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TURBULENCE MEASUREMENTS IN WATER USING THE HOT-WIRE ANEMOMETER

by

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SUMMARY

A successful technique for measuring turbulence in water using the hot-wire anemometer is presented. A simple coating process is used to protect the wire from chemical attack and to provide electrical insulation, while the problem of gas bubble and dirt contamination is solved by using an ultrasonic cleaner adjacent to the probe while making measurements.

The performance of the coated wire is compared with an uncoated wire in air flow and a drop in output is observed only at frequencies above approximately 100 hz. Mean velocity profiles and turbulence measurements for both air and water flow in a circular conduit are presented.

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It has been possible to measure the characteristics of turbulence in air flow for some time now using hot-wire anemometry. Unfortunately, it has not been possible to measure the characteristics of turbulence in water with the same precision as in air. Difficulties experienced include the fact that stable drift-free operation of hot-wire anemometers in water has not been possible, and other available velocity transducers (pitot tubes, propellers, pressure probes, etc.) are too large, have excessive time constants, or cannot separate the velocity fluctuations from such variables as pressure fluctuations. Factors that cause the wires to be unstable in water are the contamination of the wire by dissolved gases, dirt, and chemicals in the water; electrolysis of the wire; and conductivity of the water.

The development of hot-film probes (1) to replace the wir has eliminated some of the problems, but not those assoicated with the contamination of the probe. Some turbulence measurements have been made in filtered and de-aerated water using the hot-film sensor, e.g. those made by Raichlen (2), but the measurements that may be made with hot-films are limited.

This paper describes a method for measuring turbulence in water, using hot-wire anemometers. The procedure used places no special requirements on the water supply, and an ordinary laboratory supply may be used.

The method consists of coating the 0.0002" (50 microns) diameter wire with a commercially available masking solution used in the electroplating industry for protecting components during plating. This solution dries rapidly, has a low surface tension and viscosity, which allows a coating to form readily around the small diameter wire. It can also be thinned easily allowing a solution of suitable viscosity to be used.

This film protects the wire from chemical attack, gives electrical insulation and also provides increased physical strength.

The coating eliminates difficulties due to electrolysis, chemical attack and conductivity problems. It does not however, offer a solution to contamination of the wire by dissolved gases and dirt. This problem has been successfully eliminated by the use of an ultrasonic cleaner (Sanophon) with a specially adapted transducer. The cleaning unit is operated continuously while using the probe thus shaking loose any gas bubbles and dirt particles from the wire immediately they form. This leads to a stable operating condition of the probe, in contrast to brushing techniques and varying overheat ratios (3) which cannot accommodate a varying rate of deposition of particles. The anemometer used in the experiments was a DISA Type 55A01 with linearizer Type 55D10. The cleaner operates at a frequency of 22 Khz., well outside the frequency range of turbulence in water (0-100 hz.), (3,4), and if any signal from it is recorded by the probe, this may be filtered out by operating the low-pass filter on the anemometer at 1 Khz.

All measurements were made in a 6 in. (0.1525 m) diameter conduit, as shown in the sketch in Fig.1.

A number of measurements were made in both air and water, air flow being used to compare the performance of the coated wire with that of an uncoated wire. Fig.3 illustrates the voltage-velocity relation for coated and uncoated wires in air (both operating at an overheat ratio* of 1.80). As may be expected, because of the increased thermal mass of the wire and coating, the coated wire has a lower response to the flow, particularly at lower velocity. This effect is also evident in the sensitivities, as shown by the curves in Fig.4.

The use of the ultrasonic cleaner in water measurements allows higher overheat ratios than usual to be employed, as although the increased wire temperature leads to greater gas bubble formation, these are removed. The overheat ratio

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* Note - Overheat ratio $= \dfrac{\text{probe resistance under operating conditions}}{\text{cold resistance of probe}}$

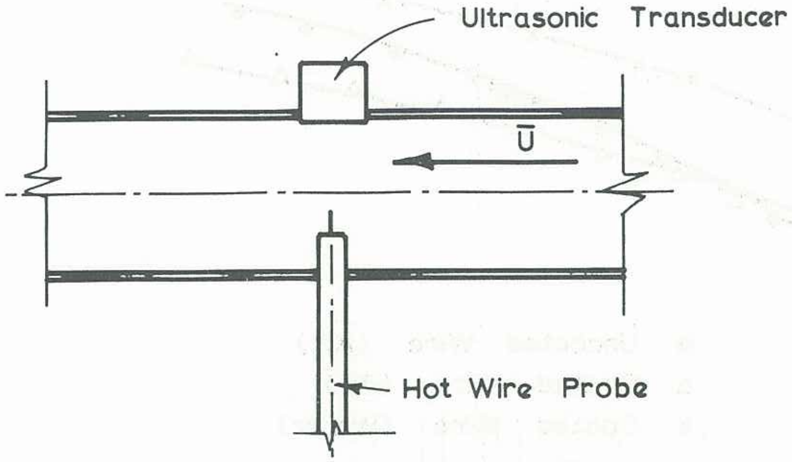

FIG. 1 SECTION THROUGH 0·1525m. DIAMETER PIPE SHOWING THE POSITIONS OF THE TRANSDUCER AND PROBE.

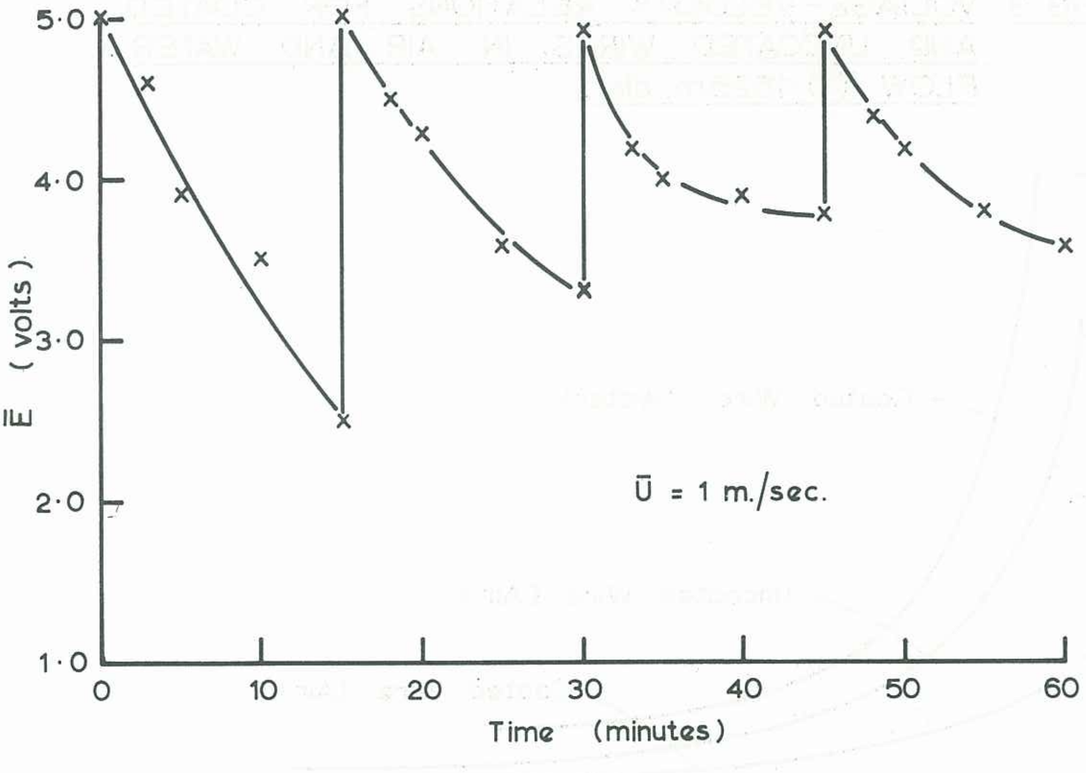

FIG. 2 VARIATION OF VOLTAGE WITH TIME WITH ULTRASONIC CLEANER OPERATED INTERMITENTLY AT 15 MINUTE INTERVALS

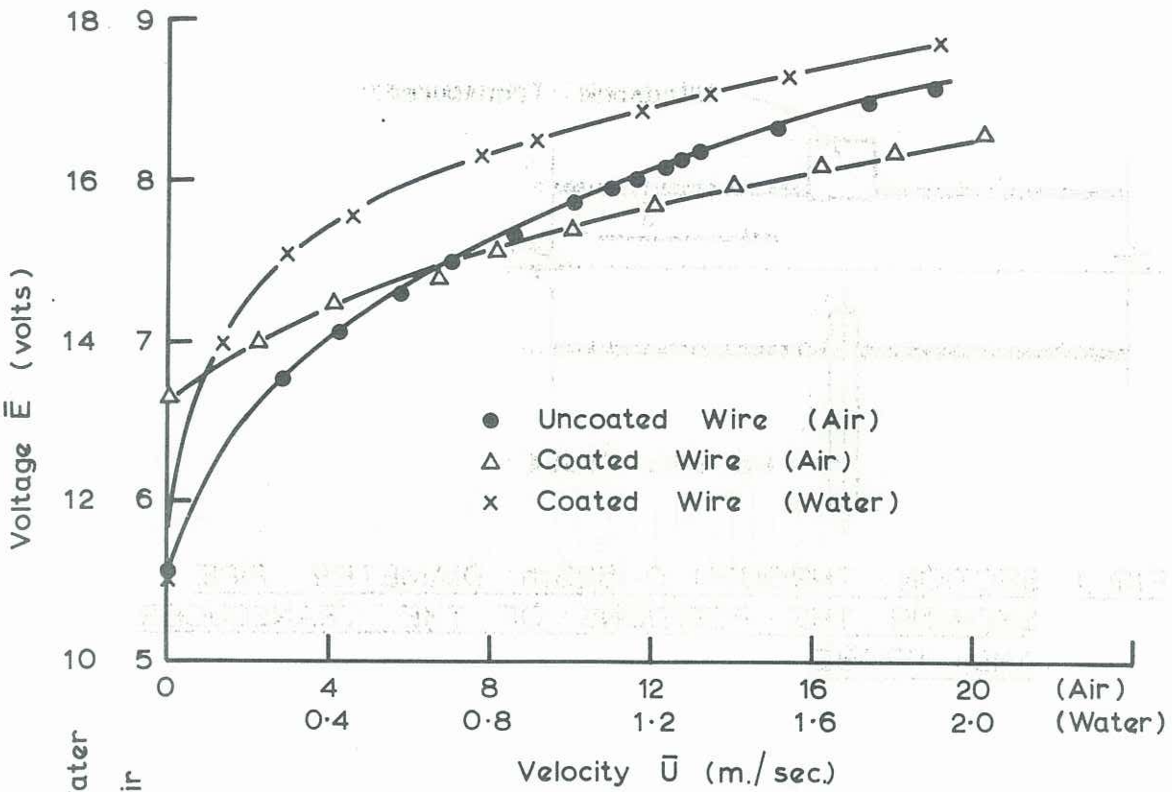

FIG. 3 VOLTAGE - VELOCITY RELATIONS FOR COATED AND UNCOATED WIRES IN AIR AND WATER FLOW (0·1525m. dia.)

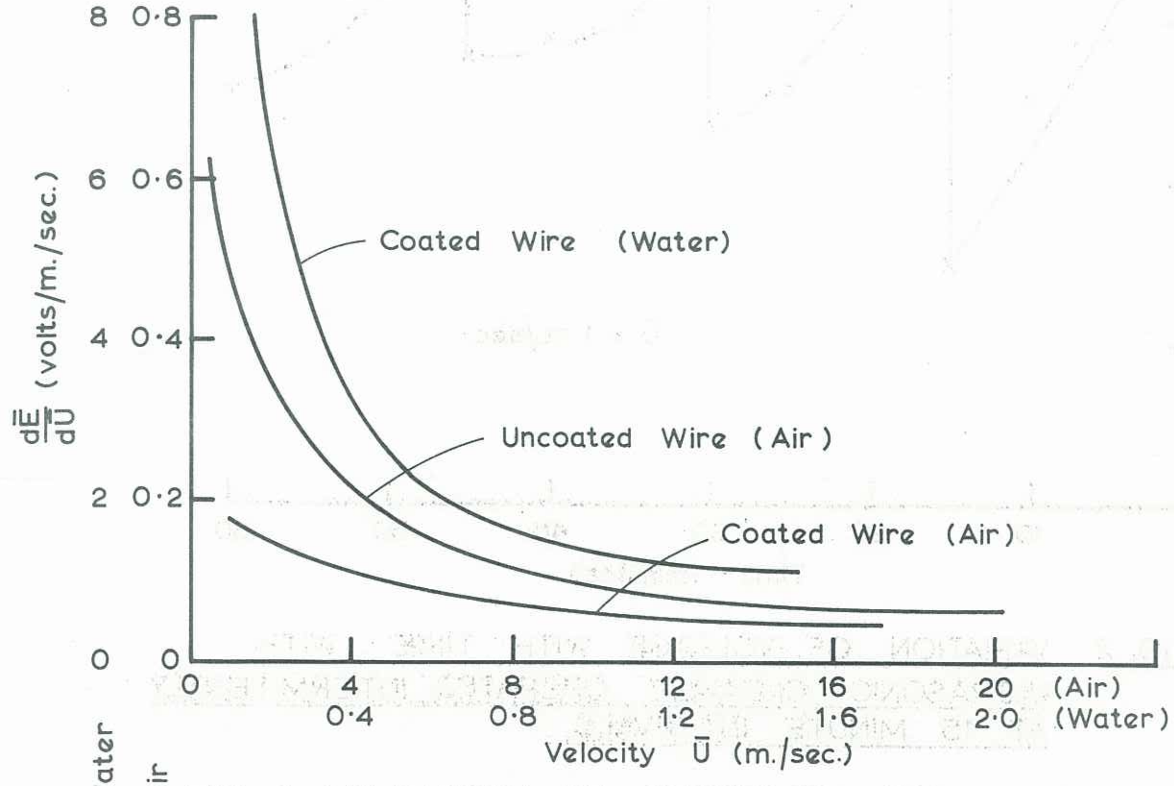

FIG. 4 COMPARISON OF SENSITIVITY FOR WIRES IN AIR AND WATER.

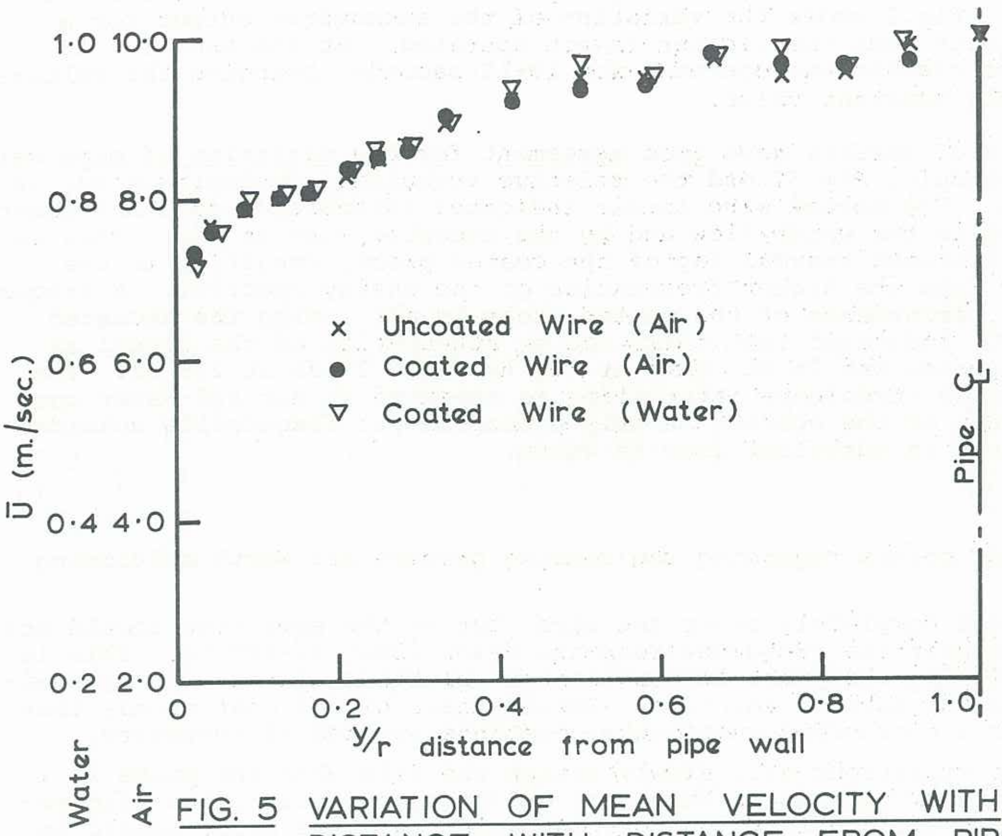

FIG. 5 VARIATION OF MEAN VELOCITY WITH DISTANCE WITH DISTANCE FROM PIPE WALL (0·1525 m. dia.)

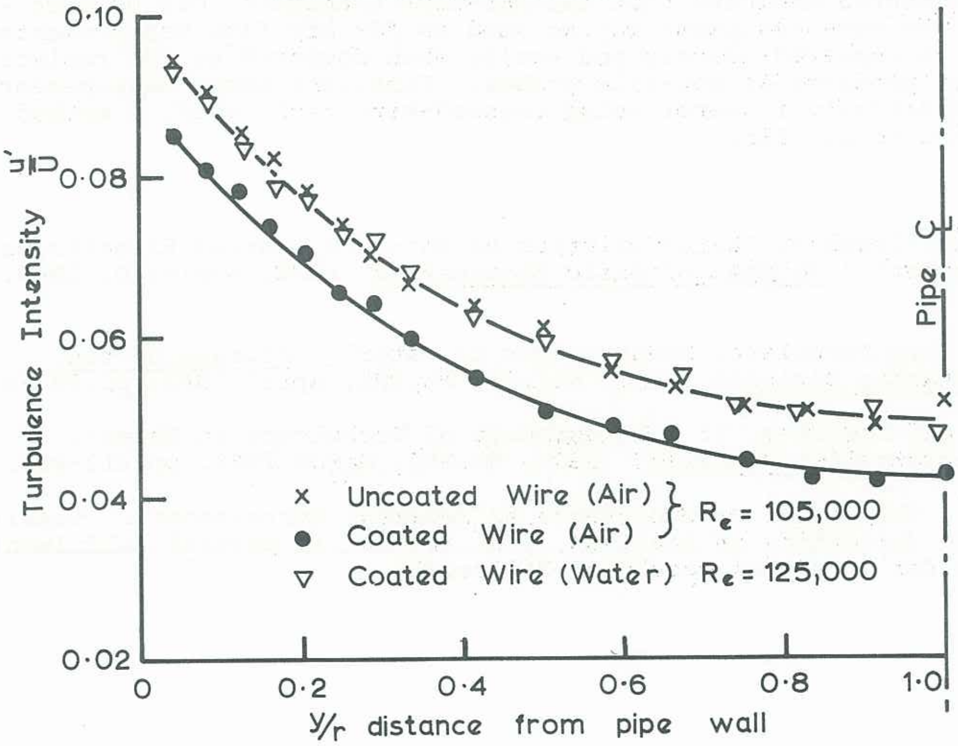

FIG. 6 VARIATION OF RELATIVE TURBULENCE INTENSITY WITH DISTANCE FROM PIPE WALL (0·1525m. dia.)

in the experiments was 1.25, giving much greater sensitivities than for the air flow measurements. Fig.2 shows the variation of the anemometer output for a constant flow velocity when the cleaner is not operated. At the end of a 15 minute interval the cleaner was operated for 10-15 seconds, bringing the voltage back to a relatively constant value.

The three sets of results gave good agreement for the variation of mean velocity across the conduit, Fig.5, and the relative turbulence intensity $u'/\bar{U}$, is presented in Fig.6. The coated wire in air indicates intensities somewhat lower than those measured in the water flow and by the uncoated wire in air. This is attributed to the increase thermal lag of the coated probe, resulting in the omission of energy from the higher frequencies of the energy spectrum. A frequency analysis of the performance of the coated probe in air (using the uncoated probe as a standard) indicated that there was no attenuation of the signal at 50 hz., but the response was 25 db. down at 100 hz., and 30 db at 200 hz. The good agreement between turbulence intensities as measured in air and water confirms that the effect of the coating is only noticeable at frequencies outside the range experienced in turbulent flow in water.

A few important points regarding the coating process are worth mentioning here.

1. The coating must completely cover the wire, but at the same time should not be so thick as to impair the frequency response below about 70-100 hz. This is best achieved by dipping the probe into a lacquer solution thinned with approximately 50% by volume of lacquer thinners. The thickness of the coating may then be observed through a microscope and further coatings applied if necessary.

2. The ultrasonic vibrations will slowly attack the film when the probe is in use, and after a period, usually in excess of 2-3 hours operation, the cold resistance of the probe will begin to change. At this stage the probe should be recoated, or replaced by another.

The results presented indicate that the hot-wire anemometer can be used with success in water. The same equipment may be used as for air flow measurements, and the probes may be repaired quickly and easily when compared to the replacement cost and repair problems of hot-film probes. Turbulent shear measurements may now be made successfully in water using crossed-wire techniques, a method previously restricted to air flow.

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