a narrow tube or channel. In view of the uncertainties and expense of obtaining suitable electronic equipment for a Kolin instrument and putting it into successful operation, it has been decided to abandon this project for the present at the Taylor Model Basin.

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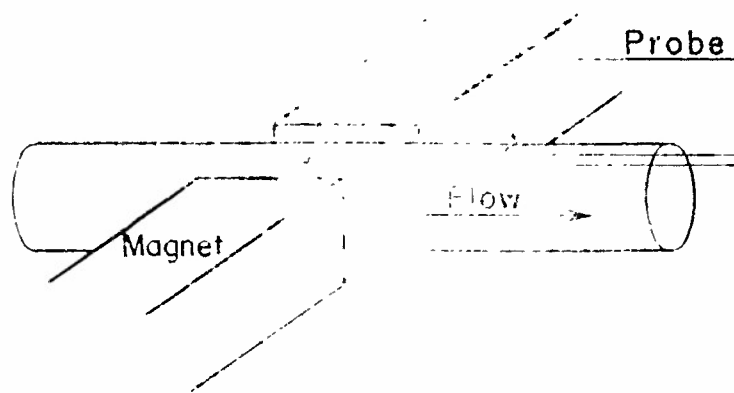


Figure 1 Schematic Diagram of Kolin Apparatus

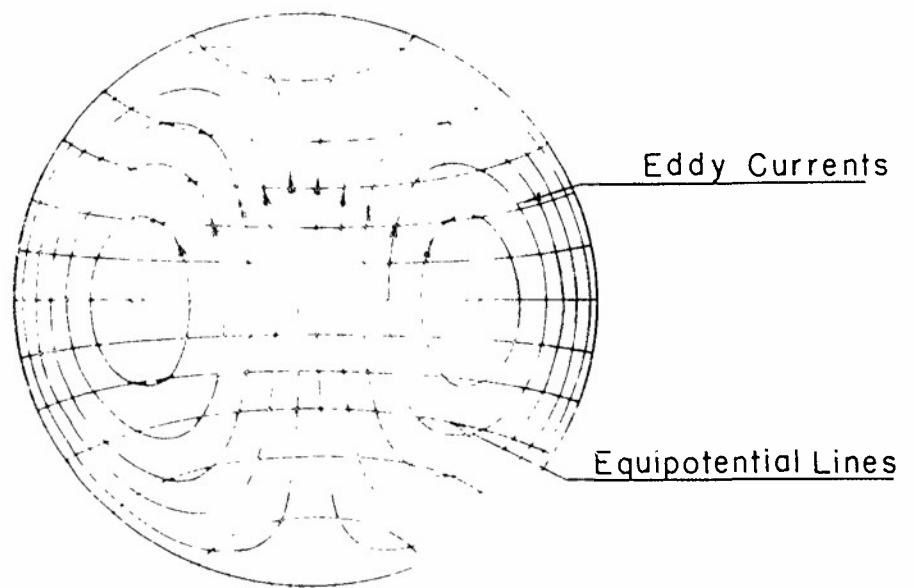


Figure 2. Configuration of Equipotential Lines and Eddy Currents in a Circular Tube When the Flow is Laminar

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